**Izunildo Fernandes Cabral**
Mestre em Engenharia e Gestão Industrial

# A Systematic Methodology to Analyse the Performance and Design Configurations of Business Interoperability in Cooperative Industrial Networks

Dissertação para obtenção do Grau de Doutor em
Engenharia Industrial

Orientador: António Carlos Bárbara Grilo, Professor Doutor,
Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa

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FACULDADE DE CIÊNCIAS E TECNOLOGIA
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**Dezembro 2015**

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Faculdade de Ciências e Tecnologia and Universidade Nova de Lisboa

## Copyright

# Dedicatory

This thesis is dedicated to the memory of Serafina Almeida Fernandes!

There is nothing in this world that can fill the gap you left in my life!

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Lisbon, April 2015

Izunildo Cabral

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# List of Abbreviations and Symbols

| | |
|---|---|
| A | Assumption |
| ABM | Agent-Based Modelling |
| ABS | Agent-Based Simulation |
| ACAP | Associação Automóvel de Portugal |
| AEC | Architecture, Engineering and Construction |
| ALBI | Actual Level of Business Interoperability |
| ANIRP | Associação Nacional dos Industriais de Recauchutagem de Pneus |
| APIB | Associação Portuguese dos Industriais de Borracha |
| ASAE | Autoridade de Segurança Alimentar e Económica |
| ATHENA | Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Applications |
| AV | Action Variables |
| BIDS | Business Interoperability Design Solution |
| BIF | Business Interoperability Framework |
| BIM | Building Information Model |
| BIP | Business Interoperability Parameter |
| BIQMM | Business Interoperability Quotient Measurement Model |
| BP | Business Process |
| BPD | Business Process Diagram |
| BPMN | Business Process Model and Notation |
| B2B | Business to Business |
| Cs | Constraints |
| CA | Customer Attribute |
| CAD | Computer-Aided Design |
| CAE | Computer-Aided Engineering |
| CAM | Computer-Aided Manufacturing |
| CMM | Capability Maturity Model |

| | |
|---|---|
| CMMI | Capability Maturity Model Integration |
| CN | Customer Need |
| CP | Collection Point |
| CPD | Collaborative Product Development |
| CRESCENDO | Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation |
| CSCW | Computer-Supported Cooperative Work |
| CTM | Customer |
| CTT | Contractor |
| C4ISR | Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance |
| D | Designer |
| DES | Discrete Event Simulation |
| DfX | Design for X |
| DoD | Department of Defense |
| DP | Design Parameter |
| DSM | Design Structure Matrix |
| DV | Decision Variables |
| DVD | Digital Versatile Disc |
| ECOLEAD | European Collaborative Networked Organisations Leadership Initiative |
| EDI | Electronic Data Interchange |
| EIF | European Interoperability Framework |
| EIMM | Enterprise Interoperability Maturity Model |
| ER | Energy Recovery |
| ETRMA | European Tyre & Rubber Manufacturers' Association |
| EU | European Union |
| FIFA | Fédération Internationale de Football Association |
| FITMAN | Future Internet Technologies for MANufacturing industries |
| FR | Functional Requirement |

| | |
|---|---|
| GDP | Gross Domestic Product |
| GUI | Graphical User Interface |
| GVA | Gross Value Added |
| ICAD | International Conference on Axiomatic Design |
| ICT | Information and Communication Technology |
| IDEAS | Interoperability Development for Enterprise Application and Software |
| IEEE | Institute of Electrical and Electronics Engineers |
| IMP | Industrial Marketing and Purchasing |
| INE | Instituto Nacional de Estatística |
| IOS | Inter-organisational Systems |
| IPR | Intellectual Property Rights |
| ISE | Institution of Structural Engineers |
| ISO | International Organization for Standardization |
| IT | Information Technology |
| JADE | Java Agent DEvelopment |
| JIT | Just in Time |
| KPI | Key Performance Indicator |
| LCIM | Levels of Conceptual Interoperability Model |
| LISI | Levels of Information System Interoperability |
| MAS | Multi Agent Systems |
| MAUT | Multi Attribute Utility Theory |
| MCDM | Multi-Criteria Decision-Making |
| MMEI | Maturity Model for Enterprise Interoperability |
| MW | Megawhatt |
| N | Normal Distribution |
| NATO | North Atlantic Treaty Organisation |
| NC3TA | NATO C3 Technical Architecture |
| NIST | National Institute of Standards and Technology |
| N.Ap. | Not Applicable |

| | |
|---|---|
| N.Av. | Not Available |
| OEM | Original Equipment Manufacturer |
| OIMM | Organisational Interoperability Maturity Model |
| OM | Operations Management |
| PAID | Procedures, Applications, Infrastructure, and Data |
| PIPs | Partner Interface Processes |
| PV | Process Variable |
| QFD | Quality Function Deployment |
| R | Recycler |
| R&D | Research and Development |
| RFID | Radio Frequency Identification |
| RL | Reverse Logistics |
| RLBI | Required Level of Business Interoperability |
| RQ | Research Question |
| RTI | Research Triangle Institute |
| S | Supervisor |
| SC | Supply Chain |
| SCM | Supply Chain Management |
| SCN | Supply Chain Network |
| SEI | Software Engineering Institute |
| SEM | Structural Equations Modelling |
| SGPU | Sistema Integrado de Gestão de Pneus Usados |
| SME | Small and Medium Enterprise |
| SNA | Social Network Analysis |
| Std | Standard Deviation |
| T | Transporter |
| TRIZ | Theory of Inventive Problem Solving |
| UK | United Kingdom |
| UML | Unified Modelling Language |

| | |
|---|---|
| UNIDEMI | Unidade de Investigação e Desenvolvimento em Engenharia Mecânica e Industrial |
| URL | Uniform Resource Locater |
| US | United States |
| TRIZ | Theory of Inventive Problem Solving |
| WEEE | Waste Electrical and Electronic Equipments |
| WSJ | Wall Street Journal |
| XML | eXtensible Markup Language |
| $\mu$ | Mean |
| $\sigma^2$ | Variance |

## Abstract

This thesis proposes a methodology for modelling business interoperability in a context of cooperative industrial networks. The purpose is to develop a methodology that enables the design of cooperative industrial network platforms that are able to deliver business interoperability and the analysis of its impact on the performance of these platforms. To achieve the proposed objective, two modelling tools have been employed: the Axiomatic Design Theory for the design of interoperable platforms; and Agent-Based Simulation for the analysis of the impact of business interoperability. The sequence of the application of the two modelling tools depends on the scenario under analysis, i.e. whether the cooperative industrial network platform exists or not. If the cooperative industrial network platform does not exist, the methodology suggests first the application of the Axiomatic Design Theory to design different configurations of interoperable cooperative industrial network platforms, and then the use of Agent-Based Simulation to analyse or predict the business interoperability and operational performance of the designed configurations. Otherwise, one should start by analysing the performance of the existing platform and based on the achieved results, decide whether it is necessary to redesign it or not. If the redesign is needed, simulation is once again used to predict the performance of the redesigned platform. To explain how those two modelling tools can be applied in practice, a theoretical modelling framework, a theoretical Axiomatic Design model and a theoretical Agent-Based Simulation model are proposed. To demonstrate the applicability of the proposed methodology and/or to validate the proposed theoretical models, a case study regarding a Portuguese Reverse Logistics cooperative network (Valorpneu network) and a case study regarding a Portuguese construction project (Dam Baixo Sabor network) are presented. The findings of the application of the proposed methodology to these two case studies suggest that indeed the Axiomatic Design Theory can effectively contribute in the design of interoperable cooperative industrial network platforms and that Agent-Based Simulation provides an effective set of tools for analysing the impact of business interoperability on the performance of those platforms. However, these conclusions cannot be generalised as only two case studies have been carried out. In terms of relevance to theory, this is the first time that the network effect is addressed in the analysis of the impact of business interoperability on the performance of networked companies and also the first time that a holistic approach is proposed to design interoperable cooperative industrial network platforms. Regarding the practical implications, the proposed methodology is intended to provide industrial managers a management tool that can guide them easily, and in practical and systematic way, in the design of configurations of interoperable cooperative industrial network platforms and/or in the analysis of the impact of business interoperability on the performance of their companies and the networks where their companies operate.



**Keywords:** Business interoperability, Cooperative industrial/Supply chain networks, Axiomatic Design Theory, Agent-Based Simulation, Impact on Performance, Network effect, Case studies

## Resumo

Esta tese propõe uma metodologia para modelar a interoperabilidade de negócio num contexto de redes industriais de cooperação. O objectivo é desenvolver uma metodologia que permite desenhar plataformas de redes industriais de cooperação capazes de garantir interoperabilidade de negócio e analisar o seu impacto no desempenho dessas plataformas. Para alcançar o objetivo proposto, dois métodos de modelação foram utilizados: a Teoria Axiomática do Projeto para o desenho de plataformas interoperáveis; e a Simulação Baseada em Agentes para a análise de impacto da interoperabilidade de negócio. A sequência de utilização dos dois métodos de modelação depende do cenário em análise, ou seja, se a plataforma de rede industrial de cooperação existe ou não. Caso a plataforma de cooperação não existir, a metodologia sugere em primeiro lugar a utilização da Teoria Axiomática do Projeto para desenhar configurações de plataformas de redes industriais de cooperação interoperáveis, e depois a utilização da Simulação Baseada em Agentes para analisar ou prever o desempenho de interoperabilidade de negócio e operacional das configurações desenhadas. Caso contrário, deve-se começar por analisar o desempenho da plataforma existente e baseado nos resultados, decidir se é necessário redesenhá-la ou não. Caso seja necessário redesenhar, deve-se utilizar novamente a simulação para prever o desempenho da plataforma redesenhada. Para explicar a forma como os dois métodos de modelação podem ser aplicados na prática, uma *framework* teórica, um modelo teórico baseado na Teoria Axiomática e um modelo teórico de Simulação Baseado em Agentes são propostos. A metodologia proposta e os respetivos modelos teóricos são validados através de um caso de estudo sobre uma rede de cooperação Portuguesa de logística inversa (rede Valorpneu) e um caso de estudo sobre um projeto de construção Português (rede de construção da barragem Baixo Sabor). Os resultados da aplicação da metodologia proposta aos dois casos de estudo sugerem que de fato a Teoria Axiomática do Projeto pode contribuir efetivamente no desenho de plataformas de redes industriais de cooperação interoperáveis e que a Simulação Baseada em Agentes fornece um conjunto de ferramentas efetivas para analisar o impacto da interoperabilidade de negócio no desempenho dessas plataformas. No entanto, estas conclusões não devem ser generalizadas uma vez que apenas dois casos de estudo foram realizados. Em termos de relevância para a teoria, esta é a primeira vez que o efeito rede é abordado na análise do impacto da interoperabilidade de negócio no desempenho de empresas ligadas em rede e também a primeira vez que uma abordagem holística é proposta para desenhar plataformas de redes industriais de cooperação interoperáveis. Em relação às implicações práticas, a metodologia proposta visa fornecer aos gestores industriais uma ferramenta de gestão que pode guiá-los de forma fácil, prática e sistemática no desenho de configurações de plataformas de redes industriais de cooperação interoperáveis e/ou na análise do impacto da interoperabilidade de negócio no desempenho das suas empresas e as redes onde as mesmas operam.



**Palavras-chave:** Interoperabilidade de negócio, Redes industriais de cooperação, Teoria Axiomática do Projeto, Simulação Baseada em Agentes, Impacto no desempenho, Efeito rede, Casos de estudo

# Chapter 1 Introduction

This chapter presents a general introduction to the PhD thesis, describes the problem background, and provides rationale and motivation for the research. It defines the Research Questions and their underlying propositions and sets the research objective. It also positions the research within the Operations Management arena and, explains the methodological approach adopted throughout this research.

*"The more valuable to a person is the result of its action, the more likely he is to perform the action"*
*(Emerson 1976) (p. 340)*

## 1.1 Problem background

Industrial networks are important for the development of any economy. Within this context, manufacturing and construction are referred to as two dominant sectors in the global economy. Their economic importance are evident: for instance, manufacturing is the driving force of Europe's economy, contributing over €6.553 billion in Gross Domestic Product (GDP) and providing more than 30 million jobs; it covers approximately 230 000 companies with 20 or more employees, from more than 25 different industrial sectors, and generates annually over €1.535 billion of value added (Flegel 2006, EPoSS 2013). Regarding to the European construction industry, it supports the EU economy by providing it with buildings and infra-structure that supports all other economic and social activities. It is the largest economic activity representing over 10% of EU GDP and the biggest industrial employer with about 20 million workers while another 20 million are indirectly affected by its activity (von Bose and Fischer 2013).

However, it is widely recognised that the industrial sector is facing increasingly difficult challenges over the past few years, not only in Europe but also in other countries. As the EU and the world economy went through a deep financial economic crisis in 2008 and 2009 (European-Commission 2010), the European industry output has decreased around 20%, and global completion is dramatically growing (Filos 2011). According to Pashev et al. (2013), the EU manufacturing declined further to around 15% of overall gross value added in 2012. From 2007 to 2010, the European manufacturing productivity as a whole, decreased by more than 1% annually. This contrast with the United States (US) manufacturing productivity, which grew by over 4% a year during the same period (European-Commission 2013). Within this context, today's manufacturing and construction companies are forced to continuously look for more innovative ways to enhance competitiveness. In this direction, one of the approaches that has been widely adopted is cooperation among network of companies.

Cooperation can be defined as the "teammates behavioural decisions about whether to act in promoting the objectives of the team" (Sinclair 2003) or as "the extent to which individual members work together toward the accomplishment of team-level goals" (Yu and Cable 2011). It is an essential process through which team effectiveness can be actualised and improved as it was found that if members of a group cooperate, they perform better (Puck and Pregernig 2014). For example, Grilo and Jardim-Goncalves (2010) argue that cooperation enables companies to obtain mutual benefits by sharing or partitioning work. van Fenema and Loebbecke (2014) acknowledge that inter-company cooperation enables value creation that exceeds what companies can achieve on their own, which is to say that it enables to create synergy among them. Kaminski et al. (2008) observed that cooperation with suppliers and customers for Small and Medium Enterprises (SMEs) could promote new product development.

A study carried out by Zeng et al. (2010) found that there are significant positive relationships between inter-company cooperation, cooperation with intermediary institutions, cooperation with research organisations and innovation performance. A cooperative industrial network is referred to as a set of three or more companies 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 time interval in order to achieve common set of objectives, and make use of Information and Communication Technologies (ICTs) to coordinate, develop and support their activities (Chituc et al. 2008). As a result of that changing business context to a cooperative and network-driven economy, competition has been occurring not only between companies but between Supply Chains (SCs) and networks (Mills et al. 2004). Min and Zhou (2002) also pointed out that individual companies no longer compete as independent entities with unique brand names, but rather as integral parts of SC links. The paradigm is also supported by Vernadat (2010), who advocates that none of business entities or organisations be they industrial firms, service companies, public organisations or government agencies and institutions can operate in isolation anymore. But the recognition of this paradigm is not new. For instance, Håkansson and Snehota (1989) discussed twenty five years ago: "no business is an island". Also, Christopher (1992), twenty two years ago, emphasised: "competition in the future will not be between individual organisations but between competing SCs".

However, due to the fact that over the years most companies created their own applications and designed their own set of services (Guédria et al. 2013), focusing their attention to the effectiveness and efficiency of separate business functions (Min and Zhou 2002), a major issue when it comes to operating in cooperative industrial networks is the existence of different business goals, different organisational structures, different business processes and management approaches, different communication languages, different human and organisational approaches, lack of trust, confidentiality issues, different cultures or methods of work, different decision-making approaches, different legal bases (legislations and regulations are not the same, data protection legislations may be different), high system heterogeneity, legacy systems, multiple sources of data, various data formats, heterogeneity of ICT solutions from different vendors (computer networks, operating systems, application serves, database systems, etc.), syntactic and semantic heterogeneity of information, semantic gap, i.e. different interpretations of the same concept, database schema integration with naming problems (e.g. homonyms and synonyms), different mechanisms to protect Intellectual Property Rights (IPR), etc. (see: (Vernadat 2010)).

As pointed out by Whitman and Panetto (2006), one of the main barriers to an effective interoperation among companies arises from the fact that systems that support the functions in many companies were created independently. The concept of business interoperability thus emerges as a key solution for overcoming those problems and to contribute for a better interoperation among networked companies. Business interoperability can be defined as *"a field of activity with the aim to improve the manner in which organisations, by means of ICTs, interoperate with other organisations, or with other business units of the same organisation, in order to conduct their business"* Li et al. (2008). Put it simple, it refers to the property of two or more business units (be they of the same organisation or different organisations) which enables them to work together (e.g. (Gottschalk 2009)). Hence, in a simple definition, one can say that business interoperability refers to the philosophy or practices that focus on the improvement of the way in which two or more companies, as well as their internal systems, work together. In other words, it aims at removing the barriers that difficult the interoperation between two or more companies, which implies that instead of focusing on the internal business processes of a company, the managers should focus on the relationships that their companies have with their business partners. Therefore, business interoperability should be viewed as a property of business relationships. This is supported, for instance, by Legner and Wende (2006) who advocated that business interoperability describes the business relationships between a company and its partners, e.g. customers, suppliers or service providers.

The value proposition of business interoperability to manufacturing systems has been widely discussed in the literature. For example, the Enterprise Interoperability Cluster (2008) stresses that "today an enterprise's competitiveness is to a large extent determined by its ability to seamlessly interoperate with others. Cornu et al. (2012) point out that "since business interoperability is a key factor for successful partnerships between companies and for high satisfaction levels of customers, it is crucial for companies to become able to manage their interoperability, i.e. to detect problems, analyse situations, improve, and generalize improvement actions". Gong and Janssen (2013) assert that "today's fast changing environment requires interoperability to ensure that changes can be quickly implemented". Jardim-Goncalves et al. (2012c) point out that "business interoperability is a high-impact productivity factor within both the private and public sector, affecting the overall quality, yield time, and cost of transactions, as well as the design of manufacturing operations and digital public services". According to Li et al. (2008), "business interoperability enables companies to, for instance, build partnerships, deliver new products and services, and/or become more cost efficient". To Panetto et al. (2012), "the more entities are interoperable the more the execution time of process activities is reduced, and a better interoperability of entities usually implies better business satisfaction since they will spend less time in non-added value activities for seamless operation".

Interoperable here is referred to as 'able to interoperate", according to the Webster Dictionary. Interoperability can also deliver value by reducing the risk that companies must encounter in business. One example is that interoperability can significantly reduce the risk of information systems investment by reducing or eliminating hardware, software and communications compatibility issues (Li et al. 2008). Another example is when companies use interoperability for inventory visibility aiming at reducing the "*bullwhip effect*" (for managing forecast-driven SCs) (Li et al. 2008).

Business interoperability is considered a challenge conditioning the success of the companies' deployment (Panetto et al. 2012). The lack of interoperability could disturb the creation of new markets, networks, can diminish innovation and competitiveness of business groups (Agostinho 2012) and may disturb creation of collaborative work and networked systems (Jardim-Goncalves *et al.* 2012c). To Ray (2002), "the lack of interoperability between systems is becoming one of the principal barriers to achievement the time-to-market demanded by today's competitive environment". Although the discussion on business value of business interoperability seems to be consensual, only very few empirical studies have been conducted on the analysis of its impact on the performance of organisations, mainly in the context of cooperative industrial networks. Following, an overview of those studies is provided.

A first study prepared for the National Institute of Standards and Technology (NIST) by Research Triangle Institute (RTI), to assess the costs of imperfect business interoperability to the US automotive SC, estimated that inadequate business interoperability imposes at least US $1 billion per year on the members of the US automotive SC (Brunnermeier and Martin 1999, Brunnermeier and Martin 2002). The majority of these costs are attributable to the time and resources spent correcting and recreating data files that are not usable by those receiving the files (Brunnermeier and Martin 1999). The study also concluded that imperfect interoperability delays the introduction of new models by at least two months.

A second study prepared for NIST by RTI International and the Logistic Management Institute, to identify and estimate the efficiency losses in the US capital facility industry resulting from inadequate business interoperability amongst Computer-Aided Design (CAD), engineering and software systems, estimates the cost of inadequate business interoperability in the US capital facilities industry to be US $15.8 billion per year, representing between one and two per cent of industry revenue (Gallaher et al. 2004). The third study, also prepared for the NIST by RTI International, estimated the economic impact of inadequate integration to be in excess of US $5 billion for the automotive industry, and almost US $3.9 billion for the electronics industry (White et al. 2004).

A more recent study, conducted by Loukis and Charalabidis (2013), to investigate the effect of adopting three types of information system**s** interoperability standards (industry-specific, proprietary and eXtensible Markup Language (XML[1])-based ones) on the four important perspectives of business performance proposed by the balanced scorecard approach (financial, customers, internal business processes, learning and innovation), concludes that all three examined types of information system interoperability standards increase considerably the positive impact of a firm's ICT infrastructure on the above four perspectives of business performance. According to this study, the adoption of industry-specific interoperability standards has the highest positive effects, while XML-based and proprietary standards have similar lower positive effects. Furthermore, these effects of the industry-specific information system interoperability standards are quite strong, as they are of similar magnitude with the corresponding effects of the degree of development of firm's intra-organisational/internal information systems, and of higher magnitude than the corresponding effects of the degree of development of firm's e-sales information systems (Loukis and Charalabidis 2013).

There are also evidences of the impact of business interoperability from the aeronautic industry. According to Matlack (2006), in 2006, Airbus® assumed that the design software used at different Airbus factories wasn't compatible. As a result, workers discovered that the pre-assembled bundles containing hundreds of miles delivered from a German factory to the assembly line in France didn't fit properly into the plane. The consequence of this business interoperability problem was 2-year delay in the A380 plane manufacturing and $6 billion in cost. Giving the significance of such impacts, the CRESCENDO[2] project addressed the Vision 2020 objectives for the aeronautical industry's Strategic Research Agenda. The expected contributions are the achievement of 10% reduction in the development lifecycle duration and cost, 50% reduction in rework, and finally, 20% reduction in the cost of physical tests (CRESCENDO 2009).

[1] XML – eXtensible Markup Language (www.w3.org/XML/)
[2] CRESCENDO – Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation

## 1.2 Rationale for this research

Bearing in mind the value proposition of business interoperability as well as its managerial challenges discussed earlier, different initiatives have been carried out with the aim of establishing a solution that can be used as a reference to deal with business interoperability challenges and to improve the ability of connected systems (computers, software, business units, etc.) to interoperate. In addition to the studies already mentioned earlier, other important contributions were analysed [The Quantification of Interoperability (Mensh *et al.* 1989), Levels of Information System Interoperability (LISI) (DoD 1998), Organisational Interoperability Maturity Model (OIMM) (Clark and Jones 1999), NATO C3 Technical Architecture (NATO 2003), The Levels of Conceptual Interoperability Model (Tolk and Muguira 2003), IDEAS[3] Interoperability Framework (IDEAS 2003d, IDEAS 2003c, IDEAS 2003e), European Interoperability Framework (EIF) (iDABC 2004, ISA 2011), ECOLEAD[4] (Romero et al. 2006), Business Interoperability Framework (BIF) (ATHENA 2007), The ATHENA[5] Interoperability Framework (Berre et al. 2007), Interoperability Classification Framework (Panetto 2007), Barriers Driven Methodology for Enterprise Interoperability (Chen and Daclin 2007), Approach for Enterprise Interoperability Measurement (Chen et al. 2008b), Maturity Levels for Interoperability in Digital Government (Gottschalk 2009), Levels of Conceptual Interoperability Model (Wang et al. 2009), Sustainable interoperability: The future of Internet based industrial enterprises (Jardim-Goncalves *et al.* 2012c), Business Interoperability Quotient Measurement Model (BIQMM) (Zutshi et al. 2012), Systematisation of Interoperability Body of Knowledge: the foundation for Enterprise Interoperability as a science (Jardim-Goncalves *et al.* 2012b), Reference framework for enhanced interoperable collaborative networks in industrial organisations (Jardim-Goncalves *et al.* 2012a), Maturity model for enterprise interoperability (Guédria et al. 2013), Maturity Model for Interoperability Potential Measurement (Campos et al. 2013), An interoperability model for ultra large scale systems (Rezaei et al. 2014b), Developing enterprise collaboration: a methodology to implement and improve interoperability (Daclin *et al.* 2014), A step-by-step methodology for enterprise interoperability projects (Chalmeta and Pazos 2014), The interoperability force in the ERP field (Boza *et al.* 2015), etc.].

Although these works contributed to the development of a remarkable amount of body of knowledge, a comprehensive solution to deal with business interoperability is still missing, mainly in a context of complex industrial networks. For instance, Grilo et al. (2013) pointed out that although there is a considerable effort in interoperability standards development, there still exists today a failure to

[3] IDEAS – Interoperability Development for Enterprise Application and Software
[4] ECOLEAD – European Collaborative Networked Organisations Leadership Initiative
[5] ATHENA – Advanced Technologies for interoperability Heterogeneous Enterprise Networks and Applications

deliver seamless Architecture, Engineering and Construction (AEC) interoperability. Corella et al. (2013) also agree that there are few real practical examples of an SC interoperability framework that can be used as a reference. Indeed, the literature reveals that there are still significant research gaps that need to be addressed.

First, much of the existing researches have focused: on the characterisation of the dimensions of business interoperability and their related sub-dimensions (e.g. (ATHENA 2007, Panetto *et al.* 2012, Zutshi *et al.* 2012)), or on the definition of business interoperability maturity models for evaluating the levels of interoperability between systems (e.g. (DoD 1998, ATHENA 2007, Campos *et al.* 2013, Guédria *et al.* 2013)). Second, most of those works have focused on the study of individual dimensions of business interoperability, e.g. information systems (e.g. (DoD 1998, Loukis and Charalabidis 2013)), semantic (Luis 2009) or on the integration of only few dimensions, e.g. media, languages, standards, requirements, environment, procedures, and human factors dimensions (e.g. (Mensh *et al.* 1989)), business, knowledge and ICT dimensions (e.g. (IDEAS 2003e)), organisational, semantic and technical dimensions (e.g. (iDABC 2004, Vernadat 2010)), business, process, services and data dimensions (e.g.(Chen 2006b)), technical, syntactic, semantic, and organisational dimensions (e.g. (Rezaei et al. 2014b)). Whereas nowadays business networks pose additional challenges to building interoperable business platforms, a holistic approach is needed in order to capture all the dimensions responsible for the interaction among networked companies. This is important because in the context of business networking, interoperability is to cover not only strategic, organisational, operational, technical and sematic aspects of interoperability, but also the factors related to the products and services, knowledge management, and network minute details. For example, Corella et al. (2013) agree that frameworks with a holistic view must be designed to guide the process of improving business interoperability.

The main purpose of an interoperability framework is to provide an organising mechanism so that concepts, problems and knowledge on enterprise interoperability can be represented in a more structured way (Chen *et al.* 2008a). Vernadat (2007) also highlights that interoperable business systems (be they SCs, extended enterprises, or any form of virtual organisations) must be designed, controlled, and appraised from a holistic and systemic point of view. Nevertheless, even those works that have explored the issues of business interoperability in a more holistic perspective (e.g. (ATHENA 2007, Zutshi *et al.* 2012, Rezaei *et al.* 2014c)) did not provide an explanation on how to simultaneously integrate the various dimensions of business interoperability nor how they relate to each other; and more importantly, did not provide a guideline on how to analyse network effect, i.e. how a business interoperability impact in dyadic business relationships can affect the performance of the neighbour dyad relationships and the network that the dyads belong to (e.g. (Brunnermeier and

Martin 1999, Brunnermeier and Martin 2002, Gallaher et al. 2004, Loukis and Charalabidis 2013)). A gap exists in knowledge on how to develop a holistic approach that supports the modelling of business interoperability in a context of complex business networks (e.g. cooperative industrial networks). In particular, the issues on how to design and redesign interoperable business platforms and how to analyse the impact of business interoperability on the performance of these platforms, both in a context of complex industrial networks, still have no answer. For instance, Panetto et al. (2012) highlight the need of real tools (e.g. design and simulation tools) for modelling large-scale systems such as cooperative business networks as one of the grand challenges in nowadays manufacturing systems. These gaps therefore form the rationale for this thesis.

## 1.3 Research questions and propositions

As a result of exploring and defining the rationale for this thesis, two Research Questions (RQs) were formulated:

***RQ1: How can we design business platforms that are able to deliver business interoperability in a context of complex cooperative industrial networks?***

This research question seeks to shed light a debate on how to design interoperable business platforms, not in a context of dyad business relationships but in a context of complex cooperative industrial networks. Specifically, it is intended to explore the appropriateness of existing design methods for designing different configurations for interoperable business platforms and then choose the most suited, according to the research question addressed. As the aim is to figure out a method that enables an effective alignment of all the dimensions of business interoperability, their decomposition to more detailed levels, and the identification of the corresponding design solutions in each level of decomposition, the Axiomatic Design theory, introduced by Suh (1990, 2001) was chosen. Thus, the following proposition was set.

***Proposition 1: The Axiomatic Design Theory can effectively contribute in the design of interoperable business platforms to support the complexity of cooperative industrial networks.***

***RQ2: How can we analyse the impact of business interoperability on the performance of companies in a context of complex cooperative industrial networks?***

This research question attempts to explore an important problem in business networks: how do dyadic business relationships affect the network of companies to which the two companies in the dyad belong. The main rationale behind this research question is that in order to fully understand how business interoperability affects the performance of companies, in a context of cooperative industrial networks, the network effect must be addressed. As concluded in the previous section, the main research gap regarding the existing works on the analysis of the impact of business interoperability on the performance of companies is that they did not address how the impact of business interoperability spreads over the network, that is, they did not take into account the network effect. This implies that the "network approach" will be adopted, which means that the relationships are viewed as part of a broader network structure, rather than as isolated entities (see e.g. (Håkansson and Snehota 1995)). As cooperative industrial networks consist of different and heterogeneous interacting agents (companies) with different behaviours, with different decision-making rules, and with different ability to influence the neighbour agents, it was realised that the dynamic and complexity of such networks need to be explored in a consistent and rational manner.

Thus, traditional approaches such as analytical modelling, Discrete Event Simulation (DES), Monte Carlo Simulation, Systems Dynamics are not considered as suitable to capture such complex interaction among a number of agents in the network, the non-linear impact of business interoperability over the network (e.g. a business interoperability problem in the network might have different impact in different agents), and the way business interoperability impact in one or more agents can spread to the neighbour agents, referred earlier as network effect. As highlighted by Panetto et al. (2012), to improve the level of business interoperability of their systems and applications, enterprises must have a suitable methodology to evaluate it, also appropriate for the assessment of the interoperability of the networked enterprise environment where they will operate. Among the various methods available for this, Agent-Based Simulation (ABS) (e.g. (Gilbert and Terna 2000, Gilbert 2008, Macal and North 2010, Railsback and Grimm 2011, Rand and Rust 2011, Helbing 2012, Held *et al.* 2014)) was chosen. This modelling tool has been widely used by researchers from different areas of knowledge to understand and analyse complex patterns that results from the interaction of many individuals within an environment (Rand and Rust 2011), as are the cases of cooperative industrial networks. Therefore, the following proposition was made:

***Proposition 2: Agent-Based Simulation provides an effective set of tools for analysing the impact of business interoperability on the performance of companies in a context of complex cooperative industrial networks.***

Offering answers to both of these research questions is of critical importance to this thesis, as the answers will contribute to both business interoperability and Operations Management (OM) research. Further rationales for choosing the Axiomatic Design Theory as the method for designing interoperable cooperative industrial network platforms and ABS for analysing the impact of business interoperability on the performance of these platforms are provided in Section 4.2.6 and Section 4.4.5, respectively.

## 1.4 Objective

By formulating the two research questions, this thesis addresses the issue of modelling business interoperability in a context of complex cooperative industrial networks with the aim of generating a more comprehensive picture of the impact of business interoperability phenomenon on the performance of companies, in a context cooperative networked environment. Specifically, the objective is to develop a methodology that can be used to design and redesign configurations of interoperable business platforms and to analyse the impact of business interoperability on the performance of these platforms, in contexts of complex cooperative industrial networks.

An important point to highlight here is that the aim of this thesis is not to provide "the solution" to the problem of lack of business interoperability among cooperative networked companies, rather to develop theoretical models that help to understand the problem of the impact of business interoperability on the performance of cooperative industrial networks and therefore contribute to the definition of ways to overcome them, through the redesign of the current cooperation arrangements.

## 1.5 Methodological approach

Considering that this research follows a qualitative deductive explanatory approach (see Section 7.5), the applied methodology (or research sequence) was designed according to a method generally adopted in this type of research. Specifically, the methodology employed to drive this research consists of the following four phases:

- ***Phase 1 – Problem statement***: in this phase the area of interest has been defined as business interoperability. Having defined the area of interest, an in-depth literature review on this research field has been carried out in order to first identify the research gaps, set the objective and the research questions for the research, and then characterise the dimensions of business interoperability that must be taken into account in the modelling of interoperable cooperative industrial network platforms. Accordingly, two relevant research gaps have been identified, which were stated in the form of the two research questions set in Section 1.3. Also, the literature on business relationships and networks was collected and analysed in order to find out which theoretical perspective is more appropriate to address the Research Question 2. As a result, the IMP network approach has been assumed to be the most appropriate theoretical perspective to achieve such objective (see Section 2.2.4). Considering the nature of the research questions posed and the propositions set, a third literature review has been carried out to identify which method is more appropriate for designing interoperable cooperative industrial networks and for analysing the impact of business interoperability on the performance of companies, in a context of cooperative industrial networks. Accordingly, the Axiomatic Design Theory has been assumed to be appropriate to address the research question concerned with the design of interoperable industrial network platforms (Proposition 1) and ABS to address the research question concerned with the analysis of the impact (Proposition 2) (see Section 1.3);

- ***Phase 2 – Development of the proposed methodology***: in this phase, the proposed methodology has been developed. Taking into account that the research is proposition-driven (see Section 1.3), two theoretical models have been developed, one to guide the researcher in the design of configurations of interoperable industrial network platforms and another in the analysis of the impact of business interoperability on the performance of those platforms. Before starting the fieldwork, the two proposed theoretical models have been tested through application scenarios in order to ensure that they were robust enough to be applied in real business contexts (see Chapter 6). This was been achieved by reviewing the theoretical Axiomatic Design model with two experts on the Axiomatic Design Theory from the UNIDEMI[6] research centre, and by reviewing the theoretical ABS model with two experts on Agent-Based Modelling (ABM), one from UNIDEMI and another from an IT Portuguese company.
- ***Phase 3 – Data collection***: the third phase of the research consisted in collecting data to explore the two research questions and to empirically validate the proposed methodology. Grounded on the type of research questions set, which are of how type, it was decided to adopt a case study research strategy. Face-to-face interviews and documents were defined as the methods for collecting data in the two case studies carried out (see Section 7.4.5, Section 8.2.5 and Section 8.3.7);
- ***Phase 4 – Analysis of the findings***: in the last phase of the research, a within-case analysis of each case study has been carried out, along with a horizontal comparison of the findings achieved in each case (i.e. cross-case analysis). Grounded on these analyses, conclusions have been drawn about the research questions and propositions set (see Chapter 9).

## 1.6 Outline of the thesis

This thesis consists of nine chapters, which are organised as follows: Chapter one has been the introduction chapter, which has stated the problem background, the rationale for this research, the research questions to be addressed as well as the propositions for addressing these research questions,

[6] UNIDEMI – Research and Development Unit for Mechanical and Industrial Engineering (http://www.unidemi.com/)

and the objective of the research. It also describes the methodological approach employed to address the research questions and achieve the research objective.

In Chapter two, the theoretical background in relation to business networks and relationships is described, with the focus on manufacturing and construction networks. The chapter begins by describing business relationships, with the emphasis on the business relationship perspective, the initial IMP interaction model, the type of business relationships and the characteristics of business relationships. Then, the main topics related to the network theory and analysis (network complexity, network effects) are reviewed before explaining what are business networks, the approaches used to study business networks (e.g. the IMP network approach) and criticisms of these approaches. The chapter ends with an overview on manufacturing and construction networks, mainly on managerial challenges faced by companies that operate in these two types of business networks.

Chapter three reports the state of the art on business interoperability research. The chapter starts to provide an historical evolution on the concept of interoperability, and explains how this concept has evolved from a technical to a business perspective. Following, the chapter discusses the fundamental concepts of business interoperability and compare them to related topics such as enterprise integration, compatibility, coordination and Supply Chain Management (SCM). Last, the chapter presents an extensive literature review on the existing (business) interoperability researches. These works are grouped into three categories: (1) business interoperability models and frameworks, (2) business interoperability maturity models, and (3) empirical studies on the impact of business interoperability.

Chapter four reviews the methods for modelling complex systems and networks makes an horizontal comparison between them in order to explain the rationale for choosing axiomatic to address the Research Question 1 (i.e. to design configurations of interoperable cooperative industrial network platforms) and ABS to address the Research Question 2 (i.e. to analyse the impact of business interoperability on the performance of cooperative industrial networks). The chapter also presents the areas of application of these two methods.

Chapter five describes in detail the methodology proposed to achieve the research objective set in Section 1.4 and to address the two research questions mentioned above. The chapter first explains the storyline of the various steps in the development of the proposed methodology. Then the proposed methodology is explained in detail. The relevant dimensions of business interoperability as well as their sub-dimensions are also characterised in this chapter. The chapter ends with the description of the proposed theoretical Axiomatic Design model and the theoretical ABS model.

Grounded on the methodology explained in Chapter five, Chapter six demonstrates the applicability of such methodology through an application scenario to implement Reverse Logistics (RL) in a context of automotive industry. First, the theoretical Axiomatic Design model is used to design a configuration for the automotive network considered, and then the theoretical ABS model is applied to estimate the impact of the designed configuration on the performance of that network.

Section seven covers the aspects of the research methods that have been applied to design this research. The chapter discuss the philosophical position of this research, the research approach, the research strategy and the steps of the research design.

Chapter eight reports the empirical findings by firstly stating the purpose of the two case studies carried out in the ambit of this thesis. Then, the two case studies are discussed, which explore the applicability of the Axiomatic Design Theory to design configurations of interoperable cooperative industrial network platforms and ABS to analyse the impact of business interoperability on the performance of these platforms. The chapter ends with a cross-case analysis on the contribution of the proposed methodology to model the two cooperative industrial networks studied in this thesis and consequently to address the two research questions set in Section 1.3.

Finally, Chapter nine marks the end of the thesis. First, it draws the conclusions about the research questions and propositions, and following discusses the theoretical and managerial implications. Then, it is reported the limitations of this thesis and future research are suggested based on these limitations.

## 1.7 Summary

This chapter provides an introduction to this thesis. The problem background and the rationale for this research has been discussed in detail and grounded on this discussion it was identified two relevant research gaps: (1) existing works do not explain how to design interoperable cooperative industrial network platforms, taking into account all relevant dimensions of business interoperability, and (2) existing works do not explain how to analyse the impact of business interoperability on the performance of networked companies, taking into account the network effect (e.g. how a business interoperability problem between two companies of a dyad can affect the performance of the other companies in the network). To address these two research gaps, two research questions raised: one to address the gap regarding the design of interoperable cooperative industrial network platforms; and another to address the gap related to the analysis of the impact of business interoperability.

# Chapter 2 Business relationships and networks

This chapter describes the theoretical background in relation to business networks and relationships, with the focus on manufacturing and construction networks. First, the chapter describes business relationships, with the emphasis on the business relationship perspective, the initial IMP interaction model, the type of business relationships and the characteristics of business relationships. Then, the main topics related to the network theory and analysis (network complexity, network effects) are discussed before explaining what are business networks, the approaches used to study business networks (e.g. the Industrial Marketing and Purchasing network approach) and criticisms of these approaches. The chapter ends with an overview on manufacturing and construction networks, mainly on managerial challenges faced by companies that operate in these two types of business networks.

*"The performance and effectiveness of organisations operating in a network, by whatever criteria these are assessed, become dependent not only on how well the organisation itself performs in interaction with its direct counterparts, but also on how these counterparts in turn manage their relationships with third parties. An organisation's performance is therefore largely dependent on whom it interacts with" (Håkansson and Snehota 1989) (p. 191)*

## 2.1 Business relationships

### 2.1.1 The business relationship perspective

The study of business relationships can be traced to early civilizations, as people tried to understand the emergence of various institutional arrangements associated with the buying and selling of products and services, including the emergence of markets, retail and wholesale institutions, and international trading systems (Wilkinson 2001). This need to understand business relationships emerged towards the end of 1970s, when researchers realised that focusing separately on industrial buyers and sellers was not sufficient for understanding exchange behaviour between these parties (Kristian K. Möller and David T. Wilson 1995). For example, Johnston (1981) (cited in (Ritter et al. 2004), p. 175) asserted that "focusing on any single company cannot provide a any great understanding of the processes of business".

A business relationship can be defined as a process where two companies or other types of organisations "form strong and extensive social, economic, service and technical ties over time, with the intent of lowering total costs and/or increasing value, thereby achieving mutual benefit" (Anderson and Narus 1991) (cited in (Ritter et al. 2004), p. 176). Business relationships can occur at the dyad level (e.g. a single supplier and buyer relationship) or at the network level (e.g. a set of relationships among upstream and downstream companies in a SC network) (see (Ritter and Gemünden 2003)).

The core of the relationship perspective is that the traditional economics perspective of free markets, pure competition (companies compete as isolated systems against each other), with unconnected and adversarial single transactions, basically co-ordinated by price mechanisms, is not considered adequate to explain inter-company phenomenon (Grilo 1998). Rather, the relationship perspective advocates that business relationships are mainly complex and rich social constructs between people in companies, which evolve over time (see e.g. (Håkansson 1982, Grilo 1998)). The implications of this perspective are twofold: Firstly, the unit of analysis is a dyad (i.e. one-to-one linkage) rather than the focal organisation. Secondly, in order to understand the processes of business, one needs to analyse the structure, and processes dynamics of the business relationship in which such processes of business will be embedded (see (Grilo 1998)). However, although recognising the significance of these implications, in this thesis the relationship perspective is not considered enough to explain business interoperability phenomenon within a context of complex industrial networks because of its limitation to a dyad.

### 2.1.2 The initial IMP interaction model

The first generation interaction model was developed in the 80s by the Industrial Marketing and Purchasing (IMP) group (see e.g. (Håkansson 1982)). The model emerged as a challenge to the traditional ways of examining industrial marketing and purchasing, which views the markets or industries as constituted by independent companies operating mainly through market competition (see (K. Möller and D. T. Wilson 1995)). Instead of analysing the industrial markets in the traditional way, researchers in/of the IMP group realised that (see e.g. (Håkansson 1982)):

1. The emphasis should be on the importance of the relationship which exists between buyers and sellers in industrial markets;
2. It was necessary to examine the interaction between individual buying and selling companies where either company may be taking the more active part in the transaction;
3. Buyers and sellers know each other well and are aware of any movements in either the buying or selling market;
4. An understanding of industrial markets can only be achieved by the simultaneous analysis of both the buying and selling sides of relationships. The focus of the interaction approach is generally on a two-party relationship, but it can also be applied to a several party relationship.

By focusing on the four components that describe and influence the interaction between buying and selling companies, the model serves a suited starting-point for understanding business-to-business settings. However, its application in a business network context may be limited, as it does not capture the effect of connectedness among dyadic relationships. The components of this interaction model as well as the relations among them are illustrated in Figure 2.1.

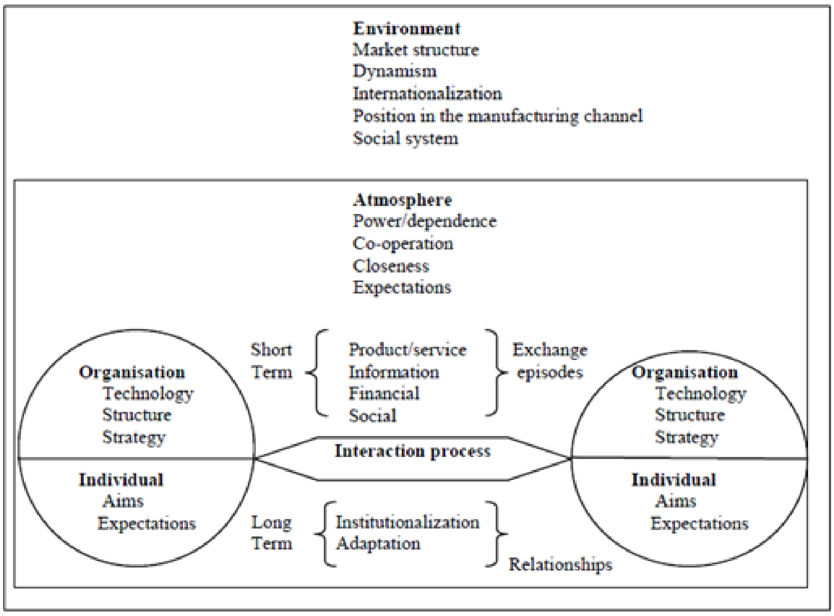



Figure 2.1: The initial IMP interaction model (in Håkansson (1982))

As shown in Figure 2.1, the marketing and purchasing of industrial goods is seen as an interaction process between two parties within a certain environment. The components of the initial IMP model are (Håkansson 1982):

- The interaction process;
- The participants involved in the interaction;
- The environment in which the interaction takes place;
- The atmosphere affecting and affected by the interaction.

Regarding to the first component, *the interaction process*, it is important to distinguish between the individual episodes in a relationship, i.e. the day-to-day exchanges (e.g. the placing or delivering of a particular order), and the long-term aspects of that relationship which both affects and may be affected by each episode. There are four components which are exchanged: products and services, information, financial and social (Håkansson 1982).

The characteristics of the product and services exchanged are likely to have a significant effect on the relationship as a whole because the exchange of product and services is often the core of the exchange. Information exchange is also an important component in relationships. Aspects such as the content (technical, commercial, or managerial), the width and depth, the personal channels, and the formality are all characteristics of the information exchange, which may contribute to the relationship. Another important component of relationships is financial exchange. The quantity of money exchange is an indicator of the economic importance of the relationship between companies.

In addition, the need to exchange money from one currency to another and the uncertainties in these exchanges over time must be considered. Finally, social exchange is perceived by the IMP model as playing an important role in overcoming short-term difficulties between the two parties and in maintaining a relationship in the periods between transactions. Moreover, individuals in business relationships tend to create personal relationships, which seem to be an important factor in the development of inter-organisational ties. Building trust is one of the important aspects to the social process and development of the relationships, but it requires time and must be based on personal experience, and on the successful execution of the three other components of exchange (see: (Håkansson 1982, Grilo 1998)).

Regarding to the second component of the IMP model, *the interacting parties*, it is considered that the process of interaction and the relationship between the organisations depends not only on the components of the interaction but also on the characteristics of the parties involved. Both the characteristics of the two companies and the individuals who represent them are considered. At the companies' level, the factors to be considered refer to the characteristics of the companies, e.g. technology, organisational size, structure, strategies and objectives, organisational experience, and available resources.

At the individuals' level, it is considered that at least two individuals, one from each company, are involved in a relationship. Individuals from different functional areas, at different levels in the hierarchy and fulfilling different roles might be involved in inter-company personal interactions. These individuals exchange information, develop relationships and build up strong social bonds which influence the decisions of each company in the business relationship. Such relationship between the individuals may be constrained by the fact that they may have varied personalities, experience, age, and motivations (Håkansson 1982).

In relation to the third component, *the interaction environment*, it is stressed that the interaction between the two companies cannot be analysed in isolation, but must be considered in a wider context. This wider context includes aspects such as market structure (the concentration of both buyers and sellers and the stability or rate of change of the market and its constituent members), dynamism (the degree of dynamism within a relationship and in the wider market), internationalisation (the internationalisation of the buying or selling market), position in the manufacturing channel (the position of an individual relationship in an extended “channel” stretching from primary producer to final consumer), and the social system (the characteristics of the wider environment surrounding a particular relationship) (Håkansson 1982).

In the fourth and last component, *the atmosphere*, it is considered that the atmosphere is a product of the relationship, which results from the combination of the other components of the interaction process, i.e. the exchange episodes, the characteristics of the companies, the adaptations and institutionalisation, and the context in which it is involved (Grilo 1998) (p. 62). The relationship is influenced by the characteristics of the parties involved and the nature of the interaction itself. This is in turn a function of the technology involved and the environment within which the interaction takes place. Organisational strategy can also affect both the short-term episodes and the long-term relationships between the parties. The atmosphere can be described in terms of the power-dependence relationship which exists between the companies, the state of conflict or co-operation and overall closeness or distance of the relationship as well as by the companies’ mutual expectations (Håkansson 1982). Atmosphere provides the way to understand the development of relationships, though its full understanding also requires the analysis of individual episodes and the interaction process. Thus, there is a very high degree of interdependency between the individual variables, meaning that sometimes it is difficult to discern individual effect (Grilo 1998).

Acknowledging the limitations of the initial IMP interaction model described above, i.e. its limitation to a single dyad relationship, the IMP group modified it, considering that the dyad relationships should be embedded in a network context (see e.g. (Håkansson 1989, Håkansson and Snehota 1995)). The second model as well as the added components will be discussed in Section 2.2.4.

### 2.1.3 Types of business relationships

In carrying out their business activities, companies may develop relationships with various types of companies and other types of organisations because they affect, directly or indirectly, their performance (Ritter et al. 2004). Brandenburger and Nalebuff (1997) proposed a company’ value net which identifies four types of companies and organisations that affect a company’ ability to produce and deliver value to an intermediate or final customer: suppliers, other customers, competitors, and complementors. This value net was later extended by Ritter et al. (2004) to incorporate intra-company relations, both within the focal company and other companies (see Figure 2.2). The authors justify this extension with the fact that: (1) companies interact with other organisations through its networks of internal interpersonal and cross-functional relations, and (2) an important strategic issue confronting management is the interfacing of intra and intercompany relationships. In addition to the types of actors in the initial value net, there are also governmental agencies, research and development institutions, educational institutions, and industry associations (Ritter et al. 2004).

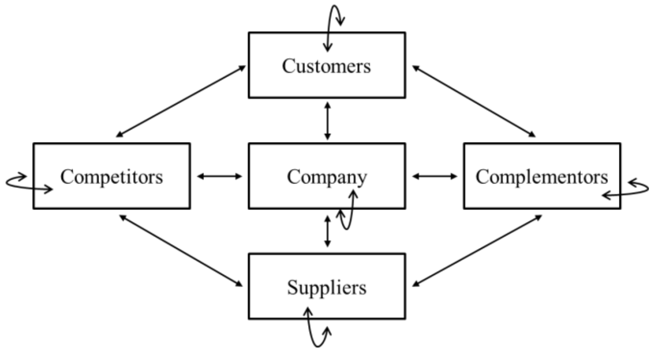



Figure 2.2: Extended company's value net (adapted by Ritter et al. (2004))

The four types of relationships are described as follows (Ritter et al. 2004):

- ***Relationships with customers***: Developing working relationships with customers is a means by which a company understands and serves customers' needs and codevelops new products and services. Relationships with intermediate as well as final customers are included here, such as those with distributors and ECR systems but also relationships to prospective customers;
- ***Relationships with suppliers***: Relationships with suppliers of strategically valuable products and services can be an important and durable source of competitive advantage and one that is hard to others to imitate or steal. Companies are embedded in production networks involving various chains of suppliers specialising in different aspects of the value creation process. The functioning of these networks depends on the capabilities of the actors as well as on the working relationships between them;
- ***Relationships with complementors***: Companies develop relationships with many other types of companies whose outputs or functions increase the value of their own outputs. One example is joint marketing schemes, whereby companies cooperate in reaching out to customers in the form of joint promotion and distribution agreements, such as Lego teaming with Hewlett Packard to serve the children's toy market and Proter and Gamble teaming up with complementary product suppliers (Coca Cola or Pizza Hut) in promotion campaigns. Suppliers of complementary products and services may also be innovation partners, as new products can arise from recombining their outputs in productive ways. Lastly, these

relationships include relationships with government agencies that can be important in entering new markets or in keeping informed about legislative developments;

- ***Relationships with competitors***: Cooperative relationships among competitors may be developed for various purposes, beyond the typical collusion to control and subvert competition. For instance, competitors cooperate to develop product and technology standards, such as the 3G mobile telephone. Cooperation among competitors from one country to enter and develop new international markets is another form of cooperative relationship among competitors.

Barringer and Harrison (2000) distinguish between the most commonly forms of inter-organisational relationships pursued in practice and discussed in the literature:

- ***Joint venture***: is an entity that is created when two or more companies pool a portion of their resources to create a separate jointly owned organisation. Usually, joint ventures are used to gain access to foreign markets or to pursue specific activities that are peripheral to the strategic priorities of the partners (Barringer and Harrison 2000). A joint venture is a legal entity of which equity ownership is shared between companies. Companies enter into a joint venture for various purpose such as a manufacturing joint venture and a sales joint venture (Yasuda 2005);
- ***Networks***: are constellations of businesses that organise through the establishment of social, rather than legally binding, contracts. In general, researchers see networks as a hub and wheel configuration with a focal organisation at the "hub" organising the interdependencies of a complex array of companies. The benefit of organising in this manner is that each participating company is permitted to focus on its specialty, leaving secondary activities to members that specialise in those activities or other suppliers. The result is a constellation of companies that each focus on their distinctive competency in an integrated effort to produce a product, service, or new technology. For instance, Toyota, and the companies that it works with on a close and persistent basis, is often characterised as a textbook example of a network (Barringer and Harrison 2000);
- ***Consortia***: are specialised joint ventures encompassing many different arrangements. Typically, consortia consist of a group of organisations that have a similar need and band together to create a new entity to satisfy that need for all of them. An example is CableLabs, which is a Research and Development (R&D) consortium of cable television system operators in North America, South America, and the Caribbean. The purpose of CableLabs, which has approximately 80 members, is to conduct pre-competitive R&D in the cable industry and to transfer findings to its members. Consortia are most popular in new technology area. It

typically focus on pre-competitive R&D, and include members that are competitors outside of the consortium (Barringer and Harrison 2000);

- ***Alliances***: a business alliance can be defined as an ongoing, formal, business relationship between two or more independent organisations to achieve common goals (Sheth and Parvatiyar 1992), as an independently initiated inter-company link that involves exchange, sharing or co-development (Gulati 1995), as a purposive strategic relationship between independent companies that share compatible goals, strive for mutual benefits, and acknowledge a high level of mutual dependence (Mohr and Spekman 1994). An alliance is an arrangement between two or more firms that establishes an exchange relationship but has no joint ownership involved, i.e. alliances tend to be informal and do not involve the creation of a new entity (such as in a joint venture) or a central administrative authority (such as in a consortium) (Barringer and Harrison 2000), or a constellation of agreements characterised by the commitment of two or more partner companies to reach a common goal, entailing the pooling of their resources and activities (Teece 1992). In other words, alliances are cooperative arrangements between two or more companies to improve their competitive position and performance by sharing resources (Ireland et al. 2002). Alliances facilitate reciprocal specialisation among companies, such as when one company does development and its partner manufacturing (Teece 1992). Thus, an alliance can be seen as a method to leverage company-specific skills and competencies in order to compete more efficiently in the market (Rao and Reddy 1995), i.e. by forming alliances, the partners can pool their resources and strengths together in order to achieve their respective goals, share risks, gain knowledge, and obtain access to new markets (Büyüközkan et al. 2008). This type of alliance is usually named of technological alliances (see e.g. (Barringer and Harrison 2000)). As in the threat of opportunism is real in alliances, its ultimate success or failure is determined by the level of commitment, trust and cooperation among the involved partners (Hoyt and Huq 2000). As an example, one can mention strategic alliances between airlines and airports (see e.g. (Albers et al. 2005)). According to Sheth and Parvatiyar (1992), all business alliances have two underlying dimensions: purpose (strategic or operations efficiency) and parties (competitors or non-competitors). Following this classification, the business networks to be analysed in this thesis can be framed into the category of cooperative alliances as they do not involve competitors and the purpose is to achieve synergistic results. Alliance can be categorised according to two different dimensions. In one dimension where attention is directed to the nature of resources, strategic alliances are categorised by whether or not the same kinds of resources are exchanged (a “symmetrical alliance”) or different kinds of resources are exchanged (an “asymmetrical alliance”). In the other dimension, where attention is paid to the relationship of the partners, strategic alliances are categorised by whether or not the partners belong to the same industry (a "horizontal alliance") or to different industries (a "vertical alliance") (Yasuda and Iijima 2005). A horizontal alliance can occur, for instance, between airlines and a vertical alliance between airline and airport companies (see e.g. (Albers et al. 2005)). Two of the most common types of alliances are strategic (marketing) and technological alliances. Strategic or marketing alliances typically match a company with a distribution system that is attractive to a company that is trying to increase the sales of a product or service. The strategic logic to this type of alliance for both partners is that by finding more outlets for its products, the partner that is supplying the product can increase economies of scale and reduce per-unit costs, and the partner that supplies the distribution channel benefits by adding products to its product line (Barringer and Harrison 2000). Technological alliances involve cooperation in activities such as R&D, engineering, information systems, and manufacturing. These types of alliances pool the intellectual prowess of two or more companies and can result in cost and risk sharing, product development, learning, and increased speed to market (Barringer and Harrison 2000). This type of inter-company relationship is particularly characteristic of high technology industries, where joint R&D, know-how, manufacturing and marketing agreements are used to access complementary technologies and complementary assets (Teece 1992). Alliances must be effectively managed for their benefits to be realised. Effective alliance management begins with selecting the right partners. To maximise cooperation among partners, a trust-based relationship must be developed;

- ***Trade associations***: are typically non-profit organisations formed by companies in the same industries to collect and disseminate trade information, offer legal and technical advice, furnish industry-related training, and provide a platform for collective lobbying. The formation of trade associations is particularly high in industries where the threat of government intervention is high and lobbying activity is strong. Trade associations are typically governed by a paid staff and a volunteer board and because they focus on information dissemination and lobbying instead of higher-priced activities like R&D, governance issues are typically no as salient as in consortia and other forms of inter-organisational collaboration (Barringer and Harrison 2000);
- ***Interlocking directorates***: a direct interlock occurs when an executive or director of one company sits on the board of another company, and an indirect interlock occurs when two companies have directors who sit on the board of a third company. An advantage of participating in an interlocking directorate is the potential to engage in co-optation - this strategy typically plays out by gaining access to resources through relationships established

through the interlock. Interlocks can also lead to opportunities for learning, e.g. an executive of one company that sits on the board of another company may pick up a number of new ideas as a result of the directorship and try to implement them in his company (Barringer and Harrison 2000).

Because it is impossible to cover all these types of relationships, this thesis is focused on alliances in business networks, particularly on cooperation among network of companies in manufacturing and construction industries, although there are other important business networks such as the high-tech and farmaceutical. The rationale for this is that alliances require greater interactions among the network partners, and consequently greater levels of business interoperability, which makes the research more challenging . Therefore, an in-depth literature review on these two types of networks is provided later in this chapter.

### 2.1.4 Characteristics of business relationships

In studying business relationships, it is important to understand their characteristics in order to facilitate our understanding on complex industrial markets. In addition to the components previously addressed in the initial IMP interaction model, Ritter et al. (2003) summarise a set of characteristics of an inter-organisational relationship:

- There is a long-term orientation in a relationship, i.e. an ongoing interaction between the two actors involved. In the interaction model described previously, individual interactions and exchanges are seen as short-term episodes that contribute through routinisation, institutionalisation, and adaptation to the development of a relationship, a long-term exchange pattern;
- Relationships change over time and, as such, are not static. In terms of development, several stages can be identified but these stages are not deterministic in the sense that a relationship will follow the order of the stages or will reach certain stages at all. Different relationships can be quite different or, even stronger, some argue that each relationship is unique;
- Barrier block the development of relationships and, therefore, relationships are no self-runners. Relationships do not come free of cost. Companies have to invest money, resources and time to make them work. Thus, access to external partners' resources should be seen as a lengthy and costly investment;
- A relationship has an atmosphere that can be described in terms of the power-dependence relationships which exists between the companies, the state of conflict or cooperation and overall closeness or distance of the relationship as well as by the companies' mutual expectations;

- Relationships are mainly maintained for an economic purpose, i.e. they fulfil an economic function. These functions can be directly related to the individual relationship (direct functions) or might have a purpose in the future of that relationship or in other relationships (indirect functions).

Relationships are also characterised by complexity, both in their development process and their structure. As described in the initial IMP interaction model, the development of relationships is a complex process for the various elements involved, i.e. the various elements of exchange, the characteristics of the parties, the process itself, the environment and the atmosphere (see (Grilo 1998)). Regarding to the dynamic of business relationships, it is interesting to discuss how a dyad may affect itself. For example, consider a bidirectional relationship between a supplier and a customer, where the goal is to implement a particular project. If the degree of involvement from the supplier to the customer is low, it may result, at long-term, in a lack of interest by the customer and consequently his degree of involvement will decrease. As a result, the two companies may consider to end the project. Just to conclude, relationships can be analysed, controlled and improved. In the example provided above, the degree of involvement could be a measure of analysis. Based on the analysis of the degree of involvement, the two companies could make better decisions towards the improvement of the relationship, and consequently increase the probability of success in the project implementation.

## 2.2 Network theory and analysis: an overview

Network is a general term for physical infrastructure or patterns of interaction that can be represented as a set of points connected by a set of linkages (Kuby et al. 2009). The term is widely used to describe a structure where a number of nodes are related to each other by specific threads (Håkansson and Ford 2002). Put it simple, it refers to a set of nodes and relationships that connect them (Fombrun 1982). What these definitions implicitly suggest is that there are two indispensable elements in any network: actors (nodes) and relationships (e.g. (Knoke and Yang 2008)). Actors or nodes can represent origins, destinations, and junctions, while the linkages, known as links, arcs, or edges, represent connections of some kind among points (Kuby et al. 2009). The nodes of the networks can be individuals, a group of individuals such as a department within an organisation, or organisations within a larger network such as a SC (Carter et al. 2007), a community, or even a nation-state (Fombrun 1982). Links can be directed (one-directional or bi-directional) or undirected, and weighted or unweighted (Mitchell 2006), i.e. they may be characterised by different levels of intensity or involvement (Knoke and Kuklinski 1982). For example, in studying trust in a buyer-seller relationship, the fact that the seller trusts the buyer is conceptually different from the notion that the buyer trusts the seller, whereas the duration of the relationship between them is less concerned with its direction. In the same context, the relationship' weight can be measured by defining different levels of trust between the buyer and the seller.

Network theory, the so-called 'new science of networks', studies the structure of interaction networks and their evolution (Kuby et al. 2009), i.e. it examines diverse relationships among units in the network, including interdependence, communication, membership, solidarity, and affect (Marsden 2005). In turn, network analysis or Social Network Analysis (SNA) has been defined as a mapping and investigation of the relations among a group of actors (Carter et al. 2007). It is a set of integrated techniques to depict relations among actors and to analyse the social structures that emerge from the recurrence of these relations (Chiesi 2001). Network analysis thus expresses the linkages among network of actors, and it is a powerful methodology for describing and analysing the interrelationships of units or nodes within a network (Carter et al. 2007). Its basic assumption is that better explanations of social phenomena are yielded by analysis of the relations among entities (Chiesi 2001), as it identifies regularities in relationships among social units, thereby measuring both relational properties of individual units and structural properties of collectives (Marsden 2005).

Relational property here refers to a property of a unit defined by information on its relationships to other units in a collective or group, whereas structural property refers to a property of a collective or group defined by information on relationships among the units it includes (Marsden 2005). According to Knoke and Kuklinski (1982), network analysis incorporates two significant assumptions about social behaviour. Its first essential insight is that any actor typically participates in a social system involving many other actors, who are significant reference points in one another's decisions. This insight is also supported by Håkansson and Snehota (1995) who stress that an actor in a social network cannot unilaterally control and decide the development of relationship as they are part of relationships and of a larger whole that affects both their outcomes and their development potential.

The second essential insight lies in the importance of elucidating the various levels of structure in a social system, where structure consists of "regularities in the patterns of relations among concrete entities" (White et al. 1976) (cited in (Knoke and Kuklinski 1982), p. 10). These two insights enable us to distinguish between two approaches in analysing networks: individualistic approach and network approach. While in the individualistic approach, often referred by economics as atomistic perspectives, the social structure is seldom an explicit focus of inquiry, i.e. individual actors are depicted as making choices and acting without regard to the behaviour of other actors (Knoke and Kuklinski 1982), in the network approach it is assumed that an individual actor is often embedded in its environment and that its behaviour is thus greatly constrained if not predetermined, which means that it is not a free and independent unit (Håkansson and Snehota 1989). This dualistic advantage of network analysis, i.e. its capacity to illuminate entire social structures and to comprehend particular elements within the structure (Knoke and Kuklinski 1982), probably accounts for its increasingly applications in different areas of research such as operations research, business networks, economics, computer science, biology, electrical engineering, social networks, communication and computer networks (Liao and Seret 1991, Potter 1991), etc. In this thesis, the focus will be on business networks, in particular on industrial networks. Therefore, the literature review will be focused on this type of networks.

### 2.2.1 Network complexity

A general definition of complexity is that a complex system is one that has a large number of elements whose relationships are not simple (Dominik T 2007). A similar viewpoint has been presented by Mitchell (2009), who defines a complex system as "a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behaviour, sophisticated information processing, and adaptation via learning or evolution". To Thompson (1967), a complex system is a set of interdependent parts, which together make up a whole because each contributes something and receives something from the whole, which in turn is interdependent with some larger environment. In a simplest form, one can refer to complex system as one made up of a large number of parts that have many interactions (Simon 1996).

Froese (2010) lists the characteristics put forward by Homer-Dixon (2001) as generally common to any type of complex system:

- Complex systems are comprised of a multiplicity of things; they have a large number of entities or parts. Generally, the more parts a system contains, the more complex it is;
- Complex systems contain a dense web of causal connections among their components. The parts affect each other in many ways;
- Complex systems exhibit interdependence of their components. The behaviour of parts is dependent upon other parts. If the system is broken apart, the components no longer function (like the parts of the human body);
- Complex systems are open to their outside environments. They are not self-contained, but are affected by outside events;
- Complex systems normally show a high degree of synergy among their components: the whole is more than the sum of its parts;
- Complex systems exhibit non-linear behaviour. A change in the system can produce an effect that is not proportional to its size: small changes can produce large effects, and large changes can produce small effects.

### 2.2.2 Network effects

Network effects, often referred to as network externalities, is a concept that is widely applied in economics and marketing research to describe, for instance, the adoption and diffusion of a (new) product (see e.g. (Gallaugher and Wang 2002, Farrell and Klemperer 2006, Goldenberg *et al.* 2010, Pontiggia and Virili 2010, Peng *et al.* 2011)). The concept of network effects describe the social phenomenon that an increase in the number of adopters of a technology will further fuel future adoption of the same technology (Peng et al. 2011), or in other words, the benefit that accrues to the user of a product or service because he or she is one of many who use it (Swann 2002). Within this context, network effects exist when consumers derive utility from a product based on the number of other users (Goldenberg et al. 2010), or in other words, when the perceived value of a product depends on the total number of users and/or the total amount of usage (Wu et al. 2013), which implies that a product that exhibits network effects becomes more valuable when more people use it (Doganoglu and Grzybowski 2007).

In the words of Peng et al. (2011), network effects represent one of the most important and powerful social influences, in the sense that individuals are increasingly exposed to others' adoption, they are more likely to adopt the same technology. According to Farrell and Klemperer (2006), network effects push large groups of users toward doing the same thing as one another. Therefore, a standard assumption of the network effect literature is that it is the overall size of the network that matters to the customers (Birke and Swann 2010). This assumption has been supported, for example, by Pontiggia and Virili (2010) who found out that the size of the user network affects technology acceptance. Their results show a significant effect of user network size on user perceptions. Such assumption is verified, for instance, in telecommunications markets where subscribers consider the size of a particular network as an additional source of value (Sobolewski and Czajkowski 2012). Other examples of network effect are the situations where the brands offer their (new) product to famous people, mainly those who usually appear in media, in order to increase the value of their products and capture new clients. It is common to see this in the football industry, where the football players are paid to use, for instance, new soccer shoes launched usually by Nike, Adidas, Puma, etc., to attract new users. Another example within this context is the automobiles offered by Audi to Real Madrid football players, in the beginning of each season, again to attract new users.

The concept of network effect is also used in other research areas such as SCM to investigate, for instance, the *bullwhip effect*, a well-known problem in SCs operations (e.g. (Ouyang 2007, Ouyang and Li 2010), add more). *Bullwhip effect* refers to a phenomenon in SC operations where the fluctuations in the order sequence are usually greater upstream than downstream of a chain. The *bullwhip effect* results in huge extra SCs costs; in some cases reported to be as much as 25% (Ouyang 2007).

The literature on network effects usually distinguishes between two types of network effects (e.g. (Clements 2004)): direct network effects and indirect effects. Direct network effects refer to the case where users benefit directly from the fact that there are large numbers of other users of the same network (Birke and Swann 2010). In other words, a good exhibits direct network effects if adoption by different users is complementary, so that each user's adoption payoff, and his incentive to adopt, increases as more others adopt (Farrell and Klemperer 2006). For example, a telephone becomes more valuable to an individual as the total number of telephone users increases – this is a direct network effect (Clements 2004). Indirect network effects, on the other hand, arise because bigger networks support a larger range of complementary products and services (Birke and Swann 2010). To Farrell and Klemperer (2006), indirect network effects arise through improved opportunities to trade with the other side of a market, i.e. although buyers typically dislike being joined by other buyers because it raises price given the number of sellers, they also like it because it attracts more sellers. If thicker markets are more efficient, then buyers' indirect gain from the re-equilibrating entry by sellers can outweigh the terms-of-trade loss for buyers, and vice versa; if so, there is an indirect network effect (Farrell and Klemperer 2006). A DVD player becomes more valuable as the variety of available DVDs increases, and this variety increases as the total number of DVD users increases – this is an indirect network effect (Clements 2004).

In the case of direct network effects, such as fax, e-mail, or other communication products, the number of adopters drives utility directly because the higher the number of adopters is, the higher is the utility of the product (Goldenberg et al. 2010), which is consistent with the assumption of the network effect literature observed by (Birke and Swann 2010). Regarding indirect network effects, such as hardware and software products, a possible increase in utility may occur through market mediation (e.g. the number of DVD rental outlets), which in turn is a function of the number of adopters. Consumers will wait for a hardware adoption until there is enough software. In the case of competing standards, early adopters take the risk of adopting the wrong standard, so many wait until the winning standard is clear, and more importantly, which standard or platform will no longer be supported (Goldenberg et al. 2010). In this thesis, it is aimed to show that the direct and indirect effects influence the performance of cooperative industrial networks in a different way.

In the context of this work, it is argued that network effects are intrinsic impacts of business networks. For example, Condeço-Melhorado et al. (2014) assert that network effects imply that an improvement in a particular dyad relationship in a business network generates effects in many other elements of that network. Similarly, a problem in a particular dyad generates effects in many other elements of that network. In short, the extent to which changes in one or more element of a network generate changes in part or in the entire network is known as the network effect (Condeço-Melhorado et al. 2014). For the purpose of this study, network effects are defined as the extent to which a business interoperability impact on one or more dyadic business relationships generate impacts on the neighbours elements and/or on the whole network. When analysing the impact of business interoperability on the performance of cooperative networked companies, the network effects must be considered. The exclusion of these effects can be argued to cause the underestimation of the impact of business interoperability problems and therefore the solutions required to overcome them.

### 2.2.3 What are business networks?

A business network can be defined as a set of two or more connected business relationships, in which each exchange relation is between business units that are conceptualised as collective actors (Emerson 1981) (cited in (Anderson et al. 1994), p. 2). Generally, a business network may be viewed as consisting of "nodes" or positions (occupied by companies, households, strategic business units inside a diversified concern, trade associations and other types of organisations) and links manifested by interaction among the positions (Thorelli 1986). It refers to the exchange of relationships among multiple companies that interact with each other (Kristian K. Möller and David T. Wilson 1995). Put it simple, it can be regarded as sets of connected companies or alternatively, as sets of connected relationships among companies (Anderson et al. 1994). Connected relationships refers to a situation where the dynamics in one relationship affects or is affected by other relationships (see e.g. (Håkansson and Snehota 1995, Grilo 1998)) or the extent to which exchange in one relation is contingent upon exchange (or non-exchange) in the other relations (Cook and Emerson 1978).

Relationships can be connected positively or negatively. Positively connected means that exchange in one relation supports or complements exchange in the other, while two relations are negatively connected if exchange in one hinders or competes with exchange in the other (Holm *et al.* 1996). Among the various definitions for business networks, the one provided by Vernadat (2010) is adopted in this thesis: "any kind of organisation structure in which three or more geographically dispersed business entities need to work in interaction". As examples, one can mention automotive SCs, construction networks, aeronautic industry, innovation networks, telecommunications industry, etc.

### 2.2.4 The IMP network approach

The network approach emerged in the area of industrial marketing (Mattsson 1985, Håkansson 1987, Håkansson and Snehota 1995) in an attempt to account for the complex reality of inter-organisational exchanges (Cova et al. 2010). The network approach was developed based on the assumption that the initial IMP interaction model (see Section 2.1.2) was inappropriate to explain the effect of connectedness among dyadic business relationships. The approach assumes that companies are often interdependent of each other (in terms of technology, economic, social, legal, etc.), and these interdependences lead to some relationships being connected to other relationships (see e.g. (Håkansson and Snehota 1995, Grilo 1998)). It implies that relationships should not be viewed as created and developed in isolation but as part of a broader context – a network of interdependent relationships (Håkansson and Snehota 1995). This is also supported by Holm et al. (1996), who stress that although business relationships are distinctive entities that can be analysed per se, they can be better understood if they are looked at in context and not in isolation. The single relationship then does not appear as an isolated entity, but as a part of a larger and complex whole. As a result, each relationship appears then as embedded in or connected to some other relationships, and its development and functions cannot be properly understood if these connections are disregarded (Håkansson and Snehota 1995). This means that the traditional economics perspective should not be considered appropriate to explain the business interoperability phenomenon within a context of complex industrial network because companies are seen as unconnected systems competing against each other. In line with Håkansson and Snehota (1989), the performance and effectiveness of organisations operating in a network, by whatever criteria these are assessed, become dependent not only on how well the organisation itself performs in interaction with its direct counterparts, but also on how these counterparts in turn manage their relationships with third parties. An organisation's performance is therefore largely dependent on whom it interacts with. For instance, when difficulties related to delivery performance are present in a business-to-business relationship, problems (e.g. increase in buffering) tend to cascade quickly forward through the SC network (Milgate 2001).

Regarding to the relationship perspective discussed in Section 2.1.1, despite recognising it as adequate to understand a two party relationship, it is not considered enough to explain business interoperability phenomenon within a context of complex industrial networks because it is not able to capture the effect of one dyad relationship on other relationships in the network. As emphasized by Håkansson and Snehota (1995), the effects of a relationship between two companies are not limited to the two companies directly involved and their relationships. Other parties and relationships may be affected. In addition, the effect of a relationship on a company will depend on its internal features, but also on the other relationships the company has (Håkansson and Snehota 2002). Therefore, the network approach will be adopted as one of the core theoretical framework in this thesis regarding the analysis of the impact of business interoperability on the performance of complex cooperative industrial networks, because it represents one the main school of thought that deals with the issue of how companies interact in industrial networks. In short, the implication of the network approach to this thesis is that in order to fully understand the impact of business interoperability on the performance of networked companies, it is necessary to analyse not only the dyad relationships in isolation, but also to explore the network effect, i.e. how a business interoperability impact in a dyad will affect the network of connected business relationships. For example, how a communication failure between a first tier supplier and a logistic provider will affect the delivery of materials in the assembler company, in an automotive industrial network.

### 2.2.5 Criticisms of network approaches

Due to the effect of market globalisation, of e-commerce, of having to be a member of a large SC, of having to maintain strong partnership with other members of a business network or a virtual organisation or, government organisations, business networks are becoming a reality for nearly any kind of business entities or organisations, be they industrial companies, service companies, public organisations or government agencies and institutions (Vernadat 2010). This network paradigm, which intensified with the emergence of the Interned and ICTs, brought new challenges to businesses, and attracted the attention of a number of researchers who have been reflecting on approaches to studying business networks.

However, despite this popularity and extent to which it has been used and adopted, network research has faced a number of criticisms. First, networks have been analysed with different theoretical backgrounds and methods, at different levels, and with different results and conclusions. This diversity, although promotes a better understanding of the antecedents, dynamics, and effects of networks, creates problems to compare and integrate results and to develop a general theory based on cumulative evidence (Ritter and Gemünden 2003). Second, although extensive work has shown networks to be important for managing activities, difficulties arise when applying the network concept as an analytical tool (Jack 2010). These difficulties are concerned not only with the lack of a core theory that in turn yields a set of well-defined propositions from which network constructs are defined but also with a need amongst researchers to "debate how concepts are operationalised rather than the underlying theoretical arguments themselves" (Hoang and Antoncic 2003).

In addition, definitions differ about what actually constitutes a business network and different units of analysis are used. For instance, Håkansson et al. (2009) (cited in (Cova et al. 2010), p. 879) state: *"network – one word but many meanings"*. As a result, network research has been accused of leading to "misapplication and inconsistent research findings (O'Donnell et al. 2001). Third, some argue network research should be more conceptual in considerations and clearer in demonstrating how knowledge is actually accumulated (Oliver and Ebers 1998). This might partly be attributed to the way researchers approaches the study of networks. Some focus on attributes of individuals (criticised for atomistic views), others on causal factors (criticised for deterministic views) and others on relations that might exist between actors (criticised for lack of coherence and underachievement) (Parkhe et al. 2006). Fourth, our appreciation of the actual content of network relations and knowledge about the importance of interactions that take place in and between individuals, groups and organisations remains fairly limited (Jack 2010). A fifth criticism is related to the preference for quantitative rather qualitative work (Jack 2010). Thus, more qualitative, longitudinal and multi-method work should be encouraged as this will provide richer and more robust theoretical understanding and deal with some of the criticisms network research has faced (Jack 2010).

From the literature on network research, it was identified at least four approaches or theories for studying business networks. One is the IMP network approach (Håkansson and Snehota 1995) already described above. The second is the transaction cost approach (Williamson 1979). Comparing the transaction cost approach with the IMP network approach there are some very clear similarities in terms of ambitions to understand how individual relationships function (Håkansson and Snehota 1995):

1. Both approaches emphasise the importance of social forms like trust to govern relationships;
2. In both approaches the assumption about an interplay between economic, social and technical factors in the development of relationships is important;
3. The actors are assumed to develop relationships (bonds) in order to achieve something – in the transaction cost approach, efficiency in exchange activities;
4. Resources features play important roles. In the transaction cost approach it is the asset specificity, and in the IMP network approach the resource ties.

There are, nevertheless, at least two major differences. One has to do with how relationships are supposed to influence each other and the other with how individual relationships are assumed to develop (Håkansson and Snehota 1995): (i) in the transaction cost approach each relationship (even each transaction) is in principle analysed as an independent unit in itself; a relationship is developed in certain situations due to specific circumstances in order to govern transactions between two actors; but it is the transaction that remains the unit of analysis, i.e. no specific connections are supposed to exist between different relationships. On the other hand, in the network approach the ties between resources can in the same way be within single relationships but also between resources used in several different relationships; (ii) in the transaction cost analysis the interest is focused on finding the "optimal" governance form for each transaction; the assumption is that in a certain transaction some given resources with some given characteristics are exchanged and the exchange has to be governed; the transaction cost is thus basically static while the IMP network approach has an important dynamic ingredient.

The third approach is the industrial organisational theory (Porter 1980). According to Grilo (1998), the IMP network approach differs from industrial organisational theory essentially in the sense that the later sees customer-supplier relationships as adversarial and atomistic, and very marginal to the central issue of rivalry between companies.

A fourth approach is the traditional economics perspective which differs from the IMP network approach in the sense that the first sees the markets as free, with pure completion, and basically co-ordinated by price mechanisms, while the later see the industrial markets as a network of relationships among buyers and sellers.

### 2.2.6 Interdependence in business networks

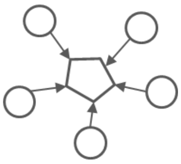
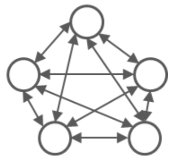
Interdependence in business networks refers to the extent to which companies are mutually dependent on each other to achieve their respective goals (Lee et al. 2014). It results from a relationship in which both companies perceive mutual benefits from interacting and in which any loss of autonomy will be equitably compensated through the expected gains – both parties recognise that the advantages of interdependence provide benefits greater than either could attain singly (Mohr and Spekman 1994). According to Thompson (1967), there are three different ways in which business units can be dependent on one another (see Table 2.1):

- ***Pooled interdependence***: in this type of interdependence, each part renders a discrete contribution to the whole and each is supported by the whole (Thompson 1967). The companies involved share and use common resources but are otherwise independent (Kumar and vanDissel 1996). An example can be the way two specialists share a crane or other major piece of equipment in a construction project. There is not necessarily a direct operational dependence between the parts, but the failure of one part can threaten the whole and the other parts involved. For example, even if the failure of one party in the project does not necessarily mean the failure of the other parties, it may impact upon their reputation (Bankvall et al. 2010). Another example is when a number of companies use a common data processing centre (Kumar and vanDissel 1996);
- ***Sequential interdependence***: refers to situations where direct interdependence exists between activities in terms of output from one activity being the input to the next (Thompson 1967). In other words, the involved companies work in series where the output from one company becomes input to another company (Kumar and vanDissel 1996). Sequential interdependence

is typical in the traditional production process of material and components along a SC (e.g. (Kumar and vanDissel 1996, Bankvall *et al.* 2010)), e.g. in the automotive network, the sub-components are supplied by third tier suppliers to second and third suppliers, in which will supply the first tier suppliers, in which will supply the components to the assembler company, in which will supply the assembled components (car) to the distributors, and so on. This type of interdependence can also be found in construction projects, where each completed task can serve as input to the following task;

- ***Reciprocal interdependence***: refers to the situation in which the outputs of each become inputs for the others (Thompson 1967), meaning that each unit poses contingency for the other, but there is also pooled and sequential aspects to it (Bankvall et al. 2010). In this type of interdependence, companies feed their work back and forth among themselves, i.e. each receives input from and provides output to others, often interactively (Kumar and vanDissel 1996). An example can be the way heating, ventilation and electricity all depend on, and have to be adjusted to, each other, in a construction project (Bankvall et al. 2010). Another example can be a concurrent engineering team consisting of customers, suppliers, distribution centres, dealers, shippers and forwarders, and the multiple within-companies units working together to concurrently design, develop, produce, and deliver the Ford Taurus automobile (Kumar and vanDissel 1996).

Table 2.1: Interdependence, complexity, and potential for business interoperability problems (adapted from (Kumar and vanDissel 1996) (p. 287))

| **Type of interdependence** | **Pooled interdependence** | **Sequential interdependence** | **Reciprocal interdependence** |
|---|---|---|---|
| Configuration |  |  |  |
| Coordination mechanism | Standards and rules | Standards, rules, schedules, and plans (coordination by planning) | Standards, rules, schedules, plans and mutual adjustment |
| Degree of structural complexity | Low | Medium | High |
| Potential for business interoperability problems | Low | Medium | High |
| Potential for conflicts | Low | Medium | High |
| Type of Inter-organisational Systems (IOS) | Pooled information resource IOS | Value/SC IOS | Networked IOS |
| Examples | A network where a number of companies would use a common distribution centre to store their products for a certain time interval (e.g. Supermarkets) | Construction projects (football stadiums, buildings, dams, etc.), automotive SCs, etc. | A concurrent engineering team consisting of multiple companies working together to concurrently design, develop, produce, and deliver a new product (e.g. innovation networks) |

These three types of interdependencies have important implications for business interoperability, as they may imply that the actors must adjust and direct their material, information and financial flows in and between numerous companies in the cooperative network. For instance, Kumar and vanDissel (1996) advocate that the degree of interdependence or coupling between companies is a key factor in determining the potential for one unit to harm the operations of another company, i.e. the closer the coupling of interdependence, the greater the intentional or accidental harm one unit can inflict upon the other. However, when the interdependence among companies increases, they are more likely to be committed to the partnership and are less likely to behave opportunistically, as advocated by Lee et al. (2014), increasing the degree of business interoperability in the dimension “management of external relationships”, more specifically in the sub-dimension “trust”.

High degrees of interdependence also signify that each party needs a lot of information from the other party to fulfil its own tasks and not to cause any disruptions in upstream and downstream activities (Lee et al. 2014). This will require high degrees of coordination to be achieved in order to avoid overlaps and perturbations. For example, Bankvall et al. (2010) argue that when companies from different SCs feed into the same construction project, the output of each chain must be synchronised with other chains in order to coordinate the chains with sequential and reciprocal interdependencies at the site. Each type of interdependences demands a different coordination mechanism which influences the degree of business interoperability, i.e. the more complex the interdependence type (pooled is least and reciprocal most complex) the more complex and indeterminate in nature the corresponding coordination mechanism becomes (ATHENA 2007).

Coordination by standardisation is appropriate for pooled interdependence, coordination by planning is appropriate for sequential interdependence, while with reciprocal interdependence, coordination by mutual adjustment is called upon (Kumar and vanDissel 1996). As each coordination mechanism demands different degrees of human intervention it affects the degree of business interoperability in the dimension "employees and work culture (ATHENA 2007). For instance, partners in pooled interdependence do not necessarily need to directly interact with each other. Therefore, the inherent risk of interpersonal conflicts is minimal. On the other hand, sequential interdependence requires more frequent and direct contact in planning and mutual adjustment. As a result, the need for human intervention and contact increases (ATHENA 2007). This need for direct contact in sequential relationships may increase the possibility of human misunderstanding and error (Kumar and vanDissel 1996), decreasing the degree of business interoperability, for instance, in the dimension "employee and work culture" (ATHENA 2007), more specifically in the sub-dimension "efficiency". In addition, due to the direct human interaction in planning and mutual adjustment, there is a need for a high degree of business interoperability in the sub-dimension "cultural differences" in order to avoid cultural and human conflicts (ATHENA 2007).

The interdependence among business partners also affects the type of inter-organisational information system that should be used to support the relationships, and thus it will affect the degree of business interoperability in the dimension "information systems" (ATHENA 2007). An inter-organisational system can be defined as technologies designed and implemented to operationalise the relationships between the partners in the partnership (Kumar and vanDissel 1996). Pooled dependencies demand for pooled information systems (e.g. common databases, common communication networks, and common applications). Sequential dependencies require value/supply- chain information systems [e.g. EDI-based transactions, transfer of CAD-based specifications]. Reciprocal dependencies are supported by networked information systems [e.g. e-mail, Computer-Supported Cooperative Work (CSCW) systems, central databases] (Kumar and vanDissel 1996, ATHENA 2007). As a result, companies have to find out the appropriate mechanisms to ensure, for example, security and speed in the exchange of data, easy access to data, effective system maintenance, etc.

## 2.3 Manufacturing networks

### 2.3.1 Manufacturing network structure

Before further exploring the concept of "manufacturing network", it is important to highlight here the adoption of the term manufacturing networks rather than SC. Also, it is to refer that though some authors attempt to make a distinction between the definitions of "manufacturing networks" and "production networks", in this thesis the terms are used synonymously.

A SC can be defined as "a network of companies that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Christopher 2011), as "a set of three or more entities directly involved in the upstream and downstream flow of products, services, finances, and/or information from a source to a customer" (Mentzer et al. 2001), as "the network of facilities and activities that performs the functions of product development, procurement of material from vendors, the movement of materials between facilities, the manufacturing of products, the distribution of finished goods to customers, and after-market support (Mabert and Venkataramanan 1998), as "a series of business units that transforms raw materials into finished products and delivers the products to customers" (Mehijerdi 2009), or as "a network of autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities, which create value for final customers in the form of one or more families of related products or services (Swaminathan *et al.* 1998).

Although these definitions highlight the notion of network, SC is widely viewed and analysed as a set of linear relationships of buyers and suppliers (e.g. (Yusoon Kim et al. 2011)) (e.g. Figure 2.4). In this context, academics are increasingly recognising that SCs should be viewed as a network of non-linear relationships rather than a linear system (e.g. Figure 2.5). For example, Christopher (2011) advocates that the word "chain" should be replaced by "network" since there will normally be multiple suppliers and, indeed, suppliers to suppliers as well as multiple customers and customers' customers to be included in the total system. Kim et al. (2011) argue that a system of interconnected buyers and suppliers is better modelled as a network than as a linear chain. Similarly, Pfohl and Buse (2000) acknowledge that through the conceptualisation of a supply system as a network rather than a chain provides a more accurate and realistic view of inter-organisational relationships. Lambert et al. (1998) observe that the SC is not a chain of businesses with one-to-one business-to-business relationships but a network of multiple businesses and relationships. Pathak et al. (2007) stress that when decision-making in manufacturing networks is based on noncomplex assumptions (e.g. linearity, a buyer-supplier dyad, sparse connectivity, static environment, fixed and non-adaptive individual company behaviour), problems are often hidden, leaving plenty of room for understanding and improving the underlying processes.

Broadly speaking, these observations can be related to the need to understand, for instance, how dyadic business relationships are connected and how they affect each other (e.g. (Håkansson and Snehota 1995)), the increasingly importance to analyse the network structure of supply relationships (Yusoon Kim et al. 2011) and the complexity inherent to a manufacturing network. For example, Choi and Kim (2008) state that while a linear perspective may be useful for planning certain mechanical aspects of transactions between buyers and suppliers, it fails to capture the complexity needed to understand a company's strategy or behaviour, as both depend on a larger supply network that the company is embedded in.

Manufacturing entails the production of physical goods, which encompasses the processing of raw materials, often into intermediate materials, which are then transformed into components, sub-assemblies and finished products (Powell 2012). It can be defined as a series of interrelated activities and operations involving the design, material selection, planning, production, quality assurance, management and marketing of discrete consumer and durable goods (APICS 2013). The business units that carry out manufacturing activities are called manufacturing companies, or manufacturing organisations (Powell 2012).

Based on the above statements, a manufacturing network can be defined as a set of three or more manufacturing companies that are involved in the transformation of raw materials in final products and in the delivery of them to the end users (see e.g. (Mills et al. 2004)). Usually, the structure of a manufacturing network consists of three levels: an upstream network level (supply base), a focal company level (manufacturing base), and a downstream network level (customer base) (Chang et al. 2012), which together create a multi-stage and environment. As each stage has more than one site, it becomes a "multi-site" and complex environment (Cheng et al. 2014), as shown in Figure 2.4. The focal company is a relative perspective, in that any company can be the focal company; in other words, all companies, big or small, have agency and the ability to make strategic choices (Chang et al. 2012). For instance, in the automotive industry, the focal company' position is usually occupied by the assembler company as the strategic decisions regarded to the whole network are mainly taken by this company. In addition, this company usually has power and control (governance) over the other companies in the network.

It is to notice that Figure 2.3 does not encompass the second and third tier suppliers, which may be part of other networks and the that connections between the various levels are not always linear, as illustrated in Figure 2.4. Companies in each level can be located in the same geographic locations, e.g.

a network of manufacturing companies operating in Portugal, or can be located in different geographic locations, e.g. Autoeuropa involves manufacturing companies from Portugal, Germany, Morocco, China, etc. Some examples of classifications, according to the Portuguese Classification of Economic Activities – INE[7], include automotive industry, aeronautic industry, food industry, recycling industry, electronic industry, beverage/drink industry, textile industry, clothing industry, etc.

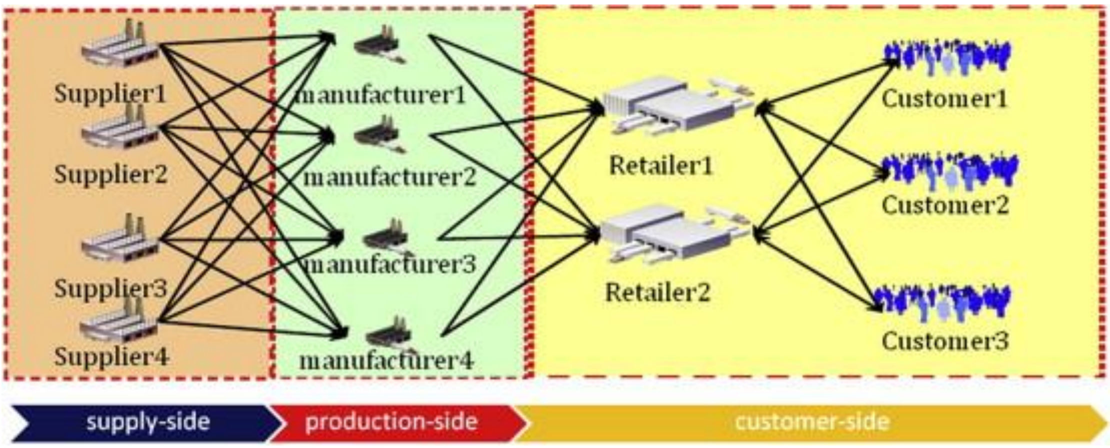



Figure 2.3: The structure of a linear manufacturing network (Cheng et al. 2014) (p. 2329)

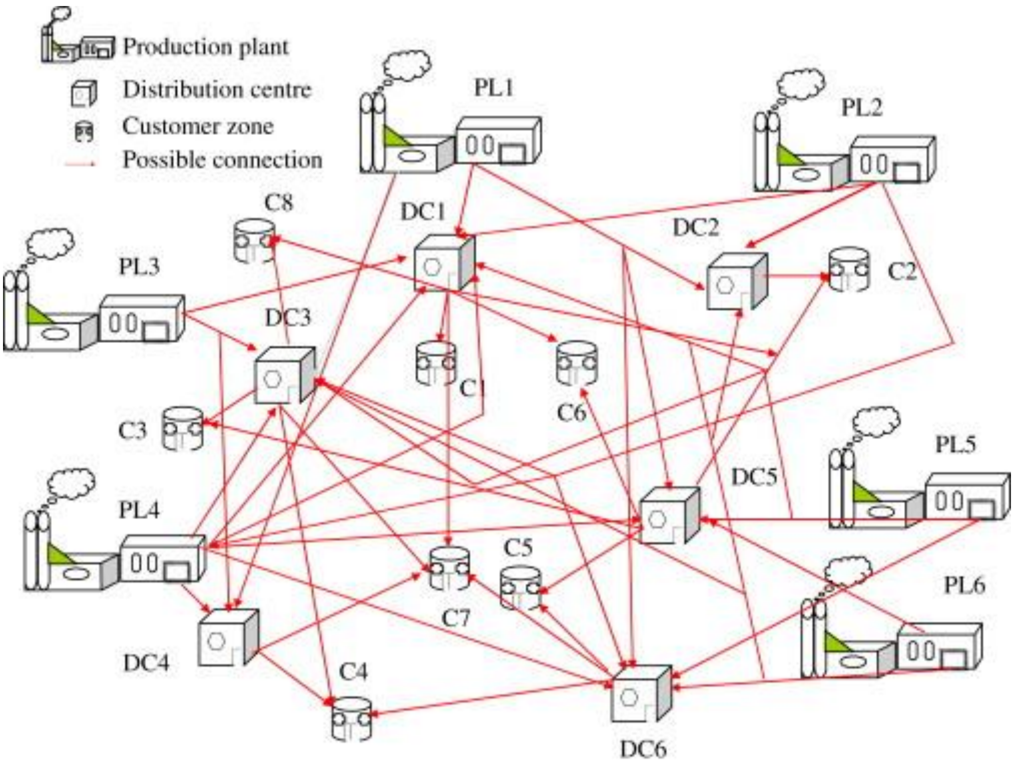



Figure 2.4: A representation of a non-linear manufacturing network (Tsiakis and Papageorgiou 2008) (p. 475)

[7] INE – Instituto Nacional de Estatística (http://www.ine.pt)

An analysis to Figure 2.3 enables us to identify three structural dimensions of a manufacturing network structure, according to the Lambert and Cooper (2000)'s classification that are the horizontal structure, the vertical structure, and the horizontal position of a company within the end points of the network : horizontal structure refers to the number of tiers or levels across the manufacturing network; vertical structure refers to the number of suppliers/customers represented within each tier; and the company's horizontal position refers to the position in which a company can be positioned within the network.

A company can be positioned at or near the initial source of supply, be at or near to the ultimate customer, or somewhere between these end points of the network. To Kim et al. (2011), there are three metrics concerning the structure of the overall network: network density, network centralisation, and network complexity. Network density refers to the number of total ties in a network relative to the number of potential ties – a network in which all nodes are connected with all other nodes would give us a network density of one. Network centralisation captures the extent to which the overall connectedness is organised around particular nodes in a network – if a network had such a highly centralised structure that all connections go through few central nodes, then that network would be high on network centralisation (Yusoon Kim et al. 2011). The network with highest possible centralisation is one star structure, wherein a single node at the centre is connected to all other nodes and these other nodes are not connected to each other (Yusoon Kim et al. 2011). Likewise, the lowest centralisation occurs when all nodes have the same number of connections to others (Yusoon Kim et al. 2011).

### 2.3.2 Managerial challenges in manufacturing networks

Managing in manufacturing networks has been pointed out as a challenging task to industrial managers mainly due to their complex nature. For example, Cheng et al. (2014) state that because their complexity, manufacturing networks are difficult to understand, describe, predict and control. Scholz-Reiter et al. (2011) refer that manufacturing networks are complex dynamical systems, which are subject to unexpected perturbations and trends of key parameters - as a consequence planned capacity levels might no longer be sufficient to handle the workload. Serdarasan (2013) stresses that understanding the inherent complexity of the manufacturing networks and taking necessary actions to reduce-manage-prevent it, would lead to better performance and higher customer satisfaction. Such complexity is related with the fact that in a manufacturing network various network members can simultaneously interact with one another in various channels via various information flows and logistics, making the entire network a complex system (Cheng et al. 2014). A complex manufacturing system is characterised in terms of the non-linear dynamic interactions of the individual parts (Pathak et al. 2007), which implies that the relationships between network participants, from upstream suppliers to downstream customers, are not single line connected (Cheng et al. 2014).

In non-linear systems, intervening to change one or two parameters a small amount can drastically change the behaviour of the whole system, and the whole can be very different from the sum of the parts (Anderson 1999). In addition, the interactions between the various information flows and logistics of the manufacturing network partners (e.g. reverse flows) make the network even more complex (Beamon 1999, Cheng et al. 2014). As emphasised by Serdarasan (2013), within this dynamic and uncertain environment, a manufacturing network chain is definitely a complex system with various companies, high number and variety of relations, processes and interactions between and within the companies, dynamic processes and interactions in which many levels of the system are involved and vast amount of information needed to control this system.

In the context of manufacturing network research, complexity has been characterised in different ways. For example, Serdarasan (2013) distinguishes between three types of manufacturing network complexity: static (structural) complexity, that describes the structure of the manufacturing network (i.e. the connectivity of the subsystems involved), the variety of its components and strengths of interactions; dynamic (operational) complexity, that results from the operational behaviour of the system and its environment, i.e. results from the uncertainty in the manufacturing network and involves the aspects of time and randomness; and decision-making complexity that involves both static and dynamic aspects of complexity. Uncertainty refers to the inherent noise or variations existing in a system (Milgate 2001), which will create risks in the manufacturing network (Christopher and Holweg 2011). Cheng et al.(2014) distinguish between structural and operational complexity. According to the authors, structural complexity is concerned with: (1) investigating the structure of manufacturing networks, including system size, degrees of order (linkage) and categories of elements, (2) analysing the relationships between those dimensions and the structural uncertainty of the manufacturing network to reduce its structural complexity and uncertainty (designing or redesigning the structure of manufacturing networks); and operational complexity is associated with: (1) investigating the dynamic logistics of manufacturing networks, including the degree of connection and the degrees of predictability and uncertainty within the system, (2) using a known and unchanged manufacturing structure to analyse the relationship between those dimensions and the uncertainty of dynamic logistics or information flow of the manufacturing network.

Milgate (2001) synthetises three dimensions of complexity: uncertainty (upstream and downstream level), technological intricacy (at product and process level), and organisational systems (at internal and external level). To Modrak and Semanco (2012), the complexity of manufacturing networks can be characterised in terms of several interconnected dimensions of the networked system: product structure; uncertainty and variety by information and material flows; number of elements or sub-systems; degree of order within the structure of elements or subsystems; degree of interaction or connectivity between the elements, sub-systems and the environment.

## 2.4 Construction networks

### 2.4.1 Construction network structure

A construction network usually involves relationships among an owner, an architect, a general contractor, designers, supervisors, fabricators, and various subcontractors (e.g. plumbing, heating, ventilation and air conditioning, electrical and framing) (Eccles 1981, Taylor and Levitt 2005) that are contracted to work together on specific construction projects (Grilo et al. 2013) (see Figure 2.5). In such network, the contractor often acts as a systems integrator and takes responsibility for actively coordinating a network of upstream subcontractors and suppliers (Martinsuo and Ahola 2010).

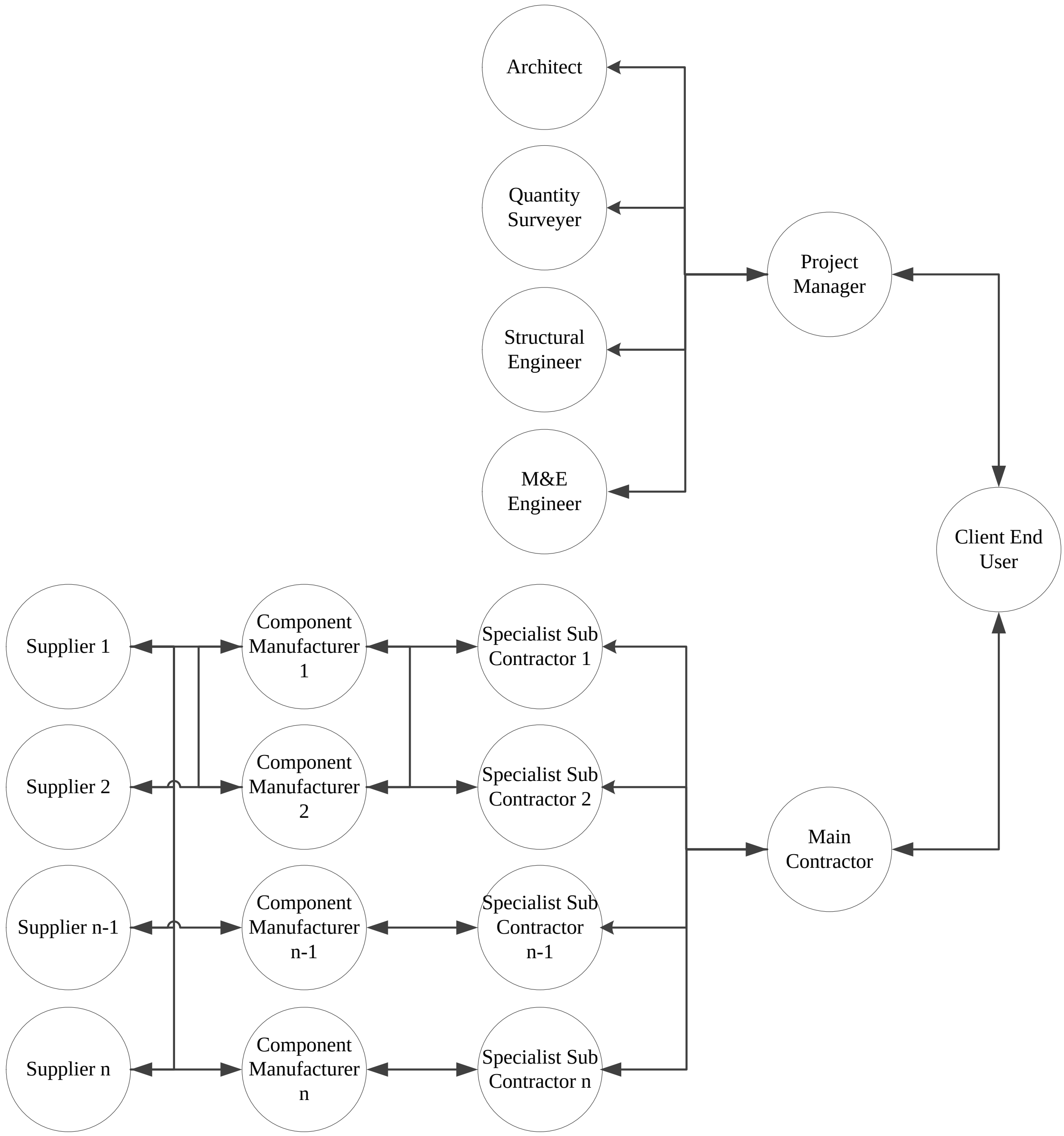



Figure 2.5: An example of a construction network structure (Singleton and Cormican 2013) (p. 20)

Construction is often referred to as "the erection, maintenance, and repair of immobile structures, the demolition of existing structures, and land development" (Eccles 1981) (cited in e.g. (Segerstedt and Olofsson 2010, Fulford and Standing 2014)). The term architectural, engineering and construction (AEC) network also includes the design, and retrofit of our built environment (Segerstedt and Olofsson 2010). Examples of projects include the design and construction of a building, the design and fabrication of a structural system for a building, or the design and construction of a home (Taylor and

Levitt 2005), the design and construction of a football stadium, the design and construction of an airport, the design and construction of a shopping centre, the construction of a dam, and the construction of road tunnel.

In large construction projects such as the construction of football stadiums, airports, and hospitals, it may be required a large number of labour specialists such as carpenters, bricklayers, plumbers, pipefitters, electricians, painters, roofers, drywallers, sheet metal workers, glaziers, and labourers, resulting in different work activities, training, skill level (Eccles 1981), work method and culture, communication mechanisms, management approaches, terminologies, etc. In addition, as within construction project-based networks, there are high levels of product, information and financial interdependencies among the relationships that are established, actions in one relationship are very likely to affect the operations of other companies. For example, the design choice of an architect will influence the actions of the structural, mechanical and electrical specialist designers and therefore the main contractors and subcontractors; the delay in the action of one subcontractor may have shared ramifications for the schedule and cost of other subcontractors; the information that subcontractors receive is dependent on the information received by the main contractor from the designers (Grilo et al. 2013). As a result, coordinating the work of those labour specialists over the course of a project is a complex task, mainly because many of them will be simultaneously involved on the project and often the work of one cannot proceed until a phase of work has been completed by several others. For instance, bricklayers cannot build the walls until the foundation has been completed, mechanical tasks (plumbing, heating and cooling, and electrical) have to complete various tasks before carpenters, masons, and painters can proceed (Eccles 1981).

Regarding to the differences between the typical mass assembly or continuous process, verified in manufacturing networks, and the construction projects, it is not uncommon to hear that the construction networks are totally different to other industries and must find other solutions and concepts for improving performance and efficiency (Segerstedt and Olofsson 2010). Eccles (1981) asserts that in a typical mass assembly process raw materials are progressively transformed over a series of separable steps into the final product and between each separate step are buffer inventories that absorb fluctuations in output at one stage in order to avoid ripple effects further down the manufacturing line. These inventories permit a decoupling of a serially related set of tasks where the input of one task is the output of the preceding task.

On the other hand, in construction the various trades do not have this serial relationship in as rigid form, although it does exist to a large extent, and the beginning of some tasks are dependent on the completion of others (Eccles 1981). In addition, within construction networks, a multitude of exchange interdependency possibilities exist, both sequential and parallel. However, as construction networks are temporary in nature, these interdependencies do not usually provoke durable major changes, and eventual adaptations (mostly small-scale) tend to last the duration of the interaction of the project. Thus, interconnections between relationships and firms exist and are complex but are not durable and tend to finish when the project ends (Grilo et al. 2013). Segerstedt and Olofsson (2010) introduced a special issue to discuss and point to some differences and possible similarities between construction and manufacturing networks. Among the conclusions, one can highlight (Vrijhoef and Koskela 2000):

1. The market of the construction industry is mostly local and highly volatile – the long durability of the construction "product" contributes to the volatility;
2. The product specification process before the customer order arrives shows different degrees of specifications: engineer to order, modify to order, configure to order (the common make-to-stock in traditional manufacturing does not exist);
3. A construction company only executes a small part of the project by its own personnel and capacity;
4. Construction companies are temporary, and site production;
5. The design specification process is mainly based on client requirements, norms and standards;
6. A construction company is often more movable and impermanent in its network compared to other industries. This can be explained with the fact that construction networks are typically make-to-order systems, with every project creating a new product or prototype

Other two important characteristics of construction networks, in terms of structures and function, provided by Vrijhoef and Koskela (2000) are:

- It is a converging network directing all materials to the construction site where the object is assembled from incoming materials. The "construction factory" is set up around the single product, in contrast to manufacturing systems where multiple products pass through the factory, and are distributed to many customers;
- It is, apart from rare exceptions, a temporary SC producing one-off construction projects through repeated reconfiguration of project organisations. As a result, the construction network is typified by instability, fragmentation, and especially by the separation between the design and the construction of the built object.

Because of such fragmentation, participants from various organisations who are involved in a project phase or in different project phases are facing ineffectiveness and inefficiency in their coordination, collaboration and communication processes (Lee and Yu 2012). The volatility of market demand and increased complexity is one cause for fragmentation of the construction industry where subcontracting and rental of expensive equipment been a way of risk mitigation for construction companies (Segerstedt and Olofsson 2010). The major distinction between construction and manufacturing is that the construction industry is project-based and of discontinuous nature, while manufacturing industries involve continuous processes and relationships. While the majority of contributions involving SC relationships in management and marketing literature deal with continuous exchanges in long-term buyer-supplier relationships, there is a lack of research on discontinuous exchanges in project-based industries, such as the construction industry (Segerstedt and Olofsson 2010). Management of SC relationships is, however, especially problematic in project- based industries due to; the discontinuity of demand for projects, the uniqueness of each project in technical, financial, and socio-political terms, and the complexity of each project in terms of the number of actors involved (Segerstedt and Olofsson 2010).

Construction industry is also a labour-intensive industry with a relatively low level of Information Technology (IT) integration. The dynamic nature of the industry requires integration and fusion of information from different construction documents in different data formats such as drawings, specifications, schedules, reports, and other documents for the support and improvement of the construction processes (Elghamrawy and Boukamp 2010). Managing construction documents is a real challenge, and many researchers believe that more efficient document management is a primary step for the construction industry to increase its productivity. However, the fragmented nature of the industry and the unstructured nature of the related data created a culture that depends on face-to-face communications and impedes the project information storage and retrieval (Elghamrawy and Boukamp 2010).

### 2.4.2 Managerial challenges in construction networks

The construction industry is widely recognised as a laggard in terms of productivity improvement (Fulford and Standing 2014). For example, Meng (2012) asserts that construction projects often suffer from poor performance in terms of time delays, cost overruns and quality defects. Fulford and Standing (2014) highlight the construction industry's poor productivity levels and assert that it lags behind other industries in terms of efficiency improvements. Bankvall et al. (2010) concluded that the construction industry is lagging behind in terms of SC practices and efficiency. Lo et al. (2006) recognise that construction delays are common in civil engineering projects in Hong Kong, inevitably resulting in contractual claims and increased project cost. The low productivity of construction industry might be justified with the global financial crisis, which had an effect, but there was not any improvement (in terms of productivity) in this sector, for example, in Australia between 1986 and

2002 or in the US between 1987 and 2003. There have been some positive years of productivity growth but there is clearly an underlying problem (Fulford and Standing 2014).

Although there is considerable effort in developing new strategies and technologies for improving the performance of construction networks, e.g. Building Information Modelling (BIM) (e.g. (Grilo and Jardim-Goncalves 2010, Grilo and Jardim-Goncalves 2011, Jung and Joo 2011, Irizarry *et al.* 2013)), there still exists today a failure to deliver timeless and cost-effective construction projects. For instance, recently we could see a number of news reporting the delays and increase of cost verified in the construction of the football stadiums for the FIFA[8] world cup in Brazil (see e.g. (ISE[9] 2013, WSJ[10] 2013, Schausteck de Almeida *et al.* 2015)). The stadiums built for the UEFA EURO 2004 in Portugal faced the same problems of delays and increase on cost (see e.g. (Record 2003, Relvado 2003)).

Due to the economic importance of the sector, a number of researchers have been addressing the managerial challenges inhibiting the achievement of high performance in the construction sector. The issues of complexity discussed in the context of manufacturing networks, is also pointed out as challenging the construction networks. For example, Bryde et al. (2013) argue that construction projects are becoming much more complex and difficult to manage. Briscoe and Dainty (2005) recognise that as construction networks or larger projects typically involve hundreds of different companies (structural complexity) supplying materials, components and a wide range of construction services (functional complexity) (Dainty et al. 2001), a continued reliance on a fragmented and largely subcontracted workforce has arguably increased the complexity of this network and delimited opportunities for process integration. Cox and Ireland (2002) assert that “it is difficult to quantify the exact number of partners that have to be integrated into a typical project”. Segerstedt and Olofsson (2010) also acknowledge that the volatility of market demand and increased complexity is one cause for fragmentation of the construction industry where subcontracting and rental of expensive equipment been a way of risk mitigation for construction companies. Froese (2010) advocates that construction projects are justifiably described as complex, largely because of the quantity and interdependence of the components that make up the project. Elghamrawy and Boukamp (2010) stress that the growing complexity of construction projects results in an increase in problems associated with document management and retrieval techniques.

[8] FIFA – Fédération Internationale de Football Association

[9] ISE – Institution of Structural Engineers

[10] WSJ – Wall Street Journal

Another major factor that sustains the inherent difficulty faced in construction industries is that clients find it difficult to fully understand the implications of the selection of suppliers as construction networks are widely misunderstood by those procuring the products and services (Cox and Ireland 2002). Significant technological advances along with the need to find extensive professional and trade skills is also pointed out as inhibiting the development of construction projects (Cox and Ireland 2002).

Beyond the issues of complexity, other managerial challenges can be identified in the construction networks' literature. For instance, Bankvall et al. (2010) list the following: the dominating focus on projects, the fragmentation of industry, the separation of the design and production processes, difficulties in integrating the participants and business processes, lack of coordination and communication between participants, difficulties in planning for the execution of activities, adversarial contractual relationships, lack of customer-supplier focus, price-based selection, ineffective use of technology or lack of effective ICT systems for dissemination of information, lack of trust and mutual understanding, lack of standards for alignment of systems and business processes, etc. Fulford and Standing (2014) conducted a qualitative case study and concluded that (1) the construction industry lacks the "strength" of relationships necessary to create a network of organisations that trust and have shared value, (2) design processes should include both value engineering and lifecycle costing, (3) procedures and information need to be standardised, and (4) there should be more emphasis on value adding project management activities.

The size of a company, in particular the large number of small companies involved in the network, is also pointed out as challenging the construction industry (e.g. (Hadaya and Pellerin 2010, Loenngren *et al.* 2010, Fulford and Standing 2014). Loenngren et al. (2010) state that many companies in the construction industry are relatively small and only have a regional focus, so that they have neither the financial nor human resources required to implement and maintain the necessary IT infrastructure. Fulford and Standing (2014) recognise that small businesses tend to lack collaboration capability, since they do not have the resources to invest in systems to support collaboration, nor do they evaluate effectively their collaboration practices. These small businesses may still using primitive business processes which rely largely on manual, paper-based data, intuition, and experience, but not ICT (Benjaoran 2009) and as a result, the investment in sophisticated ITs, made by large companies may not be fully leveraged as in the other end of their dyadic business relationships, partners may not have the financial resources necessary to implement to ITs adopted by them. Perhaps this explains the reason why the construction industry has not taken full advantage of the evolutions in IT practices that have been applied to other industries, as highlighted by Fulford and Standing (2014). Consequences can be, for example, delays in approval of drawings and payments (Fulford and Standing 2014), which in turn will create a cash flow bottleneck to labour-intensive sub-contractors (Ng and Tang 2010), conflicts in work schedules of subcontractors, slow decision-making, design errors, and labour shortages (Fulford and Standing 2014).

Bankvall et al. (2010) also acknowledged the importance of taking a holistic view that integrates the interdependence of all partners in a construction network. This is also supported by Fulford and Standing (2014), who advocate that until processes are viewed holistically across the many companies in the construction networks there will continue to be negligible productivity gains. For example, a study conducted by Singleton and Cormican (2013) to investigate the potential for improvement of the Irish construction industry indicated that investment in SC integration is crucial to tackling the current crisis in the industry. The study found that, for instance, subcontractor involvement in design development using construction collaborative technologies was crucial to the success of the project.

As acknowledged by Segerstedt and Olofsson (2010), while the majority of contributions involving SC relationships in management and marketing literature deal with continuous exchanges in long-term buyer-supplier relationships, there is a lack of research on discontinuous exchanges in project-based industries, such as the construction industry. According to Singleton and Cormican (2013), the construction industry has been slower than other industries to embrace the concept of SCM due to the circumstances in which collaboration takes place; downstream activities consist of the delivery of products and services by suppliers and subcontractors who traditionally are considered the weakest link in the chain. In addition to the difficulty of applying SCM models, Cox and Ireland (2002) advocate that the majority of companies in the construction industry do not have the necessary methodologies in place to provide the necessary knowledge to fully understand the network circumstances within which they operate. Hence, explanations for the seemingly poor SC performance in construction rest on the belief that theoretical models and concepts are inappropriate for the construction industry, or that the industry is to blame for not being able to implement practices that work well in other sectors (Bankvall et al. 2010).

Another important challenge is that many relationships in the construction networks can be characterised as adversarial, short term and lacking in trust (Fulford and Standing 2014). This can be explained with the fact that in each new construction project, companies may find partners that they have never worked with. As a result, companies may not have sufficient time to develop strong and trust based relationships, and to standardise the work procedures. Laan et al. (2011) recognise that developing relationships of trust between, for example, client and contractor seems to be difficult as in the project-based setting of the construction industry business partners lack the time to engage in lengthy interaction processes that contribute to the development of trust in more enduring organisational forms. Ng and Tang (2010) recognise that it is difficult to build up a trust and enduring relationship between the main contractor and sub-contractors when the sub-contracting team is reassembled each time a project begin.

FIATECH (http://www.fiatech.org/) (cited in (Shen et al. 2010), p. 197), identified the following major interoperability problems in the construction networks:

- It is difficult to access accurate data, information, and knowledge in a timely manner in every phase of the construction project lifecycle;
- There is a lack of interoperability between systems, with several standards competing for managing data. A common methodology for managing construction projects' information assets does not exist;
- Program plans and designs are optimized for a limited set of parameters in a limited domain. The capability to support 'total best value' decisions does not exist;
- Tools for project planning and enterprise management are maturing, but an integrated and scalable solution that delivers all needed functionalities for any kind of projects is not available;
- Lifecycle issues are not well understood and therefore modelling and planning do not effectively take all lifecycle aspects into account. Operation, maintenance, environmental impact, and end-of-life disposal issues are given limited consideration in the project planning equation;
- The ability to assess uncertainties, risks, and the impact of failures in not mature, partly due to the lack of knowledge to support these evaluations, and partly due to the limitations of available tools;
- The business foundation for addressing increased security concerns does not exist, and the ability to address these issues is limited by the lack of understanding of the risks and alternatives.

As a conclusion, the point to make here is that although the causes of poor performance have often been analysed (e.g. (Gallaher et al. 2004)), few studies have addressed the impact of network effect caused by business interoperability problems on project performance in construction.

## 2.5 Summary

This chapter provided the theoretical background regarding business networks and relationships, with emphasis on manufacturing and construction networks. Such theoretical background was collected based on relevant contributions from researches carried out in the ambit of the IMP group, more specifically on two imperatives dimensions of the IMP approach, i.e. the interaction processes (e.g. (Håkansson 1982)) and relationships and networks (e.g. (Håkansson and Snehota 1995)). One of the relevant conclusions of this chapter was that the traditional economics perspective is inappropriate to explain the business interoperability phenomenon within a context of complex industrial networks as companies are seen as unconnected or isolated systems competing against each other. Regarding the initial IMP interaction model, it is to highlight that although it views companies as connected systems, it still be inappropriate to explain the business interoperability phenomenon in a context of cooperative industrial networks because it only considers the connectedness between companies ignoring the effect of connectedness among the dyad relationships that constitute the network. In other words, it assumes that the relationships between companies can be viewed as created and developed in isolation. Therefore, it was concluded that in order to fully understand the effect of the connectedness among dyad relationships, and address the Research Question 2, the network approach must be adopted in order to understand how a dyad can affect the network of companies to which the dyad belong, i.e. the network effect.

Another relevant conclusion was that the lack of integration in construction networks is one of the responsible for the poor performance in such networks, as there are a large number of small companies who do not have the capabilities to conduct ICT-based collaboration.

# Chapter 3 Business interoperability

In previous chapter, the background behind the business relationships and networks theory has been discussed, including the identification of the challenges that companies face when it comes to operating in business networks. In this chapter, an in-depth literature review is carried out in order to analyse the definitions, related concepts, and existing works on business interoperability.

*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 a group of companies, but rather there are other relevant dimensions such as business processes, culture and values, and management of contractual issues (Grilo et al. 2013) (p. 152)*

## 3.1 Interoperability: from a technical to a business perspective

Based primarily on the military service of the US Department of Defense (DoD) (e.g. (DoD 1977)), interoperability has been regarded as one of the major domains that enable systems to improve their ability to work together with another systems (e.g. (Loukis and Charalabidis 2013, Xu et al. 2014)). Traditionally, interoperability has been mainly defined and approached from the technical point of view (see e.g. (Naudet et al. 2010, Gong and Janssen 2013)). This is particularly true if we analyse some of the definitions of interoperability available in the literature and by the number of publications regarding information systems interoperability.

Among the various definitions of interoperability provided up to date in the literature, a first sample of them was collected: “systems that are compatible and capable of mutually utilizing the information exchanged (Treiber 1981); “the ability of two or more systems or components to exchange information and use the information that has been exchanged” (IEEE 1990); “the ability of two devices or components to exchange information” (Dictionary of Information Technology); “the condition achieved among communications-electronics systems or items of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users (DoD 2001); “the ability of a system (or process) to use information and/or functionality of another system (or process) by adhering to common standards” (Vernadat 2007); “the ability of information systems to communicate with each other and exchange information”, “the conditions, achieved in varying levels, when information systems and/or their components can exchange information directly and satisfactorily among them”, “the ability to operate software and exchange information in a heterogeneous network (i.e., one large network made up of several different local area networks)”, and “systems or programs capable of exchanging information and operating together effectively" (Command 2001); "the ability of interaction between enterprise software applications" (IDEAS 2003d); "the ability of ICT systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge" (EIF 2004); "the ability to ensure coherent exchange of information and services between systems" (eGIF 2005); "the ability to exchange functionality and interpretable data between two software entities" (Luis 2009); "the ability by which system elements can exchange and understand the information required with each other" (Rezaei et al. 2014b); etc. What is subjacent to this sample of definitions is the focus on the technical aspects of exchanging information between ICTs systems.

However, as acknowledged by some authors, interoperability is not only about transferring information or communication by means of connecting ICT systems. For example, Whitman and Panetto (2006) point out that interoperability is not only about transferring information but also performing an operation on behalf of another system (be they pieces of software, processes, computers, business units, etc.). Berre et al. (2007) stress that interoperability should not only be considered a property of ICT systems, but should also concerns the business processes and the business context of an organisation. Naudet et al. (2010) assert that interoperability is not only related to communication, i.e. the components of the systems put in relation do not necessarily have to communicate, but might simply have to be composed together for a specific purpose. Grilo et al. (2013) go further and stress that 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 a group of companies, but rather there are other relevant dimensions such as business processes, culture and values, and the management of contractual issues. Acknowledging such limitations, a second sample of definitions that defines interoperability without referring specifically to the process of information and/or data exchange, was identified: "the ability of systems, units, or forces to provide 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 (DoD 1977); "the effort required to couple one system with another" (Cavano and McCall 1978); "the ability for two systems to understand one another and to use functionality of one another (Chen et al. 2008a); "a property of diverse systems and organisations enabling them to work together" (Gottschalk 2009); "a measure of the ability of performing interoperation between two or more different entities (be they pieces of software, processes, systems, business entities, etc.)" (Vernadat 2010); "the ability of a system or a product to work with other systems or products without special effort on the part of the customer" (IEEE Standards Glossary 2014)[11]; "the ability for a system or a product/service to work

[11] http://www.ieee.org/education_careers/education/standards/standards_glossary.html#Interoperability

with other systems or products/services without special effort of the part of the user ((Ducq et al. 2012, Galasso et al. 2014)).

Although the above definitions do not refer to interoperability as a technical construct, they are generic, which makes them difficult to be applicable in a context of business relationships. Again, considering these limitations, research on enterprise interoperability or business interoperability has emerged since the beginning of 2000s (Chen et al. 2008a) as an attempt to extend the concept of interoperability, to include the other relevant aspects of business relationships, such as business strategy, management of external relationships, collaborative business processes, business semantics, and knowledge management (see e.g. (Legner and Wende 2006, ATHENA 2007, Zutshi *et al.* 2012)). As a result, a number of definitions of enterprise interoperability or business interoperability have been proposed. For instance, ISO (2011) adopts the term enterprise interoperability and defines it as "the ability of enterprises and entities within those enterprises to communicate and interact effectively". Ducq et al. (2012) also refer to enterprise interoperability as "the ability of an enterprise to interact with other enterprises, not only on an IT point of view, but also on organisational and semantic points of views. Pazos Corella et al. (2013) also employ the term enterprise interoperability and define it as "the capacity that enterprises and organisations have to collaborate in an efficient manner while preserving their own identities and their own ways of doing business through mechanisms that act as facilitators". Galasso et al. (2014) also refer to enterprise interoperability as "the capacity of two or more enterprises, including all systems within their boundaries and the external systems that they utilise or are affected by, in order to cooperate seamlessly in depth of time for a common objective". ATHENA (2007), in turn, adopt the term business interoperability and defines it as "the organisational and operational ability of an enterprise to cooperate with its business partners and to efficiently establish, conduct and develop IT-supported business relationships with the objective to create value". Figay et al. (2008) also refer to business interoperability and define it as "a field of activity with the aim to improve the manner in which enterprises, by means of ICTs, interoperate with other enterprises, organisations, or with other business units of the same enterprise, in order to conduct their business".

While most research adopts the term interoperability or enterprise interoperability, this thesis adopts the term business interoperability, as its purpose is to explore the interactions among network of companies. Accordingly, the following definition of business interoperability, which has been adapted from that definition of enterprise interoperability proposed in Galasso et al. (2014), is adopted in this thesis: "the ability of two or more business units, as well as of all systems within their boundaries (e.g. human resources, business processes, information systems) and the external systems (e.g. legislations and regulations) that they utilise or are affected by, to work together. It is important to highlight here that this definition does not include the term “to cooperate” as business interoperability is needed whenever two or more business units need to work together, be in a context of cooperation, collaboration, or in a simple interaction among business units. An analysis of the definitions presented in this section, enables us to derive a smallest common factor: interoperability (or business interoperability) is about systems that interact (Naudet et al. 2010) and their ability to work together. This implies that interoperability can be considered an issue, which can arise only when some resources are put together to interoperate. Thus, interoperability simply concerns relations between systems (Naudet et al. 2010), which is to say that, for instance, in the context of business relationships, business interoperability comes into play any time that two or more business entities need to work together or need to share common information (Vernadat 2010).

## 3.2 Fundamental concepts of business interoperability

### 3.2.1 Business interoperability and related concepts

Since business interoperability is a multidimensional construct (Naudet et al. 2010) that describes the interactions between two or more companies, it is often confused with other related topics such as enterprise integration, compatibility, coordination, SCM, etc. For instance, Vernadat (2010) points out that business interoperability and enterprise integration are two closely connected concepts that are too often opposed or confused in the literature. Whitman and Panetto (2006) advocate that it is important to distinguish between these fundamentally different concepts of interoperability, integration and compatibility, since failure to do so sometimes confuses the debate over how to achieve them. In this sense, a clear distinction between is needed, not only between business interoperability and enterprise integration but also between business interoperability and the other related concepts mentioned.

According to the Webster dictionary, integration means “to make a whole” or “to bring parts into a whole“, in order to create synergy within the “whole system”, i.e. creating a situation in which the integrated system offers more capability than the sum of its components would simply do (Vernadat 2010). Enterprise integration involves breaking down organisational barriers to improve synergy within the enterprise (Panetto et al. 2012) by removing organisational barriers and/or improving interoperation and collaboration among people, systems, applications, departments and even companies (especially in terms of material flows, information/decision flows and control or work flows) (Vernadat 2010).

Analysing the last statement, one can realise that it can also be mentioned as the main objective of business interoperability. Indeed, as stated by Vernadat (2010), both enterprise integration and business interoperability aim at facilitating seamless operations between business entities, be they from a single, networked or virtual organisation. So what are the differences? In a simplistic way, we can say that while the main goal of enterprise integration is to bring diverse companies into a single network, business interoperability is concerned with how to achieve an effective integration by identifying which standards (e.g. XML, web services) should be used. In other words, one can say that business interoperability is a key to enterprise integration (Vernadat 2007) as enterprise integration nowadays strongly relies on business interoperability (Vernadat 2010). According to Whitman and Panetto (2006), integration is generally considered to go beyond mere interoperability to involve some degree of functional dependence, i.e. while interoperable systems can function independently, an integrated system loses significant functionality if the flow of services is interrupted. An integrated family of systems must, of necessity, be interoperable, but interoperable systems do not necessarily need to be integrated (Whitman and Panetto 2006, Vernadat 2010). This is also supported by Boza *et al.* (2015), who stress that while business systems function in a uniform manner or as homogeneous systems when they are integrated, business interoperability does not require this, but the alternative autonomous systems are able to work together by exchanging and using other's information and functions instead.

Regarding to the differences between business interoperability and compatibility, Whitman and Panetto (2006) state that compatibility is something less than interoperability and that interoperable systems are by necessity compatible, but the converse is not necessarily true.

With regard to coordination, it can be defined as the process of organising complex tasks, so that they fit together efficiently (Dictionary of Information Technology). The goal is to align activities for mutual benefit, avoiding gaps and overlaps, and thus achieve efficiently results (Figay et al. 2008). In sum, one can say that coordination is just one of the elements of business interoperability, which is framed into the dimension of collaborative business processes. To conclude, it is also important to distinguish between the concept of business interoperability and SCM as they can also be easily confused. Indeed, both embrace a set of closely linked concepts (e.g. integration, coordination, and visibility of inter-companies business processes) and both can be applied to improve the performance of companies.

SCM can be defined as "the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders" (Lambert and Cooper 2000, Mahmood *et al.* 2003) or "a set of approaches used to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time in order to minimize system wide costs while satisfying service-level requirements" (Mehijerdi 2009). It is concerned with cost-effective way of managing materials, information and financial flows from the point of origin to the point of consumption to satisfy customer requirements (Kamath and Roy 2007). This implies the integration and management of the key business processes associated with the flow and transformation of goods and services, as well as the attendant information flows, from the sources of raw materials to the end user (Mahmood et al. 2003).

Given the definition and purpose of business interoperability and SCM, it is possible to conclude that these two concepts are indeed closely linked. The difference can be explained as follows: while SCM focuses on the integration and coordination of the inter-organisational business processes by means of information sharing, business interoperability goes beyond those two aspects to include other aspects of business relationships such as the definition and alignment of business goals, the alignment of terminologies, the definition of contracts, the alignment of legislations, etc. In addition, business interoperability can be regarded as enabler to achieve effective SCM as its main purpose is to enhance the companies' ability to work together.

Considering the increasingly need of companies to work together, it seems to be increasingly "difficult" to achieve seamless SCM without adequate levels of business interoperability. As stated by Ye et al. (2008) a key factor for the successful implementation of SCM is business interoperability across collaborative SC partners. Another difference is that while the concept of SCM is usually applied in the context of SCs, business interoperability can be applied in any kind of business networks where interactions between two or more business units exist, whatever what kind of business networks they are (e.g. computer networks used by business units, the various departments within a company, a set of individual working in a project or within a company, etc.).

## 3.3 Existing interoperability models and frameworks

As interoperability is a multidimensional concept that can be viewed from numerous perspectives and approached from various directions (e.g. technical syntactic, semantic, organisational, etc.), a framework is necessary to reconcile all these perspectives, approaches, and directions, which are frequently different (Rezaei et al. 2014a). A framework is defined according to Webster's Dictionary (1986) as "a systematic set of relationships or a conceptual scheme, structure, or system" (Jung and Joo 2011), or according to Rezaei et al. (2014a), as "a practical tool for comparing concepts, principles, methods, standards, and models in a particular realm". It attempts to identify the universal elements that any theory relevant to the same kind of phenomena would need to include. In other words, it helps to identify the elements and relationships among these elements that one needs to consider for analysing a phenomenon (Ostrom 2005). In the context of interoperability research, an interoperability framework can be defined as "a mechanism for enabling interoperability between entities that mutually pursue an objective" or "a set of assumptions, concepts, values and practices that constitutes a way of viewing and addressing interoperability issues" (Rezaei et al. 2014a). The main purpose of an interoperability framework is to provide an organising mechanism so that concepts, problems and knowledge on interoperability can be represented in a more structured way (Chen et al. 2008a).

On the other hand, a model is defined as "a simplified representation or abstraction of reality"; and it describes, reflects, or replicates a real event, object, or process but does not "explain" it (Meredith 1993). Within the context of interoperability and/or business interoperability research, which initiated since the beginning of 2000s, a lot frameworks and/or models have been proposed. Most of those works can be grouped into two main categories: interoperability frameworks and interoperability maturity models. It is to be noted that while frameworks and maturity models applied to business interoperability research are "in abundance", "pure" models that deal with business interoperability problems are scant.

This section aims at reviewing those frameworks and models and discovering their gaps and appropriateness for this work. For example, the European Interoperability Framework (EIF 2004), the ATHENA interoperability framework (ATHENA 2004), the E-health interoperability framework (NEHTA 2005), and the Framework for Enterprise Interoperability (FEI) (Chen 2006a) are included in this review as they have been regarded by Guédria et al. (2013) as some of the most known enterprise interoperability frameworks, so far. Also, they have been pointed out by Chen et al. (2008a) as some of the most relevant interoperability frameworks, along with the IDEAS interoperability framework (IDEAS 2003b). According to Chen et al. (2008a), a piece of knowledge is considered as relevant to interoperability if it contributes to remove at least one barrier at one level. In addition to those interoperability frameworks, the ATHENA business interoperability framework (ATHENA 2007) and the BIQMM (Zutshi et al. 2012) have been included because most of the research carried out in this thesis is grounded on these two frameworks. It is important to notice that these two frameworks address business interoperability issues, which are the context of this research. Among the non-included existing models and frameworks, one can mention the Quantification of Interoperability (Mensh *et al.* 1989), the Military Communications and Information Systems Interoperability (Amanowicz and Gajewski 1996), the GridWise Interoperability Context-Setting Framework (GRIDWISE 2007), and the Ontology of Interoperability (Naudet et al. 2010). For a detailed review of these models and frameworks, the reader is guided to see, for example, Rezaei et al. (2014c), Rezaei et al. (2014a), and Guédria (2012). The review of the interoperability maturity models is carried out in Section 3.4.

### 3.3.1 The IDEAS Interoperability Framework

The IDEAS interoperability framework (IDEAS 2003b) was developed by the IDEAS project (IDEAS 2003f) on the basis that this interoperability framework had to be intuitive, allowing for contributions from a wide range of stakeholders in enterprise systems interoperability, such as end-users, analysts, solution providers, etc. On this basis, it was felt by IDEAS to base the IDEAS interoperability framework on the ECMA/NIST Toaster Model and ISO 19101 and 19119 and augment them through the quality attributes shown in Figure 3.1 (IDEAS 2003b). The original idea behind the IDEAS interoperability framework is that ‘‘interoperability is achieved on multiple levels: inter-enterprise coordination, business process integration, semantic application integration, syntactical application integration, and physical integration’’ (IDEAS 2003b).

| | Framework 1st Level | Framework 2nd Level | ONTOLOGY | QUALITY ATTRIBUTES | | | QUALITY ATTRIBUTES | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Semantics | Security | Scalability | Evolution | Performance | Availability | Portability |
| ENTERPR. MODEL | Business | Decisional Model | | | | | | | |
| | | Business Model | | | | | | | |
| | | Business Processes | | | | | | | |
| | Knowledge | Organisation Roles | | | | | | | |
| | | Skills Competencies | | | | | | | |
| | | Knowledge Assets | | | | | | | |
| ARCHITECT PLATFORM | Application | Solution Management | | | | | | | |
| | | Workplace Interaction | | | | | | | |
| | | Application Logic | | | | | | | |
| | | Process Logic | | | | | | | |
| | Data | Product Data | | | | | | | |
| | | Process Data | | | | | | | |
| | | Knowledge Data | | | | | | | |
| | | Commerce Data | | | | | | | |
| | Communicat ion | | | | | | | | |

Figure 3.1: IDEAS interoperability framework (IDEAS 2003b) (p. 40)

In order to define the scope of interoperability problematic, the IDEAS Framework also points out that interoperability between two enterprises must be achieved on different levels (application, data, communication, business, and knowledge) (Chen and Doumeingts 2003, Rezaei et al. 2014a). This includes the business environment and business processes on the business layer, the organisational roles, skills and competencies of employees and knowledge assets on the knowledge layer, and applications, data and communication components on the ICT layer. In addition, semantic descriptions can be used to get the necessary mutual understanding between enterprises that want to collaborate (Chen and Doumeingts 2003) (see Figure 3.2).

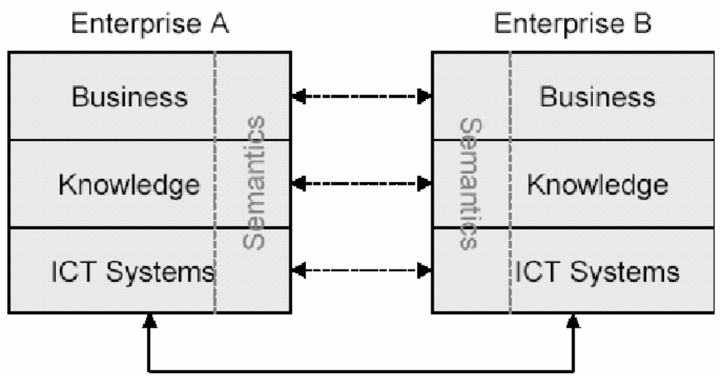



Figure 3.2: Interoperability on different layers of an enterprise (IDEAS 2003a) (p. 16)

In the business layer, all issues related to the organisation and the management of an enterprise are addressed. Amongst others, they include the way an enterprise is organised, how it operates to produce value, how it manages its relationships (internally with its personnel and externally with partners, customers, and suppliers). Interoperability at this level should be seen as the organisational and operational ability of an enterprise to factually cooperate with other enterprises (Chen and Doumeingts 2003).

The Knowledge layer is concerned with acquiring, structuring and representing the collective/personal knowledge of an enterprise. It includes knowledge of internal aspects such as products, the way the administration operates and controls, how the personnel is managed, and so on, but also of external aspects such as partners and suppliers, laws and regulations, legal obligations, and relationships with public institutions. Interoperability at knowledge level should be seen as the compatibility of the skills, competencies and knowledge assets of an enterprise with those of other enterprises. This layer addresses the methods and tools that support the elicitation, gathering, organisation and diffusion of business knowledge within an enterprise.

The ICT systems layer, which includes, application, data, and communication, allow enterprises to operate, make decisions, and exchange information within and outside its boundaries. The overall execution of the enterprise application will be orchestrated by the business process model identified in the top layer and formally (i.e. unambiguously) represented and stored in the middle (knowledge) layer. Interoperability at ICT systems level should be seen as the ability of an enterprise's ICT systems to cooperate with those of other external organisations. It is concerned with the usage of ICT to provide interoperation between enterprise resources (i.e. software, machines and humans) (Chen and Doumeingts 2003, Chen et al. 2008a).

The semantic dimension cuts across the business, knowledge and ICT layers. It is concerned with capturing and representing the actual meaning of concepts and thus promoting understanding. The holistic perspective on interoperability requires considering semantics on each layer of an enterprise. For enterprises that want to collaborate with each other and that need interoperability on a specific layer, it is of prime importance to create a mutual understanding. To ensure that semantics are exchangeable and based on a common understanding, ontology and annotation formalism for meaning can be used (Chen and Doumeingts 2003, Chen et al. 2008a).

### 3.3.2 The Layers of Coalition Interoperability

The layers of coalition interoperability model has been introduced by Tolk (2003) to deal with the nine interoperability layers, which are arranged into organisational interoperability and technical interoperability, as shown in Figure 3.3. The four upper layers deal with organisational interoperability while the four lower layers deal with technical interoperability, i.e. the ability to collect, manipulate, distribute, and disseminate data and information. The interface between the technical interoperability to organisational interoperability is made at the knowledge/awareness layer, in which serves as a fluent transition from one category to another.

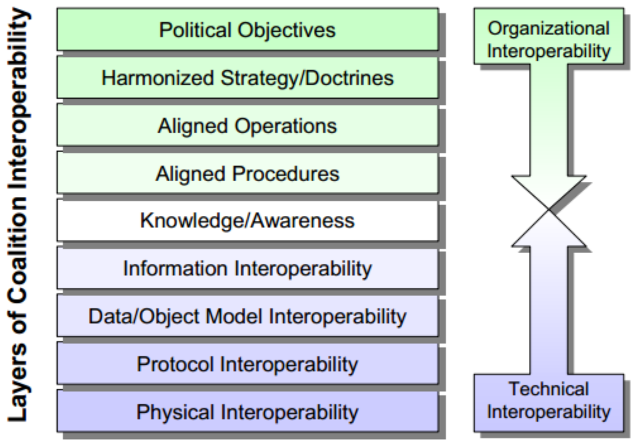



Figure 3.3: The layers of coalition interoperability (Tolk 2003) (p. 18)

Briefly, each interoperability level is explained as follows (Tolk 2003, Rezaei et al. 2014b):

- ***Physical interoperability***: relates to the physical connection of systems to the network and the procedures of information interchanges;
- ***Protocol interoperability***: refers to the protocols for communication with other capabilities using the network;
- ***Data/object model interoperability***: includes the standard data elements and meta-data for information interchanges;
- ***Information interoperability***: contains the dynamic information that could be mapped between the systems, and the cause and effect of harmonization of the information;
- ***Knowledge/awareness***: includes the common operational picture, collaboration tools, and harmonised views of operation;
- ***Aligned procedures***: relates to the tactics that are aligned across organisations, and supported by knowledge and data bases, models, simulations, with the tactical communication infrastructure available;
- ***Aligned operations***: includes the aligned procedures that are applicable at the operational/tactical level;
- ***Harmonized strategy/doctrines***: in this layer, the aligned operations are applicable. Partners' social and cultural backgrounds are aligned;
- ***Political objectives***: refers to the partner share of the same political objectives and values of the coalition.

### 3.3.3 The ATHENA Interoperability Framework

The ATHENA Interoperability Framework (AIF) (ATHENA 2004) provides a compound framework and associated reference architecture for capturing the research elements and solutions to interoperability issues that address the problem in a holistic way by inter-relating relevant information from different perspectives of the enterprise. It is structured into three levels of integration (ATHENA 2004, Berre *et al.* 2007):

- ***Conceptual integration***: focuses on concepts, meta-models, languages and model relationships. It provides us with a foundation for systemising various aspects of interoperability;
- ***Applicative integration***: focuses on methodologies, standards and domain models. It provides us with guidelines, principles and patterns that can be used to solve interoperability issues;

- ***Technical integration***: focuses on the software development and execution environments. It provides development tools and execution platforms for integrating processes, services and information.

Whereas the IDEAS interoperability framework focuses on structuring the interoperability issues into business, knowledge, semantic, and architecture and platform issues, the AIF focuses on the solution approaches, i.e. it relates the solution approaches coming from enterprise modelling, architectures and platforms, and ontology. Figure 3.4 illustrates a simplistic view of the AIF, which indicates the required and provided artefacts of two collaborating enterprises.

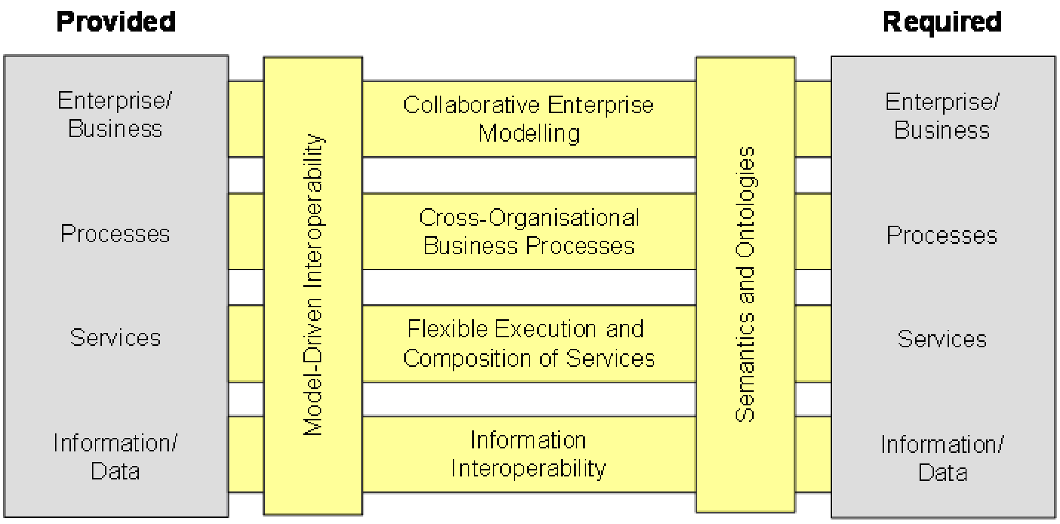



Figure 3.4: ATHENA interoperability framework (ATHENA 2004) (p. 3)

The AIF suggests that interoperations between two collaborating enterprises can take place at four levels, as follows (Berre et al. 2007):

- ***Interoperability of enterprise/business***: should be seen as the organisational and operational ability of an enterprise to factually cooperate with other, external organisations in spite of e.g. different working practices, legislations, cultures and commercial approaches;
- ***Interoperability of processes***: aims at making various processes work together. It is also concerned with the study of how to connect processes of two companies to create cross-organisational business process;
- ***Interoperability of services***: concerned with identifying, composing and executing various applications (designed and implemented independently);
- ***Interoperability of information/data***: refers to the management, exchange and processing of different documents, messages and/or structures by different collaborating entities.

For each of these levels, it is prescribed a model-driven interoperability approach where models are used to formalise and exchange the relevant provided and required artefacts that must be aligned and made compatible through negotiations and agreements. To overcome the semantic barriers which emerge from different interpretations of syntactic descriptions, precise, computer processable meaning must be associated with the models expressed on the different levels. It has to be ensured that semantics are exchangeable and based on common understanding in order to enhance interoperability. This can be achieved using ontologies and an annotation formalism for defining meaning in the exchanged models (ATHENA 2004).

### 3.3.4 The European Interoperability Framework

The European Interoperability Framework (EIF 2004) was developed in the context of a research program funded by the European commission for the interoperability development in European eGovernment services. It aims at defining a set of recommendations and guidelines for eGovernement services so that public administrations, enterprises and citizens can interact across borders, in a pan-European context. In other words, its ultimate goal is to facilitate the interoperability of services and systems between public administrations, as well as between administrations and the public (citizens and enterprises), at the pan-European level. The EIF recommends that setting-up eGovernment services at a pan-European level requires the consideration of interoperability issues with regard to three aspects (EIF 2004):

- ***Organisational interoperability***: concerned with defining business goals, modelling business processes and bringing about the collaboration of administrations that wish to exchange information and may have different internal structures and processes. Moreover, organisational interoperability aims at addressing the requirements of the user Community by making services available, easily identifiable, accessible and user-oriented;
- ***Semantic interoperability***: concerned with ensuring that the precise meaning of exchanged information is understandable by any other application that was not initially developed for this purpose. Semantic interoperability enables systems to combine received information with other information resources and to process it in a meaningful manner;
- ***Technical interoperability***: covers the technical issues of linking computer systems and services. It includes key aspects such as open interfaces, interconnection services, data integration and middleware, data presentation and exchange, accessibility and security services.

### 3.3.5 The E-health Interoperability Framework

The E-health interoperability framework (NEHTA 2005) was developed by the National E-Health Transition Authority (NEHTA) initiatives in Australia (Guédria et al. 2013). It comprises brings together organisational, information, and technical layers relating to the delivery of interoperability across health organisations, as shown in Figure 3.5.

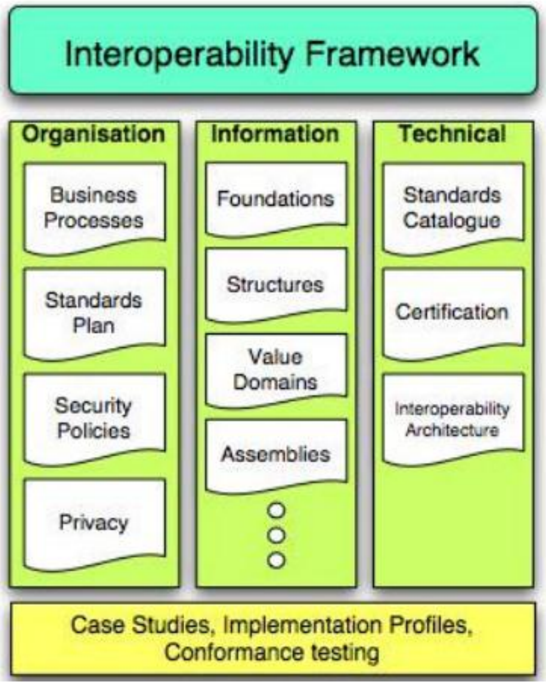



Figure 3.5: E-health interoperability framework (NEHTA 2005) (p. 11)

Each interoperability layer is described as follows (NEHTA 2005):

- Organisational layer: it considers that interoperability does not occur without organisational support for appropriate business collaboration models. It provides a shared policy and process framework across the E-health interoperability agenda covering each NEHTA initiative. It comprises the business processes, financial analysis, privacy, policy, and other legislative issues, governance, and standards plan;
- Information layer: it provides shared building blocks for semantic (information) interchange including issues such as foundation components, value domains, structures, common assemblies, relationships, and metadata;
- Technical layer: it is concerned with the specification of technical standards enabling solution delivery. It considers that connectivity of systems for information exchange and service use requires compatible technical solutions. These solutions are based on open standards providing a level playing field for competitive provision of technical solutions.

### 3.3.6 The Framework for Enterprise Interoperability

The Framework for Enterprise Interoperability (FEI) (Chen 2006a) was developed within the frame of INTEROP Network of Excellence (INTEROP 2007). The purpose of this framework is to identify the basic dimensions regarding to enterprise interoperability and to define its research domain as well as to identify and structure the knowledge of the domain. The FEI defines a classification scheme for interoperability knowledge according to three dimensions (interoperability barriers, interoperability approaches, and interoperability concerns), as illustrated by Figure 3.6.

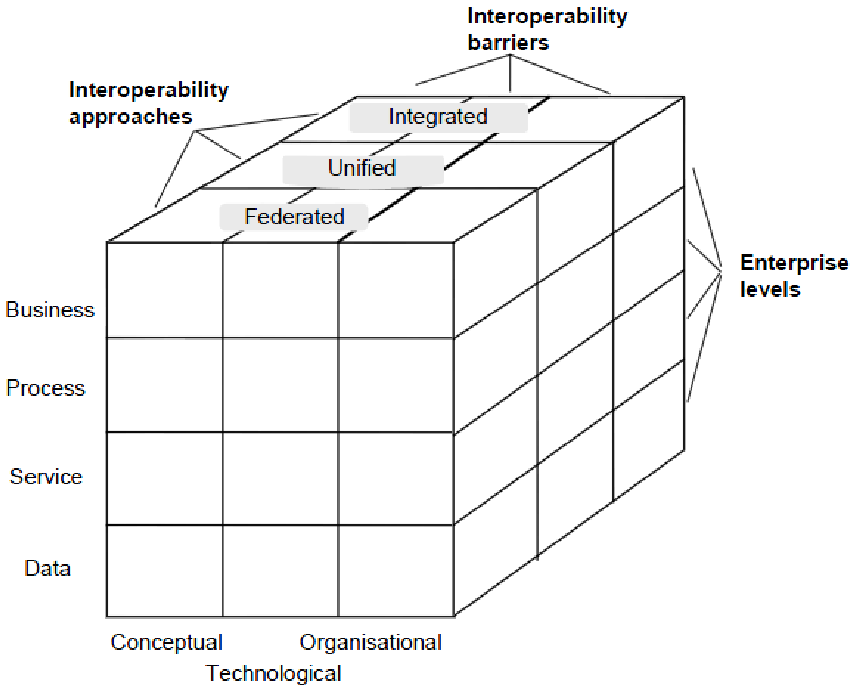



Figure 3.6: The enterprise interoperability framework (Chen 2006a)

Regarding to the dimension "interoperability barriers", the FEI suggests that the establishment of interoperability consists in removing all the identified barriers (Guédria et al. 2013). The three categories of barriers (conceptual, technological and organisational) are described as follows (Chen 2006a, Chen *et al.* 2008a):

- ***Conceptual barriers***: are concerned with the syntactic and semantic differences of information to be exchanged;
- ***Technological barriers***: refer to the incompatibility of information technologies (architectures and platforms, infrastructure, etc.). These problems concern the standards to present, store, exchange, process and communicate the data through the use of computers;

- ***Organisational barriers***: relate to the definition of responsibility (who is responsible for what?) and authority (who is authorised to do what?) as well as the incompatibility of organisation structure (e.g. matrix vs. hierarchical ones).

The dimension "interoperability concerns" represent the areas concerned by interoperability in an enterprise (Guédria et al. 2013). Four concerns are defined, as follows (Chen 2006a, Chen *et al.* 2008a):

- ***Interoperability of data***: it refers to make different data models and query languages working together. The interoperability of data deals with finding and sharing information from heterogeneous data sources, and which can moreover reside on different machines under different operating systems and data base management systems;
- ***Interoperability of services***: it is concerned with identifying, composing and making various applications function together (designed and implemented independently). The term "service" is not limited to the computer based applications; but also functions of companies and networked enterprises;
- ***Interoperability of processes***: the aim is to make various business processes work together. In a networked enterprise, it is also necessary to study how to connect internal processes of two companies to create a common process;
- ***Interoperability of business***: it refers to working in a harmonized way at the level of organisation and company in spite of, for example, the different modes of decision-making, methods of work, legislations, culture of the company or commercial approaches so that business can be developed between companies.

The third notion of the FEI is that research on interoperability is not only a matter of removing barriers but also in the way in which these barriers are removed (Chen et al. 2008a). Thus, the FEI considers that there are three basic approaches to relate entities together to establish interoperations (Chen 2006a, Chen *et al.* 2008a):

- ***Integrated approach***: characterised by the existence of a common format for all the constituent systems. The common format is not necessarily a standard but must be agreed by all parties to elaborate models and build systems;
- ***Unified approach***: characterised by the existence of a common format but only at a meta-level. This meta-model is not an executable entity as it is in the integrated approach but provides a means for semantic equivalence to allow mapping between models;
- ***Federated approach***: there is no common format. This approach implies that no partner imposes its models, languages and methods of work, and interoperability is managed in an ad-hoc manner.

Compared to other interoperability frameworks, the FEI provides three explicitly defined interoperability dimensions (interoperability barriers, interoperability concerns and interoperability approaches) to allow defining interoperability research domain (Guédria et al. 2013). Incompatibility is the fundamental concept used in defining the scope of interoperability domain. It is the obstacle to establish seamless interoperation. Another fundamental consideration is the generic characteristic of the interoperability research. Indeed, there are generic problems and solutions regardless of the content of information exchanged between two systems (Chen et al. 2008a).

### 3.3.7 The Business Interoperability Framework

The Business Interoperability Framework (BIF) was developed within the frame of ATHENA project to investigate the collaboration between networked enterprises (ATHENA 2007). The issues of business interoperability are structured into four categories, as illustrated by Table 3.1. Each category is operationalised by a set of criteria (or sub-categories), which outline the key business decisions that companies have to solve when establishing interoperable IT-supported business relationships. Broadly speaking, criteria are parameters that can be tuned in order to increase interoperability of an enterprise (ATHENA 2007). In addition to the four categories, the BIF postulates that the optimum inter-organisational design fits external (environmental) and internal contingencies.

Table 3.1: Business interoperability framework (ATHENA 2007) (p. 41)

| **Business interoperability (= organisational design of business relationships)** | | |
|---|---|---|
| **Category** | **Perspective** | **Description** |
| Management of external relationships | "How do we manage and control business relationships?" **(Governance perspective)** | Interoperable organisations manage and monitor their business relationships. |
| Employees and culture | "How do we behave towards our business partners?" **(Behavioural perspective)** | Interoperable organisations promote relationships with business partners at an individual, team-based and organisational level. |
| Collaborative business processes | "How do we collaborate with business partners?" | Interoperable organisations can quickly and inexpensively establish and conduct electronic collaboration with business partners. |
| Information systems | "How do we connect with business partners?" **(Technical perspective)** | Interoperable ICT systems can be linked up to other ICT systems quickly and inexpensively and support the cooperation strategy of the organisation. |
| **Contingencies (= factors which impact the organisational design)** | | |
| **Category** | **Perspective** | **Description** |
| Internal contingencies | "What are the characteristics of the business relationships?" | Cooperation targets and transactional characteristics impact the optimum level of business interoperability. |
| External contingencies | "Which environmental factors affect the business relationships?" | E-Business maturity, legislation and industry dynamics determine preconditions in the specific context. |

The core of the BIF describes and assesses the IT-supported business relationships of an organisation. To this purpose, each category defined in the BIF is decomposed into a set of criteria, as illustrated in Table 3.2.

Table 3.2: Categories and criteria in the business interoperability framework (adopted from (ATHENA 2007))

| Category | Criterion | Description |
|---|---|---|
| **Management of external relationships** | Cooperation model | Describes to what extent an enterprise defines its role within a business network and clear rules of engagement, which underlie any cooperation. |
| | Cooperation targets | Plans and objectives that partners pursue in the cooperation; questions whether there is reciprocity within the relationships and whether both parties feel that they are gaining (win-to-win situation). |
| | Cooperation management | Defines the roles and processes for initiation, realisation, control and monitoring of the cooperation. It takes previsions for the management of risk and conflicts as well as for the protection of property rights. |
| **Employees and culture** | Trust | Characterises the mutual respect, openness, reliability and confidence between the employees involved in the collaborative relationship. |
| | Visibility | Describes the degree to which information is shared with partners and which external partners gain visibility of the business processes. |
| **Collaborative business processes** | Public processes | Represent an abstract view of the cross-organisational business processes which focuses on the interaction between the partners (e.g. activities, roles, inputs/outputs) |
| | Business semantics | Questions whether there is a common understanding of the structure and significance of the information to be exchanged. |
| **Information systems** | Type of interaction | Describes the type of interaction during the process of exchanging/gathering information. It can be: "human-to-human", which describes traditional forms of interacting between humans which may be supported by fax, phone, or e-mail communication; "human-to-machine" (e.g. customer or supplier portals bundle data and applications on the basis of users and roles; "machine-to-machine", which denotes consistently automated processes (e.g. EDI). |
| | Connectivity | Characterises the cooperation architecture which supports the electronic interaction, i.e. the type of connection established among the ICT systems. It can be point-to-point (1:1), one-to-many (1:n) or many-to-many (m:n). |
| | Security and privacy | Cover authentication and authorisation as well as the encryption of messages. In addition, privacy and legal requirements have to be respected, e.g. In electronic contracting and invoicing, since they deal with sensitive data and additionally need to comply with e-business legislation. |
| **Internal contingencies** | Coordination area and targets | Associated with specific coordination requirements and resulting interaction frequency and intensity. For instance, the goal of SCM is to handle operative planning and execution processes as efficiently as possible. It multiplies clearly defined outputs and tries to utilise the effects of economies of scale in order to achieve profit. The goal of the coordination area innovation is the rapid creation of new products, which requires a dynamic environment in the early phases. |
| | Business partners | Characterises the size and number of partners as well as their diversity regarding industry and regional focus. For example, SMEs are reluctant to higher levels of electronic integration due to significant investments and their lacking organisational readiness for inter-organisational systems adoption. In general, ICT systems of large companies obviously tend to be more powerful and sophisticated than those of small companies. |
| | Cooperation dynamics | Characterise the duration and the intensity of the relationships among partners; can be stable or dynamic. For example, supply networks in the automotive industry are in place for several years –stable network; on the other hand, companies in the construction industry usually cooperate only for the given period of a project – dynamic networks. |

| | | |
|---|---|---|
| | Network governance | Characterises the basic mechanisms with which decisions are made within a network; it can be hierarchical or heterarchical. |
| | Interdependence | The type of interdependence among the collaborating partners (pooled, sequential, or reciprocal) |
| | Specificity | Questions whether investments made for the business relationship are non-specific, mixed or idiosyncratic. It also describes the dependency between business partners, as more specific upfront investments result in higher dependency (unidirectional or bidirectional). |
| | Frequency | The frequency of transactions within a business relationship can be one-time, occasional and recurrent. |
| **External contingencies** | Legislation and regulation | National and international legislation as well as industry-specific, national or international regulation and standards increasingly oblige companies to become more interoperable. |
| | Degree of standardisation | The availability of standards, for example, the one that enable the unique identification of product increases the interoperability between for instance retailers and their suppliers. |
| | E-business maturity | Doing business in an e-business-mature industry will imply that certain prerequisites for electronic collaboration exist (e.g. banking industry). |

In order to assess the level of business interoperability regarding each criterion defined in Table 3.2, the BIF proposes a five level-based maturity model named "Levels of Business Interoperability", which is described in Section 3.4.5.

### 3.3.8 The Business Interoperability Quotient Measurement Model

The BIQMM is a framework that has been proposed by Zutshi et al. (2012) to capture the factors that are responsible for business interoperability in the context of collaborative business processes. In other words, BIQMM is a framework that captures and extends the main dimensions of business interoperability, as well as their related sub-dimensions, proposed in previous works. Using an interdisciplinary approach to embrace the key elements responsible for collaboration performance, the BIQMM has identified eight major Business Interoperability Parameters (BIPs), representing the different levels of interactions that collaborating entities can engage in, and further identifying sub-parameters to enable measuring performance for each BIP (see Figure 3.7).

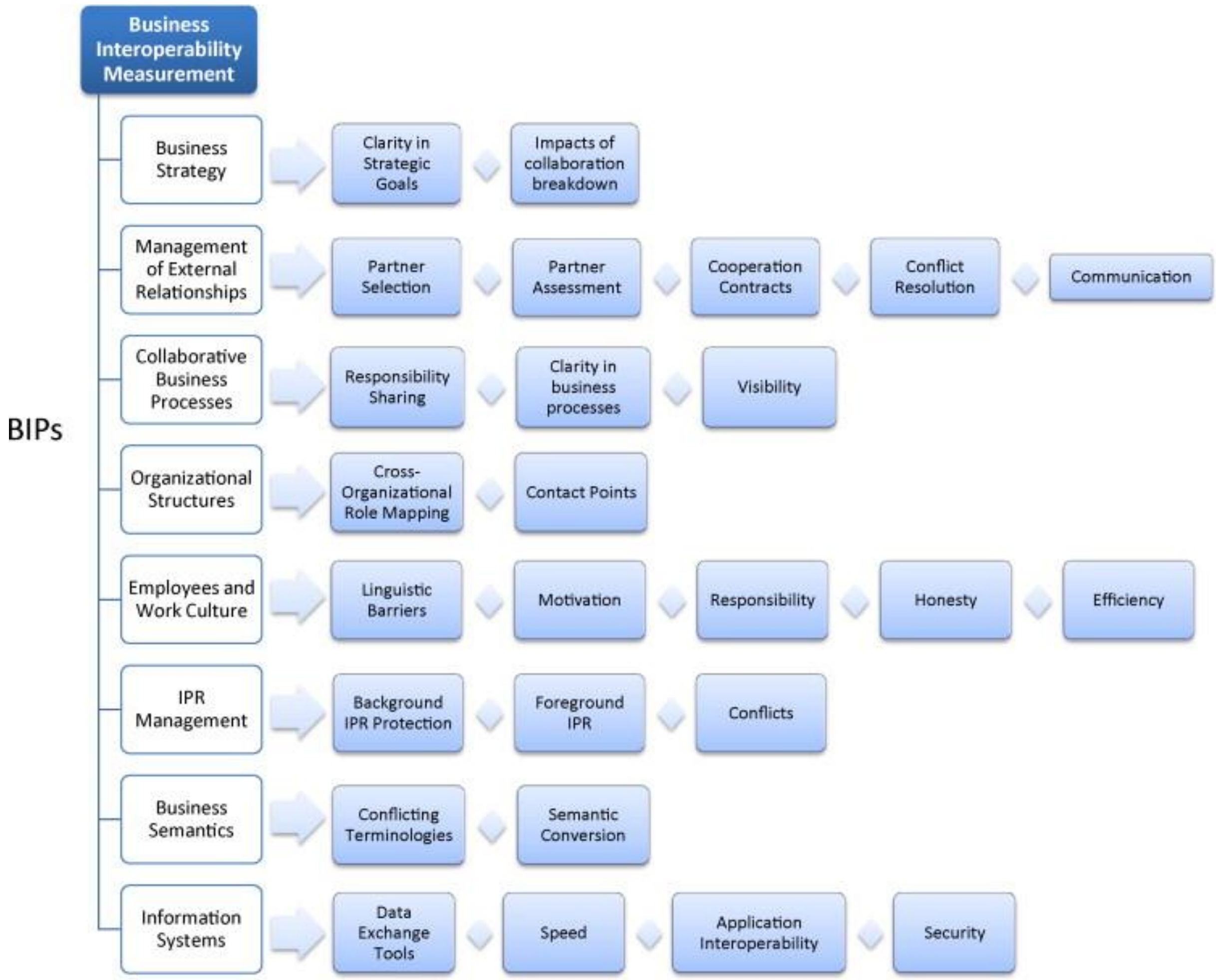



Figure 3.7: Business interoperability parameters (Zutshi et al. 2012) (p. 392)

A description of each of the above sub-parameter and an example scenario for high and low relevance of the main BIP are provided in the BIQMM. For example, the BIP "Business strategy" is considered of high relevance in a collaboration scenario where IPR are being shared, and joint product or technology development is involved (e.g. between software and hardware developers in hi-tech industries). On the other hand, "Business strategy" is considered of low relevance in a vendor-supplier scenario where ad hoc cost-based competitive procurements are made. Regarding to the description of the sub-parameters, the "Impacts of collaboration breakdown", for instance, is described as follows (Zutshi et al. 2012): it addresses questions regarding a formal commitment to the duration of collaboration, or how detrimental it would be for the organisation in the event of premature termination of the collaboration, or if there are sufficient safeguards to prevent termination, or backup plans in the event this were to occur. It is to notice that an extension of this framework will be presented later in Section 5.3, and therefore its elements are not described in detail in this section.

## 3.4 Existing interoperability maturity models

Maturity is defined as a measure to evaluate the capabilities of an organisation in regards to a certain discipline (Cuenca et al. 2013). A maturity model, in turn, can be defined as “a framework that describes, for a specific area of interest, a number of levels of sophistication at which activities in this area can be carried out” (Alonso et al. 2010) or as “a framework that defines the states or levels at which an enterprise or system can be situated, a set of good practices, goals, and quantifiable parameters that make it possible to determine on which of the levels the enterprise currently stands, and also a series of proposals with which to evolve from one level of maturity to a higher one” (Campos et al. 2013). In other words, it describes the stage through which systems, processes or organisations progress or evolve as they are defined, implemented and improved (Clark and Jones 1999), i.e. it describes the evolution of a specific system over time (Cuenca et al. 2013).

Intrinsic to a maturity model is the concept of levels – with each level used to characterise the state of the system or organisation (Clark and Jones 1999). The main objective in the application of maturity models is to assess organisations to know their maturity level with respect to a set of best practices (Cuenca et al. 2013), in the case of this research, the business interoperability level with respect to a set of business interoperability solutions. Maturity models, as a tool to achieve the level of excellence corresponding to the maximum level of maturity, with regard to the evolution of a system, can be used as (Cuenca et al. 2013): snapshot, a representation of the as-is situation (i.e. an evaluative and comparative basis for improvement); recommendation for action (i.e. in order to derive an informed approach for increasing the capability of a specific area within an organisation); and instrument for controlling (i.e. measuring the success of an action).

According to Estampe et al. (2013), maturity models first appeared in early quality management studies, which tended to identify a number of different levels (Crosby 1979). However, maturity as a measure to evaluate the capabilities of an organisation in regards to a certain discipline has become popular since the Capability Maturity Model (CMM) proposed by the Software Engineering Institute (SEI) at Carnegie Mellon University (Paulk et al. 1993), in Cuenca et al. (2013). Within this context, one of the best known maturity models, according to Estampe et al. (2013), is the Capability Maturity Model Integration (CMMI) developed by SEI (2004). Since the concept of maturity models is not exclusively restricted to the field of software engineering, examples of maturity models can be found in different research areas such as SC (e.g. (Cuenca *et al.* 2013, Estampe *et al.* 2013)), collaboration (e.g. (Alonso et al. 2010)) and interoperability (e.g. (Campos et al. 2013, Guédria et al. 2013)).

For the purpose of this research, a business interoperability maturity model is defined as a framework that describes the stages through which systems within a company should logically progress, or ‘‘mature,’’ in order to improve their capabilities to interoperate with systems from the same company or from other companies (adopted from (Rezaei et al. 2014b)). Put it simple, we can say that if interoperability is a measure of the ability of two or more systems to perform interoperation, the levels in the interoperability maturity model measure how good or how bad is this interoperation (Vernadat 2010). The main purpose of its application is to establish and define projects for improving interoperability between business units, by first evaluating 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 improvement (Campos et al. 2013). This is also supported by Guédria et al. (2013) who stress that assessing interoperability maturity allows a company to know its strengths and weaknesses in terms of interoperability with its current and potential partners, and to prioritise actions for improvement.

As many interoperability maturity models have been proposed in the literature to deal with interoperability assessment, this section attempts to provide an overview of them. The objective is not to provide an exhaustive review of the existing interoperability maturity models but rather it is to discuss the ones that are considered as the most relevant for this research. Levels of Information Systems Interoperability (LISI) (DoD 1998) is included in this review as, according to Guédria et al. (2013), it has been successfully applied in the technical interoperability domain (e.g. (Tolk and Muguira 2003)). The Levels of Conceptual Interoperability Model (LCIM) (Tolk and Muguira 2003) is also reviewed as it is featured as a reference model in various journal contributions and book chapters (Guédria et al. 2013). Other maturity models such as the ones proposed by ATHENA (2007), Guédria et al. (2013), Campos et al. (2013), and Rezaei et al. (2014b) are also included as they have been recently published and they take into account existing previous maturity models while extending them to cover the actual issues of business interoperability. In addition, these four maturity models were used as the references to develop the theoretical business interoperability maturity model proposed in Section 6.3. A more complete review can be found in Ford (2008), Guédria (2012), Rezaei et al. (2013), Rezaei et al. (2014b), and Rezaei et al. (2014c).

Among the maturity models maturity models that have not been included in this review, one can mention: Spectrum of Interoperability (LaVean 1980) and NATO C3 Technical Architecture (NC3TA) (NATO 2003). The first has not been included as it addresses interoperability between communication systems that supported the US Defence community, US civil Government community, and Allied National communities in the 1980s, and for that reason it is considered out of data. In addition, it has not been reviewed in recent publications on interoperability maturity models (e.g. (Campos *et al.* 2013, Guédria *et al.* 2013, Rezaei *et al.* 2014b). The last, NC3TA has not been included as it was not available at the time of development of this research. For its review, the reader is guided to see Tolk (2003) or Guédria (2012).

### 3.4.1 Levels of Information Systems Interoperability

The LISI model has been proposed by the Architecture Working Group of the US Department of Defence (on Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance – C4ISR) (DoD 1998). LISI is reference model and process for assessing information systems' interoperability (Kasunic and Anderson 2004), by providing a common structure and language needed to discuss interoperability between those systems (Vernadat 2010, Rezaei *et al.* 2014c). The LISI model consists of processes and a maturity model in order to determine the interoperability requirements (Rezaei *et al.* 2014c). In other words, it identifies the stages through which information systems should logically progress or "mature" in order to improve their capabilities to interoperate (Clark and Jones 1999). Also, it evaluates the information systems ability to meet the requirements (Rezaei *et al.* 2014c). Five levels have been defined to describe both the level of interoperability and the environment in which it occurs. For instance, the level 0 and level 4 are described as follows (DoD 1998, Rezaei et al. 2014b):

- ***Level 0 – isolated (interoperability in a manual environment)***: this level encompasses the wide range of isolated or stand-alone systems, i.e. no direct electronic connection is allowed or is available, so their interface is manual. In other words, this interoperability level contains manual data integration and extraction among multiple systems. Fusion of information, if any, is done off-line by the individual decision-maker by other automated means;
- ***Level 4 – enterprise (interoperability in a universal environment)***: systems are capable of operating using a distributed global information space across multiple domains. At this level, multiple users can access and interact with complex data simultaneously. Applications and data are fully shared and can be distributed to support information fusion. In addition, it is possible to have advanced forms of collaboration at this level. Common data interpretation is applied across the entire enterprise regardless of the format. The need for redundant, functionally equivalent applications is diminished since applications can be shared as readily as data at this level. Decision-making takes place in the context of, and is facilitated by, enterprise-wide information found in the global information space.

Within each of these maturity levels, LISI identifies additional factors influence the ability of information systems to interoperate. These factors are categorised into four key attributes: Procedures, Applications, Infrastructure, and Data (PAID) (DoD 1998). The procedure attribute addresses the architecture guidance and standards, policies and procedures, and doctrine that enable information exchanges between systems. The applications attribute describes the fundamental purpose and function for which any system is built, i.e. its mission. This attribute indicates applications that permit processing, exchange, and manipulation. Infrastructure is the attribute that supports the establishment and use of a connection between systems and applications. This attribute includes the environments enabling the interaction, such as system services, networks, and hardware. The security devices and technical capabilities that are used to implement security procedures also make up a part of the infrastructure. At last, the data attributes focuses on the information processed by the system, and contain both data format (syntax) and the content or meaning (semantics). This data attribute of interoperability includes protocols and formats enabling information and data interchanges (DoD 1998, Rezaei et al. 2014b).

The LISI reference model is shown in Figure 3.8. At each level, a word or phrase highlights the most important aspect of PAID needed to achieve that level. For example, a system targeting interactions with other systems working at Level 3 (domain level in an integrated environment) must build toward the specific set of capabilities that underlie the PAID thresholds of the LISI reference model at level 3 (domain level procedures, groupware applications, access to world wide networks and domain data models).

| *Description* | *Computing Environment* | *Level* | P | A | I | D |
|---|---|---|---|---|---|---|
| Enterprise | Universal | 4 | Enterprise Level | Interactive | Multi-Dimensional Topologies | Enterprise Model |
| Domain | Integrated | 3 | Domain Level | Groupware | World-wide Network | Domain Model |
| Functional | Distributed | 2 | Program Level | Desktop Automation | Local Networks | Program Model |
| Connected | Peer-to-Peer | 1 | Local/Site Level | Standard System Drivers | Simple Connection | Local |
| Isolated | Manual | 0 | Access Control | N/A | Independant | Private |

Figure 3.8: LISI reference model ((DoD 1998)

The first three columns of the LISI maturity model provide identification information for the interoperability level and sub-levels, and the next four columns associate the specific contributions of the Procedures, Applications, Infrastructure, and Data attributes to each level. Major thresholds are crossed in order to transition from one broad maturity level to the next; whereas, minor interoperability thresholds exist between the sub-levels of a given level (DoD 1998, Rezaei et al. 2014b).

Although LISI is perhaps the most widely recognised maturity model of interoperability (Rezaei et al. 2014b) and according to Campos et al. (2013), the first significant initiative carried out to measure interoperability, the model is often criticised mainly due to its “strong” focus on the information systems interoperability. For example, Clark and Jones (1999) pointed out that the LISI model is strongly technological, as its name suggests and that it focuses on system and technical compatibility. Morris et al. (2004) refer that the LISI model does not address the environmental and organisational issues that contribute to the construction and maintenance of interoperable systems. Campos et al (2013) stress that LISI is essentially focused on the technological platforms that support information systems and does not cover all the areas on interest that must be taken into account in business interoperability, such as knowledge and semantic.

To Rezaei et al. (2014c), one of the major concerns of the LISI model is that it reflects a set of standards and interoperability expectations aligned with the US Department of Defence at the time of its creation, and therefore the model contains risks in becoming out-dated and the interoperability options tables are required to be updated to reflect new technology and approaches. From this thesis point of view, LISI is considered to be inappropriate as it only address the information systems interoperability, ignoring the other dimensions of business networking in cooperative environments. Furthermore, it seems to be obvious that among the various elements that describes the information systems interoperability, LISI have only addressed the type of connectivity established between the systems and the issue of accessibility. As is discussed in Section 5.3.8, information systems interoperability is not only about connectivity and accessibility. Considering that connectivity and accessibility are the two main elements addressed in the LISI maturity model, another criticism can be pointed out: these two elements should be evaluated separately and not together as has been done. However, some insights on how to describe an interoperability maturity level have been acquired from this model.

### 3.4.2 Organisational Interoperability Maturity Model

The OIMM has been proposed by Clark and Jones (1999) to extend the LISI model into the more abstract layers of C2 Support, that is, the C2 Frameworks, C2 Processes and Information Management areas (see Figure 3.9). The OIMM extends the LISI model to assess organisation maturity issues (Guédria et al. 2013), i.e. completes the LISI model by extending it into organisational layers (Campos et al. 2013).

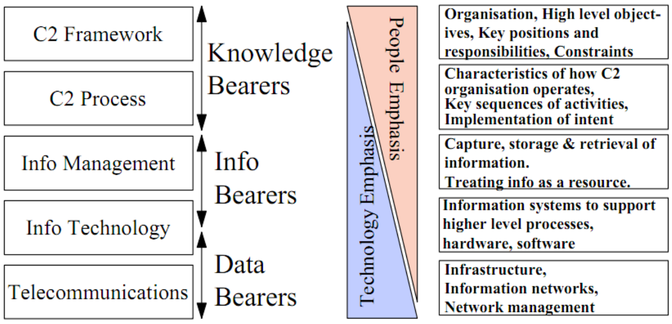



Figure 3.9: Layers of C2 support (Clark and Jones 1999)

The OIMM defines the levels of organisational maturity that describe the ability of organisations to interoperate. Five levels are identified as follows (Clark and Jones 1999):

- ***Level 0 – independent***: this level describes the interaction between independent organisations. These are organisations that would normally work without any interaction other than that provided by personal contact;
- ***Level 1 – ad hoc***: at this level of interoperability, only very limited organisational frameworks are in place which could support ad hoc arrangements;
- ***Level 2 – collaborative***: at this level, recognised frameworks are in place to support interoperability and shared goals are recognised and roles and responsibilities are allocated as part of on-going responsibilities however the organisations are still distinct;
- ***Level 3 – integrated***: at this level, there are shared value systems and shared goals, a common understanding and a preparedness to interoperate, for example, detailed doctrine is in place and there is significant experience in using it;
- ***Level 4 – unified***: a unified organisation is one in which the organisational goals, value systems, command structure/style, and knowledge bases are shared across the system. The organisation is interoperating on continuing basis.

In order to evaluate these levels, preparedness, understanding, command style, and ethos have been identified as the four enabling attributes of organisational interoperability. These attributes are described as follows (Clark and Jones 1999):

- ***Preparedness***: describes the preparedness of the organisation to interoperate. It is made up of doctrine, experience and training;
- ***Understanding***: measures the amount of communication and sharing of knowledge and information within the organisation and how the information is used;
- ***Command Style***: describes the management and command style of the organisation – how decisions are made and how roles and responsibilities are allocated/delegated;

- ***Ethos***: concerned with the culture and value systems of the organisation and the goals and aspiration of the organisation. The level of trust within the organisation is also included.

The levels proposed in the OIMM were aligned with the LISI levels, and attributes for organisational interoperability were defined for each one. However, no method of measuring the level achieved is described in detail (Campos et al. 2013). An analysis to the OIMM enables us to identify some elements that are used to describe the organisational interoperability at each level of maturity, such as “shared goals”, “arrangements”, “roles and responsibilities” “communication”. Although recognising that these elements are appropriate for defining the level of organisational interoperability, within the context of this thesis, it is advocated that more elements are needed in order to address the other elements of business networking (e.g. legislations, trust, confidence, conflicting terminologies, IPR protection, cultural differences). In addition, it is agreed that each element should be evaluated separately, as has been pointed out in discussion on the LISI model.

### 3.4.3 Levels of Conceptual Interoperability Model

The LCIM has been proposed by Tolk and Muguira (2003). The underlying idea of this model is that interoperability goes beyond the technical implementations as has been addressed in the LISI reference model (DoD 1998). The LCIM is intended to become a bridge between the conceptual design and the technical design. Similar to the technical approaches (e.g. (DoD 1998)), five levels of maturity are defined to evaluate the conceptual interoperability (see Figure 3.10). The focus lies on the data to be interchanged and the interface documentation, which is available.

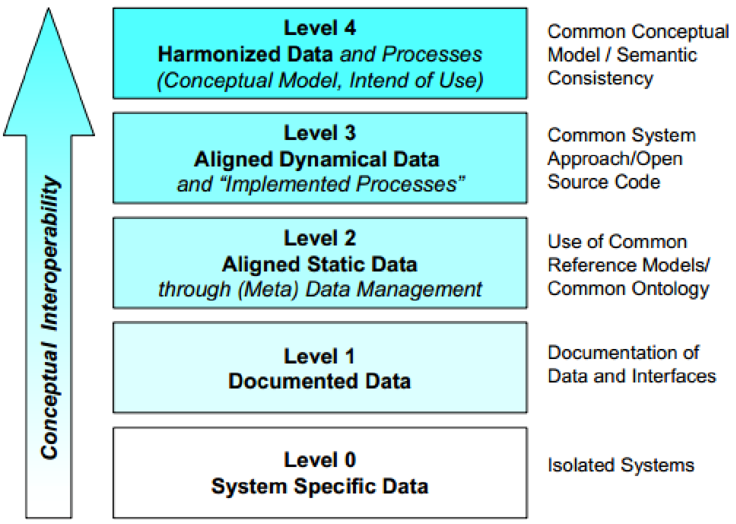



Figure 3.10: The levels of conceptual interoperability model (Tolk and Muguira 2003) (p. 3)

The five levels of conceptual interoperability are defined as follows (Tolk and Muguira 2003, Rezaei et al. 2014b):

- ***Level 0 – system specific data***: no interoperability between two systems. Data is used within each system in a proprietary way with no sharing;
- ***Level 1 – documented data***: at this level, data is documented using a common protocol and is accessible via interfaces;
- ***Level 2 – aligned static data***: at this level, data is documented using a common reference model based on a common ontology, i.e. the meaning of the data is unambiguously described;
- ***Level 3 – aligned dynamic data***: at this level, the use of data is well-defined using standard software engineering methods such as Unified Modelling Language (UML). This permits visibility into the way data is managed within the systems;
- ***Level 4 – harmonised data***: at this level, semantic connections between data that are not related concerning the execution code is made obvious by documenting the conceptual model underlying the component.

The levels of conceptual interoperability model indicates that with the aim of achieving the highest interoperability level, the assumptions underlying how systems interpret data have to be made transparently. Although LCIM provides a different view of interoperability, the proposed maturity levels are defined regarding only the interoperability of data and the conceptual design of the databases (Campos et al. 2013).

### 3.4.4 EIMM – Enterprise Interoperability Maturity Model

The Enterprise Interoperability Maturity Model (EIMM) was developed within the ATHENA project (ATHENA 2005). Contrary to what can be understood by the model’s name, it is not defined with a general view of an enterprise but from an enterprise modelling perspective (Guédria et al. 2013), i.e. it aims at assessing the maturity level of a company concerning the use of enterprise models as well as the capability of these models to enable the company to participate in collaboration (ATHENA 2007). In the EIMM, as in the previous maturity models, five maturity levels, and a set of areas of concern are defined, as illustrated by Figure 3.11.

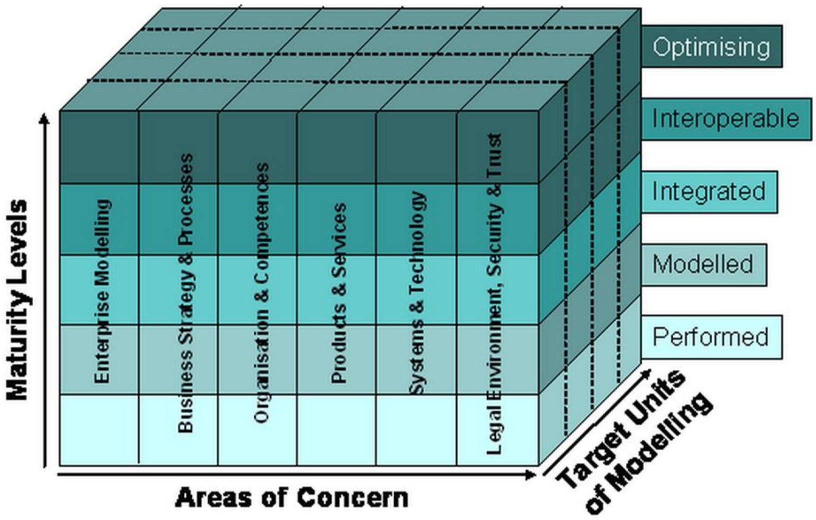



Figure 3.11: Enterprise interoperability maturity model (ATHENA 2005) (p. 5)

Each area of concern represented in the EIMM is defined as follows (ATHENA 2005, Rezaei *et al.* 2014b):

- **Business strategy and processes**: cover the alignment, improvement, execution, specification, and identification of business strategy and processes;
- **Organisation and competences**: cover the improvement, enactment, specification and identification of the organisational structure containing the skills and knowledge of the identified players;
- **Products and services**: cover the design, specification, and identification of the organisation's products and services, its lifecycle strategy and the quality characteristics;
- **Systems and technology**: cover the improvement, maintenance, operation, acquisition/construction, design, specification, and identification of enterprise systems. This contains the establishment of links and traceability to enterprise models, which, at best, are self-controlled;
- **Legal environment, security and trust**: cover the identification of legal, trust and security requirements, because of collaborating with external entities, and the provision of solutions to manage these aspects that are a key for interoperability;
- **Enterprise modelling**: all of the areas of concern that were identified previously are directly affected by aspects of all embracing sixth areas of concern.

The five maturity levels proposed in the EIMM are described as follows (ATHENA 2005, Rezaei *et al.* 2014b):

- **Performed**: at the Performed maturity level, enterprise modelling and collaboration is done, but in an ad hoc approach. Collaborations are done between the organisation, and external entities (customers, administration, suppliers), although the relationships are not planned thoughtfully;
- **Modelled**: At the Modelled maturity level, the enterprise modelling and collaboration are done similarly each time, and the technique has been found to be applicable. At this level, the defined approaches and meta-models are applied;
- **Integrated**: At the Integrated maturity level, the enterprise modelling process has been formally documented, communicated and is used consistently. At this level, organisations use a defined infrastructure and methodology for the enterprise modelling, the different dimensions are integrated among themselves and the model is traceable to the enterprise systems; there is a knowledge base used for improving the models;
- **Interoperable**: At the Interoperable maturity level, dynamic interoperability, adaptation to changes, and external entities evolution are supported by enterprise models. At this level, the people's workplace is seamlessly adapted to the enterprise model;
- **Optimizing**: At the Optimizing maturity level, the enterprise models permits the organisation to adapt and react to changes in the business environment in a responsive, flexible and agile manner. At this level, enterprise systems are systematically traced to enterprise models, and innovative technologies are continuously researched and applied to improve interoperability.

Although EIMM states that parameters and methods must be defined to measure interoperability, no complete proposal has been put forward showing the steps to be followed or the methods and tools to be used to carry out this measurement (Campos et al. 2013).

### 3.4.5 Levels of Business Interoperability

The levels of business interoperability maturity model was developed within the frame of ATHENA business interoperability framework (ATHENA 2007), described in Section 3.3.7. This business interoperability maturity model employs some input of the previous maturity models for the appropriate naming and the number of maturity levels within the business interoperability framework. As a result, five maturity levels have been adopted to describe the main constituents of business interoperability characterised in Section 3.3.7 and to outline how an enterprise may assess and improve its business interoperability. These levels are first described in a "neutral" way, as are illustrated in Table 3.3.

Table 3.3: Levels of business interoperability in the BIF (ATHENA 2007) (p. 43)

| **No.** | **Business interoperability** | **Description** |
|---|---|---|
| 1 | None | No awareness of external relationships; interaction with external partners is not planned or performed ad-hoc |
| 2 | Minimum | No previsions for interoperability; individual design of each external relationship |
| 3 | Moderate | Relevance of business interoperability is “understood”; measures for improving interoperability have been taken, but substantial room for improvement remains |
| 4 | Qualified | External relationships are designed for improved business interoperability; only few factors missing on the way to full interoperability |
| 5 | Fully interoperable | Maximum level of business interoperability; external relationships can be established at no or few cost involved |

Then, the levels of business interoperability for each criterion defined in the BIF (see Section 3.3.7) are evaluated individually grounded on three lifecycle aspects: approach, deploy, and assess & review. For instance, the criterion “Trust”, defined in the category “Employees and culture” is defined as illustrated by Table 3.4.

Table 3.4: Maturity levels for the criterion “Trust” in category “Employees and culture” (ATHENA 2007) (p. 46)

| Category | Description | Life-cycle | Level of business interoperability<br>5 (Fully interoperable) | 4 (Qualified) | 3 (Moderate) | 2 (Minimum) | 1 (None) |
|---|---|---|---|---|---|---|---|
| **Employees and culture – “How do we behave towards our external business partners?”** | | | | | | | |
| **Trust** | Behavioural dimension – individual level: Responsibility, sympathy, reliability and confidence between partners; building a climate of trust and confidence, with the development of a dependable relationship. | Approach | Mutual sense of trust and confidence; employees act as cross-organisational team with appreciation on both sides. | Good working relationship; growing sense of trust and confidence. | Initial measures are taken to establish social integration | Significance of trust and confidence in external relationships is recognised | Them and us attitude, new skills jealously protected ("Better the devil you know…"); control |
| | | Deploy | Applied in all partnerships | Applied in most partnerships | Applied in all strategic partnerships (focussing on "A partners") | Applied in some (new) partnerships | Not (yet) applied |
| | | Review and Assess | Periodic review and assessment, "lessons learned" (positive and negative) with employees involved in inter-firm relationships | Periodic evaluation of success factors is performed with employees involved in inter-firm relationships | Sporadic or occasional evaluation of success factors is performed with employees involved in inter-firm relationship | Updates/changes are only initiated in case of conflicts or pressure by the external parties | No review |

To evaluate the criteria associated with the internal and external contingencies, the authors grounded on a set of hypothesis to postulate how they are supposed to impact the optimum level of business interoperability. For example, with regard to the criterion “Business partners/Business network”, three hypotheses have been defined, as follows (ATHENA 2007):

**Hypothesis 1**: Since coordination requirements increase with the number of external relationships and partners, the level of business interoperability is negatively correlated with the number of external partners.

**Hypothesis 2**: Larger enterprises achieve higher levels of business interoperability than SMEs, which have fewer resources and are often lacking the necessary organisational and technical capabilities.

**Hypothesis 3**: A broader industry and regional focus increases the diversity of the individual business relationships and thereby leads to lower levels of business interoperability.

The operationalization of these three hypotheses into the maturity levels proposed by the “Levels of Business Interoperability” is shown in Figure 3.12.

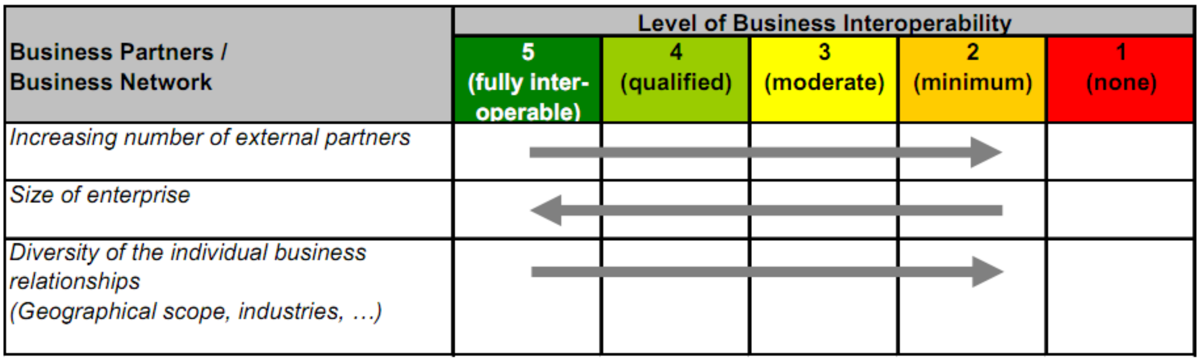



Figure 3.12: Business partners and level of business interoperability (ATHENA 2007) (p. 52)

Another example is concerned with the criterion “Cooperation dynamics”. The following hypothesis has been formulated (ATHENA 2007):

**Hypothesis 4**: In a stable network, investments in business interoperability are more likely to occur, thereby leading to higher levels of business interoperability.

The operationalization of this hypothesis into the maturity levels is illustrated in Figure 3.13.

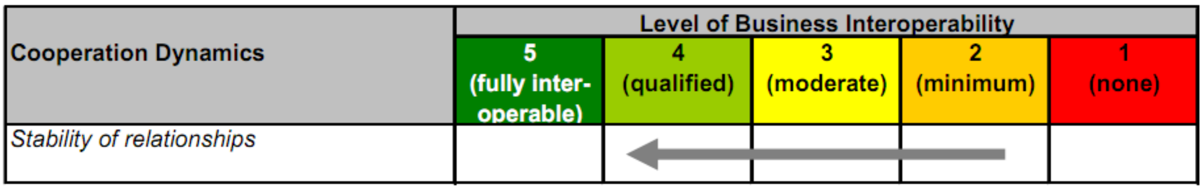



Figure 3.13: Cooperation dynamics versus level of business interoperability (ATHENA 2007) (p. 53)

### 3.4.6 Barriers driven methodology maturity model

This maturity model has been emerged as a result of the Barriers Driven Methodology for Enterprise Interoperability (Chen and Daclin 2007), which defines three types of interoperability measurement (Chen and Daclin 2007, Campos et al. 2013):

- **The interoperability potential measurement**: concerned with the ability of an enterprise/system to interoperate without the need to know its interoperation partner and, consequently, with identifying a set of characteristics that have an impact on interoperability. The objective is to measure the intrinsic capabilities of an enterprise to interoperate with an unknown partner;
- **The interoperability compatibility measurement**: evaluates a current relationship between known stakeholders. In other words, it is measured while the interoperability project is being carried out in order to establish how well two partners are suited to be able to interoperate;
- **The interoperability performance measurement**: has to be set up during the operational phase to evaluate aspects related with the costs involved in implementing interoperability between two enterprises or systems in terms of time or economic investments.

The levels defined to support interoperability potentiality measurement are: Isolated, Initial, Executable, Connectable, and Interoperable. The description for each of these levels is illustrated in Table 3.5.

Table 3.5: Interoperability potentiality measurement (from (Chen et al. 2008b, Campos et al. 2013))

| **Maturity level** | **Description** |
|---|---|
| Isolated | Total incapacity to interoperate |
| Initial | Interoperability requires strong efforts that affect the partnership |
| Executable | Interoperability is possible but the risk of encountering problems is high |
| Connectable | Interoperability is easy even if problems can appear from distant partnership |
| Interoperable | Considers the evolution of levels and where the risk of encountering problems is low |

In the context of business relationships, this maturity model can be viewed as an appropriate tool for supporting decision-making when a company is considering the hypothesis of establishing some form of partnership of potential partners, as it enables the potential partners to evaluate their ability to interoperate before operationalising the partnership, identify solutions to be implemented (e.g. type of IT, legislations, etc.) towards a better interoperation. It can contribute to avoid future interoperability barriers that when encountered in an advanced stage of the partnership could be difficult to solve or could imply a deep redesign of the partnership. In line with Campos et al. (2013), although the barriers driven methodology maturity model highlights the importance of evaluating the interoperability potentiality measurement of enterprises as a critical aspect for carrying out improvement projects, it does not put forward or define a proposal as regards how to measure this interoperability potentiality in a practical way.

### 3.4.7 MMEI – Maturity Model for Enterprise Interoperability

Maturity Model for Enterprise Interoperability (MMEI), developed by Guédria et al. (2013), has two main purposes: (1) define a common framework for assessing and measuring potential interoperability maturity – it provides information for how far along an enterprise is in terms of targeted maturity levels, (2) provide information about "best practices" that allow enterprises to improve their interoperability potential. With the exception of the first level (i.e. level 0), each maturity level is characterised by a set of criteria that need to be satisfied to reach the considered level. MMEI defines five levels of maturity for enterprise interoperability, as shown in Table 3.6.

Table 3.6: Overview of MMEI maturity levels (Guédria et al. 2013) (p. 10)

| **Maturity level** | **Description** |
|---|---|
| Level 4 - Adaptive | Capability of negotiating and dynamically accommodating with any heterogeneous partner |
| Level 3 - Organised | Capability of meta modelling to achieve the mappings needed to interoperate with multiple heterogeneous partners |
| Level 2 - Aligned | Capability of making necessary changes to align to common formats or standards |
| Level 1 - Defined | Capability of properly modelling and describing systems to prepare interoperability |
| Level 0 - Unprepared | Ad-hoc interoperability capabilities or no will to interoperate |

Each MMEI maturity level is described by a m x n matrix $M = [P_{i,j}]_{m \times n}$, where m is the number of interoperability aspects and n is the number of the enterprise interoperability concerns, as illustrated by Figure 3.14. These two dimensions constitute the problem space of enterprise interoperability. Each of the twelve areas of interoperability describes the criteria that an enterprise interoperability concern should have for a considered enterprise interoperability aspect in order to reach a given maturity level. Each area is associated with its maturity level. For example, Business-Conceptual1 contains the required criteria to prepare business interoperability at level 1, with regard to the conceptual aspect. Similarly, Process-Conceptual2 contains the required criteria to prepare process interoperability at level 2, with regard to the conceptual aspect.

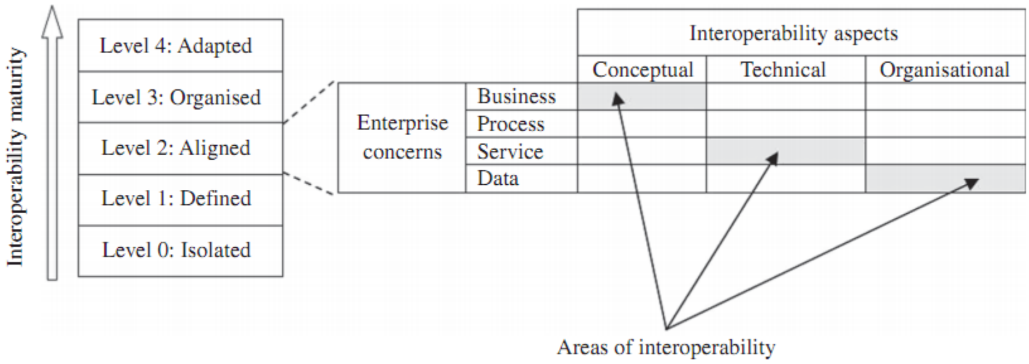



Figure 3.14: Structure of an MMEI level (Guédria et al. 2013) (p. 10)

The levels are then described in detail based on the structure presented in Figure 3.14. For example, Level 0 – unprepared, and level 4 - adaptive are described as follows (Guédria et al. 2013):

- **Level 0 – isolated**: at this level, the enterprise generally does not have an appropriate environment for developing and maintaining interoperability; systems run stand-alone and are not prepared for interoperation;
- **Level 4 – adapted**: at this level, which is the highest level, companies should be able to dynamically adjust and accommodate "on the fly". At this level, interoperability itself becomes a subject of continuous improvement (evolution and adaptation).

Table 3.7 presents an overview of the different interoperability areas, which represent the barriers that have to be removed in order to prepare for interoperability. On the other hand, Table 3.8 presents the criteria that need to be satisfied in every interoperability area in order to reach the MMEI level 4.

Table 3.7: Description of the MMEI level 0 (Guédria et al. 2013) (p. 11)

| | Conceptual | Technical | Organisational |
|---|---|---|---|
| **Business** | Business model not explicitly modelled or documented | No or unreliable IT infrastructure | No organisation structure is defined |
| **Process** | Processes models not explicitly modelled or documented | No IT support, manual processes | Processes responsibilities and authorities not explicitly defined |
| **Service** | Services models not explicitly modelled or documented | Stand-alone services and applications | Services responsibilities and authorities not explicitly defined |
| **Data** | Data models not explicitly modelled or documented | No or closed data storage devices, manual exchange | Data responsibilities and authorities not explicitly defined |

Table 3.8: Description of the MMEI level 4 (Guédria et al. 2013) (p. 14)

| | Conceptual | Technical | Organisational |
|---|---|---|---|
| **Business** | Adaptive business model | Adaptive IT infrastructure | Agile organisation for on-demand business |
| **Process** | Modelling for dynamic process re-engineering | Dynamic and adaptive tools and engines for processes | Real-time monitoring of processes, adaptive procedures |
| **Service** | Adaptive service modelling | Dynamically compassable services, networked applications | Dynamic service and application management rules and methods |
| **Data** | Adaptive data models (both syntax and semantics) | Direct database exchanges capability and full data conversion tool | Adaptive data management rules and methods |

Despite the MMEI focuses on interoperability potential assessment which is not well addressed by the existing maturity models (Guédria et al. 2013), and although it covers four important dimensions of interoperability (concerns), it is still failing in some aspects that make it difficult to be successfully applied in the context of this research. In other words, the MMEI does not decompose the dimensions of interoperability to a detailed level; MMEI mixes elements from different interoperability dimensions; MMEI does not encompass all dimensions of interoperability, e.g. elements of the network dimensions such legislations, maturity of industry, technical changes, were not addressed.

However, part of this model is used in the development of the theoretical business interoperability maturity model proposed in Section 6.3. For instance, the area of interoperability Process-Organisational in the level 0 defined as “Processes responsibilities and authorities not explicitly defined” can be adopted to describe the level 0 for the business interoperability design solution “Well-stablished roles and responsibilities.

### 3.4.8 Maturity Model for Interoperability Potential Measurement

This maturity model has been proposed by Campos et al. (2013). The proposal is composed by a methodology and a reference set of parameters to measure interoperability potential, which concerns the preparation level of an enterprise to establish an efficient collaboration with possible partners. This proposal completes and improves the current status of research in this field, where the methods and maturity models analysed only define levels and attributes but do not describe how to measure or evaluate these levels. Six interoperability views are proposed: business, process management, knowledge, human resources, ICT, and semantics, which are described as follows (Campos et al. 2013): the business view considers the strategic aspects related with the interoperability, culture, mission, vision, values, and the economic, social, and environmental policies of organisations; the business process management view includes the work methods (and therefore aspects related to productivity and cutting costs); the human resources view considers the skills, competencies, roles, culture, and collaborative capacity of employees who participate in interoperability process.

The aspects related with the three domains are evaluated from the point of view of the use and training of the personnel of the enterprise; the knowledge view includes establishment of a knowledge management system to identify, extract, represent, process, and exploit the knowledge that facilitates efficient cooperation among different enterprises; the ICT view is concerned with helping applications, data, and communication components to interconnect automatically. This view considers aspects related with data and services from the technological point of view and the supporting platforms and architectures as the domain to be evaluated; the semantic view is used to facilitate the understanding of the terminology used by the enterprises that wish to collaborate, that is to say, it considers the aspects needed to ensure that the information is interpreted in the same way. It is related with the data layer and measures aspects related with their own ontologies and barriers. The interoperability potential levels for each view are described using five levels of maturity, as has been done in previous maturity models: Isolated, Initial, Executable, Connectable, and Interoperable. One of the differences of this model in relation to the previous ones is that the authors did not assign any number to the five defined levels. As an example, the human resources view has been described as follows (Campos et al. 2013):

- ***Isolated***: there is no organised structure or plans for training;
- ***Initial***: there is a tacit, informally recognised structure;
- ***Executable***: there is a clear organised structure and the possibility of training of human resources is taken into consideration;
- ***Connectable***: there is a clear organisational structure and plans for training human resources;
- ***Interoperable***: there is a clear dynamic organisational structure, plans for continuous training, and policies and incentives for improvement.

Although this model highlights the need to evaluate the interoperability potential at five critical enterprise views, it is still failing on the decomposition of each view, i.e. it still not explaining how to describe each element represented in each view. The business view for instance should be decomposed into clarity of strategic goals, alignment of strategic objectives, and visibility of strategic objectives. Similarly, the process management view should be decomposed into its main factors, e.g. process clarity, process visibility, process alignment, process coordination, process integration, process flexibility, process adaptability, etc. In addition, from this thesis point of view, it is argued that in order to fully evaluate the business interoperability of networked companies more views are needed, especially the network view.

### 3.4.9 An Interoperability Model for Ultra Large Scale Systems

The interoperability model for ultra large scale systems has been recently proposed by Rezaei et al. (2014b) with the aim to solve the interoperability challenges facing nowadays ultra large scale systems. An ultra large scale system is defined as one that is composed a set of operationally and managerially independent systems whose interaction forms a system where its functions are very diverse, even more than the total functions of its component systems. Component systems are heterogeneous, changing and inconsistent, and are created by different people using different programming languages, in different conditions and are tuned for various platforms (Rezaei et al. 2014b). The research is divided in two main parts. In the first part, a maturity model for evaluating the interoperability of the components in ultra large scale systems is proposed. In the second part, the authors propose a framework to improve the interoperability of those components systems based on the interoperability maturity levels achieved in the first part. In this model, as in other interoperability maturity models described above, the authors define five maturity levels to evaluate four types of interoperability: technical, synaptic, semantic, and organisational. Each maturity level is identified by a number and the general nature of the interoperability, which are first defined in a generic way, as follows (Rezaei et al. 2014b):

- ***Level 0 – default level***: at this level, the systems are in the first stages of becoming familiar with interoperability concepts and some measures are taken for establishing interoperability;
- ***Level 1 – initiating level***: at this level, the initial steps for establishing interoperability are taken and systems are oriented toward the interoperability objectives;
- ***Level 2 – enabling level***: at this level, interoperable systems are implemented and deployed, data are managed and business processes are performed in technical and organisational domains of interoperability;
- ***Level 3 – integrating level***: at this level of maturity, security is established in the technical domain and services are managed and monitored in the organisational domain;
- ***Level 4 – interoperating level***: at this level, interoperability services are published and resources are managed during runtime.

Having defined the five levels of interoperability in a generic way, Rezaei et al. (2014b) then apply them to each of the four types of interoperability mentioned above. However, despite recognising the significance of such work, it is argued that as for the previous models, the ultra large scale systems interoperability maturity model still failing in the decomposition of the types of interoperability into their main elements in order to enable each element to be evaluated separately.

## 3.5 Empirical studies on the impact of business interoperability

It is widely believed that the lack or the establishment of business interoperability among companies in a business network can have impact on the business performance of these companies. However, a deeper look at the extant literature reveals that although there are a significant amount of studies on the development of reference business interoperability frameworks and maturity models, as has been shown in previous sections, only a very small number of empirical studies have been carried out on the analysis of the impact of business interoperability on the performance of companies, mainly in a context of cooperative industrial networks. According to the author' best knowledge, one of the first empirical studies on the analysis of the impact of business interoperability on the performance of companies was developed in the context of US automotive SC (Brunnermeier and Martin 1999, Brunnermeier and Martin 2002).

The objective of this study was to assess the costs of imperfect interoperability to the US automotive SC and to describe the sources of these costs. The study considered that the automotive SC incurs several types of costs related to imperfect interoperability, namely avoidance costs, mitigating costs, and delay costs. Avoidance costs consist of preventing interoperability problems before they occur. They include the costs of purchasing, maintaining, and training for redundant CAD/Computer-aided Manufacturing (CAM) systems, outsourcing incurred when outside companies are hired to provide data exchange services, investments in in-house programs aimed at addressing interoperability issues, and participating in industry consortia activities aimed at improving interoperability throughout the industry. Mitigating costs consist of the resources required to address interoperability problems after they have occurred. The main source of this cost was the poor quality CAD/CAM files, which resulted in scrapped models, designs, prototypes, parts, dies, etc., and manual data re-entry. Delay costs arise from interoperability problems that delay the introduction of a new vehicle. They include the costs of car sales forfeited, delayed profits, and delayed consumer benefits. To quantify interoperability costs described above, the authors employed two separate approaches: the cost component approach and the aggregate cost approach.

The first approach consisted of collecting company-level data on the different components of interoperability cost listed above summing those different components of cost. The total interoperability cost for a company was estimated by summing those components of cost. The second approach was to ask key industry executives to estimate the total cost of all components of interoperability costs for their company. Grounded on these two approaches, the authors concluded that imperfect interoperability imposes about US $1.05 billion per year of costs to the members of the US automotive SC. The majority of the annual costs were attributed to mitigating costs, i.e. the cost of correcting problems caused by imperfect interoperability. This source of cost totalised about US $907.645, representing 86 percent of the annual costs. Most of these costs are attributable to the resources devoted to repairing or recreating data files that are not usable by those receiving the files. The delay costs totalised US $90000, representing 9 percent of the annual costs. Last, the avoidance costs totalised US $52.799, representing only 5 percent of the annual costs. These results suggest that the investment on solutions to prevent interoperability problems was very limited, and maybe this can explain the occurrence of a large amount of interoperability problems, and consequently the high costs to correct them. The study also concluded that imperfect interoperability delays the introduction of new models by at least two months.

A second study on the impact of business interoperability has been prepared for the NIST by RTI International and the Logistic Management Institute (Gallaher et al. 2004). The purpose of this study was to identify and estimate the efficiency losses in the US capital facilities industry resulting from inadequate interoperability among CAD, engineering, and software systems. Similar to the Brunnermeier and Martin (1999)' study, three general cost categories were used to characterise inadequate interoperability: avoidance costs, mitigation costs, and delay costs. Examples of avoidance costs include, for example, the cost of purchasing, maintaining, and training for redundant CAD/Computer-aided Engineering (CAE) systems, the cost of translation services to third parties, investments in in-house programs, and the cost of participating in industry consortia activities aimed at improving interoperability, as in the previous study. Mitigation costs include the cost of design and construction rework due to interoperability problems, the cost of manually re-entering data when electronic data exchange is unavailable or when errors were made in the exchange, the cost of verifying information when original sources cannot be accessed, and the cost of duplicating business functions. Delay costs arise from interoperability problems that delay the completion of a project or the length of time a facility is not in normal operation.

According to the authors, these costs are the most difficult to quantify and include idle resources as construction activities are delayed, profits lost due to delay of revenues, losses to customers and consumers due to delay in the availability of products and services. It is to be noticed that this cost category reflects what is named in this research as network effect, i.e. a delay on the delivery of a project will have impact not only on the main parties involved but also on a series of potential users of the project outputs. The modelling approach employed to quantify the cost of inadequate interoperability was by comparing the current state of interoperability with a hypothetical counterfactual scenario in which the electronic data exchange, storage, and retrieval of building blueprints, configurations, business data, and engineering specifications are seamless, i.e. a scenario in which interoperability issues do not occur. The total economic loss associated with inadequate interoperability was calculated by the difference between the current and counterfactual scenarios represents. Part of this modelling approach is employed in this research, namely in the analysis of the impact of business interoperability, performed out in Chapter 6 and Chapter 8.

To collect data to validate the proposed modelling approach, the authors carried out one hundred and five interviews representing seventy organisations: nineteen architects and engineers, nine general contractors, five specialty fabricators and suppliers, twenty eight owners and operators, two software vendors, and seven research consortia. Based on the collected data, US $15.8 billion in interoperability costs were quantified for the US capital facilities SC in 2002. However, the US $15.8 billion of total cost was viewed as conservative estimate because it did not include such cost categories as opportunity costs and decommissioning costs. In terms of stakeholder groups, these costs were distributed as follows: owners and operators bore approximately US $10.6 billion, or about two-thirds of the total estimated costs in 2002. Architects and engineers had the lowest interoperability costs at US $1.2 billion. General contractors and specialty fabricators and suppliers bore the balance of costs at US $1.8 billion and $2.2 billion, respectively. According to the authors, this annual cost estimate corresponds to between 0.86 and 1.24 percent of annual receipts for architects and engineers, general contractors, and specialty fabricators and suppliers. When compared to the annual value of capital facilities construction put in place for 2002, owners and operators' total estimated costs were approximately 2.84 percent.

Regarding to the cost category, the total cost represented around US $6.609 (41.77 percent) billion for avoidance costs, US $7.702 billion (48.67 percent) for mitigation cost, and US $1.512 (9.56 percent) for delay costs. In comparison with the Brunnermeier and Martin (1999)' study, it is to note that despite the mitigation costs continue to represent the majority of cost, the distance to the avoidance costs is not significant as in the first study. To Grilo et al. (2013), this study is an indication of the AEC industry's inability to exploit ICT to realise its full benefits, and by 2011, the same issues were still in place.

A third study that has been identified on this research thematic has also been prepared for the NIST by RTI International (White et al. 2004). The objective was to estimate the costs associated with an inadequate standards infrastructure for SC integration in the US automotive and electronic sectors, including the portion of those expenditures due to incomplete or inefficient integration. The study has been developed on the basis that a lack of universally accepted and implemented standards for the format and syntax of messages that flow between SC partners reduces the potential for inventory and expense savings, as well as leading to duplication of effort, maintenance of redundant systems, and investment in non-ideal information processes. From the authors' point of view, if multiple systems are being used to manage different portions of the SC, however, several types of additional costs will be incurred, unless the systems have been designed to interoperate. Likewise, if systems are only partially integrated, translation or data re-entry are required for flows to and from all SC partners that do not share the improved information systems. Finally, if the lower tiers of the SC do not have the financial resources or technical capability to support integration, their internal work processes and communications are likely to be significantly less efficient than in an optimal system.

The study has identified two types of interoperability problems associated with the SC integration: inefficient integration and incomplete integration. Under inefficient integration, systems are put in place to automate information inputs and flows, but a lack of a suitable standards infrastructure leads to excessive capital investment, duplication of effort, higher than optimal staffing and support levels, and a lack of organisational flexibility. In the case of incomplete integration, key elements of a comprehensive system are missing, or improved systems are only implemented for a subset of SC partners. In the latter case, the SC as a whole still experiences costs well above optimal levels, and many of the gains from integration remain unrealized. The methodology for measuring the costs of inadequate standards for SC integration was grounded on others used successfully by RTI in previous studies prepared for NIST, including for example the one prepared by Brunnermeier and Martin (1999).

In this SC integration study, the authors first identified the scope of activities affected by the lack of an adequate standards infrastructure, striving to understand the basic sources of costs and benefits that may be affected. Following this step, they created an implicit counterfactual to compare the current state with one in which an ideal infrastructure is in use. In each of the cost categories identified, they developed technical and economic metrics that allowed quantitative estimation of costs and benefits for the firms involved, relative to the lower-cost ideal state. Data were then collected to inform the metrics, first through a series of structured interviews with representatives from several companies in the industry, and then through wide-scale placement of a more structured survey. As a result, the total estimated costs for the automotive industry were slightly in excess of US $5 billion per year, which equals about 1.25 percent of the total value of shipments. In electronics, the figures were almost US $3.9 billion per year, or an almost identical 1.22 percent of the value of shipments. In both industries, roughly 50 percent of the total costs were in dealings with suppliers, while nearly 40 percent arose from interactions with customers. Less than 1 percent of the total inefficiency resulted from purchase costs and annual expenses from software programs.

Acknowledging that more empirical research is required concerning the business value that information systems interoperability creates, Loukis and Charalabidis (2013) presented an empirical study on the effect of adopting the three types of information systems interoperability standards (industry-specific, proprietary and XML based ones) on the four perspectives of business performance proposed by the balanced scorecard approach (financial, customers, internal business processes, learning and innovation).

To carry out this study, the authors developed four research hypotheses, having as dependent variable "the impacts of ICT on the four business performance perspectives proposed by the balanced scorecard (financial performance, value offered to customers, performance of business processes, and innovation)" and having as independent variables "the adoption or not of industry-specific standards, proprietary standards, and XML-based standard, and also the degree of development of firm's intra-organisational (internal) information systems and e-sales information systems". For instance, to study the effect of adopting information systems interoperability standards on the impact of firm's ICT on the performance of its business processes, the following research hypothesis has been defined: *"H1: The adoption of information systems interoperability standards increases the impact of ICT on firm's business processes performance."*

To validate the research hypotheses defined, this study has been grounded on a dataset from 14065 European companies (from 25 countries and 10 sectors) collected through the e-Business Watch Survey of the European Commission. To test the research hypotheses, it has been estimated one regression model with the dependent and the independent variables mentioned above. It has been concluded that all three examined types of information systems interoperability standards increase considerably the positive impact of firm's ICT infrastructure on the above four perspectives of business performance; however, their effects differ significantly. The adoption of industry-specific interoperability standards has the highest positive effects, while XML-based and proprietary standards have similar lower positive effects. Furthermore, these effects of the industry-specific information systems interoperability standards are quite strong, as they are of similar magnitude with the corresponding effects of the degree of development of firm's intra-organisational/internal information systems, and of higher magnitude than the corresponding effects of the degree of development of firm's e-sales information systems.

It has also been found that those conclusions are in the same direction with the ones of the previous empirical studies on information systems interoperability business value, which have found that the adoption of information systems interoperability standards results in business benefits of both operational and strategic nature (Boh et al. 2008, Xu et al. 2014), and also reduces the effort required for Business to Business (B2B) integration of information systems (Mouzakitis et al. 2009). Although the significance of this study, the authors recognise that it is important investigate empirically the business value not only of the "technical" interoperability, but also of the "organisational" interoperability as well, and their complementarities. Also, the authors recognise that it is necessary to understand better the mediators of the relations between various information systems interoperability architectures, frameworks, methods and/or standards adoption and business performance. In this direction, the authors propose the use of Structural Equations Modelling (SEM) techniques to enable a better understand of how information systems interoperability business value is generated and how it can be increased.

To complement the literature review on the analysis of the impact of business interoperability on the performance of companies, a set of related studies that do not refer explicitly to interoperability (but that surveyed related concepts), has been analysed in order to make sure that indeed there is a gap in the OM literature regarding the analysis of the impact of business interoperability on the performance of companies, but taking into account the network effect. For instance, a study conducted by Jiménez-Martínez and Polo-Redondo (2004) identified a set of potential to analyse the benefits to be gained from the use and adoption of Electronic Data Interchange (EDI) from the point of view of administration as well as of improvement in information and relationships with business partners, concluded that there are a significant improvement in twelve of the sixteen potential benefits tested. The results show that there is a significant improvement on the consideration of all items referring to direct benefits, i.e. paper savings, avoiding filing costs and maintenance, avoiding repetitive administrative procedures, and less paper work and consequently reduction in administrative personnel.

Regarding indirect benefits, there are three cases for which the authors could not claim significant benefits, i.e. the use of EDI has not produced significant benefits on reducing stock levels, nor on avoiding production stoppages arising from lack of raw materials, nor on reducing the number of business contacts by concentrating on those that use EDI. On the other hand, significant improvements were observed on avoiding errors, faster payments/improved cash flow, and reducing inventory breaks. Finally, regarding to strategic benefits, significant improvements were perceived on five cases: increasing business relationships with companies using EDI, improving customer loyalty, improving the quality and quantity of information, faster response and access to information, and gaining new business contacts using EDI.

Another study has been carried out by Mouzakitis et al. (2009) to investigate empirically the effect of five layers of interoperability (network, data, application, process, and business) on the required effort for B2B information systems integration. In this study, the authors developed a set of hypotheses to explore the relationship between the level of interoperability with the potential partner and the expected integration effort. SEM has been used to test and validate the proposed research hypotheses. It was based on a field study using data from 239 firms. It has been concluded that interoperability at the business, process, and data levels is significantly but negatively associated with integration efforts. Interoperability at the application level showed little relation to integration efforts, and interoperability at the network level had a non-significant positive relationship with integration efforts.

Xu et al. (2014) developed a study in which the objective was to investigate empirically the effect of a single industry-specific standard (the RosettaNet[12]) extent of deployment and the extent of systems and business integration on the operational and strategic benefits that adopting companies obtain. Similar to the previous mentioned studies, the authors developed a research model based on a set of hypotheses to examine the relationships between, for instance, the extent of vertical information systems standards integration and the operational and strategic benefits obtained from implementing those standards. To test the hypotheses, a survey data was collected from organisations in China who have implemented RosettaNet Partner Interface Processes (PIPs[13]). It has been concluded that: (1) integration positively influenced both operational and strategic benefits; (2) standards deployment

[12] RosettaNet (http://www.rosettanet.org/) is a non-profit industry consortium that aims to facilitate B2BG e-commerce in tech industries (e.g. electronic components, semiconductor manufacturing, and telecommunications)

[13] PIPs specify the processes and associated business documents for data exchange

positively influenced strategic benefits; and (3) standards deployment negatively influenced operational benefits.

## 3.6 Summary

This chapter started by presenting an historical evolution on the concept of interoperability, which emerged as a technical concept and evolved to business perspective. Based on an extensive review on interoperability and business interoperability definitions, it was concluded that there are a great number of definitions for interoperability and business interoperability. These definitions differ mainly because each researcher tries to define interoperability according to the context they are studying, i.e. they try to frame the definition of interoperability to the systems they are studying. It was also stated that business interoperability is a multidimensional concept that goes beyond integration, compatibility, coordination and SCM concepts, and it is needed whenever two or more business units have to interact.

Another conclusion of this chapter was that although the significance of the existing business interoperability models and frameworks for theory and practice, there is no research that integrates all relevant dimensions of business interoperability in the design of interoperable business networks and that explains how the impact of business interoperability spreads over the network. Perhaps this second conclusion is related to the fact that over the years there was no link between researchers from the IMP group and researchers that studied the business interoperability phenomenon. With regard to this, it is to notice that from the several papers and books read, the author did not find any keyword interoperability or business interoperability in works published in the ambit of the IMP group, and the keyword IMP group or network approach was not found in works on interoperability or business interoperability.

# Chapter 4 Methods for modelling complex systems and networks

This chapter provides an overview on the tools for modelling complex systems and networks as are the example of cooperative industrial networks, and the rationale for choosing the Axiomatic Design Theory to design interoperable cooperative industrial network platforms and the ABS to analyse the impact of business interoperability on the performance of these platforms. For each investigated modelling tool, it is presented the main strengths and weakness, as well as the reason why it is suited or not for responding the research questions addressed in Section 1.3. The chapter also presents some applications of the Axiomatic Design Theory and ABS within the context of industrial networks modelling.

## 4.1 Design methods: an overview

*"When God created the world, he applied the Axiomatic Design Theory"*

Design can be defined, according to Webster's Dictionary, as a verb – "to plan and make decisions about something that is being built or created, i.e. to create the plans, drawings, etc., that show how something will be made" or as a noun – "the way something has been made, i.e. the way the parts of something (such as a building, machine, book, etc.) are formed and arranged for a particular use, effect, etc.", or "a drawing of something that is being planned or created. Within the context of this thesis, the term design is referred to as a noun (i.e. as a project, a plan, a draft, etc.) and is defined as a plan or drawing product to show the look and function or working of a building, garment, or other object before it is made (Oxford Dictionary). In other words, it is a continuous interplay between "*what we want to achieve*" and "*how we want to achieve the need, i.e. the what*" (Suh 1990, Suh 2001, Suh 2005, Dorst 2011), as illustrated in Figure 4.1. What this definition implicitly suggests is that "*if we know what the problem is, we can find a solution*" (Suh 1990). Put it simple, we can state that the problem to be solved is the "*what we want to achieve or solve*" and the solution to solve the problem is the "*how we want to achieve or solve it*". For example, if a manager wants to reduce the inventory cost in his company (the problem), he can implement, for example some of the lean strategies (e.g. Just in Time (JIT) - the solution) that enable him to reduce cost but, without compromising other performance measures such as quality of products, lead time, etc.

According to Suh (1990), design involves four distinct aspects of engineering: (1) the *problem definition* from a "fuzzy" array of facts and myths into a coherent statement of the question, (2) the *creative process* of devising a proposed physical embodiment of solutions, (3) the *analytical process* of determining whether the proposed solution is correct or rational, and (4) the *ultimate check* of the fidelity of the design product to the original perceived needs.

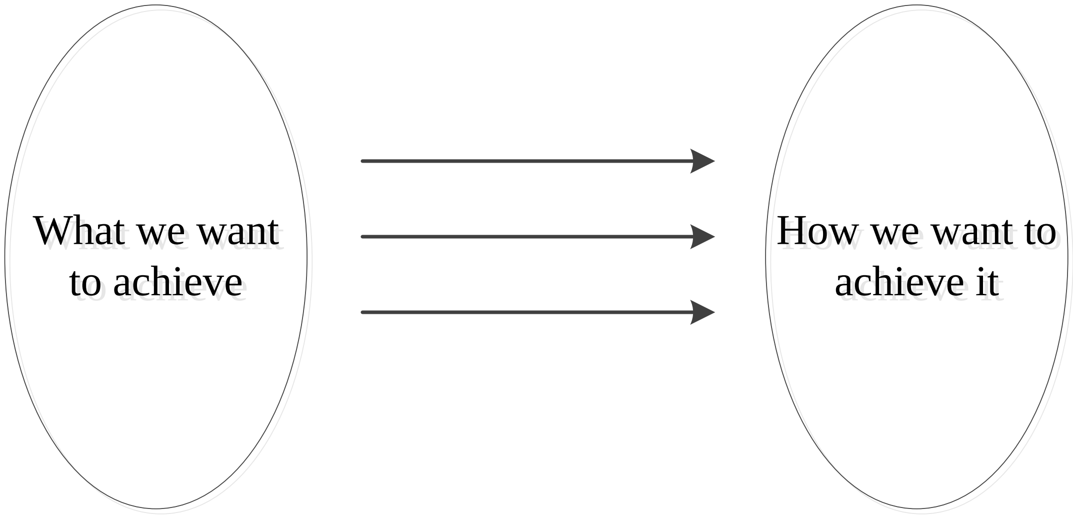



Figure 4.1: Design thinking (Suh 2001) (p. 3)

Although the literature offers several methods to deal with the design of complex systems and products in engineering, in this thesis, only a sample of them are described (see Section 4.2.6).

## 4.2 Axiomatic Design Theory

Axiomatic Design Theory introduced and described by Professor Nam P. Suh in his books entitled, "*The Principles of Design (Suh 1990)*" and "*Axiomatic Design: Advances and Applications (Suh 2001)*" is, according to Thompson (2014), one of the most comprehensive and well-established engineering design theories developed to date. Its ultimate goal is to establish a scientific basis for design and to improve design activities by providing the designer with a theoretical foundation based on logical and rational thought processes and tools (Suh 2001), to create engineered systems such as products, processes, systems, software, and organisations (Suh 1990).

In brief, the Axiomatic Design Theory is a systems design theory that uses matrix methods to systematically analyse the translation of Customer Needs (CNs) into Functional Requirements (FRs), Design Parameters (DPs), and Process Variables (PVs) (ICAD 2014). Axiomatic Design Theory can be viewed as an innovative method for solving the design problems in a rational manner as it provides an efficient framework to guide designers through the design process and reduce much of the waste associated with the trial and error method (Vinodh 2011). According to Suh (2005), there are several concepts that are fundamental to the Axiomatic Design Theory. They are the existence of domains, mapping, axioms, and decomposition by zigzagging between the domains. An overview of these concepts is provided following.

### 4.2.1 The concept of domains

To systematise the though process involved in the interplay between "what we want to achieve" and "how to achieve it", the concept of domains that create demarcation lines between four different kinds of design activities provides an important foundation of the Axiomatic Design Theory (Suh 2005). According to Suh (2001), the design world consist of four domains: the customer domain, the functional domain, the physical domain, and the process domain. Each of these domains is characterised by a vector that contains different design information (see Figure 4.2). The customer domain is characterised by the CNs or Customer Attributes (CAs), the functional domain by the FRs and Constraints (Cs), the physical domain by the DPs, and finally the process domain by the PVs.

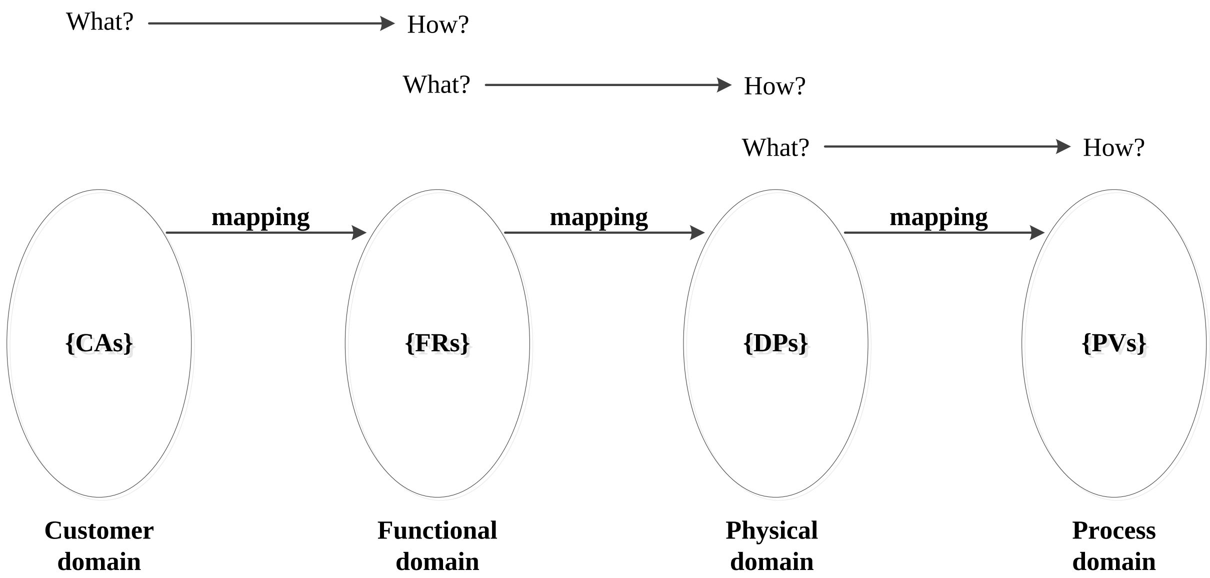



Figure 4.2: The mapping process between the four domains of the Axiomatic Design Theory (Suh 2001, Thompson 2014)

CNs or Customer Attributes (CAs) are the needs or attributes the customer is looking for in a product or process or systems or materials (Suh 2001, Suh 2005). According to Suh (2001), in many cases, the CNs or CAs cannot and need not to be decomposed, as they are often expressed in terms of the highest level needs. FRs are defined as the minimum set of independent requirements that completely characterises the design objective for a specific need (Suh 1990, Suh 2001). In other words FRs are the designer's characterisation of the perceived needs for the artefact being designed (Suh 1990), i.e. the functional needs of the artefact (product, software, organisation, system, etc.) in the functional domain (Suh 2005). Put it simple, FRs are the functions or goals to be achieved by the designed system (Suh 2005) or in other words, the list of what the design should do (Brown 2005). FRs are often defined as engineering specifications, in the case of product design, and Cs (Suh 2005).

Cs are bounds on acceptable design solutions and differ from FRs in that they do not have to be independent (Suh 2001). They can be input constraints – imposed as part of the design specifications or system constraints – imposed by the system in which the design solution must function (Suh 2005). It should be noted that by definition, each FR must be independent of every other FR at the time the FRs are established (Suh 2005), and thus can be stated without considering other FRs (Suh 1990). It is also important to notice that we always state FRs starting with verbs (Suh 2001, Brown 2005, Suh 2005). Some literature examples are: FR = Maximise the value delivered to the customers (Vinodh 2011); FR = Measure the time (Suh 2005); FR = Provide for safe landing (Brown 2005). The definition of FRs is a critical step in the Axiomatic Design Theory as defining them properly is essential for a good design, which implies that the final design cannot be better than the FRs (Brown 2005).

In designing engineered systems, DPs are the key physical (or logical) variables in the physical domain that characterise the design that satisfies the specified FRs (Suh 2001, Suh 2005). In other words, DPs are the list of what the design should look like (Brown 2005). Unlike the FRs, that start with verbs, DPs should start with nouns (Suh 2001, Brown 2005, Suh 2005). This makes it easier to distinguish between FRs and DPs (Suh 2005). Literature examples include: DP = Design the total system based on agile thinking (Vinodh 2011); DP = Pneumatic landing impact attenuation system (Brown 2005).

PVs are defined as the key variables in the process domain that characterise the process that is used to implement the design, i.e. to generate or create the specified DPs (Suh 2001, Suh 2005). PVs describe how each specified DP is made (Brown 2005) or manufactured, in the case of a product. It should be noticed that depending on the specific design tasks (e.g. materials, organisations, software, machines), FRs, DPs, and PVs take different characters, as highlighted by Suh (2005). For example, in the case of product design, the CNs consist of the needs or attributes that the customer is looking for in a product. FRs are the engineering specifications of the product being designed. DPs are the physical solutions chosen to satisfy the FRs. Finally, the PVs describe the manufacturing processes that can produce the DPs. On the other hand, in natural systems, FRs are functions of a natural system and DPs are the physical (chemical or biological) entities that perform the functions. PVs are physical processes that create the physical entities (Suh 2005).

### 4.2.2 Mapping from domain to domain

A rigorous design approach must begin with an explicit statement of “what we want to achieve” and end with a clear description of “how we will achieve it” (Suh 2001). This process is referred to as mapping, which is defined as the process of relating a set of characteristic vectors in one design domain to another design domain. The mapping is carried out from a left domain to a domain on its right (Suh 2005), as shown in Figure 4.2. It starts with the identification of the CNs. Once we identify and define the perceived customer needs, these needs must be translated into FRs and Cs, in the functional domain. The mapping from the customer domain to the functional domain is performed without any rules and can be many-to-one (m:1), one-to-many (1:m), or one-to-one (1:1) (Thompson 2014). With regard to this, Suh (2005) advocates that the translation of CNs into FRs must be done within a "solution-neutral environment", i.e. without ever thinking about something that has already been designed or what the design solution should be. Once defined a FR, the designer should provide a clear description of how he or she is going to achieve it, in the form of DPs (Suh 2001). In other words, after the FRs are chosen, we map them into the physical domain to conceive a design with specified DPs that can satisfy the FRs.

The mapping process is typically a one-to-many process, that is, for a given FR there can be many possible DPs. As a result, we must choose the right DP by making sure that other FRs are not affected by the chosen DP as per the Independence Axiom and that the FR can be satisfied within its design range as per the Information Axiom (Suh 2005). Design range is defined as the allowable tolerance of a given FR or the desired accuracy of a natural phenomenon to be determined (Suh 2005). The mapping process can also be 1:1 (one FR for one DP), which would result in an ideal design (Thompson 2014), which is defined in Suh (2005) as the one that has the same number of FRs and DPs and satisfies the Independence Axiom with zero information content (p. 294). Finally, to produce the product specified in terms of DPs, we develop a process that is characterised by PVs in the process domain (Suh, 2005). The rules for mapping from the physical domain to the process domain are the same as those applied for mapping from the functional domain to the physical domain.

### 4.2.3 Design axioms

During the mapping process described above, the designer is guided by two fundamental axioms that offer a basis for evaluating and selecting designs in order to produce a robust design (Suh 2001). Axiom is defined as self-evident truth or fundamental truth for which there are no counterexamples or exceptions (Suh 2005). Design axioms are defined by Filippone (1989) as the fundamental principles that guide a designer in the formation of an object, as specified by a given set of fundamental requirements. A robust design is the one that satisfies the specified FRs even though the DPs have a large variation (Suh 2005). The two fundamental design axioms proposed by Suh (2001) are:

- *Axiom 1: The Independence Axiom – Maintain the independence of the functional requirements.*
- *Axiom 2: The Information Axiom – Minimize the information content of the design.*

Axiom 1 states that during the design process, as we go from the FRs in the functional domain with DPs in the physical domain, the mapping must be such that a perturbation in a particular DP must affect only its referent FR (Suh 1990), i.e. the independence of FRs must always be maintained (Suh 2005). Axiom 2 states that, among all the designs that satisfy the Independence Axiom (Axiom 1), the one that has the smallest information content is the best design (Suh 1990, Suh 2005). During the mapping process, the designer must make the right decisions using the Independence Axiom. In addition, when several designs that satisfy the Independence Axiom are available, the Information Axiom can be used to select the best design. When only one FR is to be satisfied by having an acceptable DP, the Independence Axiom is always satisfied and the Information Axiom is the only axiom the one-FR design must satisfy. When there are many FRs, the Independence Axiom must always be satisfied by choosing the right set of DPs (Suh 2005).

In order to evaluate and keep the independence among the FRs generated at each level of decomposition, a design matrix [A] that relates FRs to DPs must be created (Cheng and Tsai 2008). The relationships between FRs and DPs in the design matrix [A] are signed by “X” or “0”, where “X” represents a relation and “0” represents no relation between FRs and DPs (Cebi and Kahraman 2010). Such relationships between FRs and DPs can be expressed mathematically in terms of the characteristic vectors that define the design goals and design solutions (Suh 1990, Suh 2005). Since the characteristics of the required design are represented by a set of independent FRs, these may be treated as a vector FR with *m* components. Similarly, the DPs in the physical domain also constitute a vector DP with *n* components (Suh 1990). The relationship between these two vectors can then be written as

$$\{FR\} = [A]\{DP\} \qquad \text{Equation 1}$$

where {FR} is the functional requirement vector, {DP} is the design parameter vector, and [A] is the design matrix that relates FRs to DPs and characterises the designed system (Suh 1990, Suh 2005). Each line of the vector equation above may be written as

$$FR_i = \sum_{i=1}^{n} A_{ij} DP_j \qquad \text{Equation 2}$$

where *n* = the number of DPs. The design matrix is of the following form for a design that has, for instance, three FRs and three DPs (Suh 2005):

$$\{A\} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \qquad \text{Equation 3}$$

Similarly, for the design of processes involving mapping from the {DP} vector in the physical domain to the {PV} vector in the process domain, the design equation may be written as

$$\{DP\} = [B]\{PV\} \qquad \text{Equation 4}$$

where [B] is the design matrix that defines the characteristics of the process design and is similar in form of [A] (Suh 2005).

Once the design matrix is created, a plausible question can be: how do we know whether the Independence Axiom is satisfied? To answer this question, the designer has to analyse the configuration of the design matrix [A] which according to Suh (2005), depends on the relative numbers of DPs and FRs and can be of three types: (1) the number of DPs is less than the number of FRs – the design is classified as coupled, (2) the number of DPs is bigger than the number of FRs – the design is classified as redundant (see e.g. (Goncalves-Coelho et al. 2012)), (3) the number of DPs is equal to the number of FRs – the design is classified as ideal but can also be coupled, decoupled, or uncoupled.

When the number of DPs is equal to the number of FRs, the types of design mentioned above are defined according to the relationships between FRs and DPs (Cebi and Kahraman 2010). If the design matrix [A] is diagonal, i.e. all $A_{ij} = 0$ except those where $i = j$, the design is uncoupled; if the design matrix is triangular, i.e. all upper triangular elements or all lower triangular elements are equal to zero the design is named as decoupled – an upper triangular matrix can always be changed to a lower triangular matrix; otherwise, the design is named as coupled (Suh 2005). The answer to the question posed above can then be provided as follows: in order to satisfy the Independence Axiom, the design matrix [A] must be either diagonal or triangular (Suh 2001). When the design matrix [A] is a full matrix or has any upper triangular elements different from zero (the left matrix in Figure 4.3), the independence of FRs cannot be guaranteed. When the design matrix [A] is triangular or has any lower triangular elements different from zero (matrix at the middle in Figure 4.3), the independence of FRs can be guaranteed if and only if the DPs are determined in a proper sequence. When the design matrix [A] is diagonal (the right matrix in Figure 4.3), each of the FRs can be satisfied independently by means of its respective DP (Suh 2005).

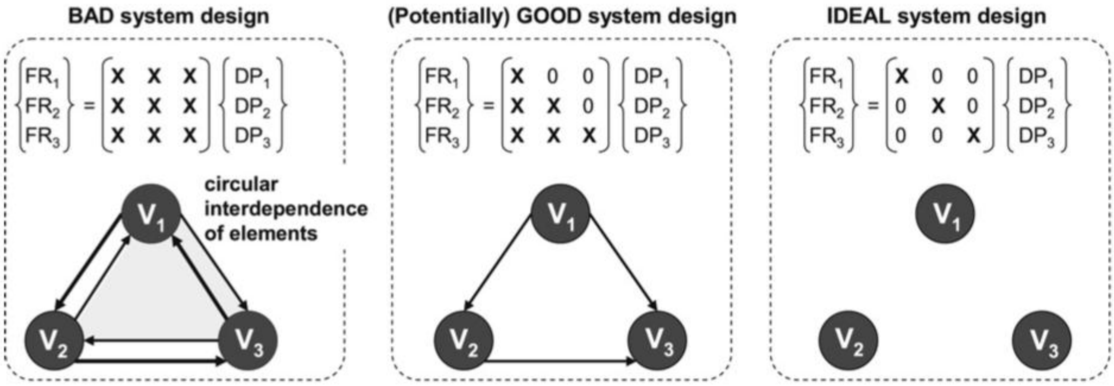



Figure 4.3: Types of design matrix in the Axiomatic Design Theory (Matt 2007) (p. 182)

Uncoupled and decoupled designs are shown to satisfy the independence Axiom and thus are acceptable. Coupled designs do not satisfy the independence Axiom and thus are unacceptable (Suh 2005). It is notice that coupled designs are referred to as "unacceptable" as they are not robust, i.e. they cannot survive random variations of DPs and the environment surrounding the design (Suh 2005).

As has been stated above, based on the form of the design matrix [A], the designer can determine whether the FRs satisfy the Independence Axiom or not (Cheng and Tsai 2008). Suh (2005) recommends that when the Independence Axiom is violated by design decisions made, that is, when the design matrix [A] is coupled, the designer should go back and redesign rather than proceed with a flawed design (Suh 2005). In other words, the designer should go back and modify the DPs or the FRs. Cheng and Tsai (2008) observed that because dependencies among the FRs would depend on the selected DPs, replacing the ill-fitting DPs might cause FRs to satisfy the Independence Axiom. On the other hand, when the design matrix [A] satisfy the Independence Axiom, the designer can go back to the functional domain and decompose the next level FRs (Cheng and Tsai 2008). According to Suh (2005), such decomposition can be achieved only by zigzagging between the two domains, as illustrated by Figure 4.4.

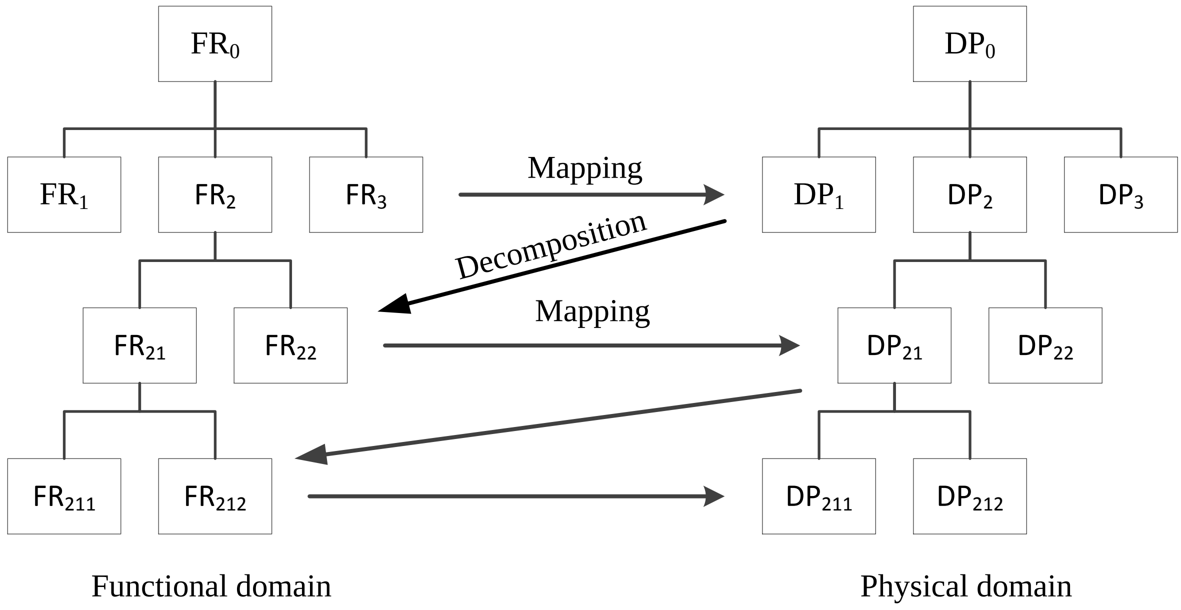



Figure 4.4: The process of decomposition: zigzagging between the functional domain and the physical domain (Suh 2005) (p. 226)

The process of decomposition can be described as follows (Suh 2005): the designer starts out in the "what" domain and goes to the "how" domain. From a FR in the functional domain, he goes to the physical domain to conceptualise a design and determine its corresponding DP. Then he comes back to the functional domain to create $FR_1$, $FR_2$ and $FR_3$ at the next level that collectively satisfy the highest-level FR. $FR_1$, $FR_2$ and $FR_3$ are the FRs for the highest-level DP. Then he goes to the physical domain and finds $DP_1$, $DP_2$ and $DP_3$, which satisfy $FR_1$, $FR_2$ and $FR_3$ respectively. Brown (2005) also advocates that at each level of hierarchy, the FRs must be collectively exhaustive and mutually exclusive, meaning that the required functions are covered without overlap between the FRs. The process of decomposition is continued until the highest-level FR can be satisfied without further decomposition, that is, when all of the branches reach the final state (Suh 2005). A common mistake to be avoided, according to Brown (2005), is to decompose a FR into only one other FR, which results in either an incomplete decomposition, i.e. the lower level FR is not collectively exhaustive, or else it makes the lower level FR redundant, just a re-definition of the higher level FR. In the FR decomposition structure, each parent must have at least two children (Brown 2005).

Information Axiom, which is the second axiom of the Axiomatic Design Theory, is about minimising the information content of the design, as stated previously. As the design effort may produce several designs, all of which may be acceptable in terms of the Independence Axiom and even for the same task defined by a given set of FRs, it is likely that different designers will come up with different designs because there can be many designs that satisfy a given set of FRs, one of these designs is likely to be superior to the others (Suh 2005). In such case, the Information Axiom should be applied in order to select the best design among those designs that are acceptable. Because the information content is defined in terms of probability of achieving the FRs (Suh 2005), the selection process is based on criterion which states that the design resulting in the highest probability of FR success is the best design (Cebi and Kahraman 2010). In other words, the Information Axiom states that the design with the smallest information content (I) is the best design, since it requires the least amount of information to achieve the design goals (Suh 2005). To calculate the information content $I_i$ for a given $FR_i$, which is defined in terms of the probability $P_i$ of satisfying $FR_i$, Equation 5 is used (Suh 2005):

$$I_i = \log_2 \frac{1}{P_i} = -\log_2 P_i \qquad \text{Equation 5}$$

As in the general case there are *m* FRs, the information content for the entire system *Isys* is calculated using Equation 6 (Suh 2005):

$$I_{sys} = -\log_2 P_{\{m\}} \qquad \text{Equation 6}$$

where $P_{\{m\}}$ is the joint probability that all m FRs are satisfied.

When all FRs are statistically independent, as is the case for an uncoupled design,

$$P_{\{m\}} = \prod_{i=1}^{m} P_i$$

then Isys may be expresses as

$$I_{sys} = \sum_{i=1}^{m} I_i = -\sum_{i=1}^{m} \log_2 P_i \qquad \text{Equation 7}$$

When all FRs are not statistically independent, as is the case for a decoupled design,

$$P_{\{m\}} = \prod_{i=1}^{m} P_{i\uparrow\{m\}} \qquad for\ \{j\} = \{1, \dots, i-1\} \qquad \text{Equation 8}$$

where $P_{i/\{j\}}$ is the conditional probability of satisfying $FR_i$ given that all other relevant (correlated) $\{FR_j\}_{j=1, \dots, i-1}$ are also satisfied. In this case, $I_{sys}$ is calculated by Equation 9:

$$I_{sys} = -\sum_{i=1}^{m} \log_2 P_{i\uparrow\{j\}} \qquad for\ \{j\} = \{1, \dots, i-1\} \qquad \text{Equation 9}$$

To conclude, it is to notice that when all probabilities are equal to 1, the information content is zero, and conversely, the information required is infinite when one or more probabilities are equal to zero. That is, if the probability is small, the designer must supply more information to satisfy the FRs (Suh

2005). In an ideal design, the information content should be zero to satisfy the FR every time and all the time (Suh 2005).

### 4.2.4 Areas of application

Axiomatic Design Theory has been one of the most applied methods to design systems. It has been applied to problems found in different research areas such as manufacturing system, product development, system design, software development, ergonomics, decision-making, construction projects, etc.

For example, with regard to manufacturing system, Matt (2012) proposes an approach for testing the validity of Axiomatic Design-based complexity theory as an explanatory construct and as a methodological guidance for the early detection of need for change in flexible manufacturing systems in order to maintain competitiveness even in turbulent environmental conditions. Specifically, the purpose of the paper was to investigate the mechanisms of dynamic complexity in terms of internal and/or external drivers and the impact on a flexible manufacturing system's performance. To accomplish the objective set, the author defined one level 1 FR and then decomposed it into three level 2 FRs. For instance, the $FR_1$ and its corresponding $DP_1$ have been defined as follows: $FR_1$: Produce to demand at best achievable operational efficiency, $DP_1$: Design of flexible assembly (or packing) operations focused on customer demand pace and value added work.

Vinodh and Aravindraj (2012) applied the Axiomatic Design Theory to develop a conceptual model for lean manufacturing. A hierarchical structure was developed to model the design process of a lean manufacturing system composed of FRs, DPs and PVs. The authors concluded that the axiomatic modelling approach serves as an efficient guideline for the design process to clarify the tools, methods and resources of designing lean manufacturing systems, as has been concluded in other works, e.g. the one carried out by Houshmand and Jamshidnezhad (2006) or the one conducted by Kulak et al. (2005).

Vinodh (2011) reports an Axiomatic Design model of agile production system design using process variables. The model is intended to serve as an efficient guideline for the design process to clarify the tools, methods and resources of designing agile production system of Indian electronic switches manufacturing organisation. From the $FR_0$: Maximising the value delivered to the customers, the authors defined five level 1 FRs, which according to the author, characterise the major elements of agility: $FR_1$: Management responsibility agility, $FR_2$: Manufacturing management agility, $FR_3$: Workforce agility, $FR_4$: Manufacturing technology agility, and $FR_5$: Manufacturing strategy agility. The DPs to satisfy these set of FRs were defined as $DP_1$: Ensure management commitment, $DP_2$: Flexible and agile management system, $DP_3$: Workforce skill improvement, $DP_4$: Design and manufacturing flexibility, and $DP_5$: Redesign of value stream. In order to produce these DPs, the paper proposes a set of PVs, as follows: $PV_1$: Methods for management and employees focus, $PV_2$: Adoption of advanced management technologies, $PV_3$: Educate the workforce, $PV_4$: Utilisation of advanced technologies, and $PV_5$: Advanced costing and pricing policies. The level 1 FRs were decomposed to the level 2 FR. Although this paper can be viewed as an important reference since it is one of the few works that propose PVs, some mistakes can be addressed. For example, the definition of the level 1 FRs does not start by verbs. On the other hand, $DP_1$ starts by a verb rather than by a noun. To improve the definition of the FRs, the authors could add the verb “to ensure”, which would result for instance, in $FR_1$: Ensure management responsibility agility, $FR_2$: Ensure manufacturing management agility, and so on.

In product development, Arsenyan and Büyüközkan (2012) developed a Collaborative Product Development (CPD) model based on the Axiomatic Design Theory by offering a system perspective in the context of software development. Three main dimensions of CPD derived from the literature were defined as CAs: effective partnership process, effective collaboration process and effective product development. Based on these three CAs, the authors defined three level 1 FRs, as follows: $FR_1$: Define effective partnership strategy, $FR_2$: Define effective collaboration strategy, and $FR_3$: Define effective product development strategy. To satisfy the level 1 FRs, the following DPs have been proposed: $DP_1$: Collaboration oriented corporate initiative, $DP_2$: Collaborative infrastructure, and $DP_3$: Product lifecycle management. The model is intended to offer a guideline for CPD practitioners to increase effectiveness in collaborative efforts in the development process, and can be used as a performance evaluator in collaborative projects.

In system design, Bang and Heo (2009) applied the Axiomatic Design Theory to systemise the design of nanofluids in order to bring its practical use forward. Grounded on the evaluation of the Independence Axiom, the authors concluded that the excessive coupling between the FRs and the parameters of a nanofluid system prevents from meeting the functional goals of the entire system. They also concluded that at a parametric level, the design of a nanofluid system is inherent coupled due to the characteristics of thermal-fluid system. Three level 1 FRs, as well as their corresponding DPs, have been defined as follows: $FR_1$: Provide high thermal performance, $FR_2$: Provide low pumping power, $FR_3$: Provide high stability of dispersion, $DP_1$: Effective thermal conductivity, $DP_2$: Effective viscosity, $DP_3$: Energy barrier.

In the ambit of decision-making, Kannan et al. (2015) combined the Axiomatic Design Theory with fuzzy in order to propose a Multi-Criteria Decision-Making (MCDM) approach that enables the selection of the best green supplier for Singapore-based plastic manufacturing company. The proposed approach allows selecting not only the most appropriate green supplier but also helps to analyse most appropriate alternative supplier. Gonçalves-Coelho and Mourão (2007) used the Axiomatic Design Theory as support for decision-making in a design for manufacturing context. The objective was to show how the Axiomatic Design Theory allows for perceiving the relationships between each product and the related manufacturing process. To accomplish such objective, one example was used to describe how the Axiomatic Design's information axiom can be applied to select the most appropriate manufacturing process in order to allow for the subsequent detail design of a mechanical component.

With regard to ergonomic systems, Taha et al. (2014) applied the Axiomatic Design Theory to explore the ergonomics DPs of the virtual environment to minimise visual symptoms, a negative effect experienced by users when interacting with virtual environment. A virtual robot manufacturing system was developed as a case study to explore ergonomic DPs that satisfy the independence of ergonomic FRs and CAs. "Desired visual comfort when using the virtual environment" has been defined as the CA. To satisfy the CA, one level 1 FR has been defined as follows: $FR_1$: Minimise visual symptoms, which is satisfied by $DP_1$: Ergonomics design parameter of the virtual environment. To achieve the ergonomics $DP_1$, the $FR_1$ has been decomposed to a second level $FR_1$ consisting of six FRs. It is to notice that in this paper the authors made the mistake pointed out by Brown (2005) and discussed in Section 4.2.3. This is because after decomposing $FR_1$ into six level 2 FRs, the authors decomposed four level 2 FRs, that are, $FR_{11}$, $FR_{12}$, $FR_{13}$ and $FR_{14}$ into only one other FR. This will increase the design complexity, as there are more design information and relationships in the design matrix to be managed.

In construction projects, Cheng and Tsai (2008) grounded on the Axiomatic Design Theory to create a fast-tracking model and to decompose design-build project into design-build modules and to analyse the dependency among them. By applying the Axiomatic Design Theory, the paper addressed a mechanism to facilitate the flexibility of cross-organisational process integration, which may assess alliance of design and construction companies for one design-build project. For an extended review on the application of the Axiomatic Design Theory until 2010, the reader is guided to see Kulak et al. (2010).

### 4.2.5 Challenges and limitations of the Axiomatic Design Theory

Although the Axiomatic Design Theory has been applied in designing many different kinds of complex engineered systems as discussed in the previous section, some challenges and/or limitations have been addressed in the literature. Starting from the process of deriving CNs and mapping them to FRs, Thompson (2013b) asserts that no concrete guidelines for stakeholder identification, requirements elicitation, or the process of mapping CNs to FRs and constraints are provided in any of the classic Axiomatic Design Theory texts. She also advocates that although the Axiomatic Design Theory acknowledges the importance of the requirements process, it offers limited guidance about how to gather, organise, and manage requirements, i.e. the Axiomatic Design Theory provides no framework for organising other types of information that are collected during the requirements process.

A second challenge is concerned with the Suh (2005)' statement "the process of decomposition is continued until the highest-level FR can be satisfied without further decomposition". This can be viewed as one of the disadvantages of the Axiomatic Design Theory as it does not provide any direction or explanation on when to stop the decomposition. In other words, a plausible question can be: "how does the designer know whether the decomposition achieved sufficient level of detail or not?" Perhaps it depends on the designer's perception, that is to say, maybe it will be subjective. Tang et al. (2009) report that one of the findings on the limitations of the Axiomatic Design Theory is its concentration on the architectural design, at the expense of the system design context, which makes such factors and constraints, such as cost, time, and physical integration not catered directly by the axiomatic model.

Tang et al. (2009) also assert that although the Axiomatic Design Theory guides the designer finding suitable DPs to meet the needs of function requirements, it cannot support the designer to know the interactions amongst the design parameters, including geometry, spatial layout, interfaces (e.g. logical and physical connectivity). What the authors implicitly advocate here is that as for a FR, there may be more than one corresponding DPs, and several candidate solutions may all satisfy the functional independency axiom, and therefore the final solution has to be decided based on the interactions among DPs. This challenge of interactions among DPs can be particularly relevant when we are redesigning a system and there are some DPs that cannot be changed. In this case, the Axiomatic Design Theory does not enable the designer to know how the new proposed DPs will affect those that cannot be changed, and vice versa. It may result in incompatible or conflicting DPs, which may result in failures of the designed system.

Another challenge is that Suh (2005) considers that in the case of a new and innovative product, the FRs should be defined in a solution-neutral environment without considering any physical solution in mind. This, however, can rarely happen in practice, particularly in complex product environments, where economic considerations dictate maximum possible utilisation of mature designs and existing knowledge (see (Tang *et al.* 2009)). This challenge was first pointed out by Suh (2005) who stated: "this is very difficult to do, especially if the designer has many years of experience in the specific field". Suh (2005) also asserts that if the FRs are chosen thinking about an existing product, the new design will be a slight of the existing design.

Another significant limitation of the Axiomatic Design Theory is provided by Cebi and Kahraman (2010) who point out that in real case problems, sometimes, the relations between FRs and DPs (assigned in the design matrix [A] by 0 and X) can be unknown or uncertain, i.e. there can be a little or indirect relationship between a FR and a DP. The authors advocated that in such cases, classical Axiomatic Design principles are in short supply for designers to define the degrees of relations between FRs and DPs under uncertainty or fuzzy. Ogot (2011) highlights that the Axiomatic Design Theory does not provide ample guidance on how to achieve the conceptual solutions to solve the design problem, i.e. once the problem has been formulated in terms of FRs and DPs, and if the resulting relationships between them are found to be coupled (bad) or too complex, the Axiomatic Design Theory does not provide ideas on how the design could be uncoupled or simplified, respectively. Shirwaiker and Okudan (2011) assert that Axiomatic Design guidelines concentrate more on problem definition rather than solution generation, i.e. although creating and optimizing solutions is a step in the Axiomatic Design methodology, it does not propose any specific techniques for generating accurate and efficient solutions.

In addition to the limitations and challenges discussed above, the difficulties associated with learning to use axiomatic and with managing the information that falls outside its boundaries cause designers to make five types of procedural errors during the definition of FRs (Thompson 2013a):

1. Mixing FRs with DPs;
2. Mixing FRs with other types of requirements;
3. Mixing the FRs of the various stakeholders and of the artifact;
4. Mixing the FRs of the artifact and of related systems;
5. Defining negative FRs.

Within this context, Thompson (2013a) defines procedural errors as errors that stem from an incorrect interpretation or application of Axiomatic Design Theory. For example, in the early stages of the design process, the mixes of "what" and "how" information manifest as the presence of DPs or physical information in the high-level FRs. These errors can usually be identified by the presence or emphasis on a noun (a physical means of performing a function) instead of a verb (the function that should be performed). The verb "to use" (i.e. "The artifact should use material, component, energy source, etc.") and "to have" (i.e. "The artifact should have component or feature") are also commonly associated with these types of errors (Thompson 2013a). To conclude, it is to notice here the difficulties faced by designers in distinguishing what are PVs, an issue that has been discussed recently by the Axiomatic Design research community in the 8th International Conference on Axiomatic Design (ICAD 2014[14]) realised in Lisbon, Portugal. One of the conclusions achieved by the research community is that probably that issue explains the reason why most papers on the Axiomatic Design Theory do not include PVs.

### 4.2.6 Rationale for choosing the Axiomatic Design Theory

In Section 1.3 it was assumed that the Axiomatic Design Theory provides us with an effective set of tools for designing interoperable industrial network platforms (Proposition 1). However, systems design in general is not limited to this method. Indeed, an analysis of the collected literature made it possible to state that there are many methods that can be used for designing systems. For example, Arsenyan and Büyüközkan (2012) refer to Quality Function Deployment (QFD) (Mizuno and Akao 1994), Design for X (DfX) (Huang 1996), Theory of Inventive Problem Solving (TRIZ) (Altshuller 1984, Altshuller et al. 1997, Altshuller et al. 1999), and Axiomatic Design Theory (Suh 1990, Suh 2001, Suh 2005) as well. Tomiyama et al. (2009) go further and provide an extensive list in which this thesis highlights the Axiomatic Design Theory, Design Structure Matrix (DSM[15]) (Steward 1981, Browning 2001, Eppinger and Browning 2012), QFD, TRIZ, and Taguchi Method (Taguchi 1987). These design methods were highlighted because they represent a cross section of research in design in the last few years.

The rationale for using the Axiomatic Design Theory to design interoperable industrial network platforms instead of the methods discussed above, even though its challenges and limitations, discussed in Section 4.2.5, is mainly due to the fact that the Axiomatic Design Theory shows that the engineering of good designs can be taught as a science (Brown 2005), establishes a scientific and systematic basis that provides structure to design process for engineers (Cebi and Kahraman 2010), provides an efficient framework to guide the designers through the design process and reduce much of the waste associated with the trial and error method (Vinodh 2011), make human designers more creative, reduce the random search process, minimise the iterative trial-and-error process, determine the best designs among those proposed (Suh 2001), helps to organise the requirements information and to differentiate it from the information (and information content) associated with various design solutions (Thompson 2013a), i.e. helps to clearly separate objectives from means (Cochran et al. 2001), assists the designer with the Independence Axiom to check whether all FRs are satisfied independent of each other and the Information Axiom to select the solution with the least information content (Shirwaiker and Okudan 2011).

[14] http://eventos.fct.unl.pt/icad2014/pages/conference-0
[15] http://www.dsmweb.org/

With regard to this last advantage of the Axiomatic Design Theory, compliance with the first axiom assures that designs will be adjustable, controllable and will avoid unintended consequences. Compliance with the second axiom assures that the design will be robust with a maximum probability of success (Tomiyama et al. 2009). Moreover, according to a Google Scholar search, carried out by Tomiyama et al. (2009), the Axiomatic Design Theory under Suh's name was one of the most cited engineering design publications up to 2009. Put it into the context of this thesis, the Axiomatic Design Theory enabled the designer to organise the business interoperability problem into three main categories, which are, business interoperability requirements and business interoperability solutions, and how business interoperability solutions will be implemented at operational level (PVs). Also, the Axiomatic Design Theory enabled the decomposition of the business interoperability requirements and the business interoperability solutions from high level to a level where they are suitable to be measured through a maturity model. This will contribute a lot to overcome the limitations associated with the interoperability maturity models discussed in Section 3.4.

## 4.3 Simulation modelling: an overview

*"Few things in this world are static. This is particularly true of simulation projects. They seek continually to redefine themselves. As project develops, discoveries are made." (Musselman 1998) (p. 721)*

Simulation is defined as a method for using computer software to imitate, or simulate, the operations of various kinds of real-world systems or processes (Law and Kelton 2000), or as a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behaviour of a system (or some component thereof) over extended periods of real time (Rubinstein and Melamed 1998). These definitions are consistent with, for instance, the one provided by Banks (1998) who defines simulation as the imitation of the operation of a real-world process or system over time.

Given its suitability to model and imitate complex systems such as Supply Chain Networks (SCNs) (e.g. (Stefanovic et al. 2009, Bottani and Montanari 2010, Gang Li et al. 2010, Carvalho et al. 2012)), simulation is viewed as an indispensable problem solving methodology for the solution of many real-world problems (Banks 1998), and is especially useful for theory development when the phenomenon under investigation involves non-linear processes and effects such as feedback loops and thresholds (Davis et al. 2007). For example, Li et al. (2010) emphasise that simulation is a powerful tool for investigating the behaviour of large-scale systems which are analytically intractable, and for examining various decisions for the improvement of a given manufacturing network. Simulation is used to describe and analyse the behaviour of a system, ask what-if questions about the real system, and aid in the modelling of real systems – both existing and conceptual systems can be modelled with simulation (Banks 1998).

Associated to the concept of simulation is the concept of simulation modelling, which can be defined as the activity of deriving the theoretical model from the real-world system (Vincent 1998), as the process of creating and experimenting with a computerised mathematical model of a physical system (Chung 2003), or as the process of developing simulation models for studying the behaviour real-world systems. Within this context, models refer to a description or an abstraction of a system (Pritsker 1998), or an abstraction of some real system that can be used to obtain predictions and formulate control strategies (Rubinstein and Melamed 1998), and simulation models are referred to as dynamic models that mimic the process of a system and predict its changes through time (Kuby et al. 2009). The importance of simulation modelling has been widely discussed in the literature. For instance, Davis et al. (2007) assert that simulation modelling is a significant methodological approach to theory development in the literature focused on organisations. Law and Kelton (2000) stress that simulation modelling is one of the most widely used operations-research and management science techniques, if not the most widely used". Simon (1990) highlights that simulation modelling is a principal-perhaps the primary-tool for studying the behaviour of large complex systems".

### 4.3.1 Purposes of simulation

According Pegden et al. (1995), there are four main purposes for conducting simulation modelling of different systems:

1. Gaining insight into the operation of a system, i.e. to learn about its models of behaviour (Lane 1997);
2. Developing operating or resource policies to improve system performance, i.e. to design policies which improve performance (Lane 1997);
3. Testing new concepts and/or systems before implementation;
4. Gaining information without disturbing the actual system.

With regard to the first purpose, Chung (2003) stresses that some systems are so complex that it is difficult to understand the operation of and interactions within the system without a dynamic model, or in other words, that it may be impossible to study the system by stopping it or by examining individual components in isolation. Regarding to the second purpose, Chung (2003) highlights the situation whereby we may also have an existing system that we understand but wish to improve. In this circumstance, the author suggests two fundamental ways for achieving the desired improvement: (1)

changes in operating policies (e.g. different scheduling priorities for work orders), and (2) changes in resource policies (e.g. stuffing levels or break scheduling). The third purpose is concerned with the situations where a system does not exist, or we are considering purchasing new systems. In this case, a simulation model can help give us an idea how well the proposed system will perform. In addition, the use of a simulation model before implementation can help refine the configuration of the chosen system.

Finally, in the fourth purpose, Chung (2003) advocates that simulation models are possibly the only method available for experimentation with systems that cannot be disturbed. To support this, the author points out that some systems are so critical or sensitive that it is not possible to make any types of operating or resource policy changes to analyse the system. The classical example of this type of system would be the security checkpoint at a commercial airport; conducting operating policy or resource level experimentation would have serious impact on the operational capability or security effectiveness of the system (Chung 2003).

### 4.3.2 Rationale and motivation for simulation modelling

At some point in the lives of most systems, there is a need to study them to try to gain some insight into the relationships among various components, or to predict performance under some new conditions being considered (Law and Kelton 2000). One of the ways in which a system might be studied is through simulation, as illustrated in Figure 4.5.

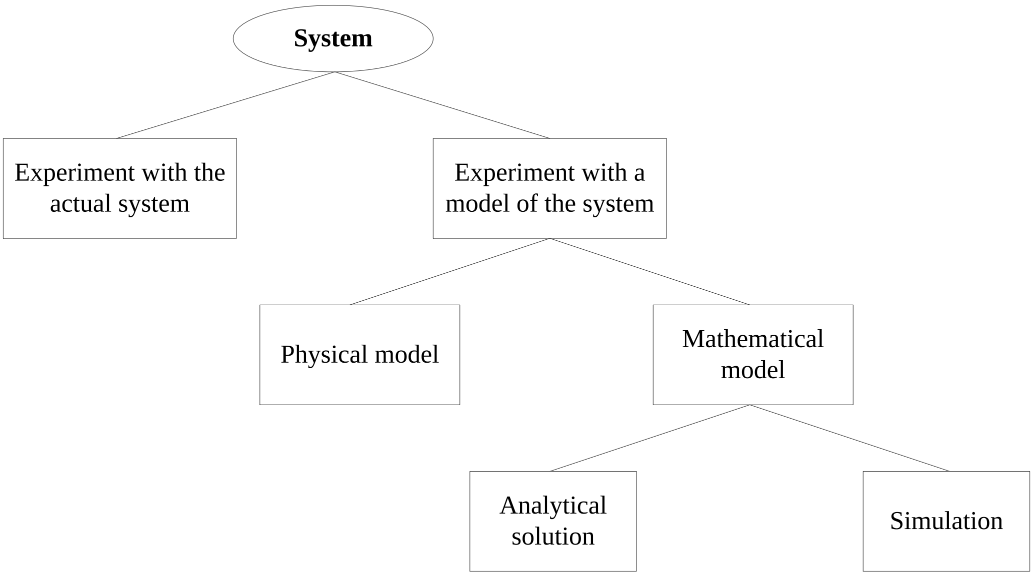



Figure 4.5: Ways to study a system (Law and Kelton 2000) (p. 4)

As shown in figure above, a system can be analysed by means of experiments with the actual system or with a model of the system. Law and Kelton (2000) point out that if it is possible (and-cost-effective) to alter the system physically and then let it operate under the new conditions, it is probably desirable to do so. However, the authors recognise that it is rarely feasible to do this, because such an experiment would often be too costly or too disruptive to the system. In line with Law and Kelton (2000), Banks et al. (2002) stress that experimentation with the real system is often disruptive, seldom cost-effective and sometimes just impossible. This is also supported by Railsback and Grimm (2011), who recognise that real systems are often too complex or develop too slowly to be analysed using experiments.

In the context of this research, conducting experiments would be an impracticable task, as disrupting the day-to-day business operations of the companies participating in the cooperative industrial networks would be too costly, too difficult (if not impossible) to do, due to the number of dyad relationships involved in the network, as well as the number of business interoperability factors to be experimented. Indeed, as cooperative industrial networks are complex and dynamic in nature. As discussed in Chapter 2, understanding their behaviour under different configurations and under different levels of business interoperability, during a certain time interval, can be a major challenge for many businesses operating in those networks. Armbruster et al. (2002) observed that within such context, there are no controlled experiments that can be done within a reasonable time period, involving the whole network or even involving a single large company. Moreover, the cooperative industrial network might not even exist, but we nevertheless want to study it in its various proposed alternative configurations for business interoperability to see how it should be built in the first place. In these circumstances, it is usually necessary to build a model as a representation of the system and study it as a surrogate for the actual system (Law and Kelton 2000). A model, which is referred to as "a purposeful representation of some real system" (Railsback and Grimm 2011), can be physical or mathematical.

Analysing the impact of business interoperability on the performance of networked companies by means of physical model of the system is regarded to be unsuitable for this research as physical models (also called iconic models) are not typical of the kinds of models that are usually of interest in operations research and systems analysis (Law and Kelton 2000). In addition, creating a physical prototype of an industrial network model, consisting of a set of companies and a set of dyad relationships connecting them, as well as analysing its business interoperability performance, do not seem to be practicable. Accordingly, a mathematical model must be developed, which can be grounded on analytical solution or simulation. Law and Kelton (2000) advocate that if the relationships that compose the model are simple enough, it may be possible to use mathematical methods (such as algebra, calculus, or probability theory) to obtain exact information on questions of interest – this is called an analytic solution. What the authors implicitly suggest here is that if an analytical solution to a mathematical model is available and is computationally efficient, it is usually desirable to study the model in this way rather than via a simulation model. In other words, simulation is not required when the systems are very simple, and it is possible to program them directly in a general-purpose language, without using any special simulation software or support programs (or than a random-number generator) (Law and Kelton 2000). However, most real-world systems are too complex to allow realistic models to be evaluated analytically, and coding them without supporting software can be a difficult and time-consuming task (Law and Kelton 2000).

With regard to the type of systems addressed in this thesis in particular, that are cooperative industrial networks, the high number of dyad relationships usually involved and the high number of factors affecting those dyads as well as the interdependencies among them make the modelling of such networks more difficult by analytical tools. Moreover, those types of social systems contain non-linear relationships, and therefore an analytical solution to solving model equations is not feasible (Angerhofer and Angelides 2000). Swaminathan (1998) also supports this by pointing out that complex interactions between different entities and the multi-tiered structure of industrial networks make it difficult to utilise closed-form analytical solutions. In the same direction, Lane (1997) advocates that social systems should be modelled as flow rates and accumulations linked by information feedback loops involving delays and non-linear relationships, and therefore computer simulation is the means of inferring the time evolutionary dynamics endogenously created by such system structures. In short, the fundamental rationale for using simulation is man's unceasing quest for knowledge about the future (Rubinstein and Melamed 1998), i.e. gaining insight on the future behaviour and/or performance of the system under analysis.

Taking into account the limitations of analytical solutions discussed above, Armbruster et al. (2002) point out that in such circumstances, simulation models will have to be developed that substitute for the real environment. Law and Kelton (2000) reinforce that as most complex, real-world systems with stochastic elements are more difficult be accurately replicated and solved by a mathematical model that can be evaluated analytically, simulation is often the only type of investigation possible.

Another relevant advantage of simulation, which is highlighted in Pidd (1998), is replication: "unfortunately, the real world is rarely kind enough to allow precise replication of an experiment. One of the skills employed by physical scientists is the design of experiments, which are repeatable by other scientists. This is rarely possible in management science. It seems unlikely that an organisation's competitors will sit idly by as a whole variety of pricing policies are attempted in a bid to find the best.

It is even less likely that a military adversary will allow a replay of a battle. Simulations are precisely repeatable." Regardless of the advantages discussed above, simulation also presents a set of disadvantages, as discussed in Banks (1998) and Rubinstein and Melamed (1998):

1. ***Model building requires special training***. It is an art that is learned over time and through experience. Furthermore, if two models of the same system are constructed by two component individuals, they may have similarities, but it is highly unlikely that they will be the same;
2. Simulation provides ***statistical estimates*** rather than the ***exact*** characteristics and performance measures of the model. Thus, simulation results are subject to uncertainty and contain "experimental errors". In addition, ***simulation results may be difficult to interpret***, i.e. as most simulation outputs are essentially random variables (they are usually based on random inputs), it may be hard to determine whether an observation is a result of system interrelationships or randomness;
3. Simulation modelling is typically time-consuming and consequently expensive in terms of analyst time. In other words, skimping on resources for modelling and analysis may result in a simulation model and/or analysis that is not sufficient to the task;
4. Simulation results, no matter how precise, accurate, and impressive, provide consistently useful information about the actual system, ***only*** if the model is a "valid" representation of the system under study;
5. ***Simulation may be used inappropriately***. Simulation is used in some cases when an analytical solution is possible, or even preferable. This is particularly true in the simulation of some waiting lines where closed-form queueing models are available, at least for long-run evaluation. However, this issue should not be seen as a shortcoming of simulation per se as it depends more on the ability of the analyst to realise which method is most appropriate for the problem under analysis.

Considering the trade-offs between the advantages and disadvantages discussed above, it seems that there is no doubt that simulation modelling has to be used in this research in order to simulate both new designed interoperable cooperative industrial networks and redesigning the existing ones.

### 4.3.3 Types of simulation models

Simulation models can be classified according to three different dimensions (Rubinstein and Melamed 1998, Law and Kelton 2000):

1. ***Static versus Dynamic Simulation Models***: a static simulation model is a representation of a system at a particular time, or one that may be used to represent a system in which time simply plays no role – example of static simulations are Monte Carlo methods (Law and

Kelton 2000). In other words, static models are those that do not evolve in time, and therefore do not represent the passage of time (Rubinstein and Melamed 1998). On the other hand, dynamic simulation models represent systems that evolve over time (e.g. a conveyor system in a factory, or a traffic light operation);

2. ***Deterministic versus Stochastic Models***: if a simulation model does not contain any probabilistic (i.e. random) components (Law and Kelton 2000), or if it contains only deterministic (i.e. non-random) components, it is called deterministic (Rubinstein and Melamed 1998). A deterministic system is one whose behaviour is entirely predictable, i.e. the one where it is possible to predict precisely what will happen (Pidd 1998). In other words, in a deterministic model, all mathematical and logical relationships between the elements (variables) are fixed in advance and not subject to uncertainty (Rubinstein and Melamed 1998). In contrast, a model with at least one random input variable is called stochastic model (Rubinstein and Melamed 1998). A stochastic system is one whose behaviour cannot be entirely predicted, though some statement may be made about how likely certain events are to occur (Pidd 1998);
3. ***Continuous versus Discrete Simulation Models***: discrete and continuous models are defined in the same way as discrete and continuous systems. A discrete model has dependent variables that remain constant over intervals of time and change value only at certain well-defined points called *event times* (Banks 1998). For example, event times in a manufacturing system correspond to the times at which orders are placed in the system; material handling equipment arrives and departs from machines; and machines change status (e.g. from busy to either idle, broken, or blocked) (Pritsker 1998). In contrast, continuous models have dependent variables that are continuous functions of time (Pritsker 1998), i.e. that may change continuously over time (Banks 1998). For example, the time required to unload an oil tanker or the position of a crane (Pritsker 1998). Also, we can also have a combined model, in which the dependent variables of a model may change discretely, continuously, or continuously with discrete jumps superimposed (Pritsker 1998).

## 4.4 Agent-based modelling and simulation

Given that the analysis of the impact of business interoperability on the performance of cooperative industrial networks must be carried out by means of simulation, as concluded in Section 4.3.2, it is necessary to select which simulation method is most appropriate to do this. Among the various simulation methods, ABS, also referred to as ABM or Individual-based Modelling (e.g. (Gilbert and Terna 2000, Gilbert 2008, Macal and North 2010, Railsback and Grimm 2011, Rand and Rust 2011, Helbing 2012, Held *et al.* 2014)), has been assumed to be appropriate for answering the Research

Question 2 (see Section 1.3). Following, an overview on this type of simulation method is provided, and the rationale for such choice is explained in detail in Section 4.4.5.

Agent-Based Simulation or ABM is a tool that can help researchers to understand and analyse complex patterns that results from the interaction of many individuals (Rand and Rust 2011). It is a relatively new approach to modelling complex systems composed of interacting, autonomous agents (Macal and North 2010). It investigates aggregate phenomena by simulating the behaviour of individual agents, such as consumers or organisations (Rand and Rust 2011). According to Gilbert (2008), ABM is a computational method that enables a researcher to create, analyse, and experiment with models composed of agents that interact within an environment. Put it simple, it is a method for modelling Multi Agent Systems (MAS) which consist of a set of elements (agents) characterised by some attributes and behaviours, which interact each other through the definition of appropriate rules in a given environment (Barbati et al. 2012). Specifically, a MAS is defined by Monostori et al. (2006) as a network of agents that interact and typically communicate with each other. Agents here refer to any autonomous entity with its own properties and behaviours (Rand and Rust 2011), and that populates a complex system (Datta 2007). In other words, agents refer to any identifiable, discrete individual with a set of characteristics or attributes, behaviours, and decision-making capability (Macal and North 2009). An agent can be a person, a machine, a piece of software or a variety of other things (Guo and Zhang 2010), and in a context of industrial networks, they may be a company, a division, a team, or an individual, or even a function of an individual's job (Datta 2007).

One of the key characteristics of ABM, in the words of Kuby et al. (2009), is that it focuses on modelling disaggregated activities and decisions by autonomous agents, rather than modelling the system as a whole. In this sense, Kuby et al. (2009) state that the essence of ABM is to model individual agents' behaviour, and then let that behaviour play out in a simulation that yields the aggregate results of their interactions. In other words, by modelling agents individually, the full effects of the diversity that exists among agents in their attributes and behaviours can be observed as it gives rise to the behaviour of the system as a whole (Macal and North 2010), which is to say that ABM takes into account that individuals generally do not exist in isolation, but are interdependent, mutually affecting each other through their action and interactions, directly and indirectly, intentionally or unintentionally (Held et al. 2014). What is implicitly suggested here is that ABM highlights the importance of the agents' interactions, exploring how they jointly generate social phenomena, analogously to the way these phenomena are brought about in real life: simple entities, interacting through simple, local rules can produce very complicated behaviour (Held et al. 2014) or complex patterns (Rand and Rust 2011).

Often called a bottom-up approach, the crux of ABM is that a group of entities (the 'agents') behave according to certain rules in a simulation environment (Kuby et al. 2009). Thus, agent-based models include models of behaviours (human or otherwise) and are used to observe the collective effects of individual agent behaviours and interactions (Macal and North 2010). A typical agent-based model consists of three elements (Macal and North 2010): (1) agents that have properties and behaviours, (2) agent' relationships and methods of interaction – an underlying topology of connectedness that define how and with whom agents interact, and (3) agents' environment where agents interact with each other and with the environment. The agent-based models necessarily include relevant aspects of the agents' environment, to provide the context for the agents' interactions. This environment can be physical or abstract, reproduce for example a geographic landscape or a social network. It can also contain passive agents, such as objects or resources that the active agents interact with. In some simulations the agents' locations are relevant, and they may be able to move through space, while others may choose to omit such a feature (Held et al. 2014). In the context of this thesis, locations can play an important role as in the sense that, for example, if the cooperative industrial network involves companies from different countries, an alignment of the applicable local legislations may be required. In relation, to the ability to move through space, it may also be important in the proposed agent-based model as, for instance, the agent "transporters" or "logistics providers" use trucks to transport products and/or materials from the origin to the point of consumption.

To develop an agent-based model, a researcher writes a description for each type of agent that details the agent's behaviours, properties, and the way the agent interacts (i.e. rules) with other agents and the environment. The power of ABM is that none of those descriptions requires knowledge of macro-dynamics; instead, the researcher encodes micro-rules of behaviour and then measures the emergent macro-level results (Rand and Rust 2011). By describing simple rules of behaviour for individual agents and then aggregating these rules, researchers can model complex systems, such as the procurement of services and products in a marketplace, the purchase of tickets for events, the adoption of innovations (Rand and Rust 2011), the adoption of information and coordination mechanisms for managing uncertainty in SCs (Datta and Christopher 2011), the interaction among online users in social networks (Zutshi et al. 2014), the effects of adopting multiple resilience strategies on the performance of production/distribution networks (Datta 2007, Datta et al. 2007), etc.

### 4.4.1 Properties of agents

Agents have behaviours, which are often described by simple rules. Agents interact with and influence each other, learn from their experiences, and adapt their behaviours so they are better suited to their environment (Macal 2010). According to Giannakis and Louis (2011), the agent-based technology is acknowledged as one of the most promising technologies for effective management of complex systems such as SCNs due to the vital properties of agents, which are summarised, for instance, in Wooldridge and Jennings (1995), Macal and North (2010) and (Barbati et al. 2012):

1. ***Autonomy***: agents are able to operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state. In other words, agents are aware of their environment operating and control their own actions as well as internal states in order to fulfil their objectives. In particular the user does not interfere with their decision-making, after they specified their rules;
2. ***Social ability***: agents are able to interact with other agents (and possibly humans) via some kind of agent-communication language or common actions;
3. ***Reactivity***: agents are able to perceive their environment, including other agents, and they are able to react on the basis of these perceptions, i.e. they are able to respond in a timely fashion to changes that occur in their environment;
4. ***Pro-activeness***: agents do not simply respond to changes in their environment, but can initiate actions in order to satisfy their specified objectives.

The key important feature of agents is that they have the ability to make decisions (Datta 2007). They also have behaviours, often described by simple rules, and interactions with other agents, which in turn influence their behaviours (Macal and North 2010). Additionally, an agent (Monostori et al. 2006): (1) makes observations about its environment, (2) has its own knowledge and beliefs about its environment, (3) has preferences regarding the sates of the environment, and finally, (4) initiates and executes actions to change the environment.

### 4.4.2 When is agent-based modelling appropriate?

In developing agent-based models, Rand and Rust (2011) suggest that before we get to the model development itself, we should discuss when ABM is appropriate, or in other words discuss the reasons to use ABM because this is really the first step in creating an agent-based model. The decision to use ABM should be based primarily on the question under investigation. If the question emphasizes groups of autonomous and heterogeneous entities that operate in a dynamic environment and if the measure of interest is an emergent result of these entities' interactions, then ABM is usually one of the tools that should be considered (Rand and Rust 2011). In this sense, ABM is regarded to be most useful when the rules of behaviour are easily written at the individual level and then the behaviour of the system emerges (Rand and Rust 2011). Kuby et al. (2009) assert that ABM is well suited for studying evolutionary processes or systems based on individual behaviours. Perhaps, what Rand and Rust (2011) and Kuby et al. (2009) implicitly suggest here, is that with ABM we are capable of formalising how individual actions and decision-making bring about aggregate characteristics of a population (Held et al. 2014). Kim and Kim (2010) advocate that ABM approach is a better choice for problems in which the behavioural characteristics of each agent can be described by sensing changes in a dynamic environment. Macal and North (2009) offer some ideas on the situations for which ABM can offer advantages to conventional approaches such DES, Systems Dynamics and other quantitative modelling techniques (see Section 4.4.5). They summarised that it is beneficial to think in terms of agents when one or more of the following criteria are satisfied:

1. When the problem has a natural representation as being comprised of agents;
2. When there are decisions and behaviours that can be well-defined;
3. When it is important that agents have behaviours that reflect how individuals actually behave (if known);
4. When it is important that agents adapt and change their behaviours;
5. When it is important that agents learn and engage in dynamic strategic interactions;
6. When it is important that agents have a dynamic relationship with other agents, and agent relationships form, change, and decay;
7. When it is important to model the processes by which agents form organisations, and adaptation learning are important at the organisation level;
8. When it is important that agents have a spatial component to their behaviours and interactions;
9. When the past is no predictor of the future because the processes of growth and change are dynamic;
10. When scaling-up to arbitrary levels is important in terms of the number of agents, agent interactions and agent states;
11. When process structural change needs to be an endogenous result of the model, rather than an input to the model.

Rand and Rust (2011) also provide a comprehensive list consisting of six guidelines for when to apply ABM. As they list these guidelines, they specify whether they are indicative (the benefit of using ABM is increased if the problem exhibits this property), necessary (ABM is inappropriate if the problem does not exhibit this property) or sufficient (ABM is one of very few approaches that will work if the problem exhibits this property) for an ABM approach to be used. The key indicators to consider in applying an ABM approach are the following (Rand and Rust 2011):

1. ***Medium numbers (indicative)***: ABM is not the appropriate tool to use when a system is composed of only one or two agents because, in that case, game theory often provides a better modelling tool. On the other hand, if the number of agents is very large and if the agents

themselves can be modelled using a representative agent, then ABM becomes inefficient compared to statistical regression;

2. ***Local and potentially complex interactions (indicative)***: ABM becomes more useful as the interactions between individuals become more complex and local. Local information and complex interactions can be modelled using game theory, but often these models break down when the number of agents reaches above a small set. At this point, ABM becomes an appropriate framework to consider;
3. ***Heterogeneity (indicative)***: because the focus of ABM is on the individual, each individual can be modelled as differently from other individuals as necessary. Alternatively, if a system contains many homogenous agents, system dynamics modelling may be more useful because it efficiently tracks populations of identical agents and examines how they change over time.
4. ***Rich environments (indicative)***: ABM facilitates the representation of rich and even dynamic environments;
5. ***Temporal aspects (necessary)***: ABM is technique for modelling processes and is well suited for examining how complex systems change over time. Therefore, temporal aspects are almost a necessary condition for the ABM approach. Many modelling approaches allow us to examine the equilibrium states of dynamics games, but ABM is one of the few that allows us to examine the dynamics that give rise to those equilibria;
6. ***Adaptive agents (sufficient)***: one of the promises of ABM is its ability to include adaptive agents within simulations. If an agent takes an action that produces a negative result, then that agent may try other actions in the future. An agent that changes its strategy (i.e., which actions to take in a given environment as a result of past information) is an adaptive agent. Because ABM is a computational method, it is possible to embed a machine learning approach within each agent that allows that agent to dynamically adopt the rules under which it operates. There are few modelling techniques besides ABM that are able to robustly represent adaptation.

By analysing this set of guidelines, it is to notice that some of them are implicitly related to the properties of agents discussed in the previous section. For example, the first guideline may be linked to the property "social ability" as one or two agents, the social influence may not be relevant. The sixth guideline may be related to the property "reactivity" and "pro-activeness" as it is concerned with the ability of agents to perceive negative changes in their state and make decisions to adapt to a new desired one. The third guideline may be related with the fact that if all agents in the system under analysis are homogeneous, their attributes, behaviour and decision-making rules will not result in complex interactions, which is the Rand and Rust (2011)' second guideline.

### 4.4.3 Areas of application

Compared with traditional tools of analysis, the use of ABM is still in its infancy, but there are signs of interest (Held et al. 2014). Indeed, the application of ABM has been increasing in the last fifteen years, mainly in the context of optimization problems. For example, Barbati et al. (2012) performed an extensive review to identify the scientific literature about the use of ABM to solve optimization problems, in the time interval 2000-2009. The application fields identified by these authors were: scheduling, transportation and logistics, SC planning, general planning, facility location and bin-packing problems. Also, Lee and Kimz (2008) contributed with an extensive review on the applications of MAS in manufacturing systems and SCM. As this thesis addresses the issue of modelling complex industrial networks, and taking into account the Barbati et al. (2012) and Lee and Kimz (2008)' contributions, a brief overview on the application of ABM in the context of industrial networks, with emphasis on manufacturing and construction networks, from 2010 to present, is provided following.

Starting with manufacturing networks, a number of contributions were identified. For example, grounded on an international business network with the same focal resource, the same source and markets, but exhibiting two different inter-related sub-networks with different internal organisation, Prenkert and Følgesvold (2014) used ABM to compare and explain differences between the two network forms and the effects this have on dyadic international relationship development. To achieve their research goal, the authors applied a qualitative experimental methodology and simulated various changes in quality variation of the focal resource as well as changing demand preferences of buyers to investigate the impact on relationship strength. The main conclusion of this work is that different organisation within the sub-network of an industrial network does not have impact on the development of relationship strength between members of the network analysed.

Long (2014) suggested an agent-based distributed computational experiment framework to study material flow, information flow and time flow modelling in SCNs. This framework provides modellers with several types of agents to build their computational experiment models rapidly by using these agents as building blocks. The implementation architecture of the framework is given and a case of virtual SCN is developed to illustrate the application of the framework. The computational experiment results of the case show that the proposed framework, not only feasible but correct, has sound advantages in virtual SCN development, computational experiment modelling and implementation.

Li and Chan (2013) proposed a common agent-based model for the simulation make-to-stock and make-to-order SCs with dynamic structures. The model contains heterogeneous agents (virtual companies), which act in a virtual environment. Each virtual company is simulated as an agent and the relationships among them are connected by their products. The production of virtual company may be supported by several sub-components, which are produced by other virtual companies. In such model, virtual companies accomplish their works with their knowledge and companies with different knowledge can produce different products. Agents in the model are assigned to satisfy certain customer requirements according to their knowledge. If an agent produces products of the system, this agent will be set in the SCs ("Agents with tasks"). On the other hand, if an agent does not contribute to the system, this agent will be put in the pool of "Agents without tasks". The paper concluded that the virtual SCs can be easily modelled with ABM.

Mishra et al. (2012) introduced a multi-agent architecture to handle recycling and RL issues. The proposed architecture addresses the different aspects of recycling such as waste classification, recycling, logistics and reuse of products. Additionally, it also discusses how the agent communicates and acts autonomously to facilitate the efficient logistics of materials between different units. The paper argued that the proposed multi-agent framework is capable of resolving recycling issues and efficient logistics management during the execution of recycling tasks.

Kim et al. (2011) presented an agent-based diffusion model consisting of tens of thousands of interacting autonomous agents for forecasting product diffusion in a full-sized car market. The central issue modelled in this work is how exactly the agent-based model can predict the market dynamics when a new car is released into the market. In the model, an autonomous agent represents a consumer and has unique characteristics as a consumer to make its own purchase decision. The decision-making process adopted in the model integrates three purchasing forces: expert's product information provided by mass media, subjective weights on product attributes assigned by individual consumers, and social influence (i.e., information delivered from a consumer's neighbours who have already adopted products). Throughout the empirical study, the authors investigated the performance of the proposed agent-based model with the sales data obtained in the automobile market in Korea. One of the main conclusions achieved was that although the empirical study showed an encouraging result, this was not sufficient to support that the agent-based model is appropriate for the markets of different types of products.

Datta and Christopher (2011) adopted an agent-based model to evaluate how the use of the different levels of information sharing and coordination in a supply network can be effective in managing uncertainty under daily operations facing a huge mismatch of actual and forecast demand. In this model, each supply network member is modelled as an independent agent with autonomous decision-making ability. The entire supply network was modelled by replicating the rules, control procedures and strategies adopted by the supply network members. The model has been tested through a case study in a supply network of a paper tissue manufacturer and the main conclusions were: (1) a centralised information structure without widespread distribution of information and coordination is not effective in managing uncertainty of supply networks, even with increased frequency of information flow; (2) coordinating material flows without widespread information sharing does not improve supply network uncertainty management; and (3) central coordination of material flows with SC wide information sharing across different members is found to be essential in managing SCs effectively under uncertainty.

Giannakis and Louis (2011) developed a framework for the design of a multi-agent based decision support system for the management disruptions and mitigation of risks in manufacturing SCs. The framework supports the fulfilment of production, event and disruption risk management constituted by coordination, communication and task agents and draws on principles and theories of SCM, agent based simulation and computer science. The roles for each of the agents within the disruption management framework were defined and a detailed description of the responsibilities for each of these roles was provided. The interactions among these agents were subsequently modelled by analysing several risk identification and mitigation processes. A generic multi-agent based model for an SCM, consisting of three basic modules is provided, as follows: (1) production fulfilment processes (e.g. order management, manufacturing, procurement, logistics), (2) SC event management, and (3) disruption risk management processes. The production fulfilment module coordinates the activities of different SC partners for the fulfilment of orders through the supply, production and delivery processes. The SC event management module is responsible for monitoring the actual fulfilment of specific orders along the SC. The role of the disruption risk management module is to initiate the necessary coordination among the agents, when a risk through a potential disruption is identified, related to a specific order or to the overall operational performance. As no computational experiments have been done, the authors directed future work on the performance of the proposed framework using ABS.

Chen and Chen (2010) used multi-agent technology to construct a multi-section flexible manufacturing system model, and utilised simulation to build a manufacturing environment based on Java Agent DEvelopment (JADE) framework for multi-agent to combine with dispatching rules, such as shortest imminent processing time, first come first serve earliest due date, and buffer sequence. The paper concluded that using multi-agent technique for multi-section flexible manufacturing system model can enhance the production efficiency in practice.

Li et al. (2010) described an agent-based approach to facilitate the integration of two complementary business functions, that are the process planning and scheduling. In the approach, the two functions are carried out simultaneously, and an optimization agent based on an evolutionary algorithm is used to manage the interactions and communications between agents to enable proper decisions to be made. To verify the feasibility and performance of the proposed approach, experimental studies have been conducted. The experimental results show that the proposed approach is very effective for the integrated process planning and scheduling problem and achieves better optimisation results.

With regard to construction networks, few works have been found in the literature, even extending the search time interval prior to 2000. Thus, some works that have been published before 2010 are discussed here. Marzouk and Ali (2013) proposed a model which utilises ABS to estimate productivity of bored piles, taking into consideration safety requirements and space availability in a construction site. The model considers traffic congestion flow, safety, space, resources, breakdown, soil behaviour (engineering constraint), uncertainty of operation's duration and how they effect on the efficient utilization of equipment resources. It captures the probabilities of equipment breakdowns based on equipment historical data. It also animates movements of equipment taking into consideration safety requirements. A case study is presented to demonstrate the practical features of the proposed ABS model.

In order to describe behavioural characteristics of construction equipment by identifying changes in a dynamic environment, Kim and Kim (2010) developed a multi-agent-based simulation system to evaluate the traffic flow of construction equipment in construction site and how they affect the efficiency of construction operations. The results of this paper are intended to help working-level construction engineers to assess the impact of traffic congestion during construction planning.

Xue et al. (2005) contributed with an agent-based framework for construction network coordination, which is designed based on the agent technology and Multi Attribute Utility Theory (MAUT). The framework, which integrates the construction companies in construction networks and multi attribute negotiation model into a MAS, provides a solution for network coordination in construction through multi attribute negotiation mechanism on the Internet. The agents included in the framework are owner, designer, general contractor, subcontractors, and suppliers. The framework also extends the internal network of general contractor to external network of designer, subcontractors and suppliers. In the decision-making process of participants in construction network, the factors cost, time, quality, safety, and environment normally are considered as the main decision-making variables.

Tah (2005) presented an agent-based prototype system for exploring the potential for the use of such an approach to model and simulate collaborative project supply network preplanning. The problem was modelled with over thirty agents, distributed across a network of computers, and representing the different disciplines and project participants involved in the project (e.g. project management, subcontractors for earthworks, concreting, steelwork, fire protection, cladding, roofing, etc.). Most disciplines were represented by more than one agent, allowing for competition and the necessary flexibility for exception handling. According to the authors, the results of the prototype have been very encouraging and provide support for the use of the approach in realising a simulator that can be used in practice through future work.

Acknowledging that unfortunately most construction claims negotiations are conducted inefficiently due to various reasons, Ren et al. (2003), described a MAS for construction claims negotiation to resolve those inefficiencies in negotiation. Such MAS has been developed based on five characteristics of construction claims negotiation: (1) contractual obliged self-interested relationship, (2) role-dependent information, (3) strategy-influenced process, (4) time, and (5) role definition and the client environment.

These works provided important contributions to the development of the theoretical ABS model that is proposed in Section 5.5 as their review enabled the author of this thesis to gain insight, not only on what have already been done, but also on what can be the behaviours, attributes and decision rules of companies (agents) operating in complex industrial networks, and how to model their interactions. A general limitation of these works, which motivates the development of this thesis, is that they do not explain how different levels of business interoperability in dyads relationships can affect the interactions among the various agents (companies) in the network. The agent-based model proposed in this thesis intends to overcome this research gap and contribute to a better understanding of how business interoperability affects the performance of companies, in a context of cooperative industrial networks. Also, such review intended to support the appropriateness of ABM for modelling complex industrial networks as well as to identify the potential benefits of the ABM approach, and to highlight some of the challenges it poses researchers developing agent-based models.

### 4.4.4 Challenges and limitations in using Agent-Based Simulation

Like any modelling method, tool or technique, ABM also presents some limitations and/or challenges, with emphasis on its acceptance in the research community. For instance, Rand and Rust (2011) agree that despite the power of ABM, widespread acceptance and publication of this method in the highest-level journals has been slow due in large part, to the lack of commonly accepted standards of how to use ABM rigorously. Therefore, they stress that guidelines are needed for the proper use of ABM so that researchers, reviewers and editors who are unfamiliar with the methodology can still ascertain whether the approach was rigorously undertaken. Gurcan et al. (2013) reinforces this by stating that although ABS had an increasing attention during the last decade, the weak validation and verification of this kind of simulation makes ABM hard to trust because there is no comprehensive tool set for verification and validation of ABS models, which demonstrates that inaccuracies exist and/or reveals the existing errors in the model. A second kind of challenge is concerned with the amount of data required to describe complex agent-based models such as those representing complex industrial networks, which usually consist of various interrelated components. For example, Pierreval et al. (2007) observed that as far as large and complex networks of production facilities are concerned, detailed modelling approaches such as ABM can be difficult to implement – the large amount of data necessary to describe the numerous products and the processes can be extremely difficult to collect, and the effort required to develop detailed models of each production unit and of their interrelations can appear unrealistic in many cases.

In line with Pierreval et al. (2007), Rand and Rust (2011) pointed out that critiques of ABS often come from two points of view: one viewpoint is that ABS does not deal with real data and is therefore only for "toy problems", while another viewpoint is that most agent-based models have so many parameters that they can fit any data and are thus nothing more than "computer games". With respect to the first criticism, Rand and Rust (2011) state that "it is definitely possible to create agent-based models that do not correspond to real-world phenomena but ABS also provides a natural way to integrate real-world data and complexities into a model". Regarding to the second criticism, the authors advocate that "this is not true if the model process, input and output are shown to be valid (i.e. they correspond to the real world)". Other challenges are provided, for instance, in Parunak (1996): (1) theoretical optima cannot be guaranteed, because there is no global view of the system, (2) predictions for autonomous agents can usually be made only at the aggregate level, and (3) in principle, systems of autonomous agents can become computationally unstable and Rand and Rust (2011): computationally intensive, not generalizable beyond the instances examined.

### 4.4.5 Rationale for choosing Agent-Based Simulation

In Section 1.3 it was assumed that ABS provides us with an effective set of tools for analysing the impact of business interoperability on the performance of cooperative industrial networks (Proposition 2). However, simulation modelling in general is not limited to this method. Indeed, an analysis of the collected literature made it possible to state that there are many methods that can be used for simulating real-world systems as are the case of industrial networks. For example, DES (e.g. (Banks 2003, Altiok and Melamed 2007, Huseby and Natvig 2013, Ross 2013)), Systems Dynamics (e.g. (Forrester 1961, Towill 1996, Angerhofer and Angelides 2000)) and Monte Carlo simulation (e.g. (Metropolis and Ulam 1949, Eckhardt 1987, Landau and Binder 2000, Binder and Heermann 2010)) are often used.

The approach used to explain the choice for ABM is the same that has been used to explain the choice for the Axiomatic Design Theory (see Section 4.2.6), i.e. first it is explained the reasons for not choosing the alterative modelling methods and then the reasons for choosing ABM. Particularly in this thesis, the modelling approach for addressing the Research Question 2 (see Section 1.3) has to take account for the network effect, that is to say it has to enable the researcher to understand how different levels of business interoperability in one or more dyad may affect the network of companies to which the dyad belong. It is important to remind here that the rationale for not using direct experimentation and analytical modelling has already been provided in Section 4.3.2, and therefore they are not discussed in this section.

The choice to use ABM for addressing the Research Question 2 (see Section 1.3) instead of the methods discussed above, even though its challenges and limitations discussed in Section 4.4.4, rests on the nature of the phenomenon that this thesis seeks to better understand, that is the aggregate pattern of behaviour resulting from the interactions among companies within a cooperative industrial network. To be specific, it rests on the type of question that this thesis is trying to give answer, which is how different levels of business interoperability in dyadic organisational relationships affect the network that the two companies in the dyad belong to. In other words, the thesis is interested in addressing the network effect resulting from the adequate and/or inadequate level of business interoperability in one or more dyad relationships.

In addition, the thesis is not interested in examining how the whole population of companies in the network reacts to a change in the network environment, but in investigating how dyads will react to that change, individually. For instance, the thesis is interested in understanding the major reactions of the dyads and companies to a particular situation, such as an introduction of a cooperative information system platform, an introduction of a new legislation, or a cooperation breakdown. Achievement these goals requires a bottom-up approach rather than a top-down approach, which is to say that the dyads that compose the network, the companies that belong to those dyads, and their interactions have to be modelled at the individual level rather than as a whole, as is done in Systems Dynamics, for instance. The rationale for this is that if the network is modelled as a whole, it would be more difficult to identify dyads in which the level of business interoperability must be improved, companies in which performance measures must be improved, and to understand the network effect. In this way, the need for ABS model in this thesis can be explained by the following reasons:

1. The impact of business interoperability on the performance of cooperative industrial networks is ***not linear***. The same level of business interoperability may have differents impact on

different dyads/companies, since they are heterogeneous agents with different behavioural attributes;

2. Agents in cooperative industrial networks ***interact with each other***. They communicate, share information, materials, resources and risks. For instance, they can exchange information in order to coordinate and/or provide visibility of the collaborative business processes;
3. Agents in cooperative industrial networks are ***socially influenced***. An improvement on the level of business interoperability in one or more dyad relationships may have an impact on other dyads and companies belonging to the network (network effect). An initiative taken by two companies in a dyad towards a higher level of business interoperability may influence the companies in the other dyads to take the same initiative. Also, the implementation of new business interoperability solution by two companies in a dyad may not reach the full potential if the neighbours relationships are not able to adopt the same solution – this is an example of negative network effect;
4. Agents in cooperative industrial networks are ***intelligent and autonomous***. They can learn from their environment and make decisions under different circumstances. The learning and decision-making processes can encompass, for example, a cost-benefit analysis regarding the cost of implementing a particular business interoperability solution and the resulted benefit;
5. Agents in cooperative industrial networks are ***proactive***. They are able to perceive changes in the business environment, and take initiatives to react to these changes. For example, in the event of a cooperation breakdown, they are able to replace effectively the exiting partner(s).

The literature also provides some theoretical backgrounds that support the choice to model industrial networks as MAS. For example, Long (2014) points out that as, the participants in SCNs have similar characteristics with agents in structure and function (both of them have certain resources, can perceive the environment, interact with other participants or agents and make self-decisions), a SCN is always modelled as a multi-agent system because there is a natural correspondence between SC participants and agents in a simulation model. Kim and Kim (2010) stress that ABM approach is a better choice for problems where the behavioural characteristics of each agent are described by sensing changes in a dynamic environment. With respect to this, Rand and Rust (2011) argue that because ABM models the individual behaviour, it can incorporate characteristics that are difficult to include in traditional models (Rand and Rust 2011). Datta (2007) emphasises that ABM helps understanding the impact of adopting different strategies/capabilities, which are beyond the individual capacities or knowledge of each agent, thus improves difficult judgement making through coordination, communication and negotiation across multiple agents.

To conclude, it is to reinforce that, the ability of describing behavioural characteristics of each agent and of understanding how individual components of a system (e.g. companies and dyads relationships of an industrial network) interact with and affect each other as well the as the whole system make ABM an ideal method for modelling interoperable cooperative industrial networks, i.e. for analysing the impact of business interoperability on the performance of companies, in a context of cooperative industrial networks.

## 4.5 Summary

This chapter started by defining the concept design and by introducing the Axiomatic Design Theory. It was explained that the design process consists of interplaying between four domains, the customer domain, the functional domain, the physical domain and the process domain. It was also explained that in order to select design, the designer must take into account the Independence Axiom and the Information Axiom. In summary, it was concluded that the Axiomatic Design Theory becomes especially useful when the designer intends to break down a complex system into a set of smaller, and hopefully, more manageable components. In the specific case of this thesis, it was concluded that the Axiomatic Design Theory was the best method to design configurations of interoperable cooperative industrial network platforms as it enables the designer to organise the business interoperability problem into three main categories, i.e., the business interoperability requirements (functional domain), the business interoperability solutions (physical domain), and how business interoperability solutions will be implemented at operational level (process domain). It also enables the decomposition of the business interoperability requirements and the business interoperability solutions from high level to a level where they are suitable to be measured through a maturity model, contributing to overcome some limitations associated with the interoperability maturity models discussed in Section 3.4.

With regard to the method to address the second research question, it was explained that simulation is the best way to analyse the impact of business interoperability on the performance of cooperative industrial network platforms as alternative methods such as experiment with the actual system, experiment with a physical model and analytical solutions are regarded to be impracticable or inappropriate. Among the various types of simulation methods, ABS has been chosen as it supports the researcher to understand how aggregate patterns of behaviour emerge from the interactions among companies within a cooperative industrial network as well as the connectedness among the dyad relationships that belong to that network. In other words, it helps the researcher to understand how different levels of business interoperability in dyadic organisational relationships affect the network that the two companies in the dyad belong to, i.e. the network effect. Another relevant rationale for choosing ABS to address the second research question is that the impact of business interoperability on the performance of cooperative industrial networks is not linear, i.e. the same level of business interoperability may have different impacts on different dyads/companies, since they are heterogeneous agents with different behavioural attributes.

# Chapter 5 The proposed methodology

Grounded on the reviewed body of knowledge regarding cooperative industrial networks, the relationship perspective and the network approach (Chapter 2), the methods for modelling complex systems and networks (Chapter 4), and the dimensions and sub-dimensions of business interoperability (Section 5.3), this chapter describes the methodology proposed in this thesis that aims to contribute to enhance the understanding on how to design interoperable cooperative industrial networks and how to analyse the impact of business interoperability on the performance of companies, in a context of cooperative industrial networks. In particular, the chapter describes the proposed methodology storyline, the proposed modelling approach, the theoretical Axiomatic Design model and the theoretical ABS model. The chapter also characterises the dimensions and sub-dimensions of business interoperability.

## 5.1 Storyline

Before proceeding further with the description of the proposed methodology, it is important to understand how each of the previous chapters contributes to the development of such methodology, and how they relate to each other. Thus, it is to be reported that Chapter 2 contributed mainly to gain insight on the managerial challenges that companies face when it comes to operating in industrial network contexts, with emphasis on the managerial challenges that they face when it comes to establishing closer forms of cooperation. Chapter 2 also enabled the understanding of the network approach and how it can be applied to the context of this research. Based on the literature on business networks, SCs, SCNs, cooperation and cooperation, a set of challenges that companies face when operating in business networks, mainly in the context of manufacturing and construction networks, have been identified. These challenges were grouped into a dimension of business interoperability called in this thesis “network minute details”.

In Chapter 3, the main initiatives and approaches to business interoperability have been reviewed. Grounded on such review, and also the review carried out in Chapter 2, the main dimensions of business interoperability have been characterised, taking the Zutshi et al. (2012)’BIQMM as a reference (see Section 5.3). It is to refer that such characterisation was performed grounded not only on the literature on business interoperability, but also on SCM, cooperation and collaboration. The characterised dimensions of business interoperability have been clustered into ten dimensions of business interoperability, namely business strategy, management of external relationships, collaborative business processes, products and services specificity, employees and work culture, knowledge management, business semantics, information systems, information quality, and network minute details (see Section 5.3).

Having completed the characterisation of these elements, which represent the main business interoperability requirements to be addressed in the modelling of interoperable cooperative industrial networks, it has been conducted an in-depth review on the methods for designing interoperable industrial network platforms and the methods for analysing the impact of business interoperability on the performance of these platforms. As a result, the Axiomatic Design Theory and ABM have been chosen for the design and analysis of the impact purpose, respectively. Taking the subjects and the arguments discussed in the second, third, fourth and fifth chapters as the main output, the methodology for modelling interoperable cooperative industrial networks has been developed. In a first step, a theoretical Axiomatic Design model has been developed and tested through an application scenario to implement RL in a context of automotive industry. The model has been verified by two experts on the Axiomatic Design Theory from the UNIDEMI research centre. The methodology adopted a holistic view to the problem of business interoperability in order to effectively answer to the research questions addressed in Section 1.3, i.e. in order to embrace all the dimensions of business interoperability that are effectively required to model interoperable cooperative industrial network platforms.

Having reached an "acceptable" stability of the theoretical Axiomatic Design model, it has been developed a second theoretical model in order to support the analysis of the impact. The development of this model has been grounded on the ABM method. The outputs of the first model, namely the last level DPs, have been used as input in the theoretical ABS model, i.e. as decision variables. To evaluate the state of these decision variables, i.e. the levels of business interoperability for each of those last level DPs, a theoretical business interoperability maturity model has also been developed. Then, the theoretical ABS model has been tested using the same application scenario used to test the theoretical Axiomatic Design model. The theoretical ABS has also been verified with the help of two experts on ABM, one from UNIDEMI and another from an IT Portuguese company. After verifying and ensuring that the two theoretical models were stable, the process of data collection to validate the proposed models has been started. This process is explained in the next two chapters. The storyline underlying the development of the proposed methodology is illustrated by Figure 5.1.

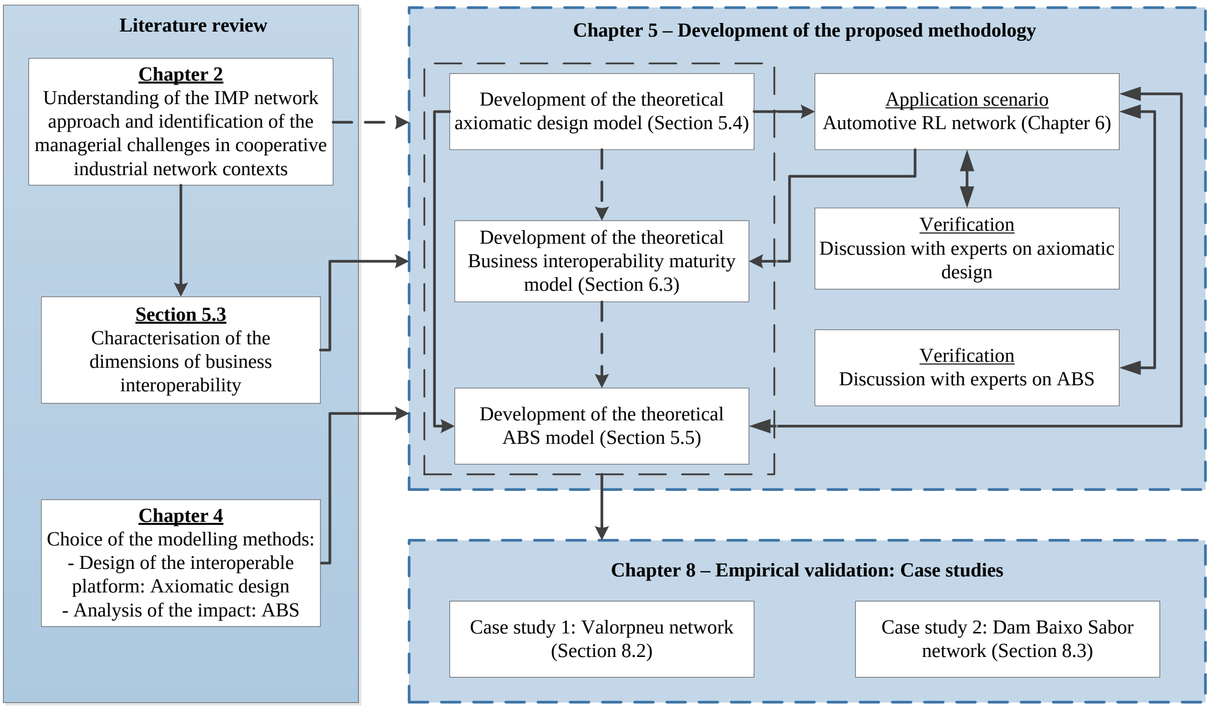



Figure 5.1: The storyline

The proposed modelling approach, as well as the theoretical models represented in figure above are described in detail in the following sections.

## 5.2 Proposed modelling approach and framework

In Chapter 2 and mainly in Section 5.3, the dimensions of business interoperability have been characterised, including the factors that characterise the network dimension. In this section, it is illustrated how these dimensions are modelled using two different methods but that are integrated in a single methodology.

As mentioned in previous section, the proposed methodology consists of an Axiomatic Design model and an Agent-Based Simulation model, which depending on the problem under analysis, can be applied in two different situations. Strictly speaking, the order by which the models are applied depends on whether the cooperative management practice is already implemented or not, as shown in Figure 5.2.

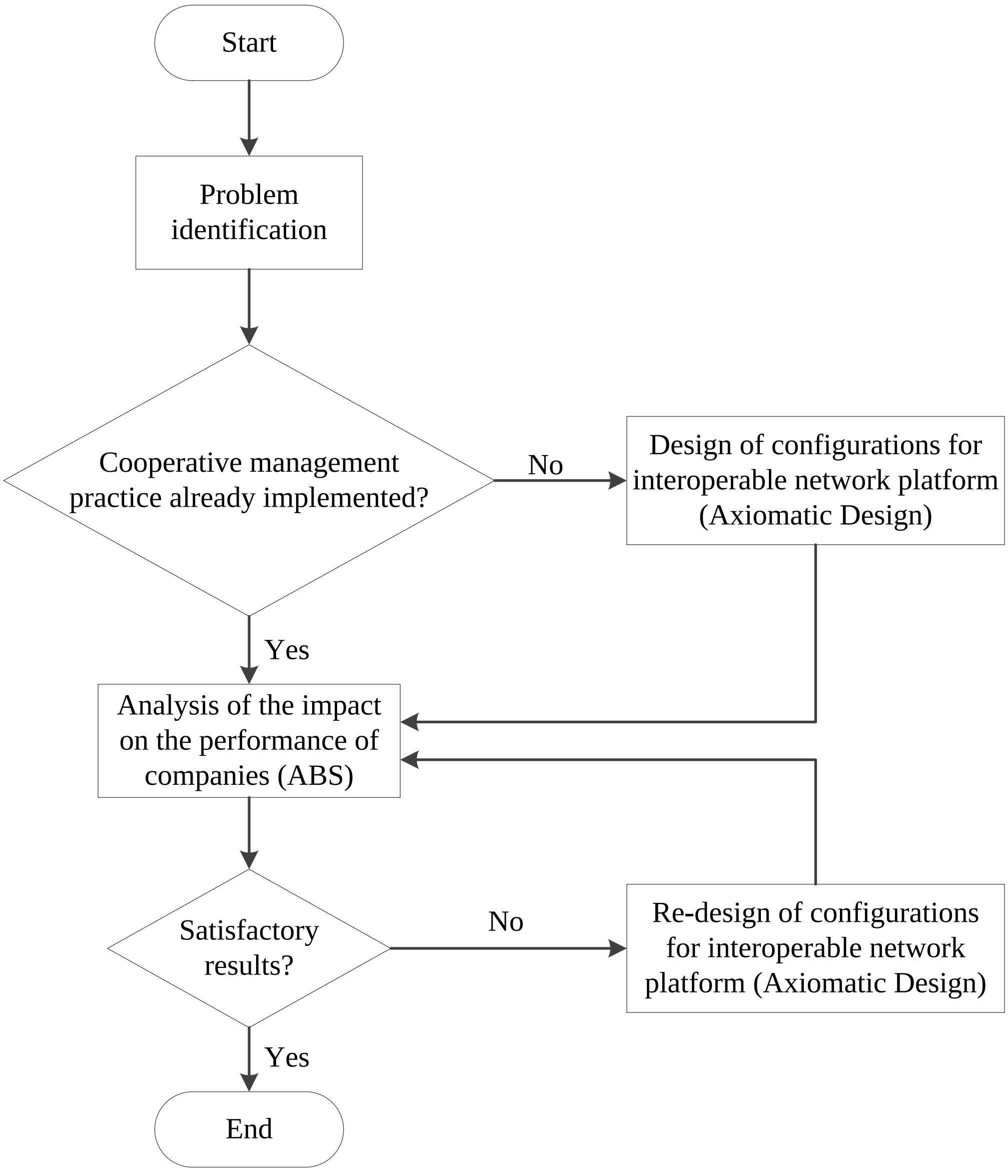



Figure 5.2: Proposed modelling approach

In short, the sequence of implementation of the proposed models is explained as follows:

1. If the mechanisms to support the implementation of the cooperative management practice are to be implemented for the first time, one should first apply the theoretical Axiomatic Design model to design what should be the "ideal" configuration for the interoperable cooperative industrial network platform that will support the implementation of the cooperative management practice. As the designer may develop more than one configuration for the interoperable cooperative industrial network platform, it is also possible to apply the theoretical ABS model to analyse the impact/benefits that the designed configurations may

bring in terms of cost, time, service level, etc., and choose the one that is able to ensure the higher performance;

2. If the mechanisms to support the implementation of the cooperative management practice are already implemented, the methodology suggests the application, in the first place, of the theoretical ABS model to analyse the impact of the identified cooperation failures on the performance of companies. As stated by Campos et al. (2013), in order to improve all the aspects that affect the capacity to interoperate, first it is necessary to be able to evaluate the "as-is" situation. Then, the methodology suggests the application of the theoretical Axiomatic Design model to redesign the cooperative network platform in order to propose new cooperation mechanisms that are able to prevent or eliminate the occurrence of the cooperation failures identified in the first step. After this, the redesigned cooperative platform should be simulated applying the theoretical ABS model to predict its future behaviour and performance. In this way, potential failures can be identified, and actions can be taken to eliminate or minimise them before the implementation of the redesigned platform.

In addition to the proposed modelling approach, a theoretical modelling framework is proposed to guide in the process of modelling interoperable cooperative industrial network platforms. The framework synthesises how to integrate the two models mentioned above. It integrates the perspective of performance measures, which is considered as a dependent variable that companies are trying to improve, the perspective of cooperative management practices that companies intend to implement in order to improve performance and achieve synergistic results, and the perspective of business interoperability, through the Axiomatic Design Theory and ABS, as illustrated in Figure 5.3.

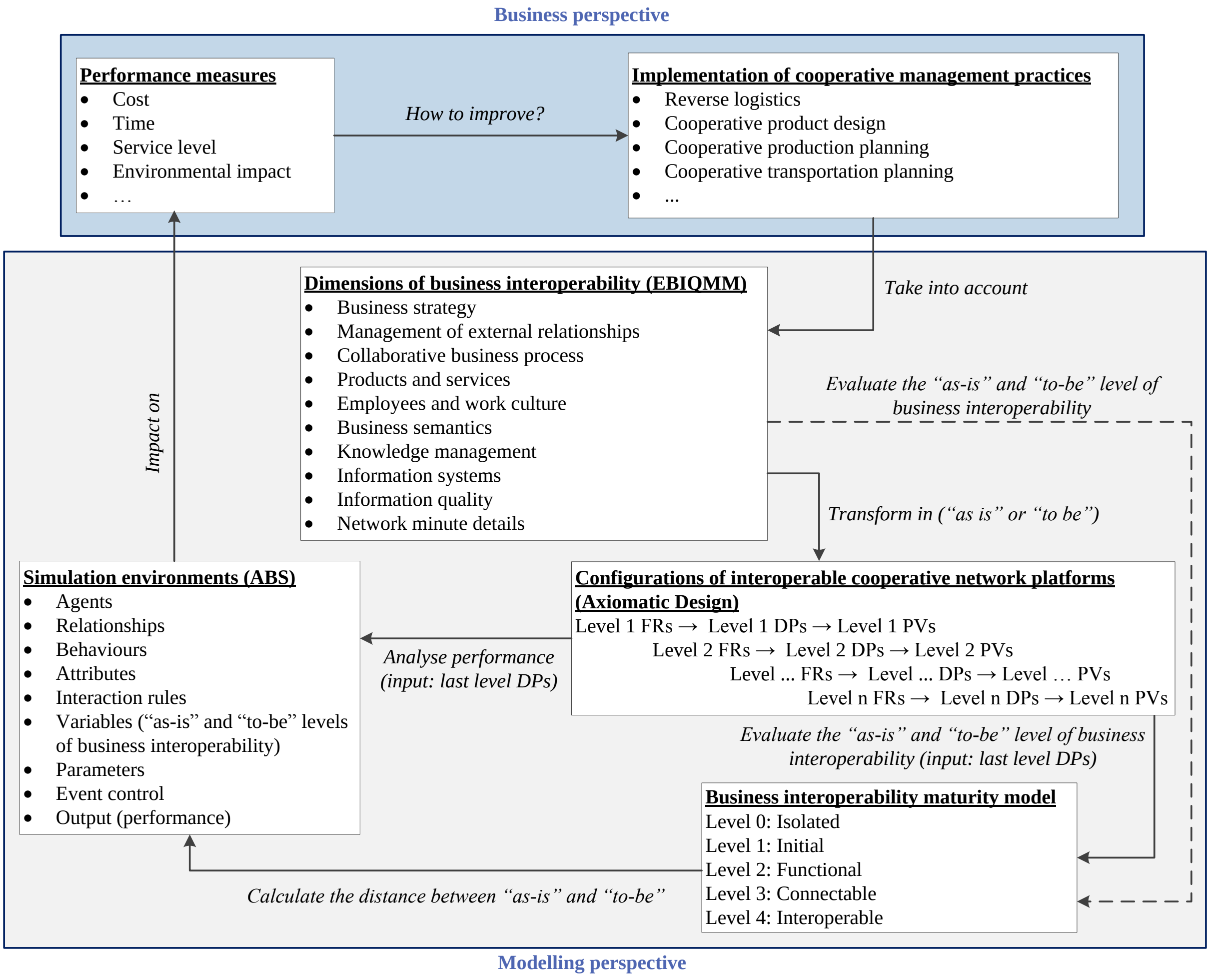



Figure 5.3: Theoretical modelling framework

The approach underlying this theoretical modelling framework is described as follows: in the "Business perspective" the customers (managers of the companies involved in the cooperative industrial networks) identify the problem(s) in terms of performance (e.g. high cost of transportation, inaccurate planning and forecasting, low service level, inadequate inventory level, high level of environmental impact, etc.) and then select the cooperative management practice(s) that may allow to improve those performance measures.

It is assumed that in order to implement the selected cooperative management practice(s) effectively, an interoperable cooperative network platform must be developed, taking into account the dimensions of business interoperability as well as their related sub-dimensions. As explained above, the cooperative management practice may be implemented or not. If the cooperative management practice is to be implemented for the first time, the managers should apply the Axiomatic Design model to design what they consider to be the ideal configuration of the cooperative network platform, taking into account the dimensions of business interoperability. Else, they should transform the existing cooperative network platform in a "as-is" state and analyse its current performance, using ABS. To do this, they should evaluate the "as-is" level of business interoperability (using a business interoperability maturity model) for the factors affecting the performance measures and compare with a hypothetical "to-be" state where the performance measures are the desired.

## 5.3 Characterisation of the dimensions of business interoperability

The interactions among companies in a general business network are function of a great number of key variables, which are often referred to as dimensions of business interoperability. As business interoperability characterises the business relationships of a company and its external partners, such as customers, suppliers and service providers (ATHENA 2007), a dimension of business interoperability can be defined as the different levels of interactions that two or more companies can engage in (Zutshi et al. 2012). In other words, it embraces the different elements that affect or are responsible for the business relationships between two or more companies (e.g. business goals, inter-organisational business processes, employees and work culture, knowledge management, business semantic, information systems, etc.). Within this context, there are some studies that have tried to identify what are the main dimensions of business interoperability. One of the first dimensions, i.e. information systems, has been addressed by the Architecture Working Group of the US Department of Defence in the LISI Reference Model (DoD 1998).

Acknowledging that interoperability is not only a property of information systems, as discussed in Section 3.1, and it is the ability of two or more systems to work together (independently of the type of systems they are), some authors realised that the concept of interoperability could be applied to the context of business relationships, and therefore more dimensions was needed to characterise such relationships. For instance, as has been discussed in Section 3.3.4, the EIF (see (Vernadat 2010)) defined three dimensions, namely technical, semantic and organisational. ATHENA (2007) distinguishes six dimensions, which are management of external relationships, employee and culture, collaborative business processes, information systems, internal contingencies, and external contingencies.

Grounded on the previous frameworks, Zutshi et al. (2012) proposed a multidisciplinary framework that captures those dimensions and extend them to a more holistic perspective. The authors identified eight dimensions of business interoperability, as illustrated in Figure 3.7. More recently, Rezaei et al. (2014c) identified twelve dimensions or types of interoperability: data interoperability, process interoperability, rules interoperability, objects interoperability, software systems interoperability, cultural interoperability, knowledge interoperability, services interoperability, social networks interoperability, electronic identify interoperability, cloud interoperability, ecosystems interoperability.

Although recognising the utility of the previous interoperability frameworks, it was realised that in a context of cooperative industrial networks a more holistic framework that takes into account the previous ones is needed. The consideration of such a more holistic framework is important to understand not only how individual dimensions operate but also how they affect each other. This is particularly important to address the Research Question 1 (see Section 1.3) because in the design of interoperable industrial network platforms all required dimensions of business interoperability, as well as their related sub-dimensions, have to be addressed in an integrated way in order to ensure that the business interoperability requirements are fulfilled in a logic and rational manner, and that unnecessary design solutions are eliminated. For example, Zutshi et al. (2012), argue that although IT plays a key role in making businesses interact seamlessly, such an information exchange infrastructure is meaningless if the other core aspects of business networking are not interoperable. This implies, for instance, if two or more companies implement an advanced cooperative information platform to manage the flow of information generated from their interactions, the full benefits of such a system will not be fully achieved if the employees of those companies do not have skills to use the system. Also, the full benefits will not be achieved if such a system is not aligned with the collaborative business processes of those companies.

Grounded on those models and frameworks mentioned above, this section presents an extension of the dimensions of business interoperability. In particular, it has been focused on the extension of the BIQMM proposed Zutshi et al. (2012) as it draws upon the literature review of some of most relevant business interoperability frameworks such as ATHENA (2007), ATHENA (2004), EIF (2004), ECOLEAD (2004), and IDEAS (2003b). Furthermore, the BIQMM focuses on the dimensions of business relationships between collaborating partners, which can also be applied to the context of cooperation. It was decided to extend the Zutshi et al. (2012)' BIQMM because it presents some limitations that hinder its application in a context of cooperative industrial networks. Among the limitations, three can be highlighted: "the lack of elements that characterise the product and service specificity, the information quality, and fundamentally, the network minute details such as legislations, industry maturity, network complexity, network dynamics, etc."

Regarding to the information quality dimension, note that its sub-dimensions (e.g. accuracy, timeliness, completeness, conciseness, accessibility, etc.) have not been addressed in any of the previous interoperability frameworks. In this thesis it is argued that in the context of cooperative business networks the information quality dimension plays a key role, for example, in facilitating decision-making, improving the accuracy of production planning and forecasts, etc. For instance, in buyer-suppliers relationships, incomplete or lack of information on the inventory level at the supplier level could difficult the decision-making regarding the production planning at the customer level. In addition, as interoperability is often defined as the ability of systems to exchange and use information (e.g. (IEEE 1990, Rezaei et al. 2014b), one can argue that the information quality dimension should already be pointed out as one of the dimensions of business interoperability. This therefore represents a gap.

Summarising, the Zutshi et al. (2012)' BIQMM has been modified with the following four major changes: (1) "business interoperability parameters" was replaced by "dimensions of business interoperability" in order to avoid confusion with design parameters, a concept applied in Axiomatic Design Theory; (2) organisational structure was eliminated as it is included in the network minute details dimension; (3) "IPR management" was replaced by "knowledge management"; and (4) three new dimensions, namely "products and services", "information quality" and "network minute details", have been added as illustrated in Figure 5.4. The network minute details dimension has been added mainly because business networking poses additional challenges (e.g. legal issues) to building interoperable systems as has been pointed out by Vernadat (2010).

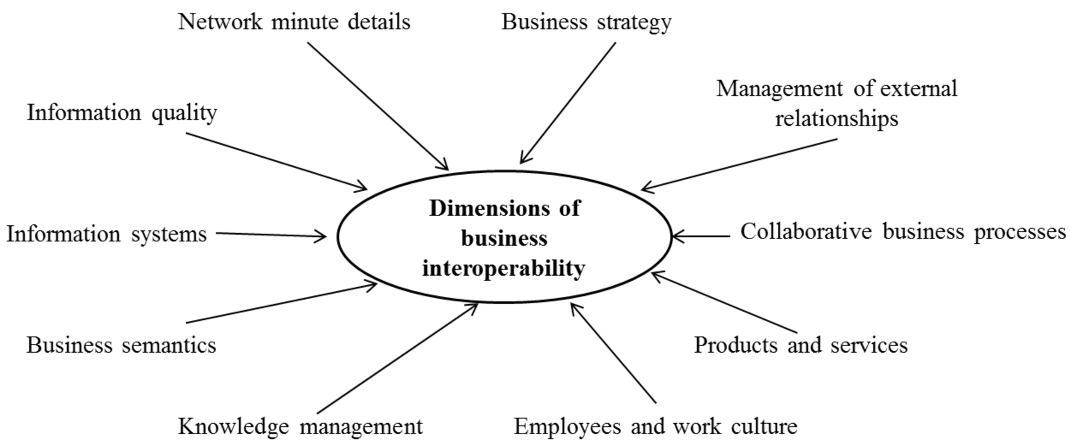



Figure 5.4: The dimensions of business interoperability (adapted from (Zutshi et al. 2012))

Table 5.1 summarises the main sub-dimensions of business interoperability, for each identified dimension of business interoperability.

Table 5.1: The dimensions of business interoperability (adapted from (Zutshi et al. 2012))

| Dimensions of business interoperability | Key sub-dimensions |
|---|---|
| **Business strategy** | Clarity, visibility, and alignment of cooperation goals. |
| **Management of external relationships** | Partner selection, inter-organisational trust, cooperation contracts, communication paths, cooperation monitoring, cooperation duration, management of inter organisational conflicts, and relationship power and reciprocity. |
| **Collaborative business processes** | Clarity, visibility, alignment, coordination, synchronization, integration, flexibility and monitoring of collaborative business processes. |
| **Products and services exchange** | Specificity, frequency, and financial exchange. |
| **Employees and work culture** | Cultural differences, linguistic barriers, interpersonal trust, motivation, competences, authorities/responsibilities and interpersonal conflicts. |
| **Knowledge management** | IPR protection, foreground IPR, IPR-related conflicts, organisational learning and individual learning capability. |
| **Business semantics** | Conflicting terminologies, and semantic conversion. |
| **Information systems** | Information system model, interaction type, connectivity/architecture, security and privacy, information systems breakdown, IT platforms, synchronization (speed), database structure, user interface, type of application and devices, and programing languages. |
| **Information quality** | Accuracy, reliability, timeliness, completeness, conciseness, relevance, understandability, and readily usable format. |
| **Network minute details** | Network governance (hierarchical networks, heterarchical networks), network dimension and diversity, type of relationships/interdependence, power relations, cooperation dynamics (entry and exit of partners), industry dynamics, maturity of industry, legislations, regulations, complexity, cooperation architecture, and external cooperation mechanisms. |

Following, it is provided an overview on each dimension, as well as the related sub-dimensions. For each of them, a definition is presented. It is to notice that the sub-dimensions that do not include the reference have been described based on the author point of view.

### 5.3.1 Business strategy

According to Zutshi et al. (2012), the highest level of interoperability between cooperating companies should be reflected in their overall business strategy. In other words, this dimension is concerned with the achievement interoperability at the strategic level of the cooperation. It implies a clear definition of the cooperation goals, the visibility/communication of the defined cooperation goals and the alignment of the cooperation goals with the individual interests of each cooperating partner. The cooperation goals of two or more companies can be said to be aligned if they satisfy the interests of each partner. According to Zutshi et al. (2012), cooperation goals alignment questions whether there are conflicting interests in the cooperation and whether these have been adequately resolved. Table 5.2 characterises these factors.

Table 5.2: Relevant sub-dimensions of business strategy

| Sub-dimensions of business strategy | Description | References |
|---|---|---|
| *Clarity* | The extent to which the cooperation goals are clear and/or well-defined from the point of view of the cooperating partners. | - |
| *Visibility* | The extent to which the defined cooperation goals are communicated to the cooperating partners. | - |
| *Alignment* | The extent to which the objective of each cooperating partner is aligned with that of the whole network, i.e. the extent to which the objectives set for the network satisfy the interests of the cooperating partners. | - |

### 5.3.2 Management of external relationships

The management of relationships is one of the most important success factors in cooperative business networks. It starts with planning and defining the cooperation, as in the selection of partners, and covers all aspects of realisation, implementation, and monitoring of the cooperation, such as cooperation contracts, managing conflicts, change management, and communication. When the cooperation is finished, management tasks include obtaining feedback, learning from good as well as bad experiences, and maintaining good relationships with the cooperation partners (Zutshi et al. 2012). These recommendations are important in project-based relationships where the cooperation tends to finish when the project is concluded (e.g. construction networks, new product development networks, etc.).

Contracts are legal instruments that explicitly define the terms of inter-organisational agreements (Handfield and Bechtel 2002). They are effectively a safeguard against opportunistic behaviour and set clear boundaries for default on contractual specifications between the cooperating partners (Simpson et al. 2007). Contracts also facilitate long-term partnership by delineating mutual concessions that favour the persistence of the relationship, as well as specifying penalties for non-cooperative behaviour (Fiala 2005). They can also be beneficial in situations where one party experiences a high degree of uncertainty about the other party’s ability to perform according to the agreement (Roxenhall and Ghauri 2004). Despite the benefits of establishing contracts, doing business without this legal instrument is generally not problematic for companies that often know their customers and suppliers well. There are also companies that draw up detailed contracts but rarely use them except in the case of conflict. In other words, those companies may use contracts only if something quite extraordinary occurs (Roxenhall and Ghauri 2004).

In addition to those sub-dimensions, the issues of inter-organisational trust and conflict management need to be considered (e.g. (Vernadat 2010)) as they are important to develop trust-based and long-term business relationships. Conflict can be broadly defined as a "process resulting from the tension between team members because of real or perceived differences" and is an inevitable part of teamwork. It is also one of the most immediate challenges to effective teamwork as it ca be an impediment for cooperation and, subsequently, performance (Puck and Pregernig 2014). In the context of business relationships, a conflict can arise when there are divergences between the involved partners and tension due to the presence of non-cooperative behaviour.

Trust can be defined as the willingness of one person or group to relate to another in the belief that the other's actions will be beneficial rather than detrimental, even though this cannot be guaranteed (Child 2001) or as the willingness to accept vulnerability based upon positive expectations of partner behaviour (Ireland et al. 2002). In the context of inter-organisational relationships, trust can mean having sufficient confidence in a partner to commit valuable resources, such as finance and know-how, to collaboration with that partner – despite the risk that the latter may take advantage of this commitment (Child 2001).

The importance of inter-organisational trust has been widely discussed in the literature. For example, Lee et al. (2014) point out that when a company believes in the integrity and benevolence of its partners, the company is more willing to make efforts at cooperative behaviour in the form of information exchange with SC partners, and that inter-organisational trust also reduces concerns about realising internal information to trustworthy partners through inter-organisational information systems, and encourages SC partners to implement exchanges of information that would otherwise be considered risky – this may increase the inter-organisational information systems visibility between SC members. Handfield and Bechtel (2002) state that trust among partners in inter-organisational relationships improves communication and dialogue and can create common strategic visions. To Child (2001), trust is a very significant condition for successful teamwork and joint knowledge creation among different companies within a network, especially when they span cultural and national boundaries. For example, a study carried out by Zaheer et al. (1998) concluded that inter-organisational trust reduces costs of negotiation and inter-organisational conflict, leading to effective performance of business relationships. Following, the description of the sub-dimensions related to the management of external relationships dimension is summarised in Table 5.3.

Table 5.3: Relevant sub-dimensions of management of external relationships

| **Sub-dimensions of management of external relationships** | **Description** | **References** |
|---|---|---|
| *Partner selection* | Addresses the issue of whether there is any mechanism for identifying the best partners available and if the cooperating partners meet the cooperation requirements. | (Zutshi et al. 2012) |
| *Partner assessment* | Addresses the issue of mechanisms for evaluating the quality of selected partners and their appropriateness for the cooperation. | (Zutshi et al. 2012) |
| *Cooperation contracts* | Considers if there are clear, well-defined cooperation contracts with partners spelling out conditions and liabilities, thereby reducing the change of conflict. | (Zutshi et al. 2012) |
| *Inter-organisational communication* | Evaluates if there are barriers to free inter-organisational communication. | (Zutshi et al. 2012) |
| *Inter-organisational conflict management* | Addresses the existence and frequency of conflicts, and in the event that they exist, if mechanisms for quick resolution are in place. | (Zutshi et al. 2012) |
| *Inter-organisational trust* | The extent to which a company believe that a partner's actions will meet its expectations, including the absence of opportunistic behaviour. | (Ireland et al. 2002) |

### 5.3.3 Cooperative business processes

Working together in cooperative business network environments implies connecting many heterogeneous business processes from different companies, which may bring a number interoperability challenges. For example, partner roles and responsibilities are often unclear and performed ad hoc, leading to conflict of resources and coordination efforts (ATHENA 2007). The internal processing status of processes are often not communicated, leading to inefficiencies, for instance in production planning and forecasting.

According to ATHENA (2007), business interoperability builds on the vision that companies can quickly and inexpensively establish and conduct a relationship of coordination with corresponding partner processes. An example of this is the placement of automatic orders when stock levels fall below an agreed safety level (Zutshi et al. 2012). The cooperative business processes dimension is therefore concerned with the issue of how companies cooperate with business partners from the operational perspective (ATHENA 2007). It implies, for instance, that responsibilities among cooperating partners must be well clarified and well specified in cooperation arrangements (Zutshi et al. 2012), tasks must be allocated, inter-organisational business processes must be aligned and coordinated (ATHENA 2007) and processing status of the inter-organisational business processes must be communicated in order to enable, for instance, better planning and alignment of the business processes of each cooperating partner (Legner and Wende 2006). As pointed out by Yu and Goh (2014), a "good" visibility in the SC can yield benefits in operations efficiency and more effective SC planning, helping in the management of risk. Caridi et al. (2010) also argue that visibility provides benefits, not only in terms of operations efficiency, i.e. increased resource productivity, but also in terms of planning effectiveness.

SC partners with high degree of inter-organisational visibility have on-time access to the information required for decision-making, and therefore when requisite information to cope with, for example, environmental changes is readily visible to SC partners, the entire SC can adapt effectively to a changing environment. This is because when inter-organisational visibility is high, the relevant information flows seamlessly to upstream partners, and all members of the SC can synchronize their operations. This in turns, allows SC participants to reduce overall SC inventory and costly duplicate practices, including forecasting by multiple participants (Lee et al. 2014).

The cooperative business processes dimension can be operationalised by a set of sub-dimensions which outline the key business decisions companies have to solve at the operational level, as illustrated in Table 5.4.

Table 5.4: Relevant sub-dimensions of cooperative business processes

| **Sub-dimensions of cooperative business processes** | **Description** | **References** |
|---|---|---|
| *Roles and responsibilities* | Addresses whether there is a clear division of roles and responsibility between the cooperating partners, i.e. whether it is clear who is responsible for what and who is authorised to do what. | (Chen *et al.* 2008a, Zutshi *et al.* 2012) |
| *Clarity in business processes* | Questions if business processes for cooperative work are well-defined and documented, i.e. whether there is a clear and logic flows of materials and information within the network. | **(**Zutshi et al. 2012**)** |
| *Visibility of business processes* | Considers whether the status of processing within one company is easily visible to the cooperating partners, i.e. whether the information which they consider as key or useful to their operations is easily visible to the cooperating partners. | (Zutshi et al. 2012, Lee et al. 2014) |
| *Coordination of business processes* | Addresses whether the business processes of each cooperating partner is aligned with that of the whole network, i.e. whether there is an alignment of activities for mutual benefit, avoiding gaps and overlaps, in order to achieve efficiency gains. It implies working harmoniously in a concerted way. | (Camarinha-Matos *et al.* 2009, Loukis and Charalabidis 2013) |
| *Integration of business processes* | Addresses whether the business processes of the cooperating partners are well connected and synchronised so that they can be viewed as a single process. | (ATHENA 2007, Vernadat 2010) |
| *Flexibility of business processes* | Questions whether the cooperating partners are able to reconfigure the established inter-organisational business processes as changing market conditions dictate, i.e. whether they are able to respond to new cooperation requirements quickly without interrupting the course of business. | (Yang and Papazoglou 2000) |

### 5.3.4 Products and services

This dimension of business interoperability is concerned with the specificity of products, services and monetary transactions exchanged among the cooperating partners, i.e. it characterises the commercial transactions carried out among them (ATHENA 2007). It can be characterised by three sub-dimensions, as shown in Table 5.5.

The sub-dimensions specificity and frequency of transactions were adopted from ATHENA (2007). The frequency of transactions within a business relationship can be one-time, occasional or recurrent. Asset specificity addresses to what extent investments made for the business relationships are non-specific, mixed or idiosyncratic. To some extent, asset specificity describes the dependency between business partners, since more specific upfront investments result in higher dependency, which can be unidirectional or bidirectional (ATHENA 2007). Those two sub-dimensions are considered to impact the level of business interoperability. In the case of low or occasional transaction frequency, for example, business interoperability level typically is low. Low specificity is associated with high levels of business interoperability. On the other hand, idiosyncratic investments imply 1:1 relationships and low levels of business interoperability. Monetary transactions also impact the level of business interoperability. For example, in business relationships where there is a large amount of money being transacted, the level of business interoperability should be higher as in the event of business interoperability problems the impact may be higher than a business relationship where the amount of money in transaction is low.

Table 5.5: Relevant sub-dimensions of products and services

| **Sub-dimensions of products and services** | **Description** | **References** |
|---|---|---|
| *Type of product(s) or service(s)* | Addresses the type of products and/or services being exchanged between partners as well as their monetary value. | - |
| *Asset specificity* | Addresses whether the investments made for the business relationships are idiosyncratic, mixed or non-specific (to some extent it describes the degree of dependence between business partners). | (ATHENA 2007) |
| *Frequency of transactions* | Questions whether the frequency of transactions within the business network is one-time, occasional or recurrent. | (ATHENA 2007) |
| *Monetary transactions* | Considers whether there is a high amount of money being transacted or not. | - |

### 5.3.5 Employees and work culture

One of the assumptions in business relationships is that interoperable companies promote relationships with business partners at an individual, team-based and organisational level (ATHENA 2007). Within this context, a key issue to be addressed is how to manage the interaction of employees involved in the cooperation. Issues such as linguistic barriers, cultural differences, different methods of work, conflicts, trust, motivation, responsibility, and honesty must be managed in order to enable employees to interact seamlessly. The alignment between work culture, for instance, is pointed out as of major importance in cooperative environments, when dealing with issues as formality or non-formality (Zutshi et al. 2012). Linguistic issues are also of major importance, mainly in international cooperation environments. This is because the world is multi-cultural and different populations do not necessarily speak the same language. For instance, in the European Union there are currently 27 member states, which use 23 different languages. While the business world tends to use international English as a common communication language, it is not always the rule (Vernadat 2010). Task conflict between employees, which refers to "disagreements among group members about the tasks being performed" (Puck and Pregernig 2014), is another issue to be addressed. The sub-dimensions needed to evaluate the employees and work culture dimension are characterised in Table 5.6.

Table 5.6: Relevant sub-dimensions of employees and work culture

| **Sub-dimensions of employees and work culture** | **Description** | **References** |
|---|---|---|
| *Interpersonal trust* | Questions whether employees involved in the cooperation trust each other and whether they believe that their colleagues will not present opportunistic behaviour. | - |
| *Interpersonal conflicts* | Addresses the existence and frequency of conflicts among employees involved in the cooperation, and in the event that they exist, if mechanisms for quick resolution are in place. | - |
| *Linguistic barriers* | Includes issues such as whether employees involved in the cooperation use a similar or different language, and in case of difference, if it causes problems with normal communication of employees. | (Zutshi et al. 2012) |
| *Cultural differences* | Considers whether employees involved in the cooperation are from different culture, and in case of differences, if it causes problems with normal interaction of employees. | (Vernadat 2010) |
| *Method of work* | Assesses whether employees involved in the cooperation employs different method of work, and in case of differences, if it causes problems in the development of the tasks. | (Vernadat 2010) |
| *Motivation* | Addresses whether employees involved in the cooperation are motivated, or if they have incentives and encouragement to take leadership roles and introduce initiatives for improving ongoing cooperative projects. | (Zutshi et al. 2012) |
| *Responsibility* | Focuses on assessing if employees involved in the cooperation take responsibility for tasks or if there is a "passing buck" syndrome, with a tendency to push responsibilities to employees from other companies. | (Zutshi et al. 2012) |
| *Honesty* | Considers if employees involved in the cooperation share the same level of honesty and openness, especially when dealing with the employees from other companies. | (Zutshi et al. 2012) |
| *Respect* | Questions whether employees involved in the cooperation respect each other. | - |
| *Efficiency* | Addresses the issue of whether employees involved in the cooperation are productive in terms of having the required training, performance, and working efficiency. | (Zutshi et al. 2012) |

### 5.3.6 Knowledge management

In the context of business networks, knowledge management can be defined as "the ability two or more companies to promote the survival capability and the competition advantage through obtaining, saving, sharing, transferring, employing, and assessing the valuable knowledge of individuals, groups, or teams that exist inside or outside the business networks" (Wu et al. 2011) or as "a regular pattern of inter-company interactions that permits the transfer, recombination, or creation of specialised knowledge" (Dyer and Hatch 2006). Hence, the knowledge management dimension is associated with the processes of creation, transformation, protection, and sharing of knowledge within the business network.

One of the most critical issues to be addressed in knowledge management is the IPR as when different companies or teamwork work together in a common project, there might be some knowledge to be protected. For instance, companies undergoing joint development of technology projects, or partnerships in which one partner needs to give the other access to its IPR, such as partner for technology licensed production, have a great need for sound IPR management policies (Zutshi et al. 2012). Within this context, trust and conflicts are to important issues as IPR related conflicts can seriously threaten trust and efficiency of innovation projects (Zutshi et al. 2012) and the lack of IPR protection can lead to conflicts and loss of trust. On the other hand, the IPR sub-dimension has low relevance in collaborations having no sharing or development of IPR, such as suppliers of simple parts to a manufacturer, or collaboration between hotels and travel agencies (Zutshi et al. 2012). In a context of cooperation between companies from different countries and with different IPR protection regulations, mechanisms for legal knowledge sharing must be in place. The knowledge management dimension can then be evaluated considering five sub-dimensions, as shown in Table 5.7.

Table 5.7: Relevant sub-dimensions of knowledge management system

| **Sub-dimensions of knowledge management** | **Description** | **References** |
|---|---|---|
| *Background IPR protection* | Questions whether the cooperation agreement clearly spells out existing IPRs to be provided by each partner and the conditions of use, and whether any compensation for the same is clearly agreed upon. | (Zutshi et al. 2012) |
| *Foreground IPR* | Considers whether the potential IPRs emerging from the collaboration have been identified and the use and sharing of rights has been agreed upon. | (Zutshi et al. 2012) |
| *IPR conflicts* | Addresses whether there are any conflicts related to IPR sharing or use implied in the cooperation. | (Zutshi et al. 2012) |
| *Reward and encouragement* | Evaluates if there are well-established mechanisms that encourage the cooperating partner's staff to share knowledge and relate the contribution of sharing knowledge with performance assessment. | (Wu et al. 2011) |
| *Knowledge wastage* | Assesses whether there are well-established mechanisms to avoid a large amount of knowledge loss (because of employee's resignation). | (Wu et al. 2011) |

### 5.3.7 Business semantics

Business semantics interoperability refers to the possibility for the exchanged information to be precisely understandable and processable by any business application (EIF 2004), i.e. it is concerned with the meaning of the exchanged information (Houssos et al. 2014). It addresses the alignment of the proprietary terminologies of the different companies and the establishment of a common business vocabulary (ATHENA 2007). The goal is to provide systems with a way to interpret the meaning of data or information (Vernadat 2010), i.e. to ensure that a common understanding of the structure and significance of the information to be exchanged is in place (Zutshi et al. 2012). In other words, it is about making sure that two or more communicating systems interpret common or shared information in a consistent way (Vernadat 2010).

The semantic unification of the concepts has been pointed out as a hard problem to solve (e.g. (Vernadat 2010)). Among the issues to be solved, Zutshi et al. (2012) point out the problem of different terminologies in each cooperative company. Other issues to be solved include (Vernadat 2010): syntactic and semantic heterogeneity of information, semantic gap, i.e. different interpretations of the same concepts, database schema integration with naming problems (e.g. homonyms and synonyms), structural logical inconsistencies, etc. For example, one can realise the complexity of the problem if we consider the number of variety and databases and information systems in use in any large corporation or within any SC (Vernadat 2010). The semantic interoperability problem can be even more complicated when cooperation occurs between companies from different countries and that do not speak the same language (Vernadat 2010). The business semantics dimension can be analysed by two sub-dimensions, as illustrated in Table 5.8.

Table 5.8: Relevant sub-dimensions of business semantics

| **Sub-dimensions of business semantics** | **Description** | **References** |
|---|---|---|
| *Conflicting terminologies* | Questions whether the cooperating partners have differences in terminologies with regard to the business area that they share. | (Zutshi et al. 2012) |
| *Semantic conversion* | Evaluates if the cooperating partners have standardised tools or processes to undertake the process of semantic conversion, so that differing terms in different companies do not create operational difficulties. | (Zutshi et al. 2012) |

Business semantics is relevant in business interactions in which companies are dealing with organisations using codification and require standardization of information exchange at different functions, such as joint product development, SCM, or pure e-procurement interactions, where standardized and uniform specifications are important for information exchange and business processes collaboration. On the other hand, business semantics has low relevance in collaborations in which the information exchanged is descriptive in nature rather than codified, as in the case of consultants specializing in performance evaluation reports for a client organisation (Zutshi et al. 2012).

### 5.3.8 Information systems

Information systems can be defined as "a set of interrelated components working together to collect, process, store, and disseminate information" or as "a set of interconnected components that involve hardware, software, people and procedures and work together to achieve some objective (Balaban *et al.* 2013). They enable the efficient and effective flow and use of information between and in organisations with the goal to contribute to the overall performance of the cooperation (ATHENA 2007). The information systems dimension, usually called as the technical dimension, is often referred to as the far most advanced dimension of business interoperability, which are still rapidly evolving due to fast technical progress in various fields of ICT (Vernadat 2010). According to Zutshi et al. (2012) information systems interoperability is the most basic of all business interoperability requirements, since most transactions and information exchanges today take place through electronic networks. This brings challenges to business partners due to the necessity to conduct transactions over the Internet that meet user's privacy and security requirements as well as existing e-business legislation, which typically involves questions of authorisation, authentication, encryption, etc. (ATHENA 2007).

It is also important to define the type of interaction, which describes the coupling depth of the electronic interaction (human-human, human-machine or machine-machine), as well as the connectivity issues, which characterise scalability of the electronic connections, i.e. reflect whether connections are formed as point-to-point (1:1) or multilateral (1:n or m:n) connections (ATHENA 2007). Technological challenges to be solved are also of critical importance. They concern system incompatibility due to high system heterogeneity, the existence of legacy systems, the various data formats in use and the heterogeneity of ICT solutions from different vendors (computer networks, operating systems, application servers, database systems, etc.) (Vernadat 2010). The main sub-dimensions needed to characterise the information systems interoperability are summarised in Table 5.9.

Table 5.9: Relevant sub-dimensions of information systems

| Sub-dimensions of information systems | Description | References |
|---|---|---|
| *Security* | Questions whether users have the confidence to securely transmit confidential information and perform secure operations across the cooperating partners. | (Zutshi et al. 2012) |
| *Privacy* | Addresses whether the business partner's privacy, as well as existing e-business legislations are respected. | (ATHENA 2007) |
| *Speed/Synchronisation* | Addresses whether the information systems are fast enough for quick communication and whether information is synchronous or asynchronous. | (Zutshi et al. 2012) |
| *Type of interaction* | Addresses the type of technical process integration among applications and devices (human-human, human-machine or machine-machine). | (Legner and Wende 2006, ATHENA 2007) |
| *Connectivity* | Focuses on evaluating the type of connections established among applications and devices (1:1, 1:m, or m:n connections). | (Legner and Wende 2006, ATHENA 2007) |
| *User interface* | Concerned with whether the systems use modern technology and provides user-friendly interfaces (such as GUI – Graphical User Interface) that can present information to users in an easy-to-understand format, enabling them to use information systems effectively. | (Gorla *et al.* 2010) |
| *Data exchange tools/IT platforms* | Considers whether there is a suitable IT infrastructure for easy exchange of data and files. | (Zutshi et al. 2012) |
| *Data accessibility (Application interoperability)* | Questions whether there are specific/standard translators or conversion applications that can be used to access data among the cooperating partners. | (Zutshi et al. 2012) |
| *Information systems flexibility* | Reflects the fact that the system is designed with useful/required features (and without unnecessary features) and the fact that software modifications can be performed by the system designer with ease. | (Gorla *et al.* 2010) |
| *Maintenance/Information systems breakdown* | Addresses whether there are well-defined and well-documented plans and mechanism for preventing and overcoming information systems breakdown. | - |
| *Information systems integration* | Questions if the information systems, applications and devices are integrated or whether they operate as isolated systems. | (Gorla *et al.* 2010, Vernadat 2010) |

One of the advantages of an information systems is that it helps to promote productivity by effectively processing and providing necessary information to an organisation and supporting their efficient work performance (Lee and Yu 2012).

### 5.3.9 Information quality

Information systems are created to provide useful decision-making information to individuals and groups by storing, maintaining, processing and managing information resources. However, in the context of business relationships their values are realised when the information provided is applied to business operations (Lee and Yu 2012), i.e. when the information that has been provided meets the companies' needs (e.g. (Caridi *et al.* 2010)). The extent to which information meets such companies' needs has been evaluated using the information quality dimension (DeLone and McLean 1992). Information quality refers to the quality of outputs the information systems produce (DeLone and McLean 1992, Petter and McLean 2009, Lee and Yu 2012). Information is defined as the aggregation of data (a representation of an object) into something that has meaning (semantics) through interpretation by human or automated process (Baskarada 2010). Quality is defined in the ISO 9000 (2005) as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated and implied needs".

Grounded on these definitions, information quality can be defined as the degree to which the information exchanged between companies satisfy stated and implied needs of the companies (Zhou and Benton Jr 2007). What this definition implicitly suggest is that shared information must exhibit certain quality attributes to create value for the business partners (Chen *et al.* 2011). Such attributes of information quality have been widely addressed in the literature, and in different context.

Petter et al. (2013) updated the DeLone and McLean (1992)' information systems success model and identified eight information quality attributes to characterise the output offered by the information systems: relevance, understandability, accuracy, conciseness, completeness, currency, timeliness, and usability. Elliot et al. (2013) developed and tested a model of virtual travel communities beliefs, attitudes, and behaviours using structural equation modelling. In the model, the authors considered four attributes of information quality: timely, complete, accurate, and useful. Balaban et al. (2013) developed an instrument for assessing electronic portfolio success model using the DeLone and McLean (1992)' information systems success model as the theoretical framework. In this work, seven information quality attributes are used: complete, up-to-date, relevant, concise, readable, easy to understand, readily usable.

Grounded on the DeLone and McLean (1992)' information systems success model, Baraka et al. (2013) identified eight attributes to track the call centre's performance: relevant, correct, complete, secure, accuracy, personalised, courtesy and professionalism, and grammar/spelling in text communication. Also, grounded on the DeLone and McLean (1992)' information systems success model, Lee and Yu (2012) developed a project management information system success model using 10 items in which were grouped into 4 main information quality attributes: format, currency, accuracy, relevance. Michel-Verkerke (2012) investigated the requirements for the perceived quality of information by means of eleven attributes: precisely, superfluous, data enter in the same way, contradiction between oral and written reports, data entered in wrong record, enter all information, availability of all information needed, up-to-date reports, accessibility to all information anytime, accessibility to all information anywhere, and quality of recordings.

Chen et al. (2011) investigated the role of information quality in the development of trust and commitment in SC relationships using five attributes: timely, accurate, complete, adequate, and reliable. Ammenwerth et al. (2011) applied five attributes to assess the impact of the introduction of a computer-based nursing information system on the quality of information processing in nursing: Readability, precision, completeness, uniformity, and accessibility. Caridi et al. (2010) proposed a structural a structured approach to quantitatively measure SC visibility using three information quality attributes: quantity, accuracy, and freshness. Gustavsson and Wänström (2009) identified ten attributes for describing information quality deficiencies on various manufacturing planning and control levels: complete, concise, reliable, timely, valid, accessible, appropriate amount, credible, relevant, and understandable. Zhou and Benton Jr (2007) used nine attributes to analyse the influence of information quality on the delivery performance in SCs: accuracy, availability, timeliness, internal connectivity, external connectivity, completeness, relevance, accessibility, and frequently updated information. Ammenwerth et al. (2007) investigated the quality of information processing in hospitals with regard to six attributes: availability, correctness and completeness, readability and clarity, usability, fulfilment of legal regulations, and time needed for information processing.

DeLone and McLean (2003) proposed an updated DeLone and McLean (1992)' information systems success model and discussed the utility of the updated model for measuring e-commerce system success, grounded on five information quality attributes: completeness, ease of understanding, personalisation, relevance, and security. From the theoretical discussion above, nine sub-dimensions of information quality have been identified and defined, as shown in Table 5.10. Those sub-dimensions can be regarded as relevant in analysing and describing the ability of cooperative networked companies to exchange information in an effective manner. It is important to notice that some sub-dimensions discussed were not included as they are overlapping in terms of semantics or irrelevant for this research. For example, accessibility and security have not been included as it was already included in the information system dimension. Validity, defined as the extent to which the information measures what it should measure (Gustavsson and Wänström 2009), has not been included as it can be generic and can be included in the sub-dimension relevance.

Table 5.10: Relevant sub-dimensions of information quality

| **Sub-dimensions of information quality** | **Description** | **References** |
|---|---|---|
| *Completeness* | The extent to which the information that has been exchanged are of sufficient breadth, and scope for the task on hand.<br>Describes the completeness of the information in relation to the requirements from the planning process, or from user in order to make an analysis and a decision. | (DeLone and McLean 1992) (Gustavsson and Wänström 2009) |
| *Conciseness* | Questions whether the information that has been exchanged can be used directly, without a need or reworking before use, in terms of format, content and/or structure. | (Gustavsson and Wänström 2009) |
| *Accuracy* | Addresses whether the information that has been exchanged is error-free, i.e. whether it can be used without correction. | (Lee and Yu 2012) |
| *Timeliness* | Evaluates whether the information is delivered on time and at correct intervals, i.e. not too often or too infrequent. | (Gustavsson and Wänström 2009) |
| *Currency* | Questions whether the information that has been exchanged is up to date, or whether the information precisely reflects the current business relationship needs. | (Lee and Yu 2012) |
| *Relevance* | Assesses whether the information that has been exchanged is informative, meaningful, important, helpful, or significant for companies' decision-making. | (Jeong and Lambert 2001) |
| *Credibility/Reliability* | Addresses whether the information that has been exchanged is accepted or regarded as true, real and believable. | (Gustavsson and Wänström 2009) |
| *Understandability* | Considers whether the information that has been exchanged is easy to use but also easy to learn and easy to manipulate, aggregate and combine with other information. | (Gustavsson and Wänström 2009) |
| *Readily usable format* | Assesses whether the information that has been exchanged is presented in a manner that is readable, understandable and interpretable to the user, i.e. clear and well formatted. | (Lee and Yu 2012, Balaban *et al.* 2013) |

Information quality is especially important in situations where the companies is sharing extensive amount of information that will support tasks coordination, production planning, forecasting, decision-making, etc. For example, it is of critical importance for a customer to have precise information on the inventory level of their suppliers in order to define an accurate production plan. Conciseness is, according to Gustavsson and Wänström (2009), mainly an issue in inter-organisational information exchange or between less integrated functions within a company. In this context, Maltz (2000) found out that too much information can be counterproductive and can lead to information overload, i.e. the recipient may process information superficially or process only parts of it. Therefore, Maltz (2000) recommended that managers should be careful not to send unnecessary information that overloads (Gustavsson and Wänström 2009). Reliability is an important information quality attribute for, among other things, the trustworthiness of the plans made and transmitted within a company. If the planning information provide the planning staff with incorrect quantities, product information, schedules or destination/sites the planning will be problematic (Gustavsson and Wänström 2009).

### 5.3.10 Network minute details

The last dimension of business interoperability addressed in this thesis is concerned with the minute details that are intrinsic to the cooperative network. These minute details can be internal (e.g. cross-organisational role mapping, contact points, cooperation dynamics, network governance, Type of interdependence, etc.) or external (e.g. legislations and regulations, strikes, new competitors, new technologies, maturity of the industry, etc.). Following, Table 5.11 characterises each of these variables.

Table 5.11: Relevant sub-dimensions of network minute details

| **Sub-dimensions of network minute details** | **Description** | **References** |
|---|---|---|
| *Cross-organisational role mapping* | Questions whether there is clarity within the organisation regarding the proper person for the collaborating organisation to contact for various different types of issues or if there are significant delays for obtaining information from the collaborating organisation on account of uncertainty on whom to contact. | (Zutshi et al. 2012) |
| *Contact points* | Considers whether there are sufficient contact points at different levels of the network that can allow the different organisational structures to cooperate seamlessly. | (Zutshi et al. 2012) |
| *Cooperation dynamics* | Questions whether the cooperative network is stable or dynamic regarding the entry or exit of partners. | (ATHENA 2007) |
| *Network governance* | Considers whether the cooperative network is hierarchical or heterarchical. | (ATHENA 2007) |
| *Cooperation breakdown (exit of partners)* | Addresses whether there are mechanisms to prevent premature cooperation termination or backup plans in the event this were to occur. | (Zutshi et al. 2012) |
| *New partner(s)* | Questions whether there are well-established mechanisms to integrate new partner(s). | (ATHENA 2007) |
| *Type of interdependence* | Addresses the different ways in which networked companies may be dependent on one another (pooled, sequential or reciprocal). | (Kumar and vanDissel 1996, ATHENA 2007) |
| *Structural complexity* | Addresses questions such as number and type of partners, number relationships, number of ties, and their interaction structure. | (Sinha *et al.* 2012, Serdarasan 2013) |
| *Legislations and regulations* | Addresses the existence of national (including city, state, federal) and international legislation as well as industry-specific, national or international regulation and standards which impose interoperability on. | (ATHENA 2007, Vernadat 2010) |
| *Strikes* | Questions whether there are mechanisms to deal with strikes that directly or indirectly affect the normal network operations. | - |
| *New technologies* | Addresses whether the cooperative network is able to deal with the introduction of new technologies. | - |
| *New competitors* | Evaluates whether there are mechanisms to deal with the entry of new competitors in the market. | - |
| *Maturity of the industry* | Assesses whether the type of industry where the network is framed is mature enough or not. | (ATHENA 2007) |

## 5.4 The theoretical Axiomatic Design model of interoperable industrial networks

The theoretical Axiomatic Design model proposed here is targeted to design or re-design cooperative industrial network platforms that are able to deliver high levels of business interoperability in the implementation of cooperative management practices. The argument underlying this model is that when three or more companies intend to establish closer forms of cooperation to implement a cooperative management practice (e.g. RL, collaborative product design, etc.), an interoperable cooperative network platform that is able to support the efficient implementation of that cooperative management practice is required. From the standpoint of this thesis, such cooperative platform must be designed so as to meet a set of business interoperability requirements, i.e. considering the dimensions and sub-dimensions of business interoperability as the FRs to be satisfied. It is important to remind here that the proposed theoretical Axiomatic Design model is not concerned with issues such as allocation and acquisition of resources, localisation of production and distribution sites. It is assumed that companies already exist and that basic resources to implement the cooperative management practice are in place. Thus, the proposed theoretical Axiomatic Design model is more concerned in ensuring that those resources are able to work together. In other words, the model is concerned with the alignment of the dimensions and sub-dimensions of business interoperability in order to eliminate or at least minimise the potential barriers that may inhibit companies to interoperate. The model captures and integrates, in a single structure, the elements to be addressed in the design or re-redesign of interoperable cooperative network platforms into four different domains, as is usually made in any design applying classic Axiomatic Design Theory (see Figure 5.5).

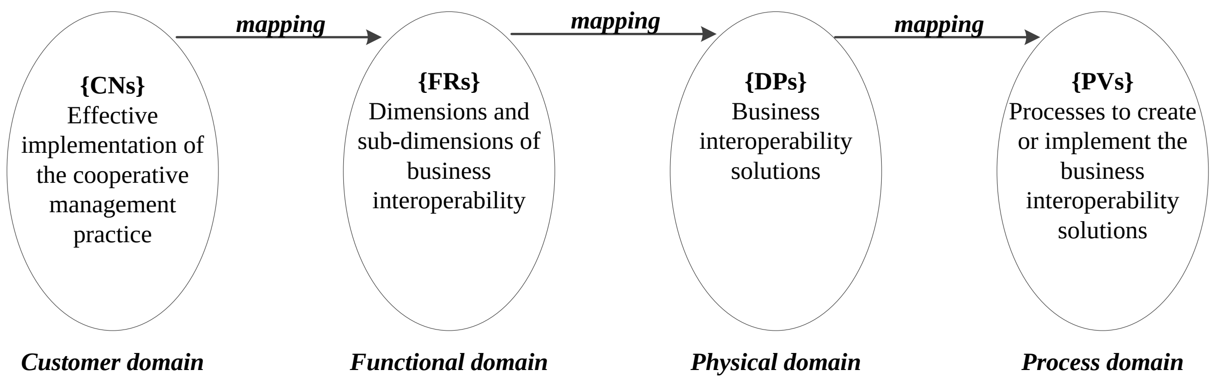



Figure 5.5: Proposed theoretical Axiomatic Design model

The first domain is concerned with capturing the CNs, or in other words, with listening what are the needs that customers expect to be satisfied with the design or re-design of the cooperative network platform. This is the core of design thinking, which is often referred to as "the process of identifying first what customers desire in the product/system being designed and then design such product/system". In the context of this research, customers are assumed to be the companies involved in the implementation of the cooperative management practice and their needs are stated as "CN – Effective implementation of the cooperative management practice" (e.g. RL, CPD, etc.). Depending on the type of industrial network to be designed, customers can be manufacturers, suppliers, distributors, retailers, logistics providers, recyclers, disposal centres, contractors, designers, architects, supervisors, software developers, etc. The second domain, which is called functional domain, captures the functional requirements of an interoperable cooperative network platform. Accordingly, the FRs are stated as "FRs – Dimensions and sub-dimensions of business interoperability". The third domain is concerned with the identification of the DPs (or the steps) needed to materialise/satisfy the FRs defined in the functional domain. Hence, the DPs are stated as "DPs – Business interoperability solutions". Example of these solutions can be contracts, protocols, tender specifications, mechanisms of conflict resolution (e.g. conversation, mediation, penalisation), performance measurement systems, reward systems, Business Process Diagrams (BPD), web-based EDI, Radio Frequency Identification (RFID) systems, Internet security protocols (e.g. https), information exchange protocols, data encryption systems, maintenance plan for information systems, etc. Last, the PVs or the processes to create or implement the DPs are captured in the physical domain. Thus, the PVs are stated as "PVs – Processes to create or implement the business interoperability solutions".

The approach behind the proposed theoretical Axiomatic Design model is described as follows (see Figure 5.6): to satisfy the CN, i.e. to ensure an effective implementation of the cooperative practice, the level 0 FR is stated as $FR_0$ – Ensure business interoperability in the implementation of the cooperative management practice. The proposed DP to materialize the $FR_0$ is stated as $DP_0$ – Development of an interoperable cooperative network platform. The proposed PV to create $DP_0$ is stated as PV0 – Approaches and procedures to create and implement $DP_0$. Having defined the Level 0 FRs, DPs and PVs, the decomposition to the level 1 FRs is carried out in order to incorporate the dimensions of business interoperability, which represent the fundamental requirements in the design of interoperable cooperative network platforms. The decomposition is executed in a logic sequence in order to ensure an effective order by which the FRs are satisfied. At each level of decomposition, a design matrix must be generated to explore the interdependence between FRs and DPs, and to evaluate the Independence Axiom (as per Axiom 1). The decomposition process should proceed if and only if the Independence Axiom is satisfied. If the Independence Axiom is not satisfied, the designer should go back and modify the FRs and DPs rather than proceed with the decomposition process. As the level 1 FRs, stated as the dimensions of business interoperability, may not provide sufficient detail to implement the cooperative management practice, a second level decomposition is needed to incorporate the sub-dimensions of business interoperability described in Section 5.3. Consequently, each level 1 FR (or each dimension of business interoperability) may be decomposed into two or more level 2 FRs (or two or more sub-dimensions of business interoperability) in order to give detail to the design. Similarly to the decomposition of the level 1 FRs, a design matrix, per each level 1 FR must be generated for evaluating the Independence Axiom. The FRs and DPs must be decomposed until the design reaches a level where design decisions are reflective for the problem under analysis, i.e. a level where the degree of detail is comprehensible to those who will implement the design. At the end, a design matrix comprising all the levels of decomposition is generated. This matrix is designated as "design matrix to implement the cooperative management practice".

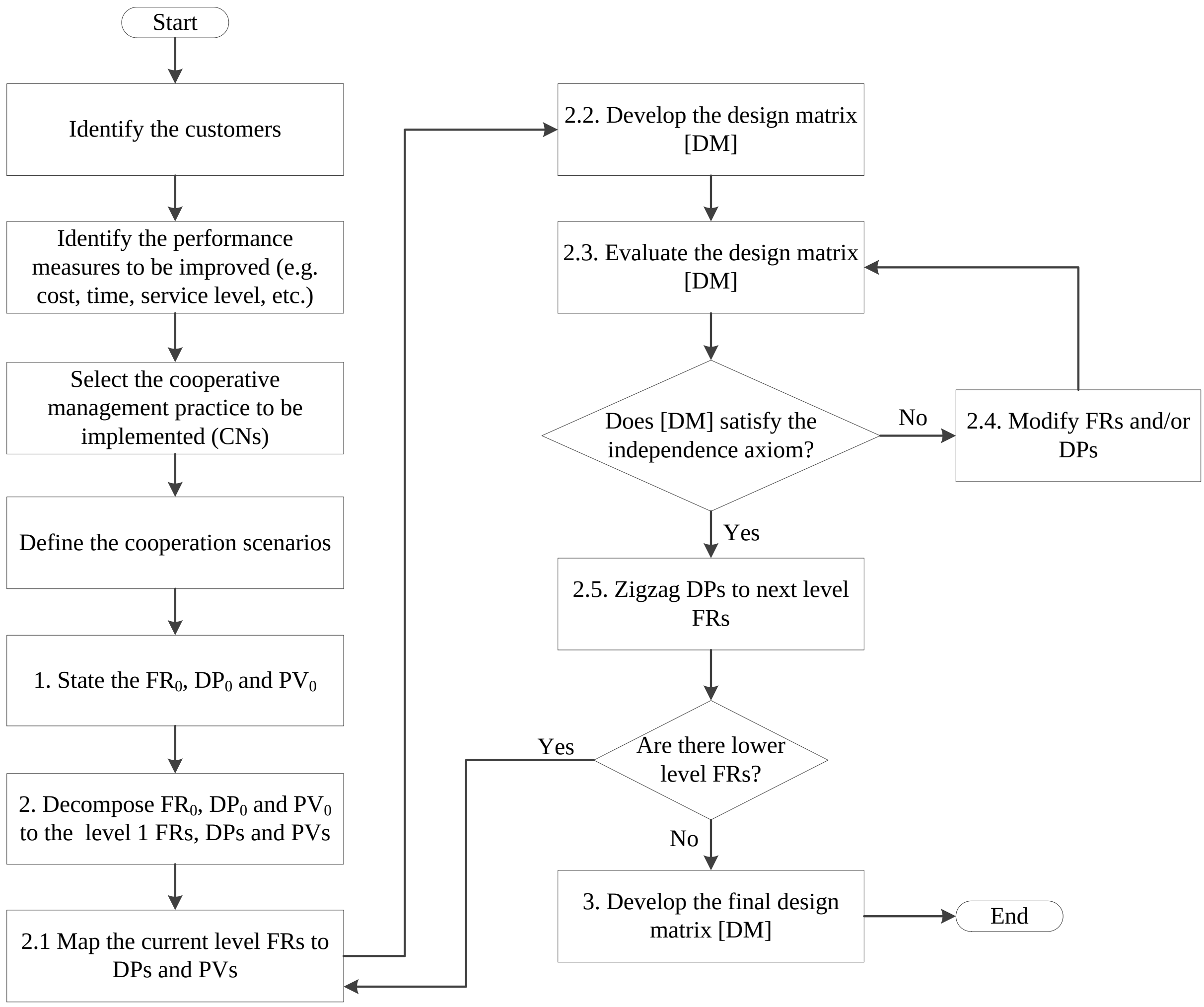



Figure 5.6: Steps to implement the the theoretical Axiomatic Design model (adapted from Cheng and Tsai 2008)

## 5.5 The theoretical Agent-Based Simulation model of interoperable industrial networks

*"It is generally known that we cannot manage for improvement if we don't measure to see what is getting" (Modrak and Semanco 2012) (p. 227)*

In previous section, a theoretical Axiomatic Design model has been proposed to design configurations for interoperable cooperative network platforms. In this section, a theoretical agent-based model is proposed to substitute those configurations and to simulate the impact of business interoperability on their performance (see Figure 5.7). In other words, it is intended to understand how different levels of business interoperability for the DPs emerged from those configurations and for different dyad relationships affect the performance of the companies that constitute those platforms. For this purpose, ABS has been used to understand these relationships. Strictly speaking, the theoretical ABS model has been developed to capture the way companies interact with each other to implement cooperative management practices in cooperative industrial network environments, and to simulate how different levels of business interoperability in dyad relationships and how the heterogeneous behaviours and attributes of companies can influence their interactions and performance. Note that the proposed model is generic and can be applied to other business network contexts such as cooperative interpersonal networks. Also, the proposed theoretical ABS model can be used to analyse the impact of business interoperability on the performance of a single company. For this, one just has to consider the single company as the network and its internal resources (e.g. departments, employees, information systems) as the agents.

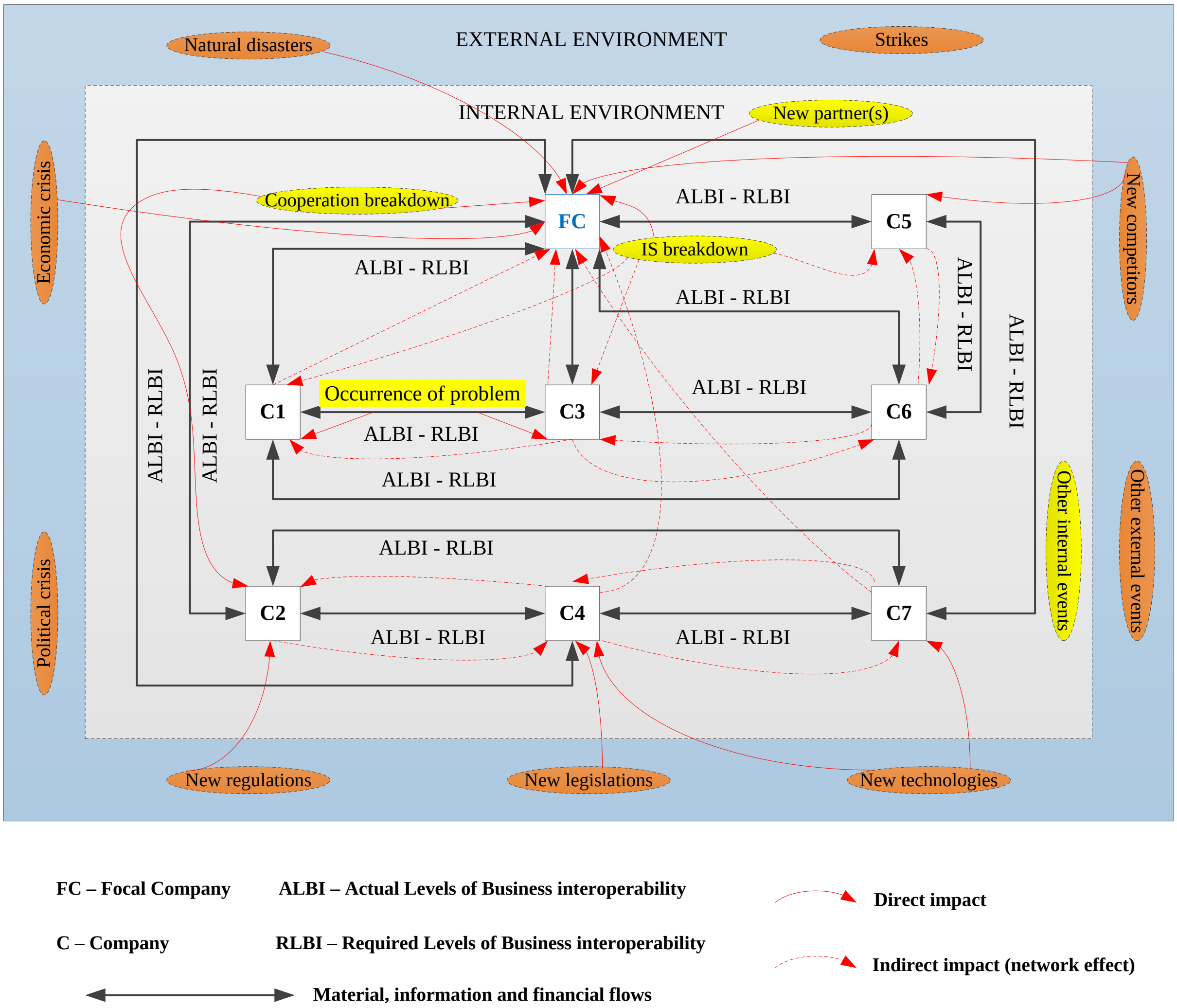



Figure 5.7: The proposed ABS model

The model consists of a set of companies and a set of dyad relationships connecting them. The relationships are modelled as bi-directional links, as material, information, and financial flows typically occur in both directions. Depending on its position or on its role within the cooperative industrial network, each company is modelled as an agent with autonomous or semi-autonomous decision-making ability, and characterised by a set of behaviours and attributes. Behaviours are referred to as the way the agents act and react toward their partners or the extent to which they comply with the rules. For example, there may be agents that not meet the lead time, do not report the occurrence of a conflict in a timely way, do not communicate the processing status of internal business processes, do not communicate the actual inventory level, do not accept delayed deliveries, do not provide timely, accurate or complete information, etc. Attributes refer to a named property of an object that describes a range of values that instances of the property may hold (Booch 1994). Examples companies attributes are production capacity, capacity surplus, safety stock, number of employees, type of product and/or service provided, official business language, second business language, type of information system used to exchange information, type of certifications and or legislation adopted, etc. Based on a set of pre-established business or interaction rules, the agents interact with each other in order to implement the cooperative management practice to achieve the cooperation goals. For example, they negotiate price and conditions, they place and delivery orders, they share information on the processing status of collaborative business processes, inventory level, lead time for delivering orders, nonconformities etc., they solve conflicts, they make transactions of money, etc. While they interact, their interactions and performance are affected by the existence or not of well-established business rules and/or well-established cooperation mechanisms. These mechanisms are the last level DPs obtained in the design of configurations for interoperable cooperative industrial network platform and are modelled as “dyad relationships variables” or as “network variables”.

Examples of DPs that are modelled as “dyad relationships variables” are mechanisms to define clear cooperation goals, mechanism to communicate cooperation goals, mechanisms to prevent conflicting interests, mechanisms to prevent or solve conflicts, mechanisms to coordinate collaborative works, mechanisms to provide visibility of the processing status of the collaborative business processes, mechanisms to deliver timely, accurate, or complete information, mechanism to prevent cooperation breakdown, mechanisms to prevent information systems breakdown, etc. On the other hand, examples of DPs that are modelled as “network variables” are external events such as introduction of new legislation, transportation strikes, natural disasters, or cyber-attacks on the information systems used by one or more agents in the cooperative industrial network, which may force the agents to change the manner in which they interoperate, impacting their performance. The theoretical ABS model captures these factors and relates them to the attributes and behaviours of each agent. For instance, the model can simulate the ability of agents to overcome a cyber-attack, a transportation strike, etc. Similarly, the model can simulate the ability of an agent to overcome cooperation breakdown scenarios by replacing the exiting partner in an effective way.

The proposed approach to analyse the impact of business interoperability is described as follows: considering that the Actual Level of Business Interoperability (ALBI) is not always the Required Level of Business Interoperability (RLBI), and vice versa, a distance (Equation 10) between these two states is calculated to measure how far the ALBI is from the RLBI.

$$business\ interoperability\ distance\ = ALBI - RLBI \qquad \text{Equation 10}$$

The ALBI and the RLBI are evaluated according to a business interoperability maturity model consisting of five levels of maturity: Level 0 (Isolated), Level 1 (Initial), Level 2 (Functional), Level 3 (Connectable) and Level 4 (Interoperable). Based on the on the value of the distance, a probability of problem occurrence is estimated. Examples of problems can be inefficient planning and forecasting due to information that is delivered incompletely, inaccurately, or with delay, interruption in the functioning of the information systems due to inefficient maintenance plans and/or security policies, or cyber-attacks. The probability of problems occurrence is grounded on the assumption that the greater the distance between the ALBI and the RLBI, the higher the probability of problems occurrence. Once, a business interoperability problem between two agents in a dyad occurs, the impact is first calculated on the performance of the two agents belonging to the dyad, and then spread over the network, to reflect the network effect.

## 5.6 Summary

This chapter started by describing the storyline behind the development of this thesis and by describing the proposed modelling approach and framework. It was explained that the proposed methodology consists of two theoretical models and that the sequence of their application depends on whether the cooperative industrial network already exists or not. Grounded on the output from previous chapter, the dimensions of business interoperability as well as their related sub-dimensions have been widely characterised and used as input to develop the theoretical Axiomatic Design model and the theoretical ABS model, also described in this chapter.

One relevant conclusion of this chapter is concerned with the characterisation of the dimensions of business interoperability. From the analysis of the collected literature on business interoperability, it was stated that although interoperability is defined as the ability of systems to exchange and use the information that has been exchanged, the dimension information quality, which measures the quality of the information that has been exchanged, has not been considered in the literature on interoperability as being a dimension of business interoperability. This is indeed strange as that definition of interoperability implicitly refers to the information quality.

# Chapter 6 Demonstration of the proposed methodology: an illustrative example

In order to test the applicability of the proposed methodology, an application scenario to implement RL in a context of an automotive industry has been developed. This section describes how this application scenario has been used to test the application of the proposed methodology. Consider that an Original Equipment Manufacturer (OEM) of an automotive manufacturing network intends to implement RL with three first tier suppliers in order to reduce the waste generated throughout the network that they are part. Specifically, they intend to recover the damaged or non-compliant components and to reuse the pallets and packages instead of buying new ones. With the implementation of RL they also expect to diminish the inventory level and the inventory cost of those materials at the OEM site and consequently maximise the availability of space. In addition to the three suppliers, two transporters and one recycler are considered to be involved in the implementation of RL, as illustrated by Figure 6.1.

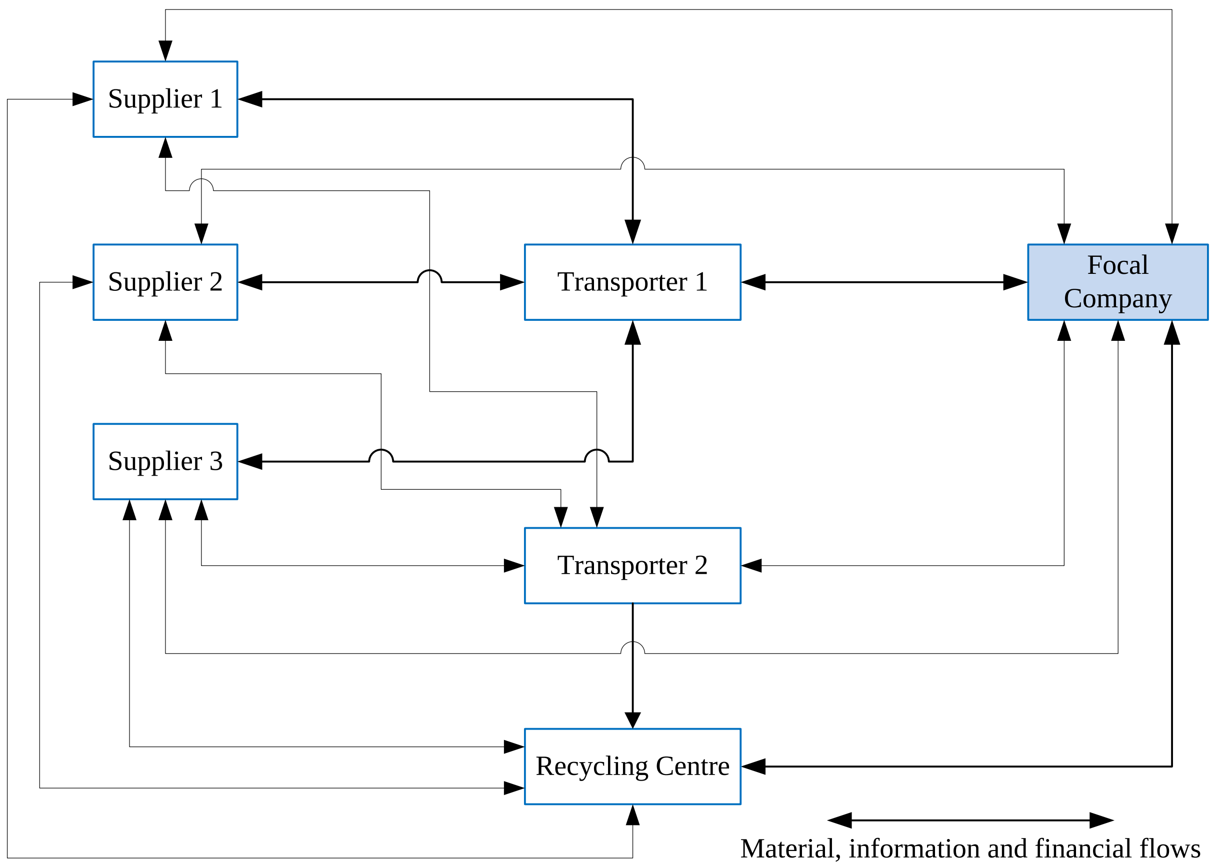



Figure 6.1: The structure of the considered RL cooperative automotive network

As shown in figure above, the Transporter 1 is responsible for the material flows between the OEM and suppliers and the Transporter 2 from the OEM and suppliers to the recycling centre. Those companies are considered to be located geographically in the same country, which means that business interoperability issues such as linguistic barriers and heterogeneity of legislations are not present. The OEM is assumed to be the responsible for managing all the RL cooperating partners and the first tier suppliers responsible for recovering damaged and/or non-compliant products. Sorting and separation of returnable items are performed internally by each company. The considered main RL operations are: sorting and separation of damaged and/or non-compliant components, return of damaged and/or non-compliant components to be recovered, re-manufacturing of damaged and/or non-compliant components, return of pallets and packages to be reutilised, transport of waste and scrap to recycling centre. The cost of RL operations, namely the transportation cost, the recovering cost and the recycling cost are allocated to the company that is responsible for the damaged item(s). For instance, if a supplier sends non-compliant components to the OEM, this supplier supports the costs of returning and recovering them. If the items are damaged during the transportation, the transporter supports all related costs. Similarly, in the event that the items are damaged in the OEM site, this company supports all associated costs. The OEM supports the costs of returning pallets and packages and the transportation costs from the OEM and suppliers to the recycling centre as well as the recycling cost are allocated to each of these companies, according to the amount of returnable items produced. It is also assumed that there is a reward provided by the OEM to all cooperating partners, according to the achievement of certain objectives, in terms of RL performance.

## 6.1 Background and motivation for Reverse Logistics

As product lifetimes become shorter, products become obsolete faster, increasing the rate at which companies generate unsalable product (Rogers and Tibben-Lembke 2001), an effective RL network is required to ensure proper recovery or disposal of these products. RL is defined as the "process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal (Rogers and Tibben-Lembke 2001).

RL has received increasing attention from both the academic world and industries in recent years (Lee and Chan 2009), and therefore its importance has been widely highlighted in the literature. As examples, the reader is guided to see Rogers et al. (1999), Daugherty et al. (2001), Rogers et al. (2001), Brito and Dekker (2004), Srivastava (2008), Kumar and Putnam (2008), Rogers et al. (2012), Mafakheri and Nasiri (2013), and Govindan and Popiuc (2014). In addition to the environmental concerns, there are many other reasons which may push a company to implement RL (e.g. (Brito and

Dekker 2004, Lambert *et al.* 2011, Chan *et al.* 2012)): they may be unavoidable returns, environmental and green concerns, enforced legislation, economics, commercial (e.g. second market), or corporate citizenship. Unavoidable returns occur (Chan et al. 2012): (1) when products suffered from production defects, which then result in product recall; or (2) when products fail to meet the quality conformities, consequently warranties applied. In this case, customers would bring their products back to repair centre where RL started (Chan et al. 2012). Environmental and green concerns are related to the awareness of people and companies on green and environmental issues. It is suggested that used products may not necessarily be disposed of in landfills, but reused and recycled (Chan et al. 2012). Legal motivations or enforced legislations are one of the most effective, but are not necessarily the most welcomed. In the case of the Waste Electrical and Electronic Equipments (WEEE) directive, governments enforce manufacturers to be responsible for the entire lifecycle of their products for the purpose of sustainability (Lambert et al. 2011). Economic forces indicate that RL activities such as remanufacturing, reuse of materials, and product refurbishing have the potential to improve profitability through cost minimization, access to new consumer segments, and increased revenues (Álvarez-Gil et al. 2007). For example, the case of recycling used cars where the scrap yard takes back the car, removes all valuable components for resale, and sells the rest for its metal value. This process usually generates profits (Lambert et al. 2011): every year, Black and Decker, a renowned consumer electronics company avoided $521.000 in landfill costs and collected $463.000 for the commodities they sold (Andel 1997), generating revenue of $1 million from their remanufactured products (Lambert et al. 2011); according to the Stock (2001)'estimates, RL costs in the US are about $35 billion per year, or 4% of total logistics costs, which represent approximately $25 billion spent on RL transportation costs in the US in 2004 (Lambert et al. 2011); in the United Kingdom, about 40% of RL costs are attributable to inefficient processes; In 2005, the cost of RL in North America was estimated at about $46 billion (Lambert et al. 2011). A fourth motivation for implementing RL is for commercial reasons which actually means that the business contacts dictate the terms for returning products, as in the case of unsold or defective products, or those requiring service (Lambert et al. 2011). The fifth reason, corporate citizenship is linked to the companies' reputations. Companies can consider RL as a means to maintain their brand reputations, to market their products as well as to gain competitive advantage. Companies can also pay more effort to RL in order to commit to Corporate Social Responsibility which is expected by customers (Chan et al. 2012).

The efficient implementation of RL requires appropriate logistics network structures to be set up for the arising products flow from users to producers (Zhou and Wang 2008). However, some barriers may inhibit its effectiveness (Rogers and Tibben-Lembke 1999, Rogers and Tibben-Lembke 2001, Autry 2005, Ravi *et al.* 2005, Lau and Wang 2009, Gonzalez-Torre *et al.* 2010, Chan *et al.* 2012): complexity of the RL network; lack of formal policy; absence of standardized processes and technologies; underdevelopment of recycling technology; lack of efficient information and technological systems; deficient industrial infrastructure; inappropriate environmental regulations on the part of government (legal issues); problems with product quality; resistance to change for activities related to RL; lack of appropriate performance metrics; scant commitment of workers (lack of training and qualifications); financial constraints; lack of commitment by top management (management inattention); lack of awareness concerning RL; lack of knowledge of RL; uncertainty regarding obtained results; lack of strategic planning; reluctance of the support of dealers, distributions and retailers; reluctance on the part of government; reluctance on the part of social actors; and lack of support from the SC.

According to Rogers et al. (2012), RL as a field of study, is sufficiently broad to support specialized research but although different from forward logistics or other areas of SCM, the tools needed to explore RL in a structured manner have not yet been completely identified and described. In this context, our work aims to contribute to fill part of this gap by developing a methodology that can be applied to RL problems, to incentive future research on RL an assist managers with a suitable tool to effectively implement RL in a context of cooperative SCN and improve RL performance.

## 6.2 Test of the theoretical Axiomatic Design model

As it was assumed that RL would be implemented for the first time, the test of the proposed methodology started with the application of the theoretical Axiomatic Design model, as suggested in Section 5.2. Accordingly, the model was used to design a cooperative network platform that is able to ensure business interoperability in the implementation of RL. Same as any design using classic Axiomatic Design Theory, the design of the RL interoperable cooperative network platform started with the identification of the customers and their needs. Customers are those companies that were assumed to be involved in the implementation of RL and the need, in this case, is the effective implementation of RL. Thus, the CN has been stated as follows: $CN_0$: Effective implementation of RL. Having identified the CN, the next step is to define the top-level FR, which represents the main objective of the design, and the corresponding DP and PV. To simplify the design, no constraints are assumed to exist. As the purpose of the design is to develop a cooperative industrial network platform that is able to ensure business interoperability in the implementation of RL, the top-level FR and the corresponding DP and PV have been defined as follows:

*$FR_0$: Ensure business interoperability in the implementation of RL.*

*$DP_0$: Development of a RL interoperable cooperative network platform.*

*$PV_0$: Defining the process, steps, or methods necessary to create or implement the $DP_0$.*

Because the defined $FR_0$ is broad and only represents the design intent, the first level decomposition is required to incorporate the dimensions of business interoperability, characterised in Section 5.3, which represent the fundamental requirements in the design of the RL interoperable cooperative network platform.

In line with Zutshi et al. (2012), the highest business interoperability requirement among cooperative firms should be reflected in their overall business strategy. The FR that reflects this dimension has been defined with regard to the establishment of cooperation goals to be achieved with the implementation of RL. The second FR is concerned with the issues of managing business relationships among the cooperative RL partners. As implementing RL implies cooperative relationships among companies, such relationships have to be established and managed from cooperation initiation until termination. The next FR captures the dimension of collaborative business processes. As RL will be implemented for the first time, collaborative business processes to support the implementation of RL have to be established. Also, interoperability of these collaborative business processes must be ensured. The fourth requirement is related to the products/services and financial transaction flows among RL partners. As an RL network can involve a high flow of transactions (products and services) and a considerable amount of investment, it becomes important to manage these transactions. According to ATHENA (2007), the frequency of transactions within a business relationship can be one-time, occasional or recurrent. The specificity and frequency of transaction usually influence the relationships among networked companies, and therefore they affect the levels of business interoperability. As emphasised in ATHENA (2007), usually companies that conduct frequent transactions tend to be more interoperable as the interaction may be more standardised.

The fifth requirement is associated with the human resources involved in the implementation of RL as well as their interactions. As the RL implementation may requires systematic and interactive efforts of human resources, all potential inefficiencies from their failures should be appropriately managed. The sixth requirement concerns the business semantic issues. Since there are a significant number of companies involved in the implementation of RL, semantics problems can emerge. For instance, the classification of returnable products/materials often differs from one RL partner to another. Thus, it is important to develop mechanisms to manage any potential semantic problem. Information systems, the seventh requirement, is often referred to be one of the most critical dimensions for designing interoperable business systems (e.g. (ATHENA 2007, Vernadat 2010, Zutshi *et al.* 2012, Loukis and Charalabidis 2013)). Indeed, information system is an essential driver to support cooperation among companies as nowadays most of the business activities and transactions are conducted electronically. Its importance to support RL operations has been highlighted by some authors. For instance, Daugherty et al. (2002) state that information support is particularly critical to achieve efficient RL operations as RL is frequently characterised by uncertainty and a need for rapid timing/processing. To Lambert et al. (2011), the information systems are responsible for managing returns, communicating efficiently between the different parties involved, and playing a role in identifying a product and deciding how to deal with it. In this sense, networked cooperative companies (as is the case of an RL network) critically need to establish interoperable information systems that are able to support the information flows in an effective way.

The ninth requirement is focused on the ability of RL partners to share information that satisfy their business needs, that is to say that satisfy the dimension of information quality. Last but not least, a tenth requirement must be defined to capture the elements related to the dimension of network minute details. This is a critical requirement in designing RL interoperable cooperative industrial network platforms as the existence of environmental national and international legislations/regulations and standards, the occurrence of external events such as introduction of new recycling technology, transportation strike, entry of a new RL partner, introduction of new legislation for recycling, etc., must be addressed in order to ensure that RL partners are able to deal with these events. Following, the decomposition of the level 1 FRs as well as the corresponding DPs and PVs is summarised in Table 6.1. It is to highlight that this decomposition does not incorporate the dimension of knowledge management because it is assumed that no intellectual property rights will be shared in the implementation of RL.

Table 6.1: Decomposition of the level 1 FRs and their related DPs and PVs

| **$FR_0$: *Ensure business interoperability in the implementation of RL*** | ***$DP_0$: Development of a RL interoperable cooperative network platform*** | ***$PV_0$: Defining the process, steps, or methods necessary to create or implement the $DP_0$*** |
|---|---|---|
| $FR_1$: Set the cooperation goals to implement RL | $DP_1$: Description of strategic goals to implement RL | $PV_1$: Defining the process, steps, or methods necessary to create or implement the $DP_1$ |
| $FR_2$: Manage business relationships from RL cooperation initiation until termination | $DP_2$: Procedures and approaches to manage RL cooperative relationships, from initiation to termination | $PV_2$: Defining the process, steps, or methods necessary to create or implement the $DP_2$ |
| $FR_3$: Establish collaborative business processes to support RL implementation | $DP_3$: Design of a business process model that fits the implementation of RL | $PV_3$: Defining the process, steps, or methods necessary to create or implement the $DP_3$ |
| $FR_4$: Manage the transactional flows among networked RL partners | $DP_4$: Description of the conditions for transactions and interaction frequency | $PV_4$: Defining the process, steps, or methods necessary to create or implement the $DP_4$ |
| $FR_5$: Manage human resources involved in the implementation of RL | $DP_5$: Description of the work environment that is suitable to the characteristics of each collaborating partner's employee involved in the RL implementation | $PV_5$: Defining the process, steps, or methods necessary to create or implement the $DP_5$ |
| $FR_6$: Ensure that collaborating RL partners interpret common or shared information in a consistent way | $DP_6$: Description of the mechanisms to prevent and/or mitigate the existence of semantics problems in RL operations | $PV_6$: Defining the process, steps, or methods necessary to create or implement the $DP_6$ |
| $FR_7$: Establish the information systems to support the implementation of RL | $DP_7$: Establishment of an interoperable information systems platform suitable to support RL operations in the network | $PV_7$: Defining the process, steps, or methods necessary to create or implement the $DP_7$ |
| $FR_8$: Deal with the network minute details related to RL implementation | $DP_8$: Well-established approaches and procedures to deal with the RL network minute details | $PV_8$: Defining the process, steps, or methods necessary to create or implement the $DP_8$ |

Having achieved the decomposition of the level 1 FRs, DPs and PVs, a design matrix must be developed in order to evaluate their independence, as per Axiom 1 – Independence Axiom. However, before presenting such design matrix the process of relating FRs to DPs is illustrated by Figure 6.2.

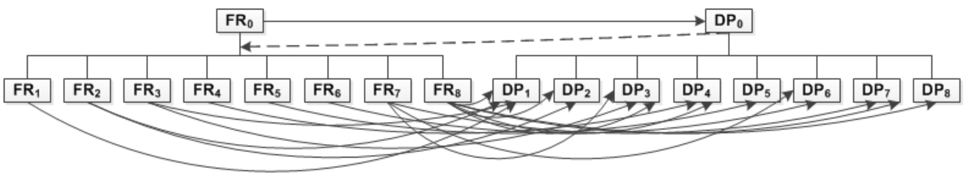



Figure 6.2: Relationships among level 1 FRs and DPs

The design matrix for the level 1 FRs is then illustrated in Figure 6.3. This matrix provides the sequence of implementation of the level 1 DPs.

| | $DP_1$ | $DP_2$ | $DP_3$ | $DP_4$ | $DP_5$ | $DP_6$ | $DP_7$ | $DP_8$ |
|---|---|---|---|---|---|---|---|---|
| **$FR_1$** | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_2$** | X | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_3$** | X | 0 | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_4$** | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 |
| **$FR_5$** | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 |
| **$FR_6$** | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 |
| **$FR_7$** | 0 | X | X | 0 | 0 | X | X | 0 |
| **$FR_8$** | X | X | X | X | 0 | 0 | X | X |

Figure 6.3: Design matrix for level 1 FRs

By analysing the configuration of the design matrix shown in figure above, it is possible to conclude that such matrix is decoupled, as all upper triangular elements are equal to zero and some lower triangular elements are different from zero. Because of those lower triangular elements that are different from zero, the independence of FRs can be guaranteed if and only if the DPs are determined in a proper sequence, as recommended by Suh (1990). For example, to achieve $FR_8$, $DP_1$, $DP_2$, $DP_3$, $DP_4$ and $DP_7$ must be achieved before of $DP_8$. $FR_2$ and $FR_3$ need to be fulfilled after achieving DP1 because they are dependent on $FR_1$. $FR_4$, $FR_5$ and $FR_6$ are independent, and therefore they can be achieved at any moment.

However, as can be seen in Table 6.1, the level 1 FRs only express abstract requirements of a RL interoperable cooperative industrial network platform, and they are not detailed enough to assist managers in the implementation of RL. Therefore, the designer went back to the functional domain and decomposed those FRs to the level 2 FRs in order to incorporate the sub-dimensions of business interoperability described in Section 5.3. Accordingly, the decomposition for the level 2 FRs of $FR_1$, $FR_2$, $FR_3$, $FR_7$ and $FR_8$ are presented following.

**Decomposition of $FR_1$ to the level 2 FRs**

As mentioned above "$FR_1$ – Set the cooperation goals to implement RL" does not provide sufficient detail to achieve the objectives of RL implementation. Requirements such as clarity, visibility and alignment of the RL cooperation goals and individual interests of RL partners must be achieved. Thus, the following level 2 FRs, DPs and PVs for FR1 are presented in Table 6.2.

Table 6.2: Decomposition of $FR_1$ to the level 2 FRs

| ***$FR_1$: Establish the cooperation goals to implement RL*** | ***$DP_1$: Description of strategic goals to implement RL*** | ***$PV_1$*: Process, steps, or methods necessary to create or implement the $DP_1$** |
|---|---|---|
| $FR_{1.1}$: Ensure clarity in the definition of the cooperation goals to implement RL | $DP_{1.1}$: A list of cooperation goals to implement RL | $PV_{1.1}$: Using the methodology SMART (**S**pecific, **M**easurable, **A**chievable, **R**ealistic, **T**imely) |
| $FR_{1.2}$: Identify the individual interests of each RL cooperating partner | $DP_{1.2}$: Communication of the individual interests of RL partners | $PV_{1.2}$: Business meetings |
| $FR_{1.3}$: Align the individual interests of RL cooperating partners to the cooperation goals to implement RL | $DP_{1.3}$: Negotiation of the individual interests of each RL partner | $PV_{1.3}$: Individual meetings with each RL partner |
| $FR_{1.4}$: Set deadlines to achieve the RL cooperation goals | $DP_{1.4}$: Deadline to achieve cooperation goals (e.g. two years) | $PV_{1.4}$: Defining a schedule that contain the deadlines |
| $FR_{1.5}$: Communicate the RL cooperation goals and deadline to achieve them to the RL cooperating partners | $DP_{1.5}$: A file with the list of RL cooperation goals and the deadline to achieve them | $PV_{1.5}$: Using, for example, e-mail system |

Similar to the level 1 FRs, the design matrix shown in Figure 6.4 has been developed to analyse the independence of the above FRs and DPs.

| | **$DP_{1.1}$** | **$DP_{1.2}$** | **$DP_{1.3}$** | **$DP_{1.4}$** | **$DP_{1.5}$** |
|---|---|---|---|---|---|
| **$FR_{1.1}$** | X | 0 | 0 | 0 | 0 |
| **$FR_{1.2}$** | X | X | 0 | 0 | 0 |
| **$FR_{1.3}$** | | X | X | 0 | 0 |
| **$FR_{1.4}$** | X | X | X | X | 0 |
| **$FR_{1.5}$** | X | X | X | X | X |

Figure 6.4: Design matrix for level 2 $FR_1$

Again, the generated design matrix is decoupled, and therefore there is no need to change FRs and DPs. Thus, there is no need to modify FRs and DPs as the independence axiom is meet. The sequence of the execution of DPs is the following: to achieve $FR_{1.5}$, $DP_{1.1}$, $DP_{1.2}$, $DP_{1.3}$ and $DP_{1.4}$ need to be fulfilled. Similarly, to achieve $FR_{1.4}$, $DP_{1.1}$, $DP_{1.2}$ and $DP_{1.3}$ have to be fulfilled first. To achieve $FR_{1.3}$, only $DP_{1.2}$ needs to be achieved.

**Decomposition of $FR_2$ to the level 2 FRs**

The "$FR_2$: Manage business relationships from RL cooperation initiation until termination" also does not provide sufficient detail to achieve the objectives of RL implementation. It implies that this FR needs to incorporate its related sub-dimensions of business interoperability, which are: partner selection, partner assessment, contractual terms and conditions, inter-organisational communication, inter-organisational conflict management, and inter-personal trust. Accordingly, Table 6.3 illustrates the incorporation of these sub-dimensions in the decomposition of $FR_2$.

Table 6.3: Decomposition of $FR_2$ to the level 2 FRs

| ***$FR_2$: Manage business relationships from RL cooperation initiation until termination*** | ***$DP_2$: Procedures and approaches to manage RL cooperative relationships, from initiation to termination*** | ***$PV_2$*: Process, steps, or methods necessary to create or implement the $DP_2$** |
|---|---|---|
| $FR_{2.1}$: Set the contractual terms and conditions to participate in the RL implementation | $DP_{2.1}$: Establishment of legal instruments (e.g. contracts) | $PV_{2.1}$: Legal department |
| $FR_{2.2}$: Safeguard against potential opportunistic behaviours or RL partners | $DP_{2.2}$: Specification of penalties in contractual specifications for non-cooperative behaviours | $PV_{2.2}$: Legal department |
| $FR_{2.3}$: Manage conflicts among RL partners | $DP_{2.3}$: Establishment of mechanism to manage conflicts (e.g. negotiation) | $PV_{2.3}$: Having meetings to manage conflicts |
| $FR_{2.4}$: Develop trust-based on long-term relationships among RL partners | $DP_{2.4}$: Mechanisms to stimulate trust and respect | $PV_{2.4}$: Process, steps, or methods necessary to create or implement the $DP_{2.4}$ |
| $FR_{2.5}$: Ensure frequent and effective communication among RL partners | $DP_{2.5}$: Mechanisms to eliminate barriers to communication among RL partners | $PV_{2.5}$: Process, steps, or methods necessary to create or implement the $DP_{2.5}$ |
| $FR_{2.6}$: Monitor the business relationships among RL partners | $DP_{2.6}$: Development of a system for monitoring the RL business relationships | $PV_{2.6}$: Process, steps, or methods necessary to create or implement the $DP_{2.6}$ |

To evaluate the independence of the above FRs and DPs, the design matrix illustrated by Figure 6.5 has been developed. Regarding to the sequence of implementation of DPs, it is to notice that $FR_{2.4}$, $FR_{2.5}$ and $FR_{2.6}$ are independent and can be satisfied at any moment. To achieve $FR_{2.2}$ and $FR_{2.3}$, $DP_{2.1}$ must be first achieved.

| | **$DP_{2.1}$** | **$DP_{2.2}$** | **$DP_{2.3}$** | **$DP_{2.4}$** | **$DP_{2.5}$** | **$DP_{2.6}$** |
|---|---|---|---|---|---|---|
| **$FR_{2.1}$** | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{2.2}$** | X | X | 0 | 0 | 0 | 0 |
| **$FR_{2.3}$** | X | X | X | 0 | 0 | 0 |
| **$FR_{2.4}$** | 0 | 0 | 0 | X | 0 | 0 |
| **$FR_{2.5}$** | 0 | 0 | 0 | 0 | X | 0 |
| **$FR_{2.6}$** | 0 | 0 | 0 | 0 | 0 | X |

Figure 6.5: Design matrix for level 2 $FR_2$

Analysing the design matrix presented above, it is to notice that it is decoupled, which means that the Independence Axiom is achieved. Therefore, there is no deed to modify FRs and DPs. However, with regard to the "$FR_{2.3}$ – Manage conflicts among RL partners", it is to report that it does not achieve a sufficient level of detail because it must incorporate the requirements related to the identification, resolution and prevention of conflicts. This should be carried out in the third level of decomposition.

**Decomposition of $FR_3$ to the level 2 FRs**

The "$FR_3$ – Establish collaborative business processes to support RL implementation" also did not achieve a sufficient level of detail to implement RL. In other words, it must incorporate factors such as roles and responsibilities, clarity in business processes, visibility of business processes, coordination of business processes, integration of business processes, and flexibility of business processes. The incorporation of these factors in the decomposition of $FR_3$ is shown in Table 6.4.

Table 6.4: Decomposition of $FR_3$ to the level 2 FRs

| ***$FR_3$: Establish collaborative business processes to support RL implementation*** | ***$DP_3$: Design of a business process model that fits the implementation of RL*** | ***$PV_3$*: Process, steps, or methods necessary to create or implement the $DP_3$** |
|---|---|---|
| $FR_{3.1}$: Spell out the roles and responsibilities for each RL cooperating partner | $DP_{3.1}$: A document that describes the role and responsibilities for each RL cooperating partner (e.g. tender specification) | $PV_{3.1}$: Using the office tools (e.g. word file) |
| $FR_{3.2}$: Communicate the roles and responsibilities to the RL cooperating partner | $DP_{3.2}$: Mechanism to communicate the roles and responsibilities to the RL partners | $PV_{3.2}$: Process, steps, or methods necessary to create or implement the $DP_{3.2}$ |
| $FR_{3.3}$: Set RL collaborative processes throughout the cooperative network | $DP_{3.3}$: A BPD of the collaborative RL processes | $PV_{3.3}$: Applying the standard Business Process Model and Notation (BPMN) |
| $FR_{3.4}$: Share the RL BPD with RL cooperating partners | $DP_{3.4}$: RL BPD sent via e-mail | $PV_{3.4}$: Using Internet tools |
| $FR_{3.5}$: Integrate the RL collaborative processes | $DP_{3.5}$: Tools to integrate the RL collaborative processes | $PV_{3.5}$: Process, steps, or methods necessary to create or implement the $DP_{3.5}$ |
| $FR_{3.6}$: Communicate the internal processing status of RL collaborative processes | $DP_{3.6}$: Mechanisms to communicate the processing status of the RL collaborative processes along the network (e.g. a cooperative information system platform) | $PV_{3.6}$: IT providers |
| $FR_{3.7}$: Coordinate the RL collaborative processes with cooperating partners | $DP_{3.7}$: Mechanisms to coordinate RL collaborative processes throughout the network (e.g. real-time information sharing) | $PV_{3.7}$: Process, steps, or methods necessary to create or implement the $DP_{3.7}$ |
| $FR_{3.8}$: Ensure that the established RL collaborative processes are flexible enough to respond to new cooperation requirements | $DP_{3.8}$: Establishment of flexible RL collaborative processes throughout the network | $PV_{3.8}$: By predicting potential changes in the network (e.g. entry of a new partner) |

Figure 6.6 illustrates the relationships among these set of FRs and DPs. The independence axiom can be fulfilled as the design matrix is decoupled. From this design matrix, some analyses can be made. For instance, to achieve $FR_{2.8}$, $DP_{2.1}$, $DP_{2.3}$ and $DP_{2.5}$ need to be fulfilled earlier. In order to achieve the $FR_{2.7}$, $DP_{2.1}$, $DP_{2.3}$ and $DP_{2.5}$ and $DP_{2.6}$ need to be implemented before of $DP_{2.7}$.

| | **$DP_{3.1}$** | **$DP_{3.2}$** | **$DP_{3.3}$** | **$DP_{3.4}$** | **$DP_{3.5}$** | **$DP_{3.6}$** | **$DP_{3.7}$** | **$DP_{3.8}$** |
|---|---|---|---|---|---|---|---|---|
| **$FR_{3.1}$** | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.2}$** | X | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.3}$** | X | 0 | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.4}$** | X | 0 | X | X | 0 | 0 | 0 | 0 |
| **$FR_{3.5}$** | X | 0 | X | 0 | X | 0 | 0 | 0 |
| **$FR_{3.6}$** | 0 | 0 | X | 0 | 0 | X | 0 | 0 |
| **$FR_{3.7}$** | X | 0 | X | 0 | X | X | X | 0 |
| **$FR_{3.8}$** | X | 0 | X | 0 | X | 0 | 0 | X |

Figure 6.6: Design matrix for level 2 $FR_3$

Although the above design matrix satisfies the Independence Axiom, it is to notice that "$FR_{3.6}$: Communicate the internal processing status of RL collaborative processes" did not achieve a level of detail that is sufficient to communicate the internal processing status of RL collaborative processes. In other words, it is not only about communicating the internal processing status but also to ensure information quality in such communication, i.e. the information must be accurate, complete, timely, reliable, concise, relevant, actual, easy to read and understand, and easy to process. Therefore, a third level of decomposition will be performed further in this section.

**Decomposition of $FR_7$ to the level 2 FRs**

The "$FR_7$: Establish the information systems to support the implementation of RL" also did not achieve a sufficient level of decomposition. Indeed, there is a set of information systems requirements that must be achieved in order to establish an interoperable information systems platform. Among these factors, one can mention, security, privacy, speed, type of interaction, connectivity, user interface, data exchange tools, data accessibility, integration, flexibility, usability, and maintenance issues. As a result, these requirements are incorporated in the $FR_7$ in the manner that is illustrated in Table 6.5.

Table 6.5: Decomposition of $FR_7$ to the level 2 FRs

| ***$FR_7$: Establish the information systems to support the implementation of RL*** | ***$DP_7$: Establishment of an interoperable information systems platform suitable to support RL operations in the network*** | ***$PV_7$:* Process, steps, or methods necessary to create or implement the $DP_7$** |
|---|---|---|
| $FR_{7.1}$: Define information systems requirements to implement RL | $DP_{7.1}$: Development of an information system model suitable to the RL cooperation requirements | $PV_{7.1}$: Using information systems modelling tools (e.g. use cases, and class diagram) |
| $FR_{7.2}$: Define the type of connectivity to be established among inter-organisational information systems | $DP_{7.2}$: Establishment of the type of connectivity (e.g. 1:n) | $PV_{7.2}$: IT consulting |
| $FR_{7.3}$: Define the type of interactions among information systems and users | $DP_{7.3}$: Establishment of the type of interactions (e.g. human-machine) | $PV_{7.3}$: IT consulting |
| $FR_{7.4}$: Integrate the ITs and applications used in the RL operations | $DP_{7.4}$: Establishment of integration standards (e.g. Web of Services, XML) | $PV_{7.4}$: Internet standards developers |
| $FR_{7.5}$: Limit the access to non-authorised users | $DP_{7.5}$: Mechanisms of identification and authentication and (e.g. user login and password) | $PV_{7.5}$: Defining an information system administrator |
| $FR_{7.6}$: Ensure that users have security and privacy to transmit confidential information and conduct secure RL operations over the network | $DP_{7.6}$: Implementation of security and privacy protocols (e.g. HTTPS) | $PV_{7.6}$: IT consulting |
| $FR_{7.7}$: Ensure that the user interface is friendly | $DP_{7.7}$: Mechanisms to ensure user-friendly interface | $PV_{7.7}$: IT developers |
| $FR_{7.8}$: Ensure that the information systems are rapid enough to support synchronous information sharing | $DP_{7.8}$: Mechanisms to ensure speed of the information systems | $PV_{7.8}$: IT consulting |
| $FR_{7.9}$: Ensure easy and quick access to RL data | $DP_{7.9}$: Mechanisms to access data (data access tools/data exchange tools) | $PV_{7.9}$: IT providers |
| $FR_{7.10}$: Ensure reliability of the information systems used in the RL operations | $DP_{7.10}$: A maintenance plan for RL information systems | $PV_{7.10}$: Using the office tools (e.g. word file) |
| $FR_{7.11}$: Safeguard against cyber attacks | $DP_{7.11}$: Establishment of appropriate security mechanisms against cyber attacks | $PV_{7.11}$: IT consulting |

The generated design matrix, which provides the relationships between the FRs and DPs proposed above, is illustrated in Figure 6.7. As the design matrix is decoupled, the Independence Axiom is achieved and therefore it is not necessary to change FRs and DPs. However, an adequate sequence of implementation of DPs must be ensured. For example, to achieve $FR_{7.11}$, $DP_{7.1}$, $DP_{7.2}$, $DP_{7.3}$ and $DP_{7.4}$ have to be implemented earlier. To achieve $FR_{7.10}$, $DP_{7.1}$, $DP_{7.2}$, $DP_{7.3}$, $DP_{7.4}$ and $DP_{7.5}$ must be implemented first.

| | $DP_{7.1}$ | $DP_{7.2}$ | $DP_{7.3}$ | $DP_{7.4}$ | $DP_{7.5}$ | $DP_{7.6}$ | $DP_{7.7}$ | $DP_{7.8}$ | $DP_{7.9}$ | $DP_{7.10}$ | $DP_{7.11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $FR_{7.1}$ | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{7.2}$ | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{7.3}$ | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{7.4}$ | 0 | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{7.5}$ | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{7.6}$ | 0 | X | X | X | 0 | X | 0 | 0 | 0 | 0 | 0 |
| $FR_{7.7}$ | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 |
| $FR_{7.8}$ | 0 | 0 | X | X | 0 | 0 | 0 | X | | 0 | 0 |
| $FR_{7.9}$ | 0 | 0 | 0 | X | X | 0 | 0 | 0 | X | 0 | 0 |
| $FR_{7.10}$ | X | X | X | X | X | 0 | 0 | 0 | 0 | X | 0 |
| $FR_{7.11}$ | X | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 | X |

Figure 6.7: Design matrix for level 2 $FR_7$

Regarding to the level of decomposition of $FR_7$, it is considered that all its sub-FRs reached a sufficient level of detail. Therefore, it is not necessary to decompose them to the level 3 FRs.

**Decomposition of $FR_8$ to the level 2 FRs**

The "$FR_8$: Deal with the network minute detail related to RL implementation" also did not achieve a sufficient level of decomposition. It needs to incorporate the elements that characterise the RL cooperative network such as network governance (decision-making), contact points, new partners, cooperation breakdown, legislations, regulations, complexity, etc. The way these elements are transformed into FRs is shown in Table 6.6.

Table 6.6: Decomposition of $FR_8$ to the level 2 FRs

| ***$FR_8$*: Deal with the network minute details related to RL implementation** | ***$DP_8$*: Well-established approaches and procedures to deal with the RL network minute details** | ***$PV_8$*: Process, steps, or methods necessary to create or implement the $DP_8$** |
|---|---|---|
| $FR_{8.1}$: Facilitate decision-making through the RL cooperative network | $DP_{8.1}$: A hierarchy structure for the RL cooperative network | $PV_{8.1}$: Using software for creating organisational chart (e.g. excel) |
| $FR_{8.2}$: Ensure clarity within each company regarding the person to be contacted for the issues related to RL implementation | $DP_{8.2}$: Establishment of contact points throughout the RL network (a list that contain the name and contact of the person to be contacted for each issue related to RL implementation) | $PV_{8.2}$: Using the office tools (e.g. word file) |
| $FR_{8.3}$: Facilitate communication among RL partners | $DP_{8.3}$: Establishment of communication channels throughout the RL network | $PV_{8.3}$: Process, steps, or methods necessary to create or implement the $DP_{8.3}$ |
| $FR_{8.4}$: Safeguard against RL cooperation breakdown | $DP_{8.4}$: Mechanisms to prevent cooperation breakdown (e.g. incentive systems) | $PV_{8.4}$: Process, steps, or methods necessary to create or implement the $DP_{8.4}$ |
| $FR_{8.5}$: Manage RL cooperation breakdown | $DP_{8.5}$: Mechanism to overcome cooperation breakdown (e.g. list of companies for RL potential cooperation) | $PV_{8.5}$: Using the office tools (e.g. word file) |

| | | |
|---|---|---|
| $FR_{8.6}$: Ensure that a new partner can be easily integrated in the implementation of RL | $DP_{8.6}$: Mechanisms to integrate new RL partners | $PV_{8.6}$: Process, steps, or methods necessary to create or implement the $DP_{8.6}$ |
| $FR_{8.7}$: Comply with the legislations and regulations required to implement RL | $DP_{8.7}$: Standards for RL operations (e.g. environmental standard ISO 14001) | $PV_{8.7}$: Process, steps, or methods necessary to create or implement the $DP_{8.7}$ |

The relationships among these level 2 FRs and DPs are shown in Figure 6.8. This design matrix is uncoupled, meaning that the FRs should be achieved in the specified order.

| | **$DP_{8.1}$** | **$DP_{8.2}$** | **$DP_{8.3}$** | **$DP_{8.4}$** | **$DP_{8.5}$** | **$DP_{8.6}$** | **$FR_{8.7}$** |
|---|---|---|---|---|---|---|---|
| **$FR_{8.1}$** | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{8.2}$** | 0 | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{8.3}$** | 0 | X | X | 0 | 0 | 0 | 0 |
| **$FR_{8.4}$** | 0 | 0 | 0 | X | 0 | 0 | 0 |
| **$FR_{8.5}$** | 0 | 0 | 0 | 0 | X | 0 | 0 |
| **$FR_{8.6}$** | 0 | 0 | 0 | X | 0 | X | 0 |
| **$FR_{8.7}$** | 0 | 0 | 0 | 0 | 0 | 0 | X |

Figure 6.8: Design matrix for level 2 $FR_8$

This design matrix is uncoupled, meaning that some FRs should be achieved in the specified order. For instance, to achieve $FR_{8.6}$, $DP_{8.4}$ has to be implemented earlier. Similarly, in order to achieve $FR_{8.3}$, $DP_{8.2}$ must be implemented first. The others FRs are independent and can be achieved at any moment. The decomposition for $FR_8$ is assumed to achieve a sufficient level of detail. Therefore, there is no need to decompose its elements to the level 3 FRs. Following, the decomposition for $FR_{3.6}$ is presented because as mentioned above it did not achieve the required level of detail.

### Decomposition of $FR_{3.6}$ to the level 3 FRs

The main objective of this decomposition is to incorporate the elements that characterise information quality. Accordingly, Table 6.7 shows how these elements are incorporated in this design.

Table 6.7: Decomposition of $FR_{3.6}$ to the level 3 FRs

| ***$FR_{3.6}$: Communicate the internal processing status of RL collaborative processes*** | ***$DP_{3.6}$: Mechanisms to communicate the processing status of the RL collaborative processes along the network (e.g. a cooperative information system platform)*** | ***$PV_{3.6}$: IT providers*** |
|---|---|---|
| $FR_{3.6.1}$: Provide accurate information on the internal processing status of RL collaborative processes | $DP_{3.6.1}$: Mechanisms to provide accurate information on the internal processing status of RL collaborative processes | $PV_{3.6.1}$: Process, steps, or methods necessary to create or implement the $DP_{3.6.1}$ |
| $FR_{3.6.2}$: Provide reliable information on the internal processing status of RL collaborative processes | $DP_{3.6.2}$: Mechanisms to provide reliable information on the internal processing status of RL collaborative processes | $PV_{3.6.2}$: Process, steps, or methods necessary to create or implement the $DP_{3.6.2}$ |
| $FR_{3.6.3}$: Provide timely information on the internal processing status of RL collaborative processes | $DP_{3.6.3}$: Mechanisms to provide timely information on the internal processing status of RL collaborative processes | $PV_{3.6.3}$: Process, steps, or methods necessary to create or implement the $DP_{3.6.3}$ |
| $FR_{3.6.4}$: Provide complete information on the internal processing status of RL collaborative processes | $DP_{3.6.4}$: Mechanisms to complete accurate information on the internal processing status of RL collaborative processes | $PV_{3.6.4}$: Process, steps, or methods necessary to create or implement the $DP_{3.6.4}$ |
| $FR_{3.6.5}$: Provide concise information on the internal processing status of RL collaborative processes | $DP_{3.6.5}$: Mechanisms to provide concise information on the internal processing status of RL collaborative processes | $PV_{3.6.5}$: Process, steps, or methods necessary to create or implement the $DP_{3.6.5}$ |
| $FR_{3.6.6}$: Provide relevant information on the internal processing status of RL collaborative processes | $DP_{3.6.6}$: Mechanisms to provide relevant information on the internal processing status of RL collaborative processes | $PV_{3.6.6}$: Process, steps, or methods necessary to create or implement the $DP_{3.6.6}$ |
| $FR_{3.6.7}$: Ensure that the information on the internal processing status of RL collaborative processes are easy to process | $DP_{3.6.7}$: Mechanisms to provide information that are easy to process | $PV_{3.6.7}$: Process, steps, or methods necessary to create or implement the $DP_{3.6.7}$ |

The relationships among these level 3 FRs and DPs are shown in Figure 6.9. This design matrix is uncoupled, meaning that the FRs should be achieved in the specified order.

| | **$DP_{3.6.1}$** | **$DP_{3.6.2}$** | **$DP_{3.6.3}$** | **$DP_{3.6.4}$** | **$DP_{3.6.5}$** | **$DP_{3.6.6}$** | **$FR_{3.6.7}$** |
|---|---|---|---|---|---|---|---|
| **$FR_{3.6.1}$** | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.6.2}$** | 0 | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.6.3}$** | 0 | X | X | 0 | 0 | 0 | 0 |
| **$FR_{3.6.4}$** | 0 | 0 | 0 | X | 0 | 0 | 0 |
| **$FR_{3.6.5}$** | 0 | 0 | 0 | 0 | X | 0 | 0 |
| **$FR_{3.6.6}$** | 0 | 0 | 0 | 0 | 0 | X | 0 |
| **$FR_{3.6.7}$** | X | 0 | 0 | X | 0 | 0 | X |

Figure 6.9: Design matrix for level 3 $FR_{3.6}$

As can be seen in figure above, the generated design matrix for the level 3 $FR_{3.6}$ is decoupled. Therefore, it is not necessary to change FRs and DPs. Only one FR ($FR_{3.6.7}$) must be achieved in a proper sequence, i.e. after implementing $DP_{3.6.1}$ and $DP_{3.6.4}$.

## 6.3 Development of the theoretical business interoperability maturity model

As explained in Section 5.1, the last level DPs will be used as input in the theoretical ABS model. However, before proceeding to the ABS model, it is necessary to evaluate the as-is and to-be state for each last level DP that will be incorporated in the ABS model. Therefore, this section describes the theoretical business interoperability maturity model that supports such evaluation. This maturity model consists of five levels as illustrated by Table 6.8. It is to notice that for the purpose of this thesis, the last level DPs are called Business Interoperability Design Solutions (BIDS).

Table 6.8: The proposed theoretical business interoperability maturity model

| Maturity level | Description |
|---|---|
| Isolated | The BIDS is not implemented and partners are not aware of its importance. |
| Initial | The BIDS is not implemented or is implemented but is ad hoc. However, partners are aware of its importance and therefore they are considering implementing it. |
| Functional | The BIDS is implemented but imposed by a dominant partner without consensus of the other partners. |
| Connectable | The BIDS is implemented but not documented. |
| Interoperable | The BIDS is well implemented and well documented, reflecting multilateral agreements. |

## 6.4 Test of the theoretical Agent-Based Simulation model

To demonstrate the applicability of the theoretical ABS model, the same application scenario that has been used to design RL interoperable cooperative industrial network platform has been used. Grounded on *NetLogo* software (Wilensky 1999), a simulation environment has been developed to simulate how different levels of business interoperability, for some of last level DPs achieved in previous section, can impact the performance of the companies involved in the implementation of RL. In particular, three BIDSs have been used as the input in the ABS model: "$BIDS_{3.1}$: A well-defined document that describes the role and responsibilities for each RL cooperating partner" and "BIDS3.6.3: Mechanisms to provide timely information on the internal processing status of RL collaborative processes". The $BIDS_{3.6.3}$ has been further decomposed into "$BIDS_{3.6.3.1}$: Mechanisms to provide timely information on the processing status of the components being remanufactured" and

"$BIDS_{3.6.3.2}$: Mechanisms to provide timely information on the inventory level of the returnable products/materials".

In order to perform the analysis of the impact, some assumptions have been made at the stage of the development of this application scenario empirical data were not available: the Supplier 1 delivers to the focal company 600 type A components per day, and five times a day; the lead time for remanufactured type A component is one hour; the Supplier 2 delivers to the focal company 1200 type B components per day, and five times a day; the lead time for remanufactured type B components is 45 minutes; the transportation of these components from the suppliers to the focal company is carried out by the Transporter 1.

In each shipment of the type A components, four pallets are used and each component is packaged using one packing; for the type B components, six pallets are used and each component is also packaged using one packing; both pallets and packaging used to ship components from the suppliers to focal company are reusable; the organisations operate eight hours a day and five days a week; the ALBI and RLBI for the BIDSs are normally distributed, i.e. ALBI/RLBI ~ N ($\mu$, $\sigma^2$); Table 6.9 shows how the average ALBI and RLBI of the links change over time.

Table 6.9: Evolution of the average ALBI and RLBI

| **BIDS** | **t = [0, 90[** | | **t = [90, 179[** | | **t = [179, 266]** | |
|---|---|---|---|---|---|---|
| | **ALBI** | **RLBI** | **ALBI** | **RLBI** | **ALBI** | **RLBI** |
| $DP_{2.3.1}$ | *ALBI ~ N (1.5; 0.5)* | *RLBI ~ N (3; 0)* | *ALBI ~ N (2.5; 0.5)* | *RLBI ~ N (4; 0)* | *ALBI ~ N (3; 0.15)* | *RLBI ~ N (4; 0)* |
| $DP_{3.2.3.1}$ | *ALBI ~ N (1; 0.3)* | *RLBI ~ N (3; 0)* | *ALBI ~ N (2; 0.4)* | *RLBI ~ N (4; 0)* | *ALBI ~ N (3; 0.3)* | *RLBI ~ N (4; 0)* |
| $DP_{3.2.3.2}$ | *ALBI ~ N (1; 0.5)* | *RLBI ~ N (3; 0)* | *ALBI ~ N (2; 0.6)* | *RLBI ~ N (4; 0)* | *ALBI ~ N (3; 0.2)* | *RLBI ~ N (4; 0)* |

The assumptions for the average amount of material received and processed by each agent as well as the performance measures are summarised in Table 6.10.

Table 6.10: Overview on the performance measures

| **Performance measures** | **Focal company** | **Supplier 1** | **Supplier 2** | **Supplier 3** | **Recycling centre** |
|---|---|---|---|---|---|
| Inventory cost of non-returned pallets (€/unit) | 4 | - | - | - | - |
| Inventory cost of non-returned packages (€/unit) | 2 | - | - | - | - |
| Cost of acquiring new pallet (€/unit) | - | 10 | 10 | 10 | - |
| Cost of acquiring new package (€/unit) | - | 5 | 4 | 4 | - |
| Time spent in planning RL operations (hour/day) | ~ N (4; 0.5) | ~ N (2; 0.15) | ~ N (2; 0.15) | ~ N (2; 0.15) | ~ N (2.5; 0.25) |
| Cost of planning RL operations (€/hour) | 1000 | 800 | 800 | 800 | 600 |

The assumptions related to the potential impact of the BIDSs on the operational performance of RL partners are shown in Table 6.11.

Table 6.11: Potential impact of the BIDSs on the performance measures

| **BIDS** | **Potential impact** |
|---|---|
| $BIDS_{3.1}$: A well-defined document that describes the role and responsibilities for each RL cooperating partner | Return rate of pallets and packages |
| $BIDS_{3.6.3.1}$: Mechanisms to provide timely information on the processing status of the components being remanufactured | Cost and time spent in production planning |
| $BIDS_{3.6.3.2}$: Mechanisms to provide timely information on the inventory level of the returnable products/materials | Cost and time spent in production planning; Return rate of pallets and packages |

Table 6.12 provides an overview on the probability of the impact on the performance measures, according to the achieved distance.

Table 6.12: Overview of the probability of the impact according to the business interoperability distance

| **BIDS** | **Performance measures** | **Impact based on the business interoperability distance (%)** | | | | |
|---|---|---|---|---|---|---|
| | | **0** | **-1** | **-2** | **-3** | **-4** |
| $BIDS_{3.1}$ | Return rate of pallets and packages | [95; 100] | [85; 94] | [65; 84] | [38; 64] | [0; 37] |
| $BIDS_{3.6.3.1}$ | Cost and time spent in production planning | 0 | [5; 12] | [13; 30] | [31; 60] | [61; 100] |
| $BIDS_{3.6.3.2}$ | Return rate of pallets and packages | [95; 100] | [85; 94] | [65; 84] | [38; 64] | [0; 37] |
| $BIDS_{3.6.3.2}$ | Cost and time spent in production planning | 0 | [5; 12] | [13; 30] | [31; 60] | [61; 100] |

### 6.4.1 Computational experiments and simulation outputs

In this application scenario the statistical analysis of the simulation outputs has not been conducted as simulation outputs have been grounded on a set of assumptions to 'get' data for the ABS model. Another reason for not analysing statistically the simulation outputs is that the purpose of this application scenario is to test and demonstrate the applicability of the proposed methodology through an application scenario, rather than to achieve generalization about the outputs obtained. As a result, 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. It has been assumed that there are six holidays during the year. In each quarter it has been discounted two holidays. The weekend days have also been discounted. Therefore, the simulation runs 255 (365 – 104 - 6) time periods (days) of 8h. The simulation run has been executed one time due to the reasons mentioned above. The average values for each performance measure considered in the application scenario are summarized in Table 6.13.

Table 6.13: Average values of the performance measures

| **Performance measure (average)** | **Focal company** | | **Supplier 1** | | **Supplier 2** | | **Recycling Centre** | |
|---|---|---|---|---|---|---|---|---|
| | **Total** | **Mean** | **Total** | **Mean** | **Total** | **Mean** | **Total** | **Mean** |
| Amount of returned pallets from the FC to | - | - | 3907 | 14.74 | 5854 | 22.09 | - | - |
| Amount of non-returned pallets from the FC to | - | - | 1388 | 5,24 | 2048 | 7,73 | - | - |
| Amount of returned packages from the FC to | - | - | 120246 | 452.49 | 23963 | 90.09 | - | - |
| Amount of non-returned packages from the FC to | - | - | 39146 | 147.72 | 7826 | 29.53 | - | - |
| Amount of non-returned pallets at the FC | 3439 | 13.10 | - | - | - | - | - | - |
| Amount of non-returned packages at the FC | 45659 | 174.72 | - | - | - | - | - | - |
| Total cost of acquiring new pallets at the suppliers (€) | - | - | 13880 | 52.37 | 20480 | 77.28 | - | - |
| Total cost of acquiring new packages at the suppliers (€) | - | - | 195730 | 738.60 | 31304 | 118.12 | - | - |
| Total inventory cost of non-returned pallets at the FC (€) | 13756 | 51.91 | - | - | - | - | - | - |
| Total inventory cost of non-returned packages at the FC (€) | 91318 | 344.60 | - | - | - | - | - | - |
| Total impact on the cost of planning RL operations (€) | 227622.55 | 858.95 | 152815.20 | 576.66 | 45376.29 | 171.23 | 117117.37 | 441.95 |
| Total impact on the time spent in planning of RL operations (hour) | 223.99 | 0.85 | 190.74 | 0.72 | 117.69 | 0.44 | 194.40 | 0.73 |

## 6.5 Summary

On the basis of the methodology described in previous chapter, this chapter demonstrated the applicability of such methodology through an application scenario to implement RL in a context of automotive industry. First, the theoretical Axiomatic Design model has been used to design a configuration for the automotive network considered, and then the theoretical ABS model has been applied to estimate the impact of the designed configuration on the performance of that network.

The results of such application scenario suggested that the Axiomatic Design Theory is a good starting point to design configurations of interoperable cooperative industrial network platforms and ABS a good starting point to analyse the impact of business interoperability on the performance of cooperative networked companies. The results also suggested that the combination of these two modelling methods is a great starting point towards a methodology for modelling business interoperability on the context of cooperative industrial networks.

# Chapter 7 Research philosophy, strategy and design

This chapter describes the methodological aspects of the research that were applied to design this research. In order to support the adopted research methodology, a review and a discussion on research philosophies, research process, research approaches, and research design are presented. Based on the nature of research questions addressed, the nature of the theoretical models, an on the resource limitations, the research design strategy is discussed. Finally, data collection methods, and data analysis and interpretation techniques used in the empirical validation part of the research are described.

*The methodological question cannot be reduced to a question of methods; methods must be fitted to a predetermined methodology (Guba and Lincon 1994) (p. 108)*

## 7.1 Research philosophy

### 7.1.1 Positivist versus constructivist paradigms

The *positivist* or *rational* stance is one of empirical validation – a belief in objective reality (Croom 2009). In other words, the main assumption of the positivist position, in its purest form, is that there exists an objective truth in the social world, which has certain properties that can be revealed through objective scientific methods (Grilo 1998), i.e. truth is viewed as an objective, innate product of pure reason (Croom 2009). It often involves measuring the relationships between specific variables, and for this reason it is often designated as quantitative research (Grilo 1998). The emphasis is on observable facts, derived from valid, reliable measurement, and providing results and conclusions which are replicable (verifiable) and generalizable (Croom 2009). According to Grilo (1998), the generic research approach of the positivist position has several specific cornerstones. However, the two most important ones are (1) researcher independence, i.e. the researcher must remain independent from the study object (Grilo 1998), or in other words, the world is external to the researcher (Croom 2009), and (2) theory or hypothesis-driven research, i.e. the research approach should start with a theory/hypothesis and data must be collected to test its veracity (Grilo 1998).

On the other hand, *constructivism* (or interpretivism) takes an opposite stance, one in which the researcher considers all observation and analysis to be socially constructed, that is, dependent upon the researcher as a participant (Croom 2009). Instead of gathering facts to measure how certain patterns occur and search for external causes to explain phenomena, research should focus on the appreciation of the different constructions and meanings of individuals and therefore try to understand and explain why people have different experiences (Grilo 1998). In this research paradigm, it is considered that the researcher(s) cannot be independent from the situation they are studying and that theory is generated or grounded from the data collected, i.e. research is more concerned with emergent themes and descriptions rather than hypotheses and theories (Grilo 1998).

In short, a positivist is one in which research is regarded as a process to find out the "facts", whilst a constructivist position is more concerned with research that attempts to make sense of, and to provide an interpretation of, the research phenomenon (Croom 2009). The main characteristics of each research paradigm are summarised in Table 7.1.

Table 7.1: Key characteristics of positivist and constructivist paradigms (adapted from (Grilo 1998) and (Easterby-Smith et al. 2002)

| | | ***Positivist*** | ***Constructivist/Interpretivist*** |
|---|---|---|---|
| Beliefs | Nature of the world | The world is external and objective | The world is socially constructed and subjective |
| | Observer | Must be independent | Is part of what is being observed |
| | Human interests | Science is value-free | Science driven by human interests |
| Researcher | Focus | On facts | On meanings |
| | Explanations | Must demonstrate causality and laws | Try to understand what is happening |
| | Unit of analysis | Should be reduced to simplest elements | Look at the totality of each situation |
| | Research approach | Formulate hypotheses and test them (deduction) | Develop ideas through induction from data |
| Methods | Generalisation through | Statistical probability | Theoretical abstraction |
| | Concepts | Need to be operationalised so that they can be measured | Using multiple methods to establish different views of phenomena |
| | Sampling | Large numbers selected randomly | Small numbers of cases chosen for specific reasons and investigated in-depth or over time |

Once described the two research paradigms characterised above, the next section provides a brief overview on the nature of quantitative and qualitative research methods in order to provide a more comprehensive rationale for the choice of the research design made in Section 7.4.

### 7.1.2 Quantitative and qualitative research

Quantitative and qualitative research methods are two broad categories used to describe the different approaches employed to understand the nature of data collection and analysis (Scanlon 2000). Ketokivi and Choi (2014) provide an interesting though on the distinction between these two broad categories of research methods:

*"For most of us, quantitative research refers to either large-sample research that relies on statistical inference (i.e. empirical quantitative) or mathematical and stochastic modelling (i.e. analytical quantitative). In contrast, qualitative research has typically been considered through what it is not.*

*Whatever is not quantitative or qualitative; what is not numerical data is textual (e.g. interviews); what is not deductive is inductive; etc. (p. 233).*

What is implicitly suggested in the above Ketokivi and Choi (2014)' statement is that the distinction between quantitative and qualitative research is often made based upon whether the research uses numerical data or not, or on whether the research uses mathematical and statistical tools to manage the analysis of these numerical data or not (see e.g. (Croom 2009)). This is referred, for example, in Spens and Kovács (2006) in the following statement: *"Quantitative methods are generally associated with numerical (quantifiable) data, and in particular, numerical data analysis. Qualitative methods, on the other hand, collect non-numerical data"*. However, as recognised by Spens and Kovács (2006), collecting quantitative data does not necessarily imply a quantitative data analysis. Taking into account these issues, Ketokivi and Choi (2014) advocate that in the qualitative–quantitative distinction, what is central is one's fundamental theoretical orientation, not the data or the analysis method used. Therefore, they submit that such distinction is misleading and, as a result, they suggest that instead of focusing on the nature of the data used, one should adopts definitions of quantitative and qualitative research based on the meaning of the words quantitative and qualitative, that are:

- ***Quantitative***: research approach that examines concepts in terms of amount, intensity, or frequency;
- ***Qualitative***: research approach that examines concepts in terms of their meaning and interpretation in specific contexts of inquiry.

In the words of Croom (2009), the distinction between the extreme stereotypes of these two types of research methods is thus fundamentally one of recognition of the influence of interpretation and subjective perception, which in turn is reflected in the research methods employed in the execution of the study. Therefore, a clear distinction between these two types of research is required, as claimed by Ketokivi and Choi (2014). With respect to this, the term quantitative research is employed in this thesis to refer to the research methods which basically incorporate a process of observation, with data collection achieved through such processes as laboratory controlled by experiments or structured surveys (Croom 2009). One of the key characteristics of such kind of research is the adoption of deductive approach, setting out to test hypotheses in order to build upon an existing body of knowledge in the particular sphere of interest (Croom 2009). The emphasis is put on the importance of measurement and analysis of causal relationships between variables, rather than processes (Silverman 1997).

The validity of a quantitative research is adjudged to be attained through the logic of a common, structured process, much akin to the "seven-step scientific method" commonly used in physical sciences such as chemistry (Croom 2009). By contrast, qualitative researches are at their extreme concerned with constructivism, interpretation and perception, rather than with identification of a rational, objective truth, i.e. the emphasis is upon a socially constructed nature of reality (Croom 2009). Qualitative researches variously recognise and attempt to account for the significance of interpretation, perception and interaction in the process of defining, collecting and analysing research evidence (Croom 2009). To Maxwell (2005), the strengths of qualitative research derive primarily from its inductive approach, its focus on specific situations or people, and its emphasis on words rather than numbers. Denzin and Lincoln (2000) share a similar point of view by pointing out that the term "qualitative" implies "an emphasis on the qualities of entities and on processes and meaning that are not experimentally examined or measured in terms of quantity, amount, intensity and frequency. It is important to highlight here that although qualitative research tends to focus on words rather than numbers, as pointed out by Maxwell (2005), the point to make is that qualitative approaches are not devoid of quantification as numbers can be ascribed to subjective and "qualitative" variables (Croom 2009).

In short, Curry et al. (2009) assert that qualitative research can be distinguished from quantitative research in the following ways: first, whereas quantitative research counts occurrences (e.g., estimates prevalence, frequency, magnitude, incidence), qualitative research describes the complexity, breadth, or range of occurrences or phenomena; second, whereas quantitative research seeks to statistically test hypotheses, qualitative research seeks to generate hypotheses about a phenomenon, its precursors, and its consequences; third, quantitative research is performed in randomized or nonrandomized experimental and natural settings and generates numeric data through standardized processes and instruments with predetermined response categories. Qualitative research occurs in natural (rather than experimental) settings and produces text-based data through open-ended discussions and observations.

To conclude, it is to notice that whilst quantitative and qualitative researches are distinctive, they are not incommensurate with each other. For example, case research often involves both quantitative and qualitative methods in the research design (Croom 2009).

### 7.1.3 The philosophical position of this thesis

The objective of this research is to understand how we can design interoperable industrial networks platforms and how we can analyse the impact of business interoperability on the performance of these network platforms. In order to position this research philosophically, a balanced view of the different philosophical questions underlying research paradigms and methods have been provided in the previous section. Taking into account the objective and nature of this research, this section attempts to clarify the researcher's own position underlying the research philosophy of this thesis, but without arguing about merits of alternatives. Rather, the discussion will be on how well the selected philosophical positions fit into the objective and nature of this research.

The approach adopted to clarify the philosophical position is the one suggested by Guba and Lincon (1994), which has been adopted, for example, by Powell (2012) – the two debated philosophical paradigms (positivist and constructivism) are matched according to each of the three questions that a researcher faces when describing the scientific approach for his or her research (ontology, epistemology and methodology). Starting by the ontological question, this research considers that the social phenomena under study, i.e. the impact of business interoperability on the performance of cooperative industrial networks, is an "objective reality", external and independent of social actors. In other words, it is considered that the way companies interact in cooperative industrial networks and the way business interoperability can affect their performance can be analysed from the outside and their meanings have an existence that is independent of social actors. This contrasts with the subjectivist perspective, which would consider that cooperative industrial networks are socially constructed, and therefore they would be understood only from the point of view of individuals who are directly involved in its activities.

In short, it is considered that the general rules and cause-and-effect-like relationships about how different levels of business interoperability in dyad relationships within a cooperative industrial network can affect the performance of companies within this network can be studied, captured, and understood from the outside through objective scientific methods. Therefore, from the ontological point of view, this thesis tends to take the ontological position of positivist. With regard to the epistemological question, this thesis's philosophical position is also slanted toward the positivist paradigm, as the researcher and the study object (cooperative industrial networks) are assumed to be independent entities, and the investigator capable of studying the object without influencing it or being influenced by it (see (Guba and Lincon 1994)). In other words, the researcher remains independent and it is assumed that his personal beliefs and experiences will not have any effect on the results, as required in positivist paradigm. This contrast with the epistemological position of a constructivist in which the investigator and the object of investigation are assumed to be interactively linked so that the "findings" are literally created as the investigation proceeds (Guba and Lincon 1994), as made in action research (see e.g. (Powell 2012)).

In addition to the researcher independence, as an engineer, he would like to think that his findings are true, even though one cannot ever be sure of reaching the certainty about truth (Popper 2002), cited by Grilo (1998). It is to notice that this is consistent with the positivist position adopted for the ontological question, i.e. because an "objective reality" has been assumed for the ontological question, the researcher adopted a detachment posture towards the study object in order to discover "how cooperative industrial networks really are" and "how cooperative industrial networks really work", as recommended by Guba and Lincon (1994). Last, depending on the positions adopted for the ontological and epistemological questions, there is usually a specific choice as to the researcher's methodological position, that are quantitative or qualitative Powell (2012).

Since a positivist position has been adopted for both ontological and epistemological questions, a positivist position would be "required" for the methodological question in order to maintain consistence. It would imply the adoption of a quantitative research as required by positivist paradigm. Although this research follows a deductive approach (see Section 7.2), which suggests that a positivist paradigm should be taken and therefore the use of quantitative methods (e.g. (Guba and Lincon 1994)), the point to make is that as cooperative industrial networks are complex in nature, involving several companies over time, non-linear relationships and non-linear effects, as has been discussed throughout this thesis (see e.g. Chapter 2), this suggests that qualitative methods would be required to capture the details of the interactions among networked companies and the impact of business interoperability on their performance, and therefore the use of a constructive or interpretive position.

Taking insight from the concepts of quantitative and qualitative research discussed in Section 6.1.2, it is to emphasise here that this thesis is not concerned with the collection of data through such processes as laboratory controlled by experiments or structured surveys but with the interpretation and perception of the way how companies interact in cooperative industrial networks and how different levels of business interoperability can affect their performance. This implies that qualitative data have to be collected in order to describe qualities and meanings of social interactions among companies, which are difficult to describe using only measures such as quantity, intensity or frequency. As pointed out by Meredith (1998),*"quantitative understanding presupposes qualitative meaning, that is, researchers cannot benefit from their use of numbers if they cannot communicate, in common sense terms, what their numbers mean (such as the "cost of quality" or even something as apparently straightforward as "order size")*. For example, when we are to evaluate the levels of business interoperability in the dyad relationships, those levels must be evaluated in a way so that they reflect a meaning. In other words, if we only assign a number to each level, for example, 0, 1, 2, 3 and 4, the natural question would be "what does it means each number?" Considering all these factors, from the methodological point of view, interpretivism is considered to be the appropriate paradigm for this research, and therefore the use of qualitative research, although Croom (2009) suggests that interpretivism is not very much suited to the quantitative methods which characterise positivist position (adopted for the ontological and epistemological questions).

Considering these rationales, from the methodological point of view, qualitative methods are seen to be the appropriate for this thesis, implying that a constructive or interpretive position should be adopted, instead of a positivist position where quantitative methods are usually employed. Indeed, this idea of using qualitative research embedded in a "positivist" framework is not new. For example, in his study on the development of electronic trading between companies, Grilo (1998) used qualitative methods, namely case studies as part of the research strategy but embedded in a "positivist" framework. In the same work, the author agrees that the two things – positivism and qualitative methods, are not necessarily in conflict. As pointed out by Voss et al. (2002), case research is used for both hypothesis testing and theory development.

## 7.2 Research approach

The term "research approach" is employed in this thesis to refer to the thinking and action processes which represent the different ways of reasoning and the specific series of actions that distinguish naturalistic and experimental-type investigators in the conduct of their research (DePoy and Gitlin 2010). It questions how the arguments are built (Karlsson 2009), or in other words, how *theory* is developed. Putting it in simple, it is concerned with the nature of the relationship between theory and research, in particular whether theory guides research (known as a deductive approach) or whether theory is an outcome of research (known as an inductive approach) (Bryman and Bell 2011). A *theory* is a scheme or system of ideas or statements held to explain a group of facts or phenomena; a statement of general laws, principles, or causes of something known or observed (Gill and Johnson 2010). It is an attempt to explain how a system or phenomenon works by identifying the constituent elements of the system and how they interact and relate to each other, and theories consist of a collection of logically interrelated *propositions* that aim to explain a set of phenomena (Croom 2009).

A *proposition* is a statement in which some relationship between two or more concepts or variables is proposed (Croom 2009). An analysis of the literature on research methodology and/or research methods (e.g. (Hyde 2000, DePoy and Gitlin 2010, Gill and Johnson 2010, Bryman and Bell 2011)) reveals that there are two general approaches to reasoning which may result in the acquisition of new knowledge or development of theory, namely inductive reasoning and deductive reasoning, as illustrated by Figure 7.1.

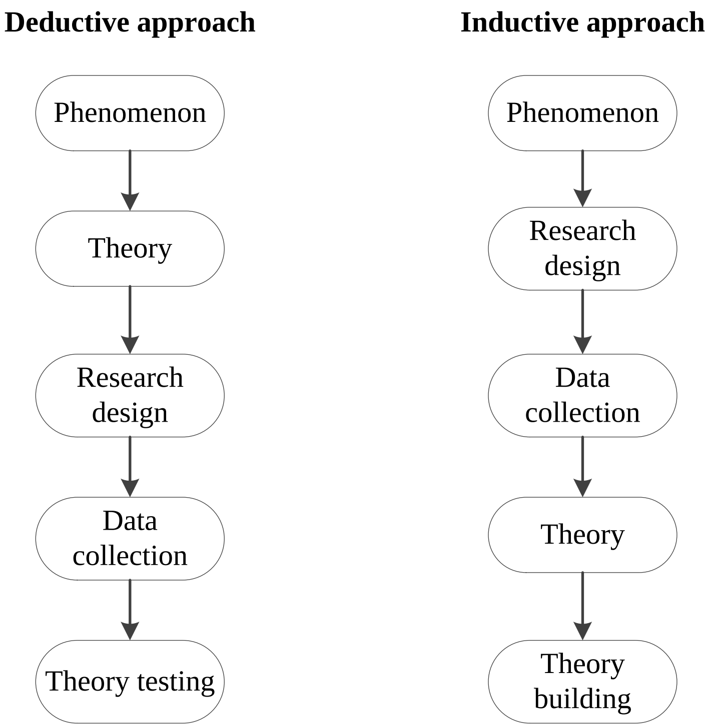



Figure 7.1: Deductive versus inductive research approaches (adapted from (Berg 2001)) (p. 18)

As illustrate by figure above, the a deductive approach, often referred to as theory-testing process, is an approach which commences with an established theory or generalisation, and seeks to see if the theory applies to specific instances (Hyde 2000). It starts by taking a position on a theory, applying it to data to reach a conclusion (Karlsson 2009). On the other and, inductive research approach, often referred to as theory-development or theory-building process, is an approach that starts with observations of specific instances and seeks to establish generalisations about the phenomenon under investigation (Hyde 2000). It is an approach that starts with something observed empirically, trying conclusions to find a theory (Karlsson 2009).

With regard to this thesis, the research approach followed is deductive, as it is proposition-driven, i.e. it started with the statement of a theory in the form of two propositions (see Section 1.3) and two theoretical models (see Section 5.4 and 5.5), and then data have been collected to test or validate the propositions and the theoretical models. It is to notice that this choice is consistent with the ontological and epistemological position of a positivist implied throughout this thesis, as positivist researches usually follow a deductive approach. On the other hand, with regard to the methodological question, it is to refer that such choice is not consistent with the choice for qualitative research made in Section 7.1.3, as deductive approaches are referred to be applicable in quantitative researches. However, as noticed by Forza (2009), hypothesis generation and testing can be achieved both through the process of deduction and the process of induction.

## 7.3 Research strategy

Once identified the philosophical position and the research approach underpin this thesis, it is now important to identify which research strategy is most appropriate for the investigation of the research questions addressed in Section 1.3. This is a critical step as it will determine which research design technique will be used to collect data in order to validate the theoretical models proposed in Section 5.4 and 5.5. Within the context of this thesis, the term research strategy is defined as the overall configuration by which data collection and analysis will be conducted. It refers to the strategy of data collection and analysis rather than the interpretation of empirical findings (Croom 2009). In Section 7.1.3, it has been concluded that for the methodological question qualitative research is more appropriate than quantitative research. An analysis to the literature made it possible to identify a range of commonly research strategy used in qualitative researches. For example, Croom (2009) lists the following: surveys, case research, longitudinal and ethnographic research, action research, true experiments, and quasi-experiments. Yin (2003) highlights experiment, survey, archival analysis, history and case study. As there is no clear link between the epistemology and the choice of research strategy in social science research studies, and from a technical perspective there is no clear dichotomy between qualitative and quantitative research strategies, an important issue, therefore, is that one chooses the most appropriate strategy for the investigation of the research question(s) (Croom 2009).

### 7.3.1 Case study research

There is no standard definition of what a case study research is (Benbasat et al. 1987), which implies that authors often have different and sometimes conflicting views about what a case research should be (Grilo 1998). Indeed, the analysis of the collected literature made it possible to state that there are many definitions of case study research. For example, Leonard-Barton (1990) defines it as “a history of a past or current phenomenon, drawn from multiple sources of evidence, including, for instance, data from direct observation and systematic interviewing as well as from public and private archives – in fact, any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study, since context is important”. Meredith (1998) defines it as “a research strategy that typically uses multiple methods and tools for data collection from a number of entities by a direct observe(s) in a single, natural setting that considers temporal and contextual aspects of the contemporary phenomenon under study, but without experimental controls or manipulations”.

Yin (2003) contributes with the following definition: "an empirical inquiry that investigates a contemporary phenomenon within real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Croom (2009) provides the following definition: "an empirical research that uses data from case studies, either alone or triangulated with data from other sources, as its basis. Beverland and Lindgreen (2010) cite the definition put forward by Creswell (1998): "an exploration of a "bounded system" [bounded by time and place] or a case (or multiple cases) over time through detailed, in-depth data collection involving multiple sources of information rich in context". Barratt et al. (2011) put forward the following definition: "an empirical research that primarily uses contextually rich data from bounded real-world settings to investigate a focused phenomenon". To Voss (2009), case research is simply a method that uses cases studies as its basis. Within this context, a case study is a unit of analysis in case research (Voss 2009).

By analysing the definitions provided above, it is possible to conclude that case study research is about performing a detailed description of an organisation, incident or phenomenon (Croom 2009). Other relevant characteristics that can be identified are the use of multiple methods and tools for data collection and analysis – but case studies are developed using either one or several research methods (Croom 2009), the use of multiple sources of evidence, the focus on contemporary phenomena within real-life context, and the collection of rich or in-depth data from real world settings. These characteristics are in line, for instance, with the Barratt et al. (2011)' statement: "the intent of case research is to build and extend theories and to explore and better understand emerging, contemporary phenomena or issues in their real world settings" and the Croom (2009)' statement: "arguably one of the reasons for the popularity of case research is the variety of methods and methodologies that can be employed to construct case analyses". According to Wacker (1998), the purpose of case research is to develop insightful relationships within a limited set of companies, i.e. by limiting the number of companies investigated, this research strategy investigates small samples using a large number of variables to identify new empirical relationships.

Case research has consistently been one of the most powerful research methods in OM, particularly in the development of new theory (Voss et al. 2002). Case research in OM differs from case research in the wider social science field in that researchers are interested in analysing the manufacturing and service processes and systems of the plant. Thus research design in OM should pay attention to what processes and systems are to be studied, the methods for studying them, and the operating data to be collected from them (Voss et al. 2002). Perhaps for this reason, it is not surprising to find that case studies in OM are typically labelled qualitative (Ketokivi and Choi 2014).

It is to notice here that case research as the survey research, can be used for different purposes. Yin (2003) distinguishes three types of case researches, depending on the type of research question addressed:

1 ***Exploratory case research***: aimed at defining the questions and hypotheses of a subsequent study (not necessarily a case study) or at determining the feasibility of the desired research procedure;
2 ***Descriptive case research***: presents a complete description of a phenomenon within its context;
3 ***Explanatory case study***: comprises data bearing on cause-effect relationships – explaining how events happened.

### 7.3.2 Rationale for the chosen strategy: case study research

In previous section, a brief overview of the research strategies has been provided. In this section, the rationale for the chosen strategy, namely case research is provided. The approach to support the choice for the chosen strategy is the same that has been used in to explain the choice for the Axiomatic Design Theory and ABS respectively, i.e. first it is presented the rationale for not using the alternatives strategies and then it is presented the rationale for choosing case research.

In line with Yin (2003), the choice of the research strategy should be made according to the research situation, as each strategy has its own specific approach to collect and analyse empirical data, and therefore each strategy has its peculiar advantages and disadvantages (Grilo 1998). It is to notice that so far the two research questions addressed in Section 1.3 did not play any role in the choice of, for example, the research philosophy or research approach, but they will play a fundamental role in the choice of the most appropriate research strategy. This is because Yin (2003) suggests that the type of question posed, along with the control an investigator has over actual behavioural events and the degree of focus on contemporary as opposed to historical phenomena are the relevant situations which should support the choice of the most appropriate research strategy.

By defining the research questions as "how can we design …?" and "how can we analyse the impact of business interoperability on the performance of…?", it is easily concluded that the form of these research questions are of *"how"* type. According to Yin (2003), the *'how'* question is more explanatory and likely to lead to the use of case studies, histories, and experiments as the preferred strategies. This is because the *"how"* and *"why"* questions deal with operational links needing to be traced over time, rather than mere frequencies or incidence (Yin 2003). Considering that the form of research questions posed are of *"how"* type, survey research is not considered to be appropriate for this research. In addition, surveys can try to deal with phenomenon and context, but their ability to investigate the context is extremely limited (Yin 2003). Through survey research, it would be very difficult to perform an in-depth investigation of the impact of business interoperability on the performance of networked companies, as survey requires large sample, which would be very difficult to achieve in the context of this research.

Considering the rationales discussed above, case research is then regarded as the most appropriate research strategy to answer the research questions that have been addressed in Section 1.3. According to Yin (2003), there is no formula to answer the question "How do we know if we should use the case study research?", but our choice depends in large part on our research questions. The author advocates that the more our research questions seek to explain some present circumstance (e.g. *"how"* or *"why"* some social phenomenon works or occurs), the more case study research will be relevant.

The choice of the case research strategy derives not only from the fact that the research questions in this thesis is of "how" form, but also because it provides ability to investigate contemporary phenomenon within some real real-life context (Yin 2003), as are the example of the impact of business interoperability on the performance of cooperative industrial networks. It is also appropriate because the researcher has no control over the events (Yin 2003), i.e. over the impact of business interoperability problems on the performance of cooperative industrial networks. Yin (2003) also advocates that this strategy is also relevant the more our questions require an extensive and "in-depth" description of some social phenomenon, as is intended in this research. One of the main advantages of case research, when compared with survey, for example, is that it increases the chance of being able to determine the link between cause and effect, something that is difficult in survey research (Voss et al. 2002). This is important in this research, as the aim is to understand how different levels of business interoperability problems (cause) affect the performance of cooperative networked companies (effect).

There are also several outstanding strengths of the case research strategy, which may contribute to support its choice for this thesis. For example, Meredith (1998) cites three of those strengths put forward by Benbasat et al. (1987): (1) the phenomenon can be studied in its natural setting and meaningful, relevant theory can be generated from the understanding gained through observing actual practice; (2) the case strategy allows the much more meaningful question of *why*, rather than just *how* and *what*, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon; and (3) the case strategy lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood. Voss et al. (2002) also point out three relevant strengths of case research: (1) the results of case research can have very high impact – unconstrained by the rigid limits of questionnaires and models, it can lead to new and creative insights, development of new theory, and have high validity with practitioners – the ultimate user of research; (2) through triangulation with multiple means of data collection, the validity can be increased further; and (3) case research enriches not only theory, but also the researchers themselves, as through conducting research in the field and being exposed to real problems, the creative insights of people at all levels of organisations, and the varied contexts of cases, the individual researcher will personally benefit from the process of conducting the research.

### 7.3.3 Challenges of case study research strategy

Case research as any research method or strategy, poses the researcher some challenges when conducting such kind of research. Some of these challenges are the requirements of direct observation in the actual contemporary situation (cost, time, access hurdles); the need for multiple methods, tools, and entities for triangulation; the lack of controls; and the complications of context and temporal dynamics (Meredith 1998). Voss (2009) stresses that some of the challenges in conducting case research are: it is time consuming, it needs skilled interviewers, car is needed in drawing generalizable conclusions from a limited set of cases and in ensuring rigorous research. Another challenge of the case research strategy is the lack of familiarity of its procedures and rigor by researchers (Meredith 1998). Perhaps for those reasons, qualitative research in general is commonly perceived as exhibiting a tendency for construct error, poor validation, and questionable generalizability (Meredith 1998).

## 7.4 Research design

### 7.4.1 Brief overview

Having in Section 7.3.2 identified the research strategy for this thesis, the next task is to design the case study. In the most elementary sense, research design can be defined as the logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions (Yin 2003). The term is usually employed by researchers to refer to a framework for the collection and analysis of data (Bryman and Bell 2011). Putting it simple, it is a plan that guides the investigator in the process of collecting, analysing, and interpreting data (Yin 2003). As its main purpose is to help to avoid the situation in which the evidence does not address the initial research questions, a research design deals with a logical problem rather than a logistical problem (Yin 2003). The choice to be made in research design reflects decisions about priority to be given regarding the methods for data collection, data analysis, unit of analysis, sampling, triangulation of data and research validity. As the research strategy of this thesis is case research, such a choice also includes decisions on whether single or multiple case studies should be adopted.

As a crucial aspect of the research design is to have a close linkage between the empirical part (data collection and analysis) with the theoretical part of the study (Grilo 1998), this research started with an in-depth literature review (Chapter 1, 2 and 3) in order to identify the research gaps and then formulate the research questions and corresponding propositions, which according to Yin (2003) are two of the five components of a research design that are especially important for case studies. The other three components referred by Yin (2003) are: unit of analysis, the logic linking the data to the propositions, and the criteria for interpreting the findings. From such in-depth literature review, it was concluded that there are no models and/or frameworks that enable researchers to design interoperable cooperative industrial network platforms, taking a holistic perspective (i.e. including all the required dimensions of business interoperability). As a result, two research questions and two propositions were formulated (see Section 1.3). Such literature review also enabled the identification a set of variables that characterise the problems of business interoperability in cooperative industrial networks. These variables were used to develop the two theoretical models described in Section 5.4 and Section 5.5. Based on those theoretical models, dyad relationships among cooperative networked companies were defined as the unit of analysis of the case studies.

In order to achieve theoretical replication and/or to demonstrate the applicability of those theoretical models in different industrial contexts, multiple case studies approach was adopted rather than single-case study. Specifically, two case studies have been chosen to be object of the study, which have been analysed individually (within-case analysis) and compared with each other (cross-case analysis). Semi-structured face-to-face interviews and documentation were the two most used methods for collecting data. Last, the quality of research design was evaluated using the four criteria usually used in qualitative case study research (e.g. (Yin 2003, Voss 2009, Beverland and Lindgreen 2010)): construct validity, internal validity, external validity and reliability. The remainder of this chapter provides the rationale and full description of the decisions and procedures that have been made in the research design phase.

### 7.4.2 Unit of analysis

Once the research focus has been specified and the research questions have been articulated, the unit of analysis must then be clearly specified (Barratt *et al.* 2011), as this is of critical importance to any research design (Yin 2003) and can help, for example, identify applicable extant literature that can help clarify the phenomenon under investigation (Barratt *et al.* 2011). In addition, when the unit of analysis is unclear, this influences the research questions and outcomes (Yin 2003) (cited in (Barratt *et al.* 2011), (p. 330)). However, the definition of the unit of analysis is not obvious in some researches (Forza 2009). For example, Yin (2003) argues that this is a problem that has plagued many investigators at the outset of case studies, as they often encounter several types of confusion in defining the unit of analysis.

In an abstract way, Miles *et al.* (2013) refer to unit of analysis as a phenomenon of some sort occurring in a bounded context. To Yin (2003), unit of analysis is related to the fundamental, of defining what the "case" is, i.e. is where the focus is (Miles *et al.* 2013). In OM research, the unit of analysis may be individuals, dyads, groups, plants, divisions, companies, projects, systems, etc. (Forza 2009). As these units of analysis are often embedded in different contexts, the definition of the boundary becomes important as it determines the limits of data collection and analysis (Yin 2003). Boundaries can be simply defined by what will not be studied (Miles *et al.* 2013). If the unit of analysis is a small group, for instance, the persons to be included within the group (the immediate topic of the case study) must be distinguished from those who are outside it (the context for the case study) (Yin 2003). Also, specific time boundaries are needed to define the beginning and end of the case (Yin 2003).

In this research the level of analysis, i.e. the "case" is the cooperative industrial network. However, to capture the variables related to business interoperability phenomenon throughout the cooperative industrial network, the unit of analysis is the individual dyad relationships that belong to the same cooperative industrial network. The focus on individual dyad relationships as the unit of analysis rather than on the individual companies derives mainly from the fact that business interoperability is a property of business relationships, which clearly requires the investigation of dyad relationships (see e.g. (Håkansson 1982, Håkansson and Snehota 1989)). This means that instead of analysing how individual companies influence each other, the focus of this research is on how dyad relationships influence the companies belonging to the neighbours' dyads, in the same network. In addition, the focus on individual dyad relationships as the unit of analysis rather than on the cooperative industrial network as a whole derives mainly from the need to understand the network effect, i.e. how different levels of business interoperability in one or more dyads affect the performance of companies belonging to other dyads in the same network. This is why ABS has been assumed to be the appropriate method for addressing the Research Question 2, as it enables us to explore how individual elements of a system or network influences each other.

If the unit of analysis was the cooperative industrial network as a whole, systems dynamics should be assumed to be the appropriate method for addressing the Research Question 2, rather than ABS (see Section 4.4.5). As has been concluded in Chapter 2, this research adopts a relationship perspective but embedded in a network approach. Also, as there are a high number of factors affecting dyad relationships in cooperative industrial networks, there is a need to limit the number of factors to be studied. In terms of the factors to be studied, some of them were excluded, e.g. the factors related to the knowledge management. We had also to limit the boundary of the dyads that we are interested in studying. For example, within the context of this research, it does not make sense to define as the unit of analysis the dyad involving the SGPU (Sistema Integrado de Gestão de Pneus Usados) operators with other companies that are not part of SGPU.

### 7.4.3 Case study design: multiple cases

There is a wide set of choices in designing and conducting case research. These include how many cases are to be used, case selection and sampling (Voss 2009). This research adopted a multiple-case design approach as the researchers would like to consider multiple experiments, that is, to follow a "replication" logic (e.g. (Yin 2003)), and to add confidence and achieve more robust conclusions (e.g. (Grilo 1998)). The logic behind the multiple case studies design in this thesis was to carefully choose each case so that it either (i) predicts similar results (a literal replication) or (ii) predicts contrasting results but for predictable reasons (a theoretical replication) (Yin 2003, Voss 2009).

Having chosen the type of case study design, a second choice is concerned with the issues of case selection and sampling. As stated by Voss (2009), if multiple case studies are to be used for research, then a vital question is the case selection or sampling. In other words, when using a multiple-case design, a further question the investigator will encounter has to do with the number of cases deemed necessary or sufficient for his/her study (Yin 2003). With regard to this, Yin (2003) advocates that replication logic, whether applied to experiments or to case studies, must be distinguished from the sampling logic commonly used in surveys. In other words, the goal is analytic generalisation rather than statistical generalisation (Yin 2003), as made, for example, in survey research. Indeed, adopting the sampling logic in this research would be a "little hard" as it would require an operational enumeration of the entire universe or pool of potential respondents and then a statistical procedure for selecting a specific subset of respondents to be surveyed (Yin 2003). Moreover, Yin (2003) suggests that the application of the sampling logic to case studies would be misplaced because: (1) case studies are not the best method for assessing the prevalence of phenomena; (2) a case study would have to cover both the phenomenon of interest and its context, yielding a large number of potentially relevant variables – in turn, this would require an impossibly large number of cases – too large to allow any statistical consideration of the relevant variables; (3) if a sampling logic had to be applied to all types of research, many important topics could not be empirically investigated.

Regarding the number of cases, the initial objective was to have at least one cooperative network (case) by each of the following types of industries: automotive industry, construction industry, aircraft industry and innovation network. The main rationale behind this was to test the applicability of the theoretical models proposed in Section 5.4 and Section 5.5 in different and contrasting industrial contexts in order to reinforce the conclusions on the assumptions that have been made in Section 1.3, and to obtain not only vertical but also horizontal conclusions. However, the possibility of conducting multiple case studies would be constrained by its requirements for extensive resources and time, especially because data from different dyad relationships in the same cooperative industrial network would be needed, which would become a major issue for a single researcher. In addition to this, and contrary to the researcher expectations, it was difficult to have access to the cases identified above. As a result, "only" two cases were investigated. The difficulties faced by the researcher to get access to the cases as well as the rationale behind the choice of the cases are provided in the next section.

### 7.4.4 Selecting cases

To achieve the desired literal and theoretical replication objectives, and therefore avoid biased results that are likely when dealing with a small numbers of cases, the selection of the case studies must be purposeful rather than random (Yin 2003, Miles *et al.* 2013). Based on this argument and those provided in the previous section, it was decided that the case studies used in this research should satisfy the following set of criteria: (1) willingness to participate in the study; (2) having implemented a cooperative management practice, preferentially RL and collaborative product development/design (as the proposed methodology was mainly tested through application scenarios to implement these cooperative management practices); (3) preferentially automotive, construction, aircraft and innovation industrial networks; (4) have the "main" entities operating in Portugal, and (5) having a "considerable" and "significant" number of interactions among the parties, rather than single and occasional transactions. The decision to limit the cases selection to Portuguese industrial networks can be explained by the reason that interviews were defined to be the main method for collecting data, and therefore resources for conducting interviews out from Portugal were limited, both in terms of money and time. Once the criteria for choosing the cases are set, a sample of cooperative industrial networks, which meets all or part of the criteria listed above, was identified to participate in this research. Specifically, three automotive industrial networks, one RL network, one construction network and one aircraft industrial network were listed. From this list, a RL network (Valorpneu network) and a construction network (Dam Baixo Sabor network) accepted to participate in this investigation (see Chapter 8).

### 7.4.5 Data collection method

One of the major issues when it comes to collecting data in case studies research is the development of a case study protocol, especially if we are doing a multiple case study (Yin 2003). It is an especially effective way of dealing with the overall problem of increasing the reliability of case research and is intended to guide the researcher in carrying out the data collection from a single case study (even if the single case is one of the several in a multiple case study) (Yin 2003). On this basis, a case study protocol was prepared based on the Yin (2003)' book (see Appendix A).

With regard to the data collection methods, Forza (2009) argues that data can be collected in a variety of ways, in different settings and from different sources. In case study research, Yin (2003) suggests that evidences may come from six main sources: documents, archival records, interviews (semi-structured, structured or unstructured), direct observation, participant-observation, and physical artifacts. Other sources of data can include informal conversations, attendance at meetings and events, surveys administered within the organisation (Voss 2009), films, photographs, and videotapes (Yin 2003). In this research, interviews and documentations were the core of the data collection, even though recognising the challenges associated with them. For example, for interviews: (i) it may be difficult to secure the interview itself, (ii) the access to people may be denied for a number of reasons, including the informants' busy schedule, their reluctance to spend time with "students", politics in the company, and sensitiveness associated with the confidentiality of information, (iii) organising, preparing for and conducting an interview can often be very time consuming (Altinay and Paraskevas 2008a), (iv) bias due to poorly constructed questions, and (v) response bias (Yin 2003). For documentation, the main challenges are: (i) access may be deliberately blocked, (ii) retrievability can be low, (iii) can be biased selectivity, if collection is incomplete and (iv) can reflects (unknown) bias of author (Yin 2003).

In the case study conducted in the Valorpneu network, data collection was carried out primarily through semi-structured face-to-face interviews. The rationale for choosing interviews was to get insightful, i.e. to get perceived causal inferences from the interviewees (Yin 2003), as "how" questions were posed. In other words, it was intended to profit from managers' perception on the facts of a matter as well as their opinions about events (Yin 2003) regarding the way how companies interoperate in the ambit of SGPU, and how business interoperability affects the performance of these companies. Also, in some situations, it was intended to ask the respondent to propose his or her own insights into certain occurrences (Yin 2003), e.g. how a certain business interoperability problems occurs and how they could be overcome, or what are the main reasons for occurring many or few business interoperability problems in the ambit of the network their companies belong to.

Face-to-face interviews were chosen because they provide flexible instruments to become familiar with the object studied, while providing a flexible mode of data gathering (Yin 2003). In addition, it was necessary to discuss and/or clarify the doubts or misunderstanding about the questions and answers (Cabral *et al.* 2012). The rationale behind the semi-structured interviews was of the need to update or change the sequence of questions whenever evidences that were not planned for the interview emerged. Other sources of evidence, such as annual reports, trimestral newsletter, and companies' website, were used to augment and complement the evidences achieved during the interviews. For example, the information on the operational performance of SGPU over the years was gathered from the annual reports, available on the Valorpneu' website[16]. The interviews were based around a case study protocol, developed specifically for this case study.

On the other hand, in the Dam construction project, interviews were not so much used, as most of the information that was needed for validating the theoretical ABS model was available in documents. Complementary information was gathered via email and skype contacts with one of the Consulgal analysts involved in the Dam construction project. The supervisor of this thesis also provided some meaningful information such as the description of the workflow, the structure of the network, etc. On this basis, this case study did not imply the preparation of a case study protocol, neither the identification of the respondents. In both case studies, triangulation through the use of multiple sources of data on the same phenomenon (e.g. in the Valorpneu case study – interviews, annual reports, quarterly newsletter and website) was used to provide increased reliability of data (Barratt *et al.* 2011). Triangulation can simply be defined as "the use and combination of different methods to study the same phenomenon (Voss 2009).

Another important issue to be clarified here is that in order to assist the researcher during the interviews that have been conducted in the ambit of the Valorpneu case study, different interview guides were prepared (see Appendix B), for each of the interviews. An interview guide is "a rather vague term that is used to refer to the brief list of memory prompts of areas to be covered that is often employed in unstructured interviewing or to the somewhat more structured list of issues to be addressed or questions to be asked in semi-structured interviewing" (Bryman and Bell 2011). The reasons for developing such interview guides are mainly associated with the evaluation of the ALBI and the RLBI, and are threefold. Firstly, it was necessary to ensure that all the interviewees would interpret the description of the levels of business interoperability in the same way, decreasing in this way the potential bias in their answers. Secondly, letting the description of each maturity level to the criteria of each manager interviewed would be impracticable and time-consuming. In addition, it would add bias and hinder the data analysis. Thirdly, it was necessary to include the description of each maturity level in the interview guide, as it would be impracticable, time-consuming and difficult for the interviewer to explain each level during the interview.

[16] http://www.valorpneu.pt/

The questions included in those interview guides were of two types. The questions regarding the mechanisms of cooperation used in the ambit of SGPU was of open-ended type, i.e. allowing respondents to answer in any way they choose (Forza 2009) and those regarding the evaluation of the ALBI and RLBI of closed type, i.e. limiting respondents to a choice among alternatives given by the researcher (Forza 2009). One of the concerns taken into the account in the preparation of those interview guides was to ensure that the language of the questionnaire is consistent with the respondent's level of understanding, as if a question is not understood or is interpreted differently by respondents, the researcher will get unreliable responses to the question, and these responses will be biased (Forza 2009). Therefore, one of the decisions was not to use the term “interoperability” or “business interoperability” in the interview guide neither during the interviews. Another important concern is that although closed questions facilitate quick decisions and easy information coding, the researcher has to ensure that the alternatives are mutually exclusive and collectively exhaustive (Forza 2009), in order to avoid hesitation among the choices. Therefore, the researcher made a great effort to ensure that the descriptions of the five business interoperability levels were mutually exclusive and collectively exhaustive.

### 7.4.6 Data analysis

Data analysis consists of examining, categorizing, tabulating, testing, or otherwise recombining both quantitative and quantitative evidence to address the initial propositions of a study (Yin 2003). It is the conceptual interpretation of the dataset as a whole, using specific analytic strategies to convert the raw data into a logical description and explanation of the phenomenon under study. In simple terms, data analysis is all about making sense of what the data say about our research topic. It requires making our own interpretations and highlighting patterns grounded on the data in a way that can be recognised and understood by the readers of our research (Altinay and Paraskevas 2008b).

In this research, and with respect to the Valorpneu case study, recordings and notes made during the interviews were transcribed as soon as possible after the interviews, and sent back to the interviewed in order to verify and confirm the accuracy. This process contributed to facilitate follow-up and identifying gaps in the collected data, and therefore the need to ask for them in the next interview or using email/telephone. The transcribed results were also verified by three additional managers within the Valorpneu company before being re-sent to the researcher. Unfortunately, due to limitations in terms of time, this approach was only used for the interviews carried out in the Valorpneu company. Also, a case study database was created in order to organise and document all the collected data into different categories and by case study.

Although the effort made by the researcher to avoid problems in the analysis of the collected data, one the main problems faced in this process was the lack of quantitative data regarding the impact of mechanisms of business interoperability on the performance of companies in the network. Many times during the interviews when the interviewees stated that a given mechanism of business interoperability had or has an impact on the performance of their companies and their partners, they were not able to quantify such impact. They were able to describe such impact in a qualitative way but not in quantitative way. Also, in the annual reports, there are many descriptions of the impact of the various mechanisms of business interoperability that have been implemented over the years, but unfortunately those impacts are only described in qualitative way and not quantitative. These limitations will difficult the spread of the business interoperability impact over the network, and therefore hindering the quantification of the network effect. Another challenge with the data analysis is that data regarding performance measures such as amount of generated and collected used tyres in the ambit of SGPU, amount of tyres sent to recycling, energy recoveries or other destinations, are available but only for trimesters or years. Because of this, the probabilistic distributions regarding these performance measures could not be estimated. Therefore, some assumptions were made in order to "convert" those qualitative data into quantitative one, and to overcome the problem of limited data, mainly in terms of probabilistic distributions.

### 7.4.7 Quality of the research design

Because a research design is supposed to represent a logical set of statements, an investigator can also judge the quality of any given design according to certain logical tests (Yin 2003). In the words of Karlsson (2009), the general criterion for research quality must be trustworthiness. To ensure such trustworthiness and to establish the quality of any empirical social research, there are four particular requirements used in social sciences that are of relevance to OM research (Yin 2003, Karlsson 2009): construct validity, internal validity, external validity and reliability.

The efforts made in this research to ensure the quality of the case studies are summarised in Table 7.2.

Table 7.2: Quality criteria of the case studies design (modified from (Yin 2003))

| Quality criteria | Operationalised through | Phase of research | This research |
|---|---|---|---|
| Construct validity | Triangulation through multiple sources of data or interviews | Data collection | **Yes:** Interviews, documentation, newsletter, reports, and websites were used to gather data |
| | Providing readers with a chain of evidence using cross-case tables or quotes from informants | Data collection | **Yes:** The chain of evidence regarding the levels of business interoperability and impact on the performance is provided in Chapter 8 |
| | Allowing interviewees to review the draft case and give feedback | Data collection | **Yes**: After each interview, the collected data were transcript by the researcher and verified and validated by the manager interviewed and more three managers |
| Internal validity | Pattern matching through cross-case analysis | Data analysis | **Yes**: A cross-case analysis is performed in Section 8.4 |
| | Searching for negative cases, ruling out or accounting for alternative explanations | Data analysis | - |
| | Time series analysis | Data analysis | - |
| External validity | Specification of the population of interest | Research design | **Yes**: The population of interest was specified in Section 7.4.4 |
| | Replication logic in multiple case studies | Research design | **Yes**: The approach employed to validate the theoretical models has been replicated in two different case studies |
| Reliability | A standardised interview protocol | Data collection | **Yes**: A case study protocol was prepared, based on Yin (2003)' book (see Appendix A) |
| | Constructs well-defined and grounded in extant literature | Research design | **Yes**: The dimensions and sub-dimensions of business interoperability were defined grounded in extant literature on business interoperability, industrial networks, cooperation, and collaboration |
| | Providing an audit-trail by providing access to data | Data collection | **Yes**: Collected data are provided in Chapter 8. |

## 7.5 Summary

This chapter started by discussing the philosophical position of this thesis. Three philosophical questions, namely ontology, epistemology and methodology were used to position this research with regard to positivist and interpretivist paradigms. As a result, it was concluded that with regard to the ontological and epistemological question, the research follows the positivist paradigm. Regarding the methodological question, the conclusion was that this research follows an interpretivist (or constructivist) paradigm, that is to say that the research is of qualitative nature rather than quantitative.

The research approach behind this thesis was also discussed. With regard to this, the research approach followed is deductive, as it is propositions-driven, i.e. it started with the statement of a theory in the form of two propositions (see Section 1.3) and two theoretical models (see Section 5.4 and 5.5), and then data have been collected to test or validate the propositions and the theoretical models. Following, some reflections were made regarding the most appropriate research strategy for answering the research questions and achieving the research objectives that were set. It was argued that case research should be used, mainly because “how questions” were posed. On the basis of these discussions, it was concluded that this research follows a qualitative deductive explanatory approach. Last, the choices that were made to operationalise the research design were presented and discussed. The rationale for these choices were also provided. For example, it was argued that multiple case study design should be employed in order to achieve literal and theoretical replication. It was also highlighted that in this research, the aim of the case studies was to achieve analytical generalisation rather than statistical generalisation. Therefore, the typical criteria regarding sample size are irrelevant, as a sampling logic was not used.

Regarding the data collection methods, interviews (semi-structured face-to-face interviews) and documentation (internal reports) were the main sources of evidence. Because multiple sources of evidence were used, triangulation was used to corroborate evidence coming from the different sources. The issues related to data analysis were also discussed, and the main conclusion regarding this was that some assumptions were needed in order to fill missing data. The chapter ended with a brief discussion on the quality of the research design. For this purpose, the general criteria used to ensure the research trustworthiness (construct validity, internal validity, external validity and reliability) were discussed. It was concluded that this research fulfils most of the constructs used to operationalise those criteria. As examples, the population of interest was specified, a standard case study protocol was prepared, interviews were transcript and verified by the interviewees, multiple sources of evidence were used, etc.

# Chapter 8 Empirical validation: case studies

In Section 5 a methodology consisting of two theoretical models has been described and in Section 7.3.2 it has been concluded that case research is the most appropriate research strategy for validating those theoretical models and answering the research questions addressed in Section 1.3. This chapter demonstrates how the proposed methodology is empirically validated through two case studies conducted in two different industrial network contexts. Firstly, a brief overview of the case studies is provided, along with the purpose of each case. Then, each case study is presented in detail, including the characterisation of the participants (companies and managers), the description of the network workflow, the data collected, the simulation results, the analysis of the results and respective conclusions and limitations. Last, a cross-case analysis is carried out in order to identify the differences and similarities between the results achieved in each case.

## 8.1 Case studies overview

As both case studies are concerned with existing cooperative industrial networks, the theoretical ABS model will be first applied to both cases, as the proposed modelling approach suggests (see Section 5.2). The aim is to demonstrate the applicability of the proposed theoretical ABS model in real-world contexts. According to Yin (2003) the case study goal is to explore and demonstrate the applicability of the model in a specific and real situation, rather than to achieve generalization about the application of the method or the practices. The first case has been conducted in a RL cooperative industrial network responsible for organising and managing the system of collecting and ultimate disposal of used tyres in Portugal. This RL cooperative industrial network is called Valorpneu network. The purpose this case study is to demonstrate how the Valorpneu network has evolved over time and how business interoperability has helped to improve its performance year after year. This network is designated to be a case of success in Portugal, and the results of the first case study shall contribute to understand the reasons behind such designation. The second case study has been carried out in a Dam construction project, also in Portugal. Its aim is to propose the design of a new configuration for the Dam construction project and then analyse the impact of the implementation of the new designed configuration. To be specific, its purpose is to analyse the impact of the introduction of a cooperative information system trial platform and a RFID system, first on the business interoperability performance, and then on the operational performance of the companies involved in the dam construction project. The purpose of the introduction of those two systems is to help in the better management of the dam construction processes, with the focus on the concrete handling. Following each case study is presented and discussed in more detail. The cooperative management practice being modelled in the ambit of the first case study is RL, while in the second case study is cooperative product development (the Dam construction).

## 8.2 Case Study 1: Valorpneu network

### 8.2.1 Characterisation of the network

Valorpneu network is an RL cooperative industrial network that is responsible for collecting and processing used tyres in Portugal. It is the only system licensed to manage used tyres in Portugal. The system that supports the activities inherent to this network is called "Used Tyres Management Integrated System (SGPU)", which started its operation on February 1, 2003. The system involves nine types of companies or agents: Valorpneu – the managing entity, producers, distributors, collection points, retreaders, recyclers, energy recoveries, shredders and transporters.

Valorpneu is the company responsible for organising and managing the SGPU, and is therefore called the "managing entity". Producers are any entity that manufactures, imports, or in any way introduces new or second hand tyres into the Portuguese market, including those that manufacture, import or sell vehicles, aircraft or other equipment that contains tyres. Distributors are companies, entities, or individuals (workshops, service stations, specialised trade, dismantlers, large fleet companies, municipalities, private citizens, etc.) that, for whatever reason, hold used tyres. Collection points are locations dully licensed for temporary storage of used tyres, and work as an upstream "reservoir" for recyclers and energy recovery agents. These operators are the first visible face of the SGPU and they accept any type of tyres from the tyre holders, free of charge. The two main objectives of collection points are: (1) to control and quantify all used tyres flows directed towards recyclers, energy recoveries and other destinations, and (2) to provide an adequate collection network evenly distributed throughout Portugal. The main RL operations carried out at collection points are collection, sorting and temporary storage.

Retreaders are companies that may acquire reusable used tyres (carcasses) at collection points to retread. They can also deliver used tyres resulting from the triage of carcasses to retread to the collection points, free of charge. Recyclers are disposal centres that receive whole or shredded tyres coming from collection points and process them into granulated rubber (separating metal and textile materials incorporated into the tyres), which is then used for different purposes (rubber modified bitumen, synthetic football pitches, paving, children playgrounds, etc.). Similarly, energy recoveries are disposal centres that receive used tyres from collection points and utilise them as an alternative source of fuel for energy production, benefiting from the excellent heating power of the tyre (similar to that of coal), therefore saving on traditional fuel consumption (fossil fuel), and also reducing emissions due to the tyre's biomass combustion (from the natural rubber of the tyre). Transporters are logistic providers companies that are responsible for the transportation of used tyres from collection points to recycler and energy recovery agents. An important point to make here is that although these nine types of agents are involved in the Valorpneu network, only collection points, recyclers, energy recoveries and transporters are considered as operators of SGPU.

Currently Valorpneu's collection network has forty collection points in mainland Portugal, eight collection points in the Autonomous Region of the Azores and one collection point in the Autonomous Region of Madeira. The retreading network that is part of Valorpneu is made up of twenty seven companies, of which twenty-two operate in mainland Portugal, two in the Autonomous Region of the Azores and three in the Autonomous Region of Madeira. Regarding to the recycling network, at present, Valorpneu works together with 3 recycling companies: Biosafe, located in Ovar, Biogoma, located in Tremês, and Recipneu, located in Sines. The first two operate through a mechanical process, while the third uses a cryogenic process.

At present, Valorpneu works together with 4 energy recovery facilities: the three cement production plants from the Secil Group, located in Maceira, Pataias and Outão, and the cogeneration facility of the Recauchutagem Nortenha company, located in Penafiel. Last, the transportation network is currently made up of twenty-three agents, or companies responsible for their subcontracting, of which twenty-one operate in mainland Portugal, one in the Autonomous Region of the Azores and one in the Autonomous Region of Madeira. In addition to these types of agents, there may also be some operators (individuals or companies) which recover used tyres through reutilisation for other purposes, such as, for example, civil works construction, protection of marine piers, protection of race tracks, etc.). However, these types of agents are not part of the SGPU. Figure 8.1 shows the evolution of the number of producers and distributors, and Figure 8.2 provides an overview of the evolution of the number of collection points, retreaders, recyclers, energy recoveries, shredders and transporters, from the beginning of the SGPU activity (in 2003) to 2014.

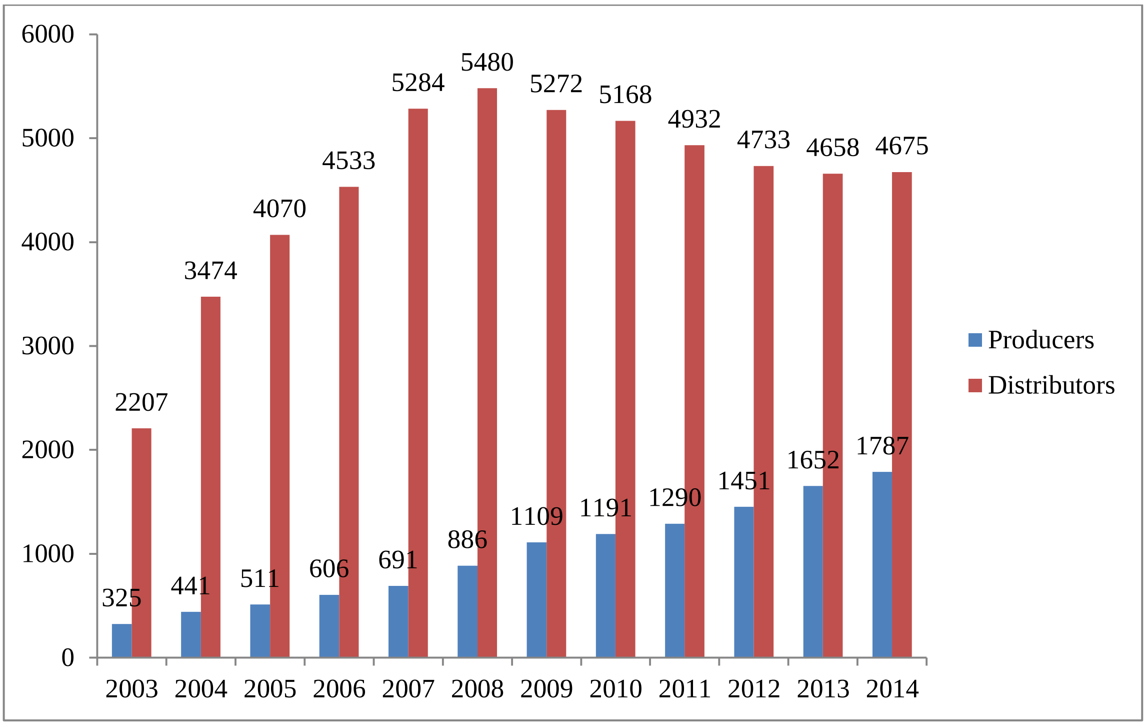



Figure 8.1: Evolution of the number of producers and distributors, from 2003 to 2014

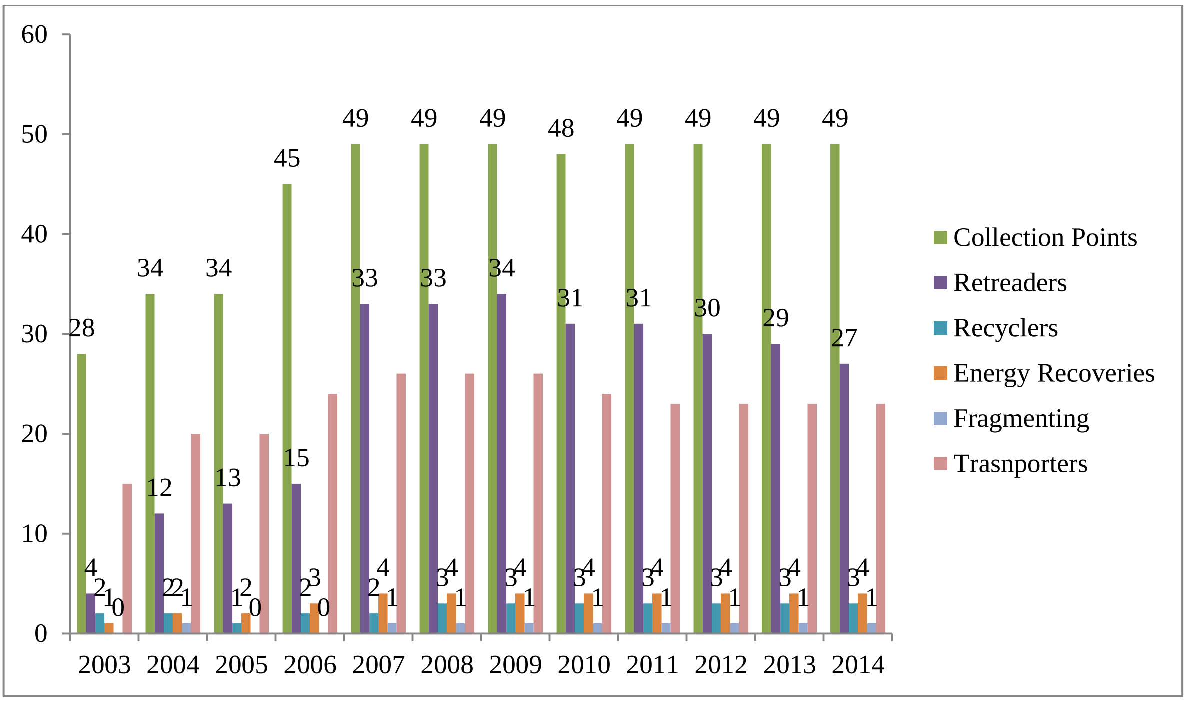



Figure 8.2: Evolution of the number of SGPU operators, from 2003 to 2014

Due to the amount of operators involved in the SGPU activities, the processing rate and the turnover generated, the Valorpneu network is regarded as an important industrial network, not only in Portugal but also in Europe. Its economic, social, and environmental importance is evident. For instance, a study published in 2014 by Valorpneu about management of used tyres in Portugal had a considerable impact on the activities of the Valorpneu network's operators in three areas of sustainability: economic, social, and environmental. In terms economic, the study concluded that the system contributes € 78.000.000 to the Portuguese Gross Value Added (GVA) (with reference to the year 2011). With regard to the social impact, the system created 970 direct jobs, 315 indirect jobs, and 698 induced jobs. Finally, in terms of the environmental impact, the study estimated that on average, this system reduces 1560 kg of $CO_2$ and 46,5 GJ of energy per ton of used tyre managed, per year. These results demonstrate the contribution of the Valorpneu network in the reduction of environmental impact, leverage and creation of jobs, and creation of richness.

When compared with the other used tyres management systems in Europe, the results are also very positive. Based on the latest available data from the European Tyre & Rubber Manufacturers' Association (ETRMA), the system managed by Valorpneu presents high performance in comparison to the average of its European counterparts, with a total self-sufficiency. The major difference regards the retreading rate, where Portugal is 7,4 percentage above that of the European countries. For example, in 2013, the SGPU managed by Valorpneu retreaded 16,9 % of used tyres, while the European average was 9,5. Portugal is also pointed out to be one of the countries that recycle more used tyres in Europe. In 2013, SGPU recycled 48,8 % of the collected used tyres, while the European average was 39,2. There are also differences in terms of collection rate. While SGPU had a collection rate of 110,3% in 2013, the European average was 95,3. It is also important to highlight here that since 2007 to now, the amount of used tyres sent to landfill in Portugal has been Zero, while, for instance, the European average in 2012 was 4,7%.

### 8.2.2 Characterisation of the participants

In this case study a sample comprising four companies in the Valorpneu industrial network was chosen. For each company participating in the study, a manager was chosen to be the respondent. The profiles of the four companies and the respondents are summarised in Table 8.1.

Table 8.1: Companies' and managers' profiles

| | **Companies** | | | |
|---|---|---|---|---|
| | **Company 1** | **Company 2** | **Company 3** | **Company 4** |
| Name | Valorpneu | Renascimento | Biogoma | Transportes Bizarro Duarte |
| Position in the network | Managing Entity | Collection Point and Transporter | Recycler | Transporter |
| Sector of activity | Waste management industry | Waste management industry | Waste management industry | Road transport of merchandise |
| Main service provider | Management of the used tyres flows in Portugal | Waste management/Logistics provider | Production and commercialisation of products derived from used tyres | Logistics transport |
| Years in Valorpneu network business | More than 10 years | More than 10 years (from 2003 to present) | Less than 10 years (from 2008) | More than 10 years (from 2003 to present) |
| Turnover (millions €) | 10 – 20 (11.346.863) | 10 – 20 (14.600.000) | Less than 10 (1.400.000) | Less than 10 (4.500.000) |
| Company size (employees) | Fewer than 50 (6) | 100 – 200 (180) | Fewer than 50 (20) | Fewer than 50 (46) |
| Geographic location | Mainland Portugal (Lisbon) | Mainland Portugal (Loures) | Mainland Portugal (Santarém) | Mainland Portugal (Malveira) |
| | **Interviewees** | | | |
| | **Respondent 1** | **Respondent 2** | **Respondent 3** | **Respondent 4** |
| Job title | Logistics manager | Quality, environment, and security manager | Production manager | Top management |
| Years in business | More than 10 years 10 – 15 | More than 15 years (15 – 20) | More than 20 years | More than 10 years 10 – 15 |
| Years in Valorpneu network business | More than 10 years 10 – 15 | More than 10 years 10 – 15 | Fewer than 10 years | More than 10 years (10) 10 – 20 |

The profile of each company is described in greater detail, as follows:

- ***Company 1***: Valorpneu – Sociedade de Gestão de Pneus, Lda., is a non-profit limited company, located in the city of Lisbon, Portugal, and created on February the 27th, 2002, with the objective of organising and managing the system for collection and ultimate disposal of used tyres. Valorpneu has a capital stock of 30.000 €, divided into three shares, which are distributed as follows: ACAP (Associação Automóvel de Portugal) – 18.000 €, a 60% share of the capital stock; ANIRP (Associação Nacional dos Industriais de Recauchutagem de Pneus) – 6.000 €, representing 20% of the capital stock; APIB (Associação Portuguese dos Industriais de Borracha) – 6.000 €, representing 20% of the capital stock. The society was licensed, for the first time, on October the 7th, 2002, by the Ministries of Economy and

Cities, Land Management and Environment, as the managing entity of the SGPU, which started production on February 1st, 2003. It is to notice that as a non-profit society, Valorpneu does not distribute dividends amongst its associates. Its net results are reinvested and/or provisioned for activities falling within the society's mission range;

- ***Company 2***: Renascimento – Gestão e Reciclagem de Resíduous, Lda., is a company dedicated to the global management of wastes, located in the region of Loures, Portugal, and created on 1995. Renascimento is a company that works mainly in the area of waste management, by providing environmental training, a wide range of activities and services, a wide range of containers, as well as a service of characterisation, containerisation, collection and transportation of hazardous and non-hazardous wastes. The company is also involved in the business area of demolition, industrial cleaning and soil decontamination. In addition, the company dedicates to the waste management of parks and sorting units, recycling and treatment of waste, contributing to a sustainable development of the recycling industry. In terms of facilities, the company has three units, one in Loures (about 50.000 $m^2$ area), another in the district of Faro (Silves) (about 3000 $m^2$ area) and another in the north of Portugal, in Santa Maria da Feira (about 4000 $m^2$ area). Currently the company has about 175 employees and generate an annual turnover of 14.600.000 €. Renascimento is one of the collection points that is part of the SGPU since the beginning of activity in 2003, and operates simultaneously as a collection point and transporter;
- ***Company 3***: Biogoma, is a company specialised in the production of recycled rubber granules, by mechanical process at room temperature, and in the commercialisation of these granules. The company has been created in cooperation with the managing entity (Valorpneu) in 2008. This recycler receives at its facility any category of used tyres. Unlike Renascimento, this company only operates in the ambit of SGPU;
- ***Company 4***: Transportes Bizarro Duarte, Lda., is a transportation company that began operating in 1968 when it acquired its first car, a Dodge. In the early years the company has grown in the districts of Lisbon and Setúbal, carrying mostly cereals and fertilisers. Its internationalisation happened in 1987 when the business expands to the entire Iberian Peninsula. Already in 1992, reached other countries in Europe: France, Germany, Benelux, Italy and England. The involvement in the normal and hazardous industrial waste business happened with the beginning of the XXI century, where the company intensified the renovation and modernisation of the fleet, namely through the acquisition of new equipment with valences as the movable floor and new trucks. The company is part of the SGPU since 2003. On average, Transportes Bizarro Duarte, Lda., performs between 10 and 15 charges a

week, from Collection Points to Recyclers and Energy Recoveries. Similarly to Renascimento, this company operates in the ambit of other industrial networks.

### 8.2.3 Adopted modelling approach

On the basis of what has been explained in Section 5.2 about the application of the proposed methodology, which depends on whether the cooperative network platform is already implemented or not, this section explains the approach adopted for modelling the Valorpneu network. As mentioned in previous section, the Valorpneu network already exists, which means that the mechanisms to support the cooperation among the SGPU operators are already implemented. Therefore, the theoretical ABS model has been first applied to analyse the "as-is" situation, i.e. to analyse the impact of the identified business interoperability problems on the performance of the SGPU operators, as suggested by the proposed methodology.

As a result of this analysis, and together with the manegers interviewed, it was concluded that the current business interoperability performance of the Valorpneu network is satisfactory. Therefore, the theoretical Axiomatic Design model was not applied to design a new configuration for the Valorpneu network, as suggested in Section 5.2. The main dimensions of business interoperability modelled in this case study were business strategy, management of external relationships, cooperative business processes, information quality, information systems, and network minute details. These dimensions were chosen because together with the managers interviewed it was realised that they are the most important dimensions to the Valorpneu network. For example, the dimension "Products and services" was not modelled because the product involved (used tyres) has low level of specificity and there is diversity of the products in flows. The dimension "Knowledge management" was not modelled because the managers interviewed asserted that there are no IPR issues among the SGPU operators. The dimension "Employees and work culture" was also not modelled because the interactions among the employees from the different companies the Valorpneu network are not very frequent, in words of the managers interviewed. Last, the dimension "Business semantics" was not modelled because there are no conflicting terminologies.

### 8.2.4 Description of the SGPU working model

The SGPU starts with the introduction of new or second hand tyres into the Portuguese national market. Any company producing and/or importing new or second hand tyres, and/or vehicles, aircraft, or equipment that contains tyres, new or used, must celebrate a contract with Valorpneu, so that the Ecovalue due on the imported tyres can be charged. If the company that sells tyres buys them in the national market, there is no need to celebrate any sort of contract with Valorpneu, since the company they are buying the tyres from is already charging the Ecovalue (i.e. has already paid to Valorpneu). This implies that the contract with Valorpneu and the payment of the respective Ecovalue is only made when tyres are introduced in Portugal for the first time. Each tyre introduced in the national market must pay for its Ecovalue a single time only. This Ecovalue, which pays for the provision of a service and is charged by tyre producers, funds Valorpneu's system. The Ecovalue Table (unitary) is available in the Valorpneu's website[17], in "Producers and Retreaders – Ecovalue Table". This table is adjusted periodically to compensate the fluctuations in the tyre market or to cover infringements on the part of producers, regarding the payment of the Ecovalue to Valorpneu. For example, Table 8.2 summarises the Ecovalue charged by Valorpneu from January 1, 2009 to June 30, 2012, and from July 1 to present.

Table 8.2: Ecovalue charged from 2009 to present

| | | **Ecovalue charged (€/tyre)** | |
|---|---|---|---|
| **Code** | **Category** | **January 2009 to June 2012** | **July 2012 to present** |
| T | Passenger/Tourism | 1,00 | 1,20 |
| 4x4 | 4x4 "on/off road" | 1,99 | 2,11 |
| C | Commercial | 1,57 | 1,84 |
| P | Heavy | 7,81 | 8,86 |
| A1 | Agricultural (diverse) | 2,55 | 3,06 |
| A2 | Agricultural (driving wheels) | 9,47 | 11,03 |
| E1 | Industrial (8" a 15") | 2,74 | 2,10 |
| E2 | Massifs (<= 15") | 4,10 | 3,65 |
| G1 | Civil engineering and massifs (<24") | 8,91 | 9,01 |
| G2 | Civil engineering and massifs (>=24") | 36,54 | 41,43 |
| M1 | Moto (> 5occ) | 0,67 | 0,76 |
| M2 | Moto (up to 5occ) | 0,23 | 0,24 |
| F | Aircrafts | 1,00 | 1,20 |
| B | Bicycles | 0,07 | 0,09 |

After reaching the end of their life cycle, tyres may be delivered by distributors (or any individual holders of used tyres) to collection points spread throughout the country (mainland Portugal, and the Autonomous Regions of Madeira and the Azores), at zero cost to the tyre holders. The only cost distributors or individuals have to support is transportation until the nearest collection point. The collection points should be contacted in order to mark the discharge of used tyres and each discharge should be accompanied by a waste accompaniment guide. To locate the most convenient collection point to deliver tyres, there is a Network Map available on the Valorpneu website. At collection points the discharged used tyres are separated through a well-established sorting process, consisting of five categories (see Table 8.3), and stored temporarily.

[17] http://www.valorpneu.pt

Table 8.3: Categories of tyres at collection points

| Category | Dimension/Description |
| --- | --- |
| Passenger | Diameter ≤ 0,70 m and width ≤ 0,35 m |
| Heavy | Diameter ≤ 1,20 m and width ≤ 0,35 m |
| Industrial | Higher dimensions |
| Damaged | Heavy tyres whose structure is damaged to the point that it is not possible to stand them vertically |
| Massive | All dimensions of massive tyres, excluding bandages |

Later, and based on the inventory level of each of the above categories, tyres are routed by Valorpneu from collection points to destination points, where they are processed according to the established goals (essentially recycling and energy recovery). Other destinations of used tyres are reutilisation and retreading. Transportation of the used tyres from collection points to recyclers and energy recoveries is provided by transportation agents, controlled and financed by Valorpneu. The information management inherent to this complex material, information, and monetary transaction network is supported by an online information system that ensures the interaction of the different operators within the SGPU, while simultaneously allowing Valorpneu to manage and control the whole SGPU. This information system, named "SGPU Online", is a restricted access system and works via the Internet. The working model of SGPU is illustrated in Figure 8.3.

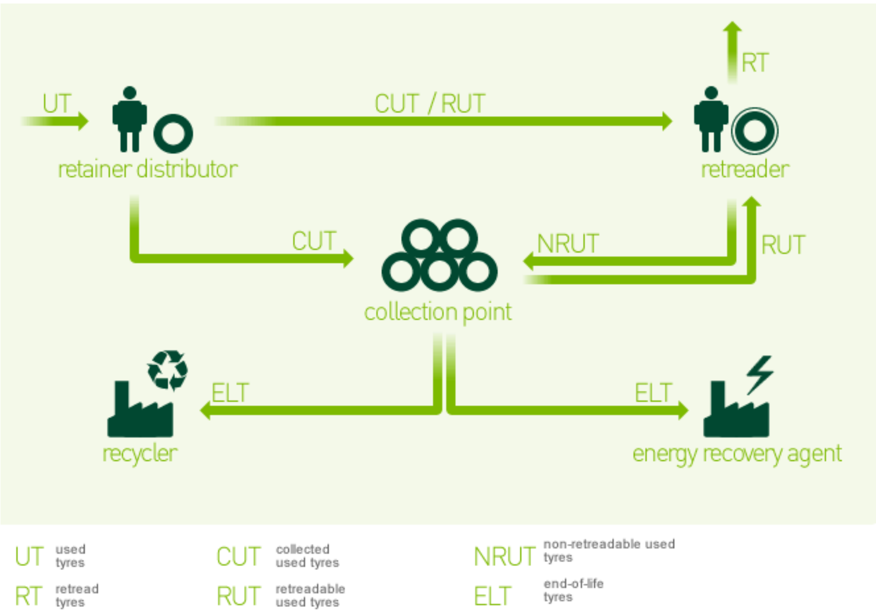



Figure 8.3: The working model of SGPU (source: Valorpneu's website)

As explained in Section 8.2.1, the SGPU developed and managed by Valorpneu encompasses a significant amount of business agents, institutional entities, and different types of operators, as well as a series of material, financial and information flows which make SGPU a complex system with its own specifications. This implies that a set of interaction and decision-making rules must be defined to ensure an effective interaction among the involved agents and to avoid opportunistic behaviours, as in any cooperative industrial network. In the ambit of SGPU there are a number of rules that were defined and imposed by the managing entity, Valorpneu. Table 8.4 summarises those that are regarded as the most important within the context of this thesis, i.e. those that are most important to demonstrate the theoretical ABS model. The characterisation of these rules is of critical importance for modelling the interaction among the agents, as shall be demonstrated in Section 8.2.6. Therefore a graphical Business Process Diagram was developed to help understanding how the SGPU operators interact with eact other and how they make decisions (see Appendix C).

Table 8.4: Interaction and decision-making rules in the ambit of SGPU

| Interaction | Involved agents | Interaction and/or decision-making rules |
|---|---|---|
| Charge of Ecovalue | Producers and Valorpneu | Any company importing new or used tyres must celebrate a contract with Valorpneu, so that the Ecovalue due on the imported tyres can be charged. Each tyre introduced in the national market must pay for its Ecovalue a single time only. |
| Discharge of used tyres at collection points or retreaders | Distributors and collection points, distributors and retreaders or retreaders and collection points | Collection points should provide a sheet of origin characterisation, available in the SGPU Online (in the area of “SGPU documents”), to each distributor to fill before discharge of used tyres. This information should be complemented with the photocopy of the identification card of distributor. Both elements should be maintained in archive for all distributors that utilised the collection point, which should provide those information whenever they are solicited by Valorpneu. Collection points should reject used tyres from distributors that refuse to fill, stamp and sign the sheet. The non-compliance with these rules may be subject to monetary penalties. Whenever a new distributor ask the discharge of used tyres at collection points, the collection point should identify the origin of these tyres and whether these have been acquired in other country, and then inform the distributor about the rules and procedures to be followed. The reception of used tyres must be accompanied by their waste guide accompaniment, on the part of the producer. Collection points should ensure the conditions for receiving and organising the storage of the used tyres according to the five categories provided in Table 8.3. Collection points should inform Valorpneu whenever they suspect that a distributor or producer is using the SGPU without performing their financial contribution, i.e. importing new or used tyres/cars without declaring them to Valorpneu. Collection points should reject used tyres from distributors that are part of the list of blocked distributors, available in the SGPU Online. Again, the non-compliance with these rules may be subject to monetary penalties. |
| Reception recording | Collection points and Valorpneu | The collection points should nominate one responsible for recording the discharges made at their facilities and keeping this information updated in its SGPU online area. |
| Transportation request | Collection points and Valorpneu | Collection points must request to Valorpneu loads to destinations defined in the SGPU online (recycling, energy recovery or reuse for other purposes), mentioning the following information: shipping date, estimated weight, type of tyres (Table 8.3), identification of the recycler or energy recovery of destiny and the transporter established in the SGPU online. The number of transportation requests should take into account the inventory level and resources available at collection point. The transportation request, carried out in the SGPU online, should be done after the update of the reception and expedition recording, every Thursday up to 1 pm, regarding the following week. If Thursday is a holiday, the update of the transportation recording and requests should be made the day before. From 9 am on Friday morning, the collection points may consult in the SGPU online, the transportation charges approved for the following week. The collection points should develop efforts to fulfil the date of charges realisation. If for reasons of force majeure, the realisation of the charges in the planned data does not occur, the charge should be performed no later than five business days, after the planned date. |
| Tyres loading at collection | Collection points and transporters | The tyres loading at collection points to the points of destiny are a responsibility of collection points. The load operation in the transporter vehicle should not exceed two hours, after the arrival of the vehicle to the |

| | | |
|---|---|---|
| | | collection point's installations, and should be performed using the collection point own resources. Each load should be constituted solely by one of the categories previously specified in Table 8.3. The tyres that are painted (usually coming from kart tracks or race tracks) or with coloured letters (usually used in vehicles 4 x 4) may not be sent to recycling destinations indicated in SGPU online. When this occurs, the collection point should contact Valorpneu in order to organise a specific load of this type to the energy recovery. The counterpart to be paid to collection points by Valorpneu refers to clean tyre loads and free of contamination, so the collection point will be obligated to keep them and to carry out loads under these conditions. The transporter may refuse to transport loads, if these are contaminated. The costs resulting from non-conforming charges at recyclers or energy recoveries (transportation cost or cleaning fee imposed by recycler or energy recovery) are a responsibility of the collection point of origin, and there is a possibility a monetary penalty be applied by Valorpneu or, in recurrent and more serious situations, suspend or exclude the activity of the collection point. At the moment of each load, the collection point shall deliver the transporter a waste guide accompaniment and the authorised requested transportation guide (which should be print from the SGPU online). The waste guide accompaniment should be completed in triplicate by the collection point, which must retain a copy, and deliver the remaining two to the transporter, which in turn, will retain one and deliver the other to the recycler or energy recovery of destiny. |
| Discharge of used tyres at recyclers and/or energy recoveries | Transporters and recyclers or transporters and energy recoveries | At each load arrival, the recycler or energy recover receiving the charge should evaluate whether the charge is in conformity or not. If the charge is not in conformity, the recycler or energy recover may accept or reject it. Else, the charge should be accepted. When a charge is not in conformity, even if it is accepted, the recycler or energy recover has to take a picture of the non-conformity and send to Valorpneu via SGPU online. The rejected charge should be delivered at the collection point of origin. It is considered that a batch of tyres is contaminated if those contain more than one categories (Table 8.3) or any other material, such as: stones, sands, lamas, rims, oils or other fats, inks or other chemical products, wood, metal or plastic waste. |
| Expedition recording | Collection points and Valorpneu | The recording of the expeditions to the recyclers and energy recoveries set by Valorpneu are automatically created by the SGPU online at the time the load requested by the collection point and authorised by Valorpneu, is accepted in the recycler or energy recovery facility, and should include the following information: waste guide accompaniment, reception date, and the weight of the recycler or energy recovery bascule. The update of the receptions should be done at least once a week, on Thursday, and before the transportation request. The records can only be changed until January 15 of the following year. |
| Communication of the inventory level | Collection points and Valorpneu, recyclers/energy recoveries and Valorpneu | Collection points, recyclers and energy recoveries should communicate the inventory level at each Friday, before 12 am. This information will be used by Valorpneu to plan the loads to be carried out in the following week. If those operators do not provide such information, they will be penalised in the quality report and may not be attributed charges in the following week. |

### 8.2.5 Data for validating the theoretical Agent-Based Simulation model

The data collected in the ambit of this case study can be summarised according to three categories: the description of how companies interoperate within the ambit of SGPU, the interaction and decision-making rules, companies' behaviours, the type of business interoperability mechanisms used for facilitating the interoperations (called throughout this thesis as BIDSs), the evaluation of the ALBI and the RLBI for each BIDS, the identification of the sources of business interoperability problems, the characterisation of the impact of business interoperability on the performance of companies, regarding cost, time, service level and environmental impact, the characterisation of the mechanisms to overcome the identified business problems, and the performance measures. As the aim is not to provide an historical evolution of the SGPU from the beginning of its activity (2003) the time boundaries for data collection were set between 2007 and 2014. The main reason for this is that the annual reports, which contain much of the information needed for this case study, are not available for the years previous to 2007.

First, the data regarding the most relevant BIDSs used in the ambit of SGPU to ensure business interoperability were collected. These data were collected during the interviews and then complemented through the examination of the Annual Reports, available in the Valorpneu's website. Once these BIDSs were identified, the knowledge acquired through the test of the theoretical Axiomatic Design model in the application scenario presented in Section 6.2 were used to map the BIDSs to their corresponding FRs, as shown in Table 8.5 – Table 8.10.

Table 8.5: Overview on the BIDSs used in the dyad between Valorpneu and producers, and related FRs

| Dyad | BIDS | Related FR |
|---|---|---|
| Valorpneu – Producers | BIDS1 – Decree-Law 111/2001, from April the 6th | FR1 – Ensure that the Producers' responsibilities are transferred to the managing entity (Valorpneu) |
| | BIDS2 – Producers: Procedures to adhere the SGPU (available in the Valorpneu website) | FR2 – Facilitate the adhesion of producers to the SGPU |
| | BIDS1 – Ecovalue Table | FR1 – Define the Ecovalue to be charged for each category of tyres |
| | BIDS 2 – A contract celebrated between Valorpneu and Producers | FR2 – Charge the Ecovalue for the tyres that are introduced into the market |
| | BIDS4 – Trimestral declaration of the imported tyres | FR4 – Declare the tyres imported at each trimester |
| | BIDS5 – Trimestral declaration of the imported tyres | FR5 – Declare the tyres imported at each trimester |
| | BIDS6 – Technology of Internet communication encryption (using *thawte* SSL123 certificate) | FR6: Ensure confidentiality of data when declaring the imported tyres |
| | BIDS7 – Audit to producers (in collaboration with ASAE – Autoridade de Segurança Alimentar e Económica) | FR7 – Ensure that producers (actual or new) pay the Ecovalue for each new tyre introduced into the market |

Table 8.6: Overview on the BIDSs used in the dyad between Valorpneu and Collection Points, and related FRs

| Dyad | BIDS | Related FR |
|---|---|---|
| Valorpneu – Collection Points | BIDS1 – Selection criteria for new collection points (available in the Valorpneu website) | FR1 – Ensure that the selected Collection Points are able to offer better service and at the lowest cost |
| | BIDS2 – A contract celebrated between Valorpneu and Collection Points | FR2 – Define the terms and conditions of cooperation with Collection Points |
| | BIDS3 – Collection Points: Norms and procedures | FR3 – Ensure that all Collection Points operate in the same conditions and way |
| | BIDS4 – Used tyres classification system (Table 7.3) | FR4 – Organise the storage of collected used tyres per type of tyres |
| | BIDS5 – Rules for accepting discharges at Collection Points | FR5 – Ensure that collection points only accept tyres with characterised origin |
| | BIDS6 – List of blocked distributors (available in SGPU online) | FR6 – Ensure that Collection Points only accept tyres from non-blocked distributors |
| | BIDS7 – Sheet of origin characterisation | FR7 – Characterise the origin of used tyres being discharged at Collection Points |
| | BIDS8 – Rules and procedures to communicate the inventory level from Collection Points to Valorpneu | FR8 – Communicate the inventory level from Collection Points to Valorpneu |
| | BIDS9 – Trimestral performance evaluation report for Collection Points | FR9 – Evaluate the quality of the service provided by Collection Points |
| | BIDS10 – Communication of the trimestral performance evaluation report to Collection Points | FR10 – Communicate the results of the evaluation of the service provided by Collection Points from Valorpneu to these operators |
| | BIDS11 – Mechanisms to ensure confidentiality of the Collection Points' quality reports (a report that contains the results of all Collection Points but each Collection Point is only able to identify its own results) | FR11 – Ensure confidentiality in the communication of the Collection Points' quality reports |
| | BIDS12 – Rules to perform charges at Collection Points | FR12 – Ensure that Collection Points send the right tyres to the right recycler or energy recover |
| | BIDS13 – Rules for sending tyres to Recyclers and Energy Recoveries | FR13 – Specify the roles and responsibilities of Collection Points regarding the charges to Recyclers and Energy Recoveries |
| | BIDS18 – Rules and procedures to request transportation from Collection Points to Valorpneu | FR18 – Request transportation from Collection Points to Valorpneu |

Table 8.7: Overview on the BIDSs used in the dyad between Valorpneu and Recyclers, and related FRs

| Dyad | BIDS | Related FR |
|---|---|---|
| Valorpneu - Recyclers | BIDS1 – Visit to the Recycler installations before selecting it | FR1 – Ensure that the selected Recyclers are able to offer better service and at the lowest cost |
| | BIDS2 – A contract celebrated between Valorpneu and Recyclers | FR2 – Define the terms and obligations between Valorpneu and Recyclers |
| | BIDS3 – Rules and procedures for accepting charges at Recyclers | FR3 – Ensure that Recyclers only accept charges that are proper for recycling |
| | BIDS4 – Rules and procedures to communicate inventory level from Recyclers to Valorpneu | FR4 – Communicate the inventory level from Recyclers to Valorpneu |
| | BIDS5 – Rules and procedures to communicate rejected charges from Recyclers to Valorpneu | FR5 – Communicate the rejected charges from Recyclers to Valorpneu |
| | BIDS6 – Periodic visits to the Recyclers' installations | FR6 – Evaluate the quality of the service provided by Recyclers |

Table 8.8: Overview on the BIDSs used in the dyad between Valorpneu and Energy Recoveries, and related FRs

| Dyad | BIDS | Related FR |
|---|---|---|
| Valorpneu – Energy Recoveries | BIDS1 – Visit to the Energy Recovery's installations before selecting it | FR1 – Ensure that the selected Energy Recoveries are able to offer better service and at the lowest cost |
| | BIDS2 – A contract celebrated between Valorpneu and Energy Recoveries | FR2 – Define the terms and obligations between Valorpneu and Energy Recoveries |
| | BIDS3 – Rules and procedures for accepting charges at Energy Recoveries | FR3 – Ensure that energy recoveries only accept charges that are proper for energy recovering |
| | FR4 – Rules and procedures to communicate inventory level from Energy Recoveries to Valorpneu | FR4 – Communicate the inventory level from Energy Recoveries to Valorpneu |
| | FR5 – Procedures to communicate rejected charges from Energy Recoveries to Valorpneu | FR5 – Communicate the rejected charges from Energy Recoveries to Valorpneu |
| | BIDS6 – Periodic visits to the Energy Recoveries' installations | FR6 – Evaluate the quality of the service provided by Energy Recoveries |

Table 8.9: Overview on the BIDSs used in the dyad between Valorpneu and Transporters, and related FRs

| Dyad | BIDS | Related FR |
|---|---|---|
| Valorpneu – Transporters | BIDS1 – Criteria for selecting Transporters | FR1 – Ensure that the selected Transporters are able to offer better service and at the lowest cost |
| | BIDS2 – A contract celebrated between Valorpneu and Transporters | FR2 – Define the terms and obligations between Valorpneu and Transporters |
| | BIDS3 – Waste guide accompaniment | FR3 – Ensure that the transportations from collection points to recyclers or energy are made in accordance with the transportation legislations |
| | BIDS4 – Semi-annual performance evaluation report for Transporters | FR4 – Evaluate the quality of the service provided by Transporters |
| | BIDS5 – Communication of the semi-annual performance evaluation report to Transporters | FR5 – Communicate the results of the evaluation of the service provided by Transporters from Valorpneu to these operators |
| | BIDS6 – BIDS6 – Mechanisms to ensure confidentiality of the Transporters' quality reports (a report that contains the results of all Transporters but that is not possible to identify who is each Transporter; each Transporter is only able to identify its own results) | FR6 – Ensure confidentiality in the communication of the Transporters' quality reports |

Table 8.10: Overview on the BIDSs used between Valorpneu and all operators, and related FRs

| Dyad | BIDS | Related FR |
|---|---|---|
| Valorpneu – SGPU operators | BIDS1 – Despatch nº 2261/2014 of November 18, 2014 (provided by the Ministries of Economy and Cities, Land Management and Environment) | FR1 – Ensure that Valorpneu is the only managing entity authorised to manage the flows of used tyres in Portugal |
| | BIDS2 – Establishment of the cooperation goals in the tender specifications | FR2 – Set clear cooperation goals to be achieved in the ambit of SGPU |
| | BIDS3 – Adjustment through negotiations between Valorpneu and SGPU operators | FR3 – Align the individual interests of SGPU operators to the cooperation goals |
| | BIDS4 – SGPU Online, email, telephone (if it is a specific and punctual subject) or through training actions | FR4 – Communicate the cooperation goals from Valorpneu to SGPU operators |
| | BIDS5 – Establishment and communication of rules to send tyres (e.g. Collection Points know that they cannot send contaminated tyres to Recyclers and/or Energy Recoveries) | FR5 – Prevent the occurrence of conflicts between Valorpneu and SGPU operators, and among these operators |
| | BIDS6 – Communication of conflicts by operators, using telephone or email | FR6 – Facilitate the identification of conflicts between SGPU operators |
| | BIDS7 – Mechanisms for conflicts resolution (e.g. conversation/negotiation via telephone or email; for critical situations, conflicts are solved in meetings) | FR7 – Solve conflicts between Valorpneu and SGPU operators |
| | BIDS8 – Mechanisms for conflicts resolution (e.g. mediation by Valorpneu, negotiation among SGPU operators via email or telephone; for critical situations, conflicts are solved in meetings) | FR8 – Solve conflicts among SGPU operators |
| | BIDS9 – First through SGPU online, second via email, and last via telephone | FR9: Ensure easy information exchange among the SGPU operators |
| | BIDS10 – Norms and procedures, tender specifications and contracts (for each type of operator) | FR10: Clarify the roles and responsibilities for each SGPU operator |
| | BIDS11 – A document with the description of the collaborative business processes, defined based on a set of idealised rules | FR11: Define clear collaborative business processes in the ambit of SGPU |
| | BIDS12 – A table with the classification and destiny of each category of used tyres | FR12: Define the flows of materials within the SGPU |
| | BIDS13 – Procedures to communicate the processing status of collaborative business processes via SGPU Online (if it is a situation that was not predicted in the SGPU online, telephone is used) | FR13: Communicate the processing status of the collaborative business processes from SGPU operators to Valorpneu |
| | BIDS14 – Agreement between the involved parties | FR14: Align the collaborative business processes |
| | BIDS15 – Planning of the loads to be made in the following week (elaborated by Valorpneu); operators can also make agreements to change the loads date. | FR15: Coordinate the collaborative business processes among SGPU operators |
| | BIDS16 – Visit to the installations of the SGPU operators | FR16: Monitor the collaborative business processes |
| | BIDS17 – Attribution of username and password to each SGPU Online user | FR17: Ensure user privacy when using the SGPU Online |
| | BIDS18 – SGPU Online (Procedures for inserting data and files) | FR18: Ensure effective exchange of data and files through SGPU Online |
| | BIDS19 – HTTPS (Hyper Text Transfer Protocol Secure) | FR19: Ensure secure exchange of data and files through SGPU Online |

Second, by triangulating the BIDSs presented in Table 8.5 – Table 8.10 with the ones that were achieved through the application scenario presented in Section 6.2, a sample of them was chosen for the evaluation of the ALBI and RLBI. The results of this evaluation will then be used to calculate the distance proposed in Equation 10. To achieve this, the theoretical business interoperability maturity model presented in Section 6.3 was used. The average ALBI and RLBI for the BIDSs that were evaluated by the managers interviewed in the four companies that participated in the study are summarised in Table 8.11 – Table 8.15.

Table 8.11: Overview of the ALBI and RLBI for BIDSs related to cooperation goals

| | Average level | |
|---|---|---|
| **BIDS – Cooperation goals** | **ALBI** | **RLBI** |
| A well-defined list of cooperation goals | 4 | 4 |
| Mechanisms to communicate the cooperation goals | 3,25 | 3,75 |
| Mechanisms to align the individual interests of operators with the cooperation goals | 3 | 3 |

Table 8.12: Overview of the ALBI and RLBI for BIDSs related to management of external relationships

| | Average level | |
|---|---|---|
| **BIDS – Management of external relationships** | **ALBI** | **RLBI** |
| Mechanisms to select new partners | 4 | 4 |
| Cooperation contracts (terms and conditions) | 4 | 4 |
| Mechanisms to evaluate SGPU operators | 3,75 | 4 |
| Mechanisms to ensure confidentiality and trust | 4 | 4 |
| Mechanisms to prevent conflicts | 4 | 4 |
| Mechanisms to identify conflicts | 3 | 3,5 |
| Mechanisms to solve conflicts | 3,25 | 3,5 |
| Mechanisms to facilitate communication | 4 | 4 |
| Frequency of communication among Valorpneu and SGPU operators | 4 | 4 |

Table 8.13: Overview of the ALBI and RLBI for BIDSs related to collaborative business processes

| | Average level | |
|---|---|---|
| **BIDS – Collaborative business processes** | **ALBI** | **RLBI** |
| Definition of roles and responsibilities | 4 | 4 |
| Definition of collaborative business processes | 4 | 4 |
| Definition of materials flows | 4 | 4 |
| Definition of information flows | 4 | 4 |
| Mechanisms to communicate the processing status of collaborative business processes | 4 | 4 |
| Mechanisms to align collaborative business processes | 3,25 | 3,5 |
| Mechanisms to coordinate collaborative business processes | 3 | 3,75 |
| Mechanisms to ensure flexibility of collaborative business processes | 3,5 | 4 |
| Mechanisms to monitor collaborative business processes | 4 | 4 |

Table 8.14: Overview of the ALBI and RLBI for the BIDSs related to information systems

| | Average level | |
|---|---|---|
| **BIDS – Information Systems** | **ALBI** | **RLBI** |
| Mechanisms to exchange data and files | 4 | 4 |
| Mechanisms to ensure security and privacy in the exchange of data and files | 4 | 4 |
| Mechanisms to ensure easy access of data and files | 4 | 4 |
| Mechanisms to ensure proper maintenance of the SGPU Online | 4 | 4 |

Table 8.15: Overview of the ALBI and RLBI for the BIDSs related information quality

| | Average level | |
|---|---|---|
| **BIDS – Information quality** | **ALBI** | **RLBI** |
| Mechanisms to provide accurate information | 3,75 | 4 |
| Mechanisms to provide complete information | 3,5 | 4 |
| Mechanisms to timely information | 4 | 4 |

Then, Table 8.16 summarises the main SGPU performance measures, for the time interval 2007 to 2014. These data are documented in the Annual Reports of the Valorpneu network.

Table 8.16: SGPU performance measures (2007 – 2014)

| SGPU Performance measures | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| Tyres Introduced into the Market in the ambit of SGPU (ton) | 83722 | 83139 | 78349 | 83294 | 72785 | 62431 | 70625 | 79375 |
| Ecovalue Charged (€) | 9123255 | 10540148 | 9965251 | 10369402 | 9081006 | 8234916 | 9993644 | 11265797 |
| Ecovalue Charged by ton (€/ton) | 108,97 | 126,78 | 127,19 | 124,49 | 124,76 | 131,90 | 141,50 | 141,93 |
| Used Tyres Generated in the ambit of SGPU (ton) | 93747 | 90304 | 86959 | 89058 | 78881 | 65231 | 71319 | 77946 |
| Used Tyres Generated and Collected by SGPU (ton) | 92322 | 96210 | 89575 | 94373 | 90373 | 78267 | 78695 | 84681 |
| Used Tyres sent to Retreading (ton) | 25421 | 22317 | 18638 | 18107 | 17071 | 13962 | 13291 | 13672 |
| Used Tyres sent to Reutilisation (ton) | 400 | 2057 | 1019 | 550 | 563 | 620 | 864 | 609 |
| Used Tyres sent to Recycling (ton) | 43603 | 48332 | 48039 | 49957 | 47595 | 39203 | 38408 | 43779 |
| Used Tyres sent to Energy Recovering (ton) | 22897 | 23504 | 21878 | 25759 | 25144 | 24483 | 26132 | 26621 |
| Total Used Tyres Collected and Processed by SGPU | 92321 | 96210 | 89574 | 94373 | 90373 | 78268 | 78695 | 84681 |
| Existences sent to Reutilisation (ton) | 54 | 0 | 1 | 0 | 900 | 0 | 0 | 0 |
| Existences sent to Energy Recovering (ton) | 4870 | 4895 | 4190 | 3643 | 2094 | 846 | 788 | 796 |
| Total Existences Processed (ton) | 4925 | 4895 | 4191 | 3643 | 2994 | 846 | 788 | 796 |
| Total Collected and Processed + Total Existences Processed (ton) | 97246 | 101105 | 93765 | 98016 | 93367 | 79114 | 79483 | 85477 |
| Stock at Collection Points (ton) | 10153 | 9487 | 9909 | 10193 | 10531 | 11471 | 11480 | 7354 |
| Inventory Cost at Collection Points (€) | 43553,41 | 40696,47 | 42506,72 | 43725 | 45174,92 | 49207,25 | 49245,85 | - |
| Operational expenditures – Collection Points €) | 1562739 | 1766300 | 1790308 | 1919697 | 1837568 | 1596483 | 1610799 | 1756842 |
| Operational expenditures – Transporters (€) | 1864954 | 2130661 | 2031665 | 1987633 | 1898601 | 1653207 | 1648926 | 1778545 |
| Operational expenditures – Recyclers (€) | 3203910 | 3515209 | 3500083 | 3694921 | 3518372 | 2888800 | 2813461 | 3150101 |
| Operational expenditures – Energy Recoveries (€) | 1497220 | 1443804 | 1128443 | 705658 | 624354 | 527928 | 370903 | 306222 |
| Losses due to impairment of customers (€) | 0 | 0 | 0 | 173421 | 131254 | 442728 | 866952 | 86596 |
| Total operational expenditures (€) | 8128823 | 8855974 | 8450499 | 8307909 | 7878895 | 6666418 | 6444089 | - |
| Average expenditures – Storage at Collection Points (€/ton) | 21,90 | 22,69 | 24,01 | 24,20 | 24,56 | 24,75 | 24,67 | 24,69 |
| Average expenditures - Transporters (€/ton) | 26,14 | 27,37 | 27,25 | 25,06 | 25,38 | 25,63 | 25,26 | 24,99 |
| Average expenditures – Recyclers/Energy Recoveries (€/ton) | 66,23 | 64,53 | 62,47 | 61,82 | 61,13 | 57,99 | 55,44 | 54,37 |

Following, Table 8.17 summarises the main evidences regarding the impact of business interoperability on the performance of the SGPU operators, according to the analysed BIDSs. The quantitative data on the BIDSs with greater impacts from 2007 to 2014 are summarised in Table 8.18 – 8.21: Table 8.18 provides the impact of the follow up visits to Collection Points, carried out by the Managing Entity; Table 8.19 provides the impact of the introduction of the system for evaluating the quality of the services provided by Collection Points; Table 8.20 provides the impact of the introduction of the system for evaluating the quality of the services provided by Transporters; and Table 8.21 provides the impact of the system for sorting used tyres at Collection Points.

Table 8.17: Chain of evidences on the BIDSs implemented in the ambit of SGPU and estimated impact

| BIDS | Year | Before implementation | After implementation |
|---|---|---|---|
| Legislation which prohibits the sending of tyres to landfill | 2006 | On average, 2280,67 tons of tyres was sent to landfill, in the ambit of SGPU. | No tyres were sent to landfill, in the ambit of SGPU. |
| Introduction of the SGPU Online | 2004 | The weekly planning of charges was made (at managing entity) in papers, in two days, using 2 persons, and sent to SGPU operators via fax. | The weekly planning of charges began to be made by one person, in 2,5 – 3 hours, without papers, and inserted immediately in the SGPU Online. |
| System for evaluating the quality of service provided by SGPU operators | 2007 | See Table 8.18 | See Table 8.18. |
| Economic crisis | 2008 | In the first two years, the economic crisis did not have impact on the losses due to impairment of customers. | After the economic crisis, which started in 2008, the losses due to impairment of customers, was about 173421 in 2010, 131254 in 2011, 442728 in 2012, and 866952 in 2013. Because of this, the Ecovalue Table was to be updated (an increase). For example, the Ecovalue charged for the category “Civil engineering and massifs (>=24")” was increased from 36,54 to 41,43 €. |
| Public consultation to transporters (renewal of the transport fleet) | 2010 | The average operational expenditures with transportation was about 2.003.728 €. | The average operational expenditures with transportation was about 1.733.578 €, representing a saving of 13, 48%. |
| Follow up visits to Collection Points | Previous to 20007 | – | Diminution of the occurrences of incidents in the characterisation of origins (15%, with reference to 2012), and the number of charges contaminated sent to Recyclers/Energy Recoveries (20%, with reference to 2012). |
| Reformulation of the SGPU Online | 2012 | – | From that date it became possible, for example, better control the logistics related to the tyres of transport used between Collection Points and Recyclers/Energy Recoveries. |
| Training actions | 2012 | In order to facilitate the migration | The impact of this training was that the |

| | | | |
|---|---|---|---|
| (reformulated SGPU Online) | | process between the old platform and the new SGPU Online, Valorpneu carried out a special training for 82 SGPU operators. It was first performed an exhibition. that highlighted the main functional changes regarding the previous version, and later a demonstration of the new system. Additionally, was distributed to the participants of the training one summary document of the changes in the SGPU Online. | SGPU operators did not have difficulty to carry out the normal operations via the new SGPU Online. |
| Joint action with the ASAE to identify producers, potentially adherent to SGPU and that are still failing to fulfil their legal obligations in the management of tyres that they supply | 2013 | – | It is expected that in 2014 the results of such collaboration is visible, with a possible reduction of "free riders" in the market (around 40%). |

Table 8.18: Impact of the follow up visits to Collection Points

| **Performance measure(s)** | **Impact of the follow up visits to Collection Points** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** |
| Contaminated charges sent from collection points to recyclers and energy recoveries (%) | 2 | 1,20 | 0,37 | 0,30 | 0,23 | 0,54 | 0,12 | 0,23 |

Table 8.19: Impact of the introduction of the system for evaluating the quality of the services provided by Collection Points

| **Performance measure (s)** | **Impact of the system for evaluating the quality of the services provided by Collection Points** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** |
| Receptions registered with delay (%) | 40 | 20 | 11 | 11 | 9 | 8 | 7 | 4 |
| Number of incidents in the characterisation of the origin (per trimester) | 64 | 51 | 32 | 23,80 | 20,30 | 18,60 | 17 | 15,30 |

Table 8.20: Impact of the introduction of the system for evaluating the quality of the services provided by Transporters

| **Performance measure (s)** | **Impact of the system for evaluating and the quality of service provided by Transporters** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** |
| Charges delivered with delay (%) | 32 | 16 | 8 | 6 | 4 | 2 | 2 | 1,20 |

Table 8.21: Impact of the System for sorting used tyres at Collection Points

| **Performance measure(s)** | **Impact of the System for sorting used tyres at Collection Points** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** |
| Non-conforming charges sent from collection points to recyclers and energy recoveries (%) | 2 | 0,70 | 0,13 | 0,03 | 0,05 | 0,06 | 0,08 | 0,09 |

### 8.2.6 Demonstration and validation of the theoretical Agent-Based Simulation model

As has been discussed in Section 7.4.2, when analysing industrial networks, there is a need to set the boundaries of the study object, i.e. what will be investigated and what will not be. In the context of this case study, retreaders and shredders are not included in the demonstration of the theoretical ABS model because according to the managing entity manager, they are not relevant in terms of interaction with the other SGPU operators. Although only one company per each type of agent participated in the study, the theoretical ABS model is demonstrated with the agents illustrated in Figure 8.4. The rationale behind this choice was of having more agents in order to better understand the complex behaviour that can emerge from the interactions among multiple agents and how business interoperability affects the performance of agents at the same level and to demonstrate the spread of the network effect. It is to notice that although Producers and Distributors are not included in the structure provided below, they are modelled in the simulation environment, as it is important to make producers interact with the Managing Entity and distributors with Collection Points.

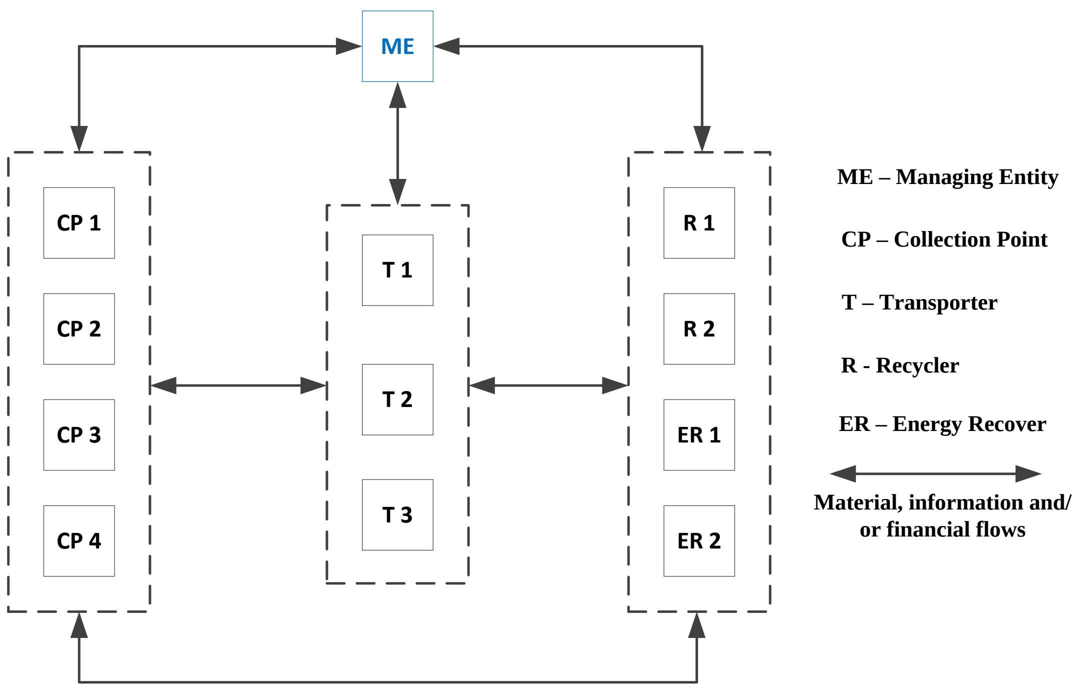



Figure 8.4: The structure of the considered SGPU

Also, there is a need to set the boundaries regarding the variables (BIDSs) to be analysed in the ABS model. In this case study, the impact of business interoperability on the performance of companies is analysed using the BIDSs provided in Table 8.18 – 8.21. In addition, some additional BIDSs are included in the simulation environment but modelled based on assumptions, as quantitative data regarding their impact were not available (see Table 8.22). The ALBI and RLBI of these BIDSs are provided in Table 8.23.

Table 8.22: Relationships between BIDSs and performance measures

| BIDSs | Designation | Dyad relationships | Impact on the performance measures |
|---|---|---|---|
| $BIDS_1$ | Mechanism to plan the flows of used tyres from Collection Points to Recyclers and Energy Recoveries | Managing Entity – Collection Points, Transporters, Recyclers and Energy Recoveries | Time spent in planning the flows of used tyres from Collection Points to Recyclers and Energy Recoveries;<br>Cost of planning the flows of used tyres from Collection Points to Recyclers and Energy Recoveries |
| $BIDS_2$ | Mechanism to communicate the route of tyres from Collection Points to Recyclers and Energy Recoveries | Managing Entity – Collection Points, Transporters, Recyclers and Energy Recoveries | Lead time needed to communicate the route of tyres from Collection Points to Recyclers and Energy Recoveries;<br>Number of pages needed to communicate the route of tyres from Collection Points to Recyclers and Energy Recoveries. |
| $BIDS_3$ | Rules for accepting discharges of used tyres at Collection Points[18] | Managing Entity – Collection Points | Number of rejected discharges at Collection Points. |
| $BIDS_4$ | Mechanism to communicate the discharges made at Collection Points | Collection Points – Managing Entity | Lead time needed to communicate the discharges made at Collection Points;<br>Number of pages needed to communicate the discharges made at Collection Points. |
| $BIDS_5$ | Mechanism to communicate the receptions of charges at Recyclers and Energy Recoveries | Recyclers/Energy Recoveries – Managing Entity | Lead time needed to communicate the receptions of charges at Recyclers and Energy Recoveries;<br>Number of pages needed to communicate the receptions of charges at Recyclers and Energy Recoveries. |

[18] A discharge is rejected by a Collection Point if the Distributor is blocked by the Managing Entity or if it is not possible to characterise the origin

| | | | |
|---|---|---|---|
| $BIDS_6$ | Mechanism to communicate the current inventory level at Collection Points, Recyclers and Energy Recoveries | Collection Points/Recyclers/ Energy Recoveries – Managing Entity | Lead time needed to communicate the current inventory level at Collection Points, Recyclers and Energy Recoveries;<br>Number of pages needed to communicate the current inventory level at Collection Points, Recyclers and Energy Recoveries. |
| $BIDS_7$ | System for sorting used tyres at Collection Points | Managing Entity – Collection Points | Number of non-conforming charges[19] sent from Collection Points to Recyclers and Energy Recoveries. |
| $BIDS_8$ | Follow-up visits to Collection Points | Managing Entity – Collection Points | Number of contaminated charges sent to Recyclers and/or Energy Recoveries. |
| $BIDS_9$ | System for evaluating the service provided by Collection Points | Managing Entity – Collection Points | Percentage of receptions registered with delay;<br>Number of incidents in the characterisation of origins at Collection Points. |
| $BIDS_{10}$ | System for evaluating the service provided by Transporters | Managing Entity – Transporters | Number of charges delivered with delay |
| $BIDS_{11}$ | Follow-up visits to Recyclers and Energy Recoveries | Managing Entity – Recyclers/Energy Recoveries | Number of receptions of charges registered with delay, at Recyclers and Energy Recoveries |

Table 8.23: ALBI and RLBI for each BIDS

| BIDSs | 2007 | | 2008 | | 2009 - 2014 | |
|---|---|---|---|---|---|---|
| | ALBI | RLBI | ALBI | RLBI | ALBI | RLBI |
| $BIDS_1$ | 1 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_2$ | 1 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_3$ | 4 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_4$ | 1 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_5$ | 1 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_6$ | 1 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_7$ | 3 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_8$ | 4 | 4 | 4 | 4 | 4 | 4 |
| $BIDS_9$ | 0 | 4 | 3 | 4 | 4 | 4 |
| $BIDS_{10}$ | 0 | 4 | 3 | 4 | 4 | 4 |
| $BIDS_{11}$ | 4 | 4 | 4 | 4 | 4 | 4 |

As mentioned elsewhere in this chapter, some assumptions were made in order to overcome the lack of quantitative data regarding the performance measures and the impact of business interoperability.

[19] Charges that include more than one category of used tyres

Therefore, Table 8.24 presents the main assumptions made in the simulation experiment. It is to notice that these assumptions were made grounded on the interviews the author had with the manager of the managing entity (Valorpneu).

Table 8.24: Assumptions made for Case Study 1

| A | Designation | Assumed value |
|---|---|---|
| A1 | Probability of a Distributor to be blocked by the Managing Entity | 0,008 |
| A2 | Probability of an origin of used tyres to be not characterised | 0,010 |
| A3 | Probability of truckers strike | 0,005 |
| A4 | Probability of a contaminated charge to be rejected | 0,030 |
| A5 | Probability of a non-conforming charge to be rejected | 0,020 |
| A6 | Probability of contaminated and non-conforming charge to be rejected | 0,050 |
| A7 | Number of discharges per week | ~ N (500; 50) |
| A8 | Inventory cost for each ton of rejected charge (€/ton) | 25 |
| A9 | Penalty value charged to Collection Points for each rejected charge (€/charge) | ~ N (120; 10) |
| A10 | Washing fee imposed by Recyclers or Energy Recoveries due to contaminated charges (€/charge) | ~ N (25; 2) |
| A11 | Amount of non-conforming tyres per each accepted charge (ton/charge) | ~ N (0,13; 0,015) |
| A12 | Amount of contaminated tyres per each accepted charge (ton/charge) | ~ N (0,15; 0,025) |
| A13 | Penalty value charged to Transporters for each charge delivered with delay (ton/rejected charge) | ~ N (25; 2) |
| A14 | Weight of each charge to Recyclers and Energy Recoveries (ton/charge) | ~ N (12,5; 1,2) |
| A15 | Salary of each manager responsible for routing tyres in the ambit of SGPU (€/month) | 3000 |
| A16 | Number of pages used to route tyres at the Managing Entity | Before introduction of the SGPU Online: ~ N (5; 1)<br>After introduction of the SGPU Online: 0 |

| | | |
|---|---|---|
| A17 | Lead time needed to communicate the route of tyres to SGPU operators (hours) | Before introduction of the SGPU Online: ~ N (10/60; 1/60)<br>After introduction of the SGPU Online: ~ N (1/60; 0,1/60) |
| A18 | Number of pages needed to communicate the route of tyres to SGPU operators | Before introduction of the SGPU Online: ~ N (3; 1)<br>After introduction of the SGPU Online: 0 |
| A19 | Lead time needed to communicate the discharges of tyres from Collection Points to the Managing Entity (minutes) | Before introduction of the SGPU Online: ~ N (4; 1)<br>After introduction of the SGPU Online: ~ N (1; 0,2) |
| A20 | Number of pages needed to communicate the discharges of tyres from Collection Points to the Managing Entity | Before introduction of the SGPU Online: 2<br>After introduction of the SGPU Online: 0 |
| A21 | Lead time needed to communicate the reception of a charge from Recyclers/Energy Recoveries to the Managing Entity (minutes) | Before introduction of the SGPU Online: ~ N (6; 1,2)<br>After introduction of the SGPU Online: ~ N (1,2; 0,2) |
| A22 | Number of pages needed to communicate the reception of a charge from Recyclers/Energy Recoveries to the Managing Entity | Before introduction of the SGPU Online: 1<br>After introduction of the SGPU Online: 0 |
| A23 | Number of working weeks per year | 51 |

To more easily understand how the theoretical ABS model is implemented, a detailed simulation process flowchart is shown in Figure 8.5.

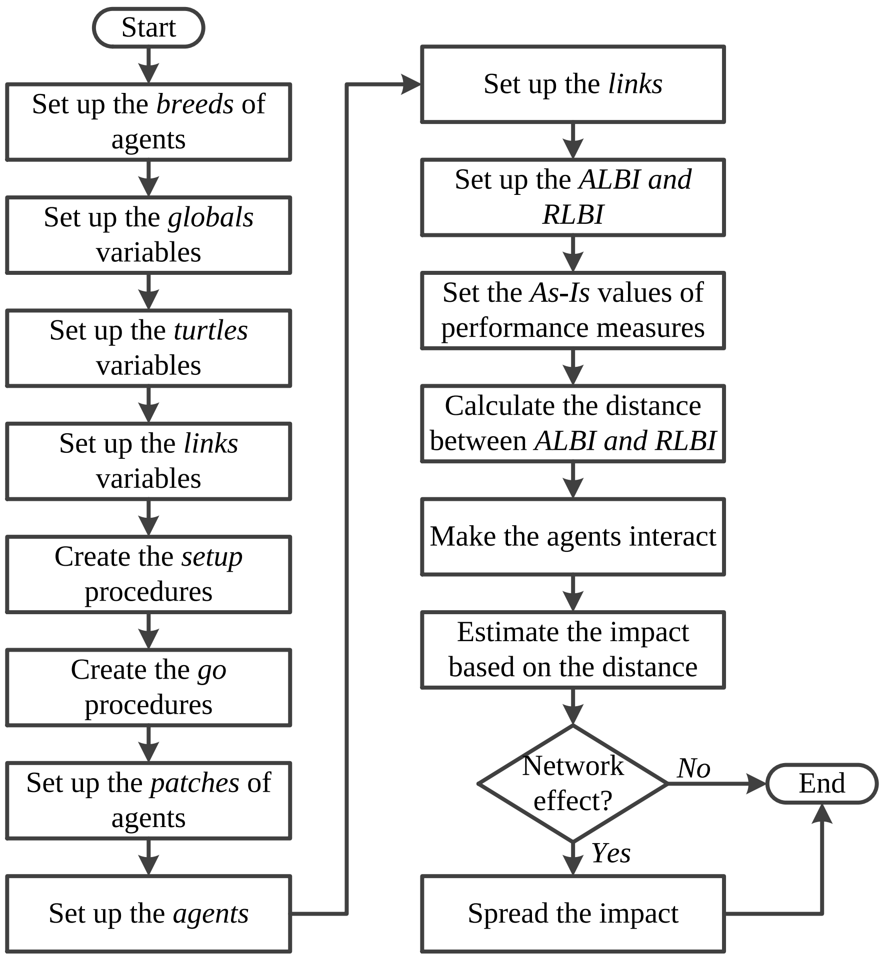



Figure 8.5: Steps to implement the theoretical ABS model

As can be seen in Figure 8.5, the first step in implementing the simulation model is to set the breeds of agents. Breeds are the type of agents involved in the system being modeled. In this case study the system being modeled consists of the five types of agents shown in Figure 8.4. In addition, three more types of breeds were included in the simulation environment, namely trucks, Producers, and Distributors. Trucks were included to simulate the flows of used tyres from Collection Points to Recyclers and Energy Recoveries; Producers were included to simulate the process of celebrating contracts with the Managing Entity; Distributors were created to simulate the process of delivering tyres to Collection Points.

Step two consists of defining the global variables, i.e. those that characterise the network as a whole (e.g. number of Collection Points, number of Transporters, probability of strike, number of loads a week, etc.).

Step three is to set up the turtles' variables. Turtles here are the agents in the system, i.e. the breeds defined previously. These types of variables can be turtles' variables or breeds' variables. The first can be accessed by any turtle, while the second can only be accessed by turtles of the same breed. In this simulation environment, examples of turtles' variables are type of information system used, time spent in reworking information, time spent in planning, geographical location, type of service/product provided, etc. Examples of breeds' variables, for Collection Points, are storage capacity, reference stock, amount of collected tyres per day, etc.

The fourth step is to set the links' variables, which are those that characterise each dyad relationship. In the scope of this study, these variables are the ALBI, the RLBI, and the distance between ALBI and RLBI.

Step five is to create the setup and go procedures. These are buttons created in the interface to allow the user to initialize (setup) and start (go) the simulation.

Following this, the patches of agents are created. Patches are the virtual world where the agents operate and interact. Although it is possible to have one or more patches, the simulation environment developed in this work consists of only one patch.

The next step is to create the agents, their position (can be random or fixed), and their shape (factory, truck, person, computer, etc.). Once agents are created, it is necessary to set the links among them. In this work, directed links have been established. The next step is to set the corresponding values of the links' variables, which are the ALBI and RLBI measured through the maturity model (see Table 6.8), and the performance measures being analysed. Grounded on these values, the business interoperability distance is calculated using Equation 10.

The last three steps consist of making the agents interact, estimating, and spreading the impact of business interoperability on performance. To make the agents interact, the interaction and decision rules in Table 8.4 and Appendix C were used. For each type of interaction (e.g. delivery of tyres at Recyclers and/or Energy Recoveries) it is necessary to identify the BIDS(s) that affect(s) the interaction and relate the BIDS(s) to performance measures (see Table 8.22). For example, in the process of delivering tyres to Recyclers and/or Energy Recoveries, upon the arrival of the truck the recovery agent receiving the load should evaluate whether it is contaminated, in conformity, or delayed, and decide whether the charge is accepted or not. The probability of a charge to be delivered with delay depends on the distance between the ALBI and RBI for BIDS10 (measured using data provided in Table 8.23), and the performance measure related to this process is "Percentage of charges delivered with delay" (see Table 8.20). Similarly, in Table 8.22, it was set that the probability of a non-conforming charge sent from collection points to recyclers and energy recoveries is dependent on the BIDS7. For example, to model whether a charge is contaminated or not, the following condition has been used:

```
if (random-float 1) < probability of a charge to be contaminated
  set contaminated-charge true
else
  set contaminated-charge true
  set number-of-contaminated-charges number-of-contaminated-charges + 1
end
```

The approach used to model whether a charge is not in conformity or delivered with delay is the same shown above. In the event that a charge is contaminated, non-conforming, or delivered with delay, the probability of rejection, as well as the potential impact, is modeled on the basis of the assumptions made in Table 8.24. For example, when a charge is contaminated, the decision on its rejection is dependent on the A4 – Probability of a contaminated charge to be rejected. For this purpose, the following condition has been used:

```
if (random-float) 1 < probability of a contaminated charge to be rejected
   reject charge
   set number-of-rejected-charges number-of-rejected-charges + 1
else
  accept charge
end
```

Once a charge is rejected, the impact is then spread to the agents directly or indirectly involved in the delivery of the charge. The assumptions used to estimate the impact of this scenario are A8, A9, and A10. For example, the penalty value charged by the Managing Entity to Collection Points due to each rejected charge follows a normal distribution with mean 120 and variance 10. The transportation cost charged by Transporters to the Collection Point responsible for the rejected charge is the round trip cost of the value paid by the Managing Entity to Transporters (€/ton – see Table 8.16).

### 8.2.7 Simulation experiment and results

One of the issues that is not yet consensual regarding the execution of ABS models is the number of replications that are needed. For example, North and Macal (2007) consider the need for designing sets of many simulation runs, many more than is the usual practice for standard simulation models, to fully understand system and agent behaviours. However, they do not specify a concrete number. In this thesis, the two ABS models (Case Study 1 and Case Study 2) are replicated 100 times using the *NetLogo*'s BehaviourSpace tool (Wilensky 1999), although, for example, Rand and Rust (2011) suggest that 30 runs are acceptable. In the Case Study 1, the model was run from 2007 to 2014 using a mix of real data collected during the interviews and through the Annual Reports, and the assumptions made in Table 8.24.

It was decided to start the simulation from 2007 because most of the BIDSs tested in the scope of this case study had a low level of business interoperability in that year. For example, in that year there were no systems to evaluate and reward the performance of the service provided by Collection Points and Transporters, which corresponds to level zero of the business interoperability maturity model presented in Section 6.3. These performance evaluation systems were introduced in 2008 and integrate the BIDS9 and BIDS10 (see Table 8.22 – 8.23). These BIDSs was implemented by the Managing Entity not only for the evaluation purpose but also to distinguish the best Collection Point and the best Transporter at the end of each year.

For Collection Points, the criteria for selecting the best Collection Point are: number of rejected charges at Recyclers and/or Energy Recoveries; number of contaminated charges sent to Recyclers and/or Energy Recoveries; number of non-conforming charges sent to Recyclers and/or Energy Recoveries; number of incidents in the characterisation of origins; number of discharges of used tyres registered with delay; and number of attendance to training. From these set of criteria, the only that is not measured in this case study is the last one. For Transporters, the criterion to select the best Transporter is the number of charges delivered with delay. In addition to these performance measures, it was decided to model the beginning of the SGPU' activities in 2003. This scenario was modelled for the year 2007 and represents the time interval the integrated information system platform that supports the information exchange between all SGPU' operators did not exist.

In such scenario, the communication of the discharges made at Collection Points and the communication of charges delivered at Recyclers and Energy Recoveries were made via fax, which resulted in the use of large amount of papers, long lead time to prepare and send fax, long lead time to process information, etc. For example, before the introduction of the SGPU Online, the weekly planning of the tyres flows from Collection Points to Recyclers and Energy Recoveries was made using three people and during one day (8 hours). With the introduction of the SGPU Online, only one person is needed and this person spends only three hours in carrying out the weekly planning. These impacts are captured in the ABS model and the BIDSs related to them are the BIDS1, BIDS2, BIDS4, BIDS5 and BIDS6. Another BIDS modelled was the "System for sorting used tyres at Collection Points – BIDS7". In 2007 this system was well-defined and implemented but it was not documented, corresponding to level 3 of the maturity model. In 2008, Valorpneu created the document "Ponto de

Recolha: Normas e Procedimentos" where such system is well-defined and well documented (level 4 of business interoperability).

Regarding the network variables, the model was designed to capture the impact of the truckers' strike, which may have several impacts on the performance of all SGPU operators. For example, when there is a truck strike, if all SGPU' transporters adhere to this strike there is no flow of used tyres from Collection Points to Recyclers and Energy Recoveries. The potential impacts are on the inventory level at Collection Points (increase), inventory cost at Collection Points (increase), inventory level at Recyclers and Energy Recoveries (decrease), and payoff to Transporters for each ton of tyres transported (they will not receive any payment if they do not carry out any charge). These scenarios are captured by the simulation model and represent clearly the network effect, i.e. one external event different impacts for each type of agents.

Regarding the simulation environment, it comprises three main components. The first component is related to the choices that are provided to users in order to change the simulation parameters, as illustrated by Figure 8.6. For example, the user can change the number of each type of agents, the simulation time step (daily, weekly, monthly or quarterly), the probability of truckers strike, the duration of cooperation, the number of discharges a week, the weight of each charge, etc. This component also includes the button to set up the agents and to start the simulation ("go"). The second component is concerned with the environment where the agents interact. In *NetLogo*, such environment is called "Patch". This environment sets the position of agents and the relationships among them, as shown in Figure 8.7.

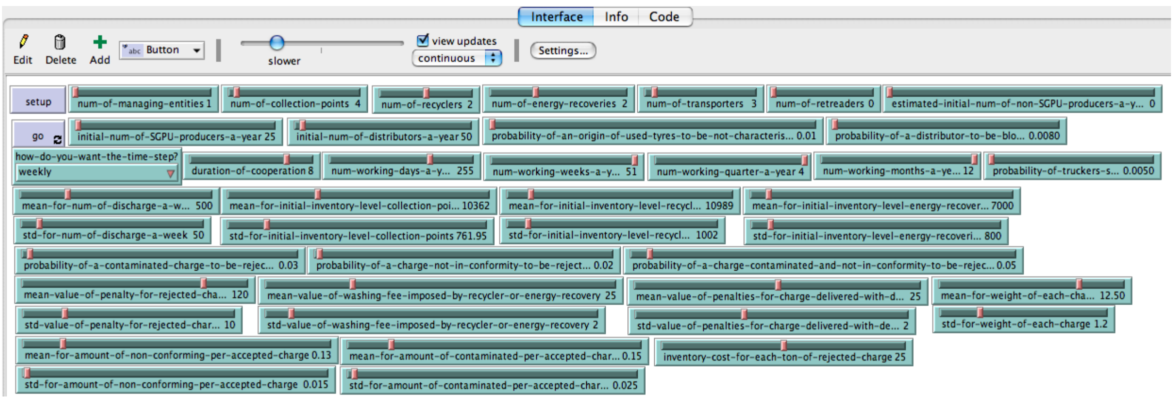



Figure 8.6: Options for changing the simulation parameters

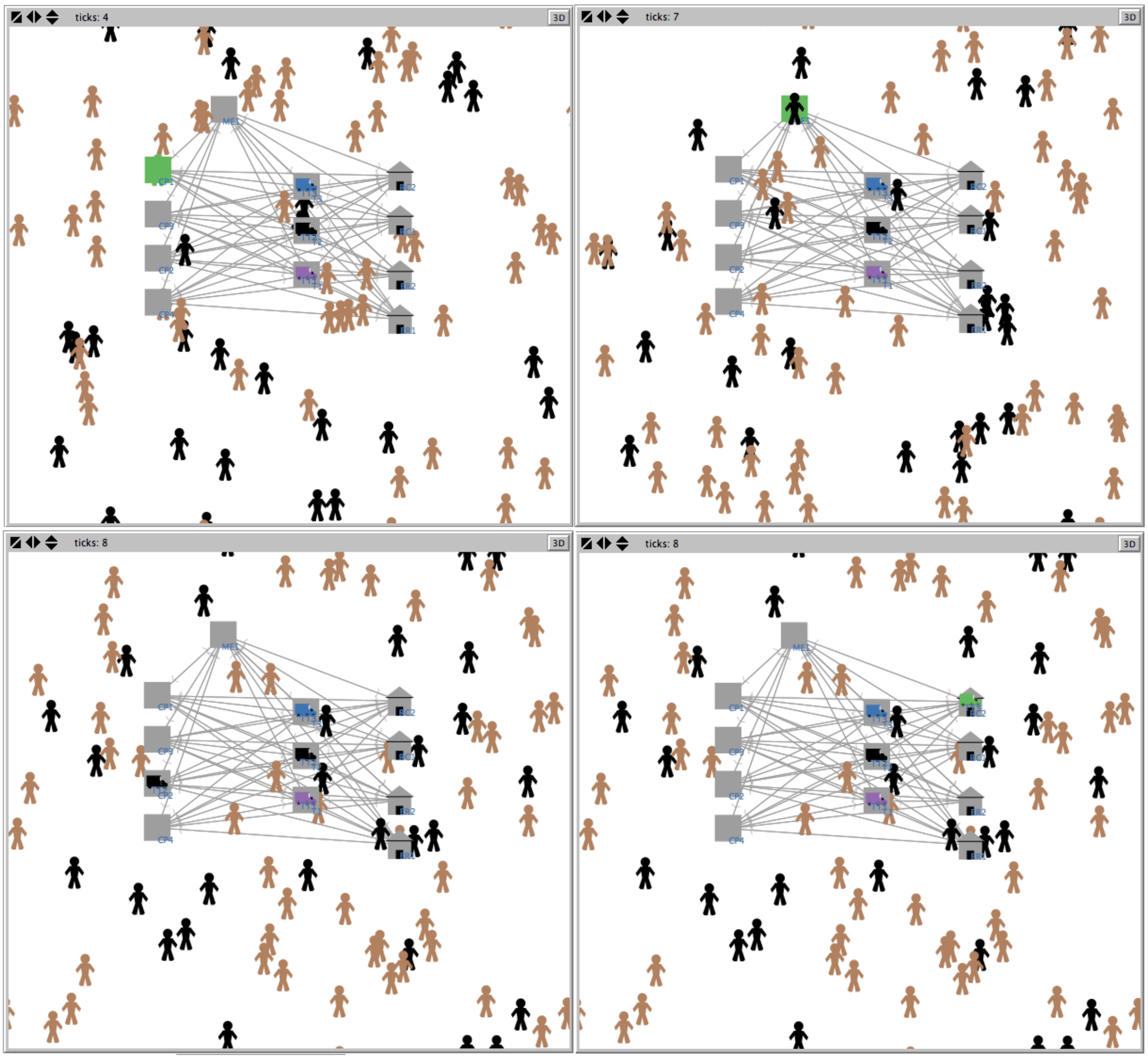


Figure 8.7: The environment for agents' interactions

As can be observed from Figure 8.7, the agents are interacting with each other over time. The turtles represented by human shape are Producers (black colour) and Distributors (brown colour). In the first spreadsheet (ticks equal to 4), it is possible to observe a distributor interacting with the Collection Point 1 (CP1). In that time, the colours of both agents were green, which means that the Collection Point accepted the discharge from the distributor. In the second spreadsheet (ticks equal to 7) we have a distributor that is celebrating a contract with the Managing Entity, i.e. declaring the tyres introduced into the market. In the third spreadsheet (ticks equal to 8) we have a truck that is being charged at CP2, and in the last picture we have the same truck delivering the charge at Recycler 2. As can be observed, the colour of the truck is green, meaning that the charge has been accepted. Last, the third component represents the plots where the performance measures are monitored over time, as illustrated in Figure 8.8.

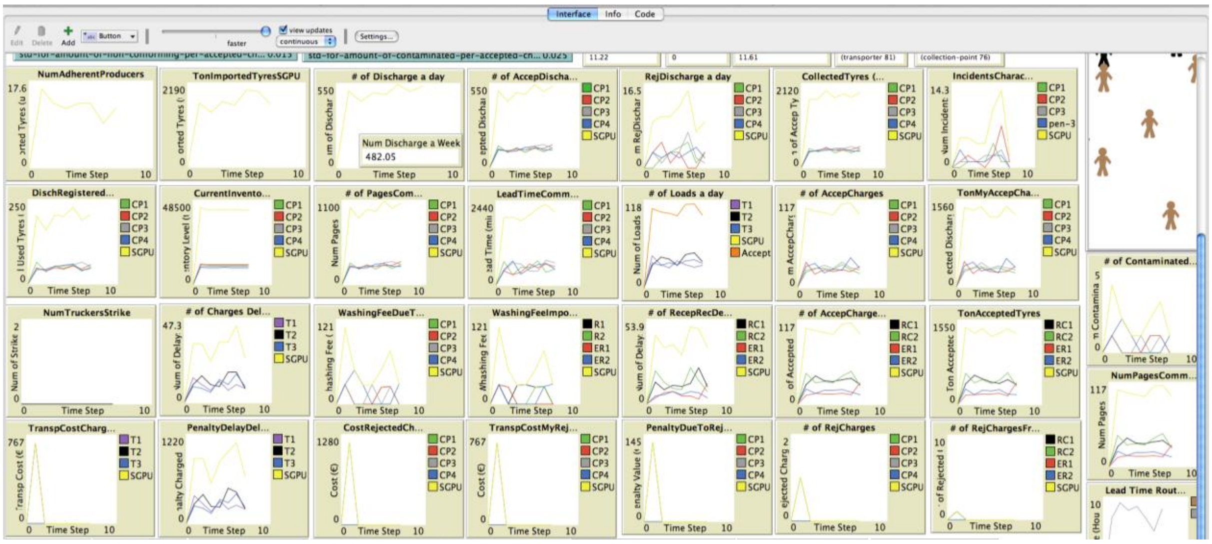


Figure 8.8: Plots to monitor the performance measures over time

As can be seen in Figure above, several performance measures were monitored over time by the simulation model implemented here. Following, Table 8.25 – 8.34 report the simulation outputs for the performance measures analysed in the ambit of this case study.

Table 8.25: Simulation outputs for the process of declaring tyres introduced into the market

| Year | Number of adherent Producers | | | Amount of declared tyres (ton) | | |
|---|---|---|---|---|---|---|
| | Model output | Real data | Error (%) | Model output | Real data | Error (%) |
| 2007 | 703 | 691 | 1,74 | 85720,50 | 83722 | 2,39 |
| 2008 | 897 | 886 | 1,24 | 85536,09 | 83139 | 2,88 |
| 2009 | 1160 | 1109 | 4,60 | 80755,76 | 78349 | 3,07 |
| 2010 | 1241 | 1191 | 4,20 | 83735,07 | 83294 | 0,53 |
| 2011 | 1304 | 1290 | 1,09 | 77345,01 | 72785 | 6,27 |
| 2012 | 1476 | 1451 | 1,72 | 63283,32 | 62431 | 1,37 |
| 2013 | 1671 | 1652 | 1,15 | 66930,74 | 70625 | 5,23 |
| 2014 | 1678 | 1787 | 6,10 | 75211,70 | 74962 | 0,33 |

Table 8.26: Simulation outputs for the process of routing tyres at Managing Entity

| Performance measure | Before the introduction of the SGPU Online (2007) | | | Before the introduction of the SGPU Online (2008 to 2014) | | |
|---|---|---|---|---|---|---|
| | **Model output** | **Real data** | **Error (%)** | **Model output** | **Real data** | **Error (%)** |
| Average time spent in routing tyres at the Managing Entity (hours) | Mean: 8,16<br>Std[20]: 1,13 | Mean: 8<br>Std: 0,95 | 2 | Mean: 2,94<br>Std: 0,50 | Mean: 3<br>Std: 0,31 | 2 |
| Average cost of routing tyres at the Managing Entity (€) | Mean: 417,12<br>Std: 57,71 | N.Av.[21] | N.Ap.[22] | Mean: 50,16<br>Std: 8,47 | N.Av. | N.Ap. |
| Average lead time needed to communicate the route of tyres to all SGPU operators (hours) | Mean: 1,77<br>Std: 0,19 | N.Av. | N.Ap. | Mean: 0,18<br>Std: 0,02 | N.Av. | N.Ap. |

[20] Std – Standard Deviation
[21] N.Av. – Not Available
[22] N.Ap. – Not Applicable

Table 8.27: Simulation outputs for the process of discharges of tyres at Collection Points

| Performance measures | Year | CP1 | CP2 | CP3 | CP4 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Number of accepted discharges | 2007 | 6405 | 6372 | 6248 | 6386 | 25411 | N.Av. | N.Ap. |
| | 2008 | 6376 | 6480 | 6564 | 6497 | 25917 | | |
| | 2009 | 6474 | 6409 | 6528 | 6271 | 25682 | | |
| | 2010 | 6336 | 6383 | 6310 | 6402 | 25431 | | |
| | 2011 | 6587 | 6647 | 6505 | 6604 | 26343 | | |
| | 2012 | 6327 | 6301 | 6335 | 6251 | 25214 | | |
| | 2013 | 6459 | 6346 | 6328 | 6201 | 25334 | | |
| | 2014 | 6501 | 6461 | 6397 | 6396 | 25755 | | |
| Number of incidents in the characterisation of origin | 2007 | 62 | 65 | 71 | 78 | 276 | 256 | 7,81 |
| | 2008 | 64 | 65 | 50 | 67 | 246 | 204 | 20,59 |
| | 2009 | 23 | 37 | 37 | 27 | 124 | 128 | 3,13 |
| | 2010 | 27 | 30 | 31 | 23 | 111 | 95,2 | 16,60 |
| | 2011 | 17 | 22 | 20 | 25 | 84 | 81,2 | 3,45 |
| | 2012 | 20 | 16 | 16 | 19 | 71 | 74,4 | 4,57 |
| | 2013 | 18 | 18 | 16 | 10 | 62 | 68 | 8,82 |
| | 2014 | 14 | 18 | 16 | 16 | 64 | 61,2 | 4,58 |
| Number of accepted discharges registered with delay | 2007 | 2603 | 2589 | 2519 | 2547 | 10258 (40,37%) | 40% | 0,92 |
| | 2008 | 1294 | 1295 | 1354 | 1376 | 5319 (20,52%) | 20% | 2,62 |
| | 2009 | 756 | 751 | 729 | 720 | 2956 (11,51%) | 11% | 4,64 |
| | 2010 | 725 | 698 | 679 | 687 | 2789 (10,97%) | 11% | 0,30 |
| | 2011 | 574 | 574 | 565 | 598 | 2311 (8,77%) | 9% | 2,53 |
| | 2012 | 511 | 504 | 524 | 512 | 2051 (8,13%) | 8% | 1,68 |
| | 2013 | 417 | 427 | 434 | 426 | 1704 (6,73%) | 7% | 3,91 |
| | 2014 | 268 | 254 | 243 | 260 | 1025 (3,98%) | 4% | 0,50 |
| Number of rejected discharges | 2007 | 99 | 120 | 120 | 112 | 451 | N.Av. | N.Ap. |
| | 2008 | 121 | 134 | 118 | 118 | 491 | | |
| | 2009 | 127 | 112 | 113 | 116 | 468 | | |
| | 2010 | 109 | 125 | 106 | 119 | 459 | | |
| | 2011 | 110 | 134 | 125 | 122 | 491 | | |
| | 2012 | 123 | 101 | 135 | 117 | 476 | | |
| | 2013 | 113 | 99 | 122 | 108 | 442 | | |
| | 2014 | 117 | 110 | 118 | 130 | 475 | | |
| Amount of tyres accepted from distributors (ton) | 2007 | 22714,87 | 22589,73 | 22144,83 | 22730,85 | 90180,28 | 92322 | 2,32 |
| | 2008 | 23280,91 | 23688,52 | 23922,43 | 23771,69 | 94663,55 | 96210 | 1,61 |
| | 2009 | 23190,23 | 22934,19 | 23337,48 | 22455,33 | 91917,23 | 89575 | 2,61 |
| | 2010 | 23564,33 | 23770,47 | 23484,74 | 23821,07 | 94640,60 | 94373 | 0,28 |
| | 2011 | 23062,49 | 23291,75 | 22769,13 | 23140,19 | 92263,56 | 90373 | 2,09 |
| | 2012 | 19562,22 | 19492,78 | 19559,88 | 19344,22 | 77959,10 | 78267 | 0,39 |
| | 2013 | 19403,84 | 19122,57 | 19040,94 | 18676,81 | 76244,17 | 78695 | 3,11 |
| | 2014 | 21465,87 | 21341,51 | 21196,54 | 21162,87 | 85166,79 | 85841 | 0,79 |

Table 8.28: Simulation outputs for final inventory level at Collection Points, Recyclers and Energy Recoveries

| Performance measures | Year | CP1 | CP2 | CP3 | CP4 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Final inventory level at Collection Points | 2007 | 2654,12 | 2469,26 | 2345,53 | 2654,96 | 10123,86 | 10153 | 0,29 |
| | 2008 | 2662,10 | 2446,46 | 2361,74 | 2663,96 | 10134,25 | 9487 | 6,82 |
| | 2009 | 2631,86 | 2495,11 | 2356,22 | 2628,38 | 10111,58 | 9909 | 2,04 |
| | 2010 | 2638,43 | 2472,63 | 2374,15 | 2630,58 | 10115,79 | 10193 | 0,76 |
| | 2011 | 2656,46 | 2398,02 | 2343,54 | 2657,86 | 10055,88 | 10531 | 4,51 |
| | 2012 | 2617,62 | 2467,94 | 2319,02 | 2624,40 | 10028,99 | 11471 | 12,57 |
| | 2013 | 2632,01 | 2460,55 | 2319,68 | 2578,10 | 9990,34 | 11480 | 12,97 |
| | 2014 | 2653,54 | 2462,14 | 2342,40 | 2600,21 | 10058,29 | N.Av. | N.Ap. |
| **Performance measures** | **Year** | **R1** | **R2** | **ER1** | **ER2** | **Total** | **Real data** | **Error (%)** |
| Final inventory level at Recyclers and Energy Recoveries | 2007 | 11181,47 | 12605,95 | 7671,35 | 8400,79 | 39859,56 | N.Av. | N.Ap. |
| | 2008 | 11135,96 | 12626,44 | 7725,48 | 8374,19 | 39862,07 | | |
| | 2009 | 11127,44 | 12718,79 | 7731,92 | 8378,88 | 39957,04 | | |
| | 2010 | 11112,60 | 12697,96 | 7839,61 | 8511,48 | 40161,64 | | |
| | 2011 | 11246,18 | 12652,40 | 7787,63 | 8377,01 | 40063,22 | | |
| | 2012 | 11128,57 | 12584,84 | 7712,80 | 8290,18 | 39716,39 | | |
| | 2013 | 11058,70 | 12517,36 | 7676,96 | 8460,42 | 39713,44 | | |
| | 2014 | 11097,65 | 12615,80 | 7913,38 | 8477,58 | 40104,42 | | |

Table 8.29: Simulation outputs of Transporters regarding the process of delivering charges at Recyclers and Energy Recoveries

| Performance measures | Year | T1 | T2 | T3 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|
| Number of loads made | 2007 | 1810 | 1774 | 1733 | 5317 | 5400 | 1,54 |
| | 2008 | 1932 | 1880 | 1908 | 5720 | | 5,93 |
| | 2009 | 1857 | 1900 | 1885 | 5642 | | 4,48 |
| | 2010 | 1996 | 2068 | 2017 | 6081 | | 12,61 |
| | 2011 | 2021 | 1953 | 1975 | 5949 | | 10,17 |
| | 2012 | 1736 | 1741 | 1659 | 5136 | | 4,89 |
| | 2013 | 1616 | 1667 | 1644 | 4927 | | 8,76 |
| | 2014 | 1882 | 1852 | 1807 | 5541 | | 2,61 |
| Number of charges delivered with delay | 2007 | 519 | 572 | 542 | 1633 (30,71%) | 32% | 4,02 |
| | 2008 | 324 | 298 | 306 | 928 (16,22%) | 16% | 1,40 |
| | 2009 | 153 | 141 | 148 | 442 (7,49%) | 8% | 2,07 |
| | 2010 | 123 | 140 | 119 | 382 (6,28%) | 6% | 4,70 |
| | 2011 | 95 | 88 | 80 | 263 (4,42%) | 4% | 10,52 |
| | 2012 | 29 | 32 | 44 | 105 (2,13%) | 2% | 2,22 |
| | 2013 | 36 | 31 | 39 | 106 (1,91%) | 2% | 7,57 |
| | 2014 | 15 | 14 | 15 | 44 (0,83%) | 1,2% | 33,83 |
| Value charged by Valorpneu due to charges delivered with delay (€) | 2007 | 13326,91 | 14629,35 | 13826,75 | 41783,02 | N.Av. | N.Ap. |
| | 2008 | 8029,06 | 7298,44 | 7579,66 | 22907,16 | | |
| | 2009 | 3809,02 | 3516,81 | 3697,10 | 11022,94 | | |
| | 2010 | 3119,15 | 3529,90 | 2992,77 | 9641,82 | | |
| | 2011 | 2453,83 | 2242,62 | 2058,46 | 6754,91 | | |
| | 2012 | 720,82 | 809,24 | 1107,34 | 2637,40 | | |
| | 2013 | 908,18 | 769,84 | 993,57 | 2671,59 | | |
| | 2014 | 386,03 | 344,35 | 364,08 | 1094,47 | | |
| Number of truckers strike | 2007 | 0 | | | | N.Av. | N.Ap. |
| | 2008 | 0 | | | | | |
| | 2009 | 0 | | | | | |
| | 2010 | 1 | | | | | |
| | 2011 | 0 | | | | | |
| | 2012 | 0 | | | | | |
| | 2013 | 0 | | | | | |
| | 2014 | 2<br>1 | | | | | |
| Value charged to Collection Points due to rejected charges (€) | 2007 | 662,01 | 0,00 | 657,82 | 1319,82 | N.Av. | N.Ap. |
| | 2008 | 1399,02 | 813,17 | 838,14 | 3050,33 | | |
| | 2009 | 0,00 | 719,98 | 0,00 | 719,98 | | |
| | 2010 | 0,00 | 643,21 | 0,00 | 643,21 | | |
| | 2011 | 0,00 | 0,00 | 765,94 | 765,94 | | |
| | 2012 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2013 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2014 | 0,00 | 0,00 | 0,00 | 0,00 | | |

Table 8.30: Simulation outputs for Collection Points regarding the process of delivering charges at Recyclers and Energy Recoveries

| Performance measures | Year | CP1 | CP2 | CP3 | CP4 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Number of accepted charges at Recyclers and Energy Recoveries | 2007 | 1354 | 1299 | 1359 | 1302 | 5314 | N.Av. | N.Ap. |
| | 2008 | 1371 | 1512 | 1378 | 1453 | 5714 | | |
| | 2009 | 1379 | 1389 | 1414 | 1459 | 5641 | | |
| | 2010 | 1514 | 1517 | 1523 | 1526 | 6080 | | |
| | 2011 | 1544 | 1470 | 1438 | 1496 | 5948 | | |
| | 2012 | 1308 | 1307 | 1292 | 1229 | 5136 | | |
| | 2013 | 1212 | 1250 | 1228 | 1236 | 4926 | | |
| | 2014 | 1405 | 1314 | 1458 | 1364 | 5541 | | |
| Number of rejected charges at Recyclers and Energy Recoveries | 2007 | 1 | 0 | 1 | 1 | 3 | N.Av. | N.Ap. |
| | 2008 | 1 | 0 | 2 | 3 | 6 | | |
| | 2009 | 0 | 1 | 0 | 0 | 1 | | |
| | 2010 | 0 | 0 | 0 | 1 | 1 | | |
| | 2011 | 0 | 0 | 1 | 0 | 1 | | |
| | 2012 | 0 | 0 | 0 | 0 | 0 | | |
| | 2013 | 0 | 1 | 0 | 0 | 1 | | |
| | 2014 | 0 | 0 | 0 | 0 | 0 | | |
| Number of contaminated charges sent from Collection Points to Recyclers and Energy Recoveries | 2007 | 29 | 18 | 20 | 29 | 96 (1,81%) | 2% | 9,50 |
| | 2008 | 13 | 12 | 19 | 25 | 69 (1,21%) | 1,2% | 0,83 |
| | 2009 | 5 | 5 | 3 | 8 | 21 (0,38%) | 0,37% | 2,70 |
| | 2010 | 9 | 1 | 6 | 4 | 20 (0,32%) | 0,3% | 6,66 |
| | 2011 | 8 | 2 | 1 | 2 | 13 (0,22%) | 0,23% | 4,34 |
| | 2012 | 8 | 5 | 7 | 6 | 26 (0,51%) | 0,54% | 5,55 |
| | 2013 | 2 | 0 | 0 | 3 | 5 (0,11%) | 0,12% | 8,33 |
| | 2014 | 7 | 4 | 3 | 1 | 15 (0,27%) | 0,23% | 17,39 |
| Number of non-conforming charges sent from Collection Points to Recyclers and Energy Recoveries | 2007 | 38 | 29 | 25 | 16 | 108 (2,03%) | 2% | 1,50 |
| | 2008 | 11 | 12 | 17 | 13 | 53 (0,92%) | 0,7% | 31,42 |
| | 2009 | 2 | 2 | 2 | 4 | 10 (0,18%) | 0,13% | 38,46 |
| | 2010 | 0 | 0 | 0 | 2 | 2 (0,03%) | 0,03% | 0,00 |
| | 2011 | 1 | 1 | 1 | 2 | 5 (0,08%) | 0,05% | 60,00 |
| | 2012 | 1 | 1 | 0 | 0 | 2 (0,04%) | 0,06% | 33,33 |
| | 2013 | 1 | 2 | 2 | 0 | 5 (0,10%) | 0,08% | 25,00 |
| | 2014 | 0 | 2 | 3 | 1 | 6 (0,10%) | 0,09% | 0,11 |

Table 8.31: Simulation outputs of cost for Collection Points due to contaminated, non-conforming and rejected charges at Recyclers and Energy Recoveries

| Performance measures | Year | CP1 | CP2 | CP3 | CP4 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Total cost due to rejected charges (€) | 2007 | 0,00 | 0,00 | 1110,37 | 1089,30 | 2199,67 | N.Av. | N.Ap. |
| | 2008 | 1182,57 | 0,00 | 1350,83 | 2391,51 | 4924,91 | | |
| | 2009 | 0,00 | 1171,42 | 0,00 | 0,00 | 1171,42 | | |
| | 2010 | 0,00 | 0,00 | 0,00 | 1041,36 | 1041,36 | | |
| | 2011 | 0,00 | 0,00 | 1244,13 | 0,00 | 1244,13 | | |
| | 2012 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2013 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2014 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| Transportation cost paid to Transporters due to rejected charges (€) | 2007 | 0,00 | 0,00 | 662,01 | 657,82 | 1319,82 | N.Av. | N.Ap. |
| | 2008 | 724,42 | 0,00 | 838,14 | 1487,77 | 3050,33 | | |
| | 2009 | 0,00 | 719,98 | 0,00 | 0,00 | 719,98 | | |
| | 2010 | 0,00 | 0,00 | 0,00 | 643,21 | 643,21 | | |
| | 2011 | 0,00 | 0,00 | 765,94 | 0,00 | 765,94 | | |
| | 2012 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2013 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2014 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| Penalty value paid to Transporters due to rejected charges (€) | 2007 | 0,00 | 0,00 | 131,79 | 116,92 | 248,72 | N.Av. | N.Ap. |
| | 2008 | 127,31 | 0,00 | 129,91 | 224,26 | 481,48 | | |
| | 2009 | 0,00 | 122,62 | 0,00 | 0,00 | 122,62 | | |
| | 2010 | 0,00 | 0,00 | 0,00 | 103,10 | 103,10 | | |
| | 2011 | 0,00 | 0,00 | 126,84 | 0,00 | 126,84 | | |
| | 2012 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2013 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| | 2014 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | |
| Washing fee imposed by Recyclers and Energy Recoveries do to contaminated charges (€) | 2007 | 701,61 | 452,93 | 473,87 | 685,14 | 2313,55 | N.Av. | N.Ap. |
| | 2008 | 301,85 | 288,91 | 426,30 | 585,78 | 1602,85 | | |
| | 2009 | 129,64 | 123,38 | 70,79 | 195,88 | 519,68 | | |
| | 2010 | 216,89 | 23,20 | 144,03 | 71,21 | 455,33 | | |
| | 2011 | 192,35 | 46,79 | 22,96 | 47,67 | 309,76 | | |
| | 2012 | 207,13 | 128,57 | 178,16 | 146,98 | 660,85 | | |
| | 2013 | 51,07 | 0,00 | 0,00 | 79,72 | 130,80 | | |
| | 2014 | 171,04 | 104,98 | 76,13 | 23,47 | 375,62 | | |

Table 8.32: Simulation outputs of washing fee imposed by Recyclers and Energy Recoveries to Collection Points, due to contaminated charges

| Performance measures | Year | R1 | R2 | ER1 | ER2 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Washing fee imposed to Collection Points due to rejected charges (€) | 2007 | 640,98 | 732,75 | 431,73 | 508,08 | 2313,55 | N.Av. | N.Ap. |
| | 2008 | 366,00 | 724,14 | 317,72 | 194,98 | 1602,85 | | |
| | 2009 | 148,00 | 175,99 | 20,96 | 174,73 | 519,68 | | |
| | 2010 | 143,31 | 120,59 | 49,71 | 141,72 | 455,33 | | |
| | 2011 | 93,17 | 120,59 | 73,05 | 22,96 | 309,76 | | |
| | 2012 | 202,34 | 126,18 | 105,93 | 226,39 | 660,85 | | |
| | 2013 | 0,00 | 27,41 | 77,67 | 25,71 | 130,80 | | |
| | 2014 | 102,37 | 152,16 | 99,96 | 21,13 | 375,62 | | |

Table 8.33: Simulation outputs of Recyclers and Energy Recoveries regarding the process of receiving charges from Collection Points

| Performance measures | Year | R1 | R2 | ER1 | ER2 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Number of accepted charges from Collection Points | 2007 | 1776 | 1778 | 854 | 906 | 5314 | N.Av. | N.Ap. |
| | 2008 | 1887 | 1957 | 940 | 930 | 5714 | | |
| | 2009 | 1911 | 1905 | 884 | 941 | 5641 | | |
| | 2010 | 1990 | 2004 | 979 | 1107 | 6080 | | |
| | 2011 | 1927 | 1879 | 1080 | 1062 | 5948 | | |
| | 2012 | 1584 | 1577 | 985 | 990 | 5136 | | |
| | 2013 | 1454 | 1487 | 989 | 996 | 4926 | | |
| | 2014 | 1706 | 1632 | 1133 | 1070 | 5541 | | |
| Number of receptions of charges registered with delay | 2007 | 690 | 690 | 345 | 366 | 2091 | N.Av. | N.Ap. |
| | 2008 | 400 | 411 | 178 | 182 | 1171 | | |
| | 2009 | 383 | 392 | 171 | 167 | 1113 | | |
| | 2010 | 394 | 394 | 190 | 207 | 1185 | | |
| | 2011 | 417 | 390 | 230 | 195 | 1232 | | |
| | 2012 | 322 | 301 | 207 | 198 | 1028 | | |
| | 2013 | 298 | 315 | 185 | 209 | 1007 | | |
| | 2014 | 377 | 336 | 228 | 203 | 1144 | | |
| Number of rejected charges from Collection Points | 2007 | 2 | 0 | 1 | 0 | 3 | N.Av. | N.Ap. |
| | 2008 | 1 | 3 | 2 | 0 | 6 | | |
| | 2009 | 0 | 1 | 0 | 0 | 1 | | |
| | 2010 | 1 | 0 | 0 | 0 | 1 | | |
| | 2011 | 1 | 0 | 0 | 0 | 1 | | |
| | 2012 | 0 | 0 | 0 | 0 | 0 | | |
| | 2013 | 0 | 0 | 0 | 1 | 1 | | |
| | 2014 | 0 | 0 | 0 | 0 | 0 | | |
| Number of pages needed to communicate the reception of charges to Managing Entity | 2007 | 1776 | 1778 | 854 | 906 | 5314 | N.Av. | N.Ap. |
| | 2008 | 62 | 73 | 36 | 37 | 208 | | |
| | 2009 | 0 | 0 | 0 | 0 | 0 | | |
| | 2010 | 0 | 0 | 0 | 0 | 0 | | |
| | 2011 | 0 | 0 | 0 | 0 | 0 | | |
| | 2012 | 0 | 0 | 0 | 0 | 0 | | |
| | 2013 | 0 | 0 | 0 | 0 | 0 | | |
| | 2014 | 0 | 0 | 0 | 0 | 0 | | |
| Time spent to communicate the reception of charges to Managing Entity | 2007 | 11036,87 | 10830,09 | 5535,77 | 5920,31 | 33323,05 | N.Av. | N.Ap. |
| | 2008 | 2575,91 | 2755,05 | 1396,94 | 1399,01 | 8126,92 | | |
| | 2009 | 2271,85 | 2404,48 | 1133,03 | 1235,91 | 7045,27 | | |
| | 2010 | 2436,87 | 2448,73 | 1273,48 | 1445,31 | 7604,39 | | |
| | 2011 | 2308,58 | 2277,80 | 1380,92 | 1341,01 | 7308,31 | | |
| | 2012 | 1860,66 | 1925,79 | 1274,48 | 1277,49 | 6338,42 | | |
| | 2013 | 1814,84 | 1825,16 | 1332,25 | 1299,40 | 6271,66 | | |
| | 2014 | 2071,74 | 2017,93 | 1474,58 | 1363,86 | 6928,10 | | |

Table 8.34: Simulation outputs - flow of tyres from Collection Points to Recyclers and Energy Recoveries

| Performance measures | Year | CP1 | CP2 | CP3 | CP4 | Total | Real data | Error (%) |
|---|---|---|---|---|---|---|---|---|
| Amount of tyres routed to Recyclers and Energy Recoveries (ton) | 2007 | 17071,74 | 16375,84 | 17107,74 | 16272,05 | 66827,37 | 66500 | 0,49 |
| | 2008 | 17186,61 | 18937,76 | 17272,25 | 18298,92 | 71695,54 | 71836 | 0,20 |
| | 2009 | 17105,33 | 17367,01 | 17588,34 | 18183,77 | 70244,45 | 70375,21 | 0,19 |
| | 2010 | 18812,62 | 18851,49 | 18938,36 | 18989,55 | 75592,03 | 75724,61 | 0,18 |
| | 2011 | 19529,28 | 18614,44 | 18183,75 | 18953,36 | 75280,83 | 73611,54 | 2,27 |
| | 2012 | 16677,53 | 16649,17 | 16492,88 | 15603,95 | 65423,53 | 63685,82 | 2,73 |
| | 2013 | 15418,49 | 15824,34 | 15594,93 | 15704,96 | 62542,74 | 64540,04 | 3,09 |
| | 2014 | 17625,11 | 16458,52 | 18312,32 | 17169,08 | 69565,02 | 71493,49 | 2,70 |
| | **Year** | **R1** | **R2** | **ER1** | **ER2** | **Total** | **Real data** | **Error (%)** |
| Amount of tyres received from Collection Points (ton) | 2007 | 22346,21 | 22326,97 | 10770,19 | 11387,80 | 66831,18 | 66500 | 0,50 |
| | 2008 | 23649,29 | 24607,14 | 11887,67 | 11783,58 | 71927,69 | 71836 | 0,13 |
| | 2009 | 23735,13 | 23692,01 | 11103,41 | 11832,03 | 70362,58 | 70375,21 | 0,02 |
| | 2010 | 24758,91 | 24812,28 | 12312,28 | 13972,44 | 75855,91 | 75724,61 | 0,17 |
| | 2011 | 24378,79 | 23814,73 | 13855,82 | 13522,04 | 75571,38 | 73611,54 | 2,60 |
| | 2012 | 20204,06 | 20040,03 | 12494,33 | 12590,90 | 65329,33 | 63685,82 | 2,51 |
| | 2013 | 18437,27 | 18851,65 | 12308,54 | 12540,92 | 62138,38 | 64540,04 | 3,84 |
| | 2014 | 21368,12 | 20480,09 | 14664,59 | 13810,49 | 70323,29 | 71493,49 | 1,68 |

Having summarised the simulation outputs, the next section provides a brief analysis of the case and explains the main rationale supporting the results reported here.

### 8.2.8 Analysis of the case

According to one of the managers interviewed, Valorpneu network is known as one of the industrial networks with the best performance in Portugal. Indeed, the results of the simulation experiment reported in previous section support this idea and in the words of the managers interviewed a great part of the Valorpneu network success can be attributed to the high ability of its partners to work together. Issues such as the high commitment and willingness of managers to achieve common objectives, the involvement of people from different companies in the resolution of problems, the existence of a common information system platform, and the definition of clear interaction rules by Valorpneu, were mentioned during the interviews as the main reasons for the high business interoperability performance of the SGPU. The low economic value of the product (used tyres) being circulated in the ambit of SGPU was also pointed out by one of the managers interviewed as one of the reasons for such success.

Regarding the benefits of having a common information system platform, the simulation model developed in this case study tried to understand how the SGPU operators exchanged information before and after the introduction of the SGPU Online. The most significant benefit of the introduction of such platform was achieved at the Managing Entity. Before the introduction of such information system, the routing of tyres from Collection Points to Recyclers and Energy Recoveries was made by two employees with average duration of eight hours. The simulation model presented in previous section captured this impact and estimated that the introduction of that system enabled a reduction of the time spent in routing tyres from 8,16 hours to 2,94 hours, as shown in Table 8.26. As a consequence of this time saving, the cost of routing tyres per week decreased from 417,12 € to 50,16 €.

In addition, several benefits regarding the time and number of pages needed to communicate the route of tyres to Recyclers, Energy Recoveries and Transporters were estimated. For example, the model estimated that before the introduction of the SGPU Online, the Managing Entity spent, on average, 1,77 hours to prepare and to send via fax the weekly planning to those companies. With the introduction of the SGPU Online, the time to prepare and send the weekly planning was reduced to 0,18 hours. There were also great benefits regarding to the use of paper. For example, whenever a Collection Point had to communicate the reception of a discharge from a Distributor to the Managing Entity, two fax pages were needed, one for characterising the origin of tyres and another for identifying the Distributor (a copy of the identification card). Similarly, the receptions of charges at Recyclers and Energy Recoveries were communicated via using at least one fax page. With the introduction of the SGPU Online, all these communications are made electronically and immediately. It also has impact on the time needed for processing information and time needed to access information.

Regarding the existence of well-defined documents specifying the interaction rules, the BIDS tested in the simulation experiment explained above was the “System for sorting used tyres at Collection Points”. This system is clearly defined in the document “Ponto de Recolha: Normas e Procedimentos”, and its main impact is on the number of non-conforming charges sent to Recyclers and/or Energy Recoveries. This document was created in 2007 but only documented in 2008. Therefore the level of business interoperability for this BIDS was considered to be to 3 in 2007 and equal to 4 from 2008 to 2014. As can be seen in Table 8.30, the impact of this BIDS is evident. From the 5400 charges performed every year, fewer than 2% of non-conforming charges are sent from Collection Points to Recyclers and Energy Recoveries. In 2007 the number of non-conforming charges was around 2% due to the level 3 of business interoperability. Since the documentation of such BIDS in 2008, this number has decreased year after year. For example, in 2008 it was around 0,7% and in 2014 around 0,07%.

Despite the significance of the impacts discussed above, the most important improvements achieved in the last seven years in the Valorpneu network, are related to the introduction of the “System to evaluate and reward the quality of service provided by Collection Points and Transporters”. The main impacts of this system are in the percentage of charges delivered with delay and the percentage of receptions registered with delay. As can be seen in Table 8.29, the percentage of charges delivered with delay fell from 30,71% in 2007 to 0,83% in 2014. The reason behind the high percentage of delays in 2007 is that at that time such system to evaluate and reward operators did not exist, corresponding to the level zero of business interoperability. With the introduction of this system in 2008, which increased the level of business interoperability to three, there was a considerable reduction from 30,71% to 16,22%, a reduction of 47,18% (with reference to previous year). However, the system reached the maximum level of maturation (level 4) only in 2009. As a result, a reduction of 53,82% (16,22% in 2008 and 7,49% in 2009) was achieved in 2009. With the maturation of this system in 2009, the amplitude of its impact stabilised and in 2014 the corresponding value was about 0,83%.

Regarding the registration of receptions, Table 8.27 shows that the introduction of such system has also helped to significantly reduce the percentage of receptions registered with delay. Similarly to the metric number of charges delivered with delay, in the year of the introduction of such system to evaluate and reward the SGPU operators (2008), there was a substantial reduction of 49,17% (40,37% in 2007 to 20,52% in 2008) in the percentage of receptions registered with delay. In the same way, in second year of maturation (2009) the reduction was around 50% with reference to 2008. After 2009 the amplitude of the impact stabilised, as we see with the metric number of charges delivered with delay. In addition to these impacts, the introduction of the system to evaluate and reward the SGPU operators has also helped to reduce the number of incidents in the characterisation of origins at Collection Points and the number of contaminated charges sent from Collection Points to Recyclers and Energy Recoveries. Before the introduction of this system, the only mechanism implemented by the Managing Entity to improve the performance of operators was the one of carrying out follow-up visits to Collection Points, Recyclers and Energy Recoveries. This mechanism, along with the system to evaluate the performance of operators, has helped to decrease significantly the number of incidents in the characterisation of origins and number of contaminated charges sent to Recoveries agents. For example, in 2009 the average number of incidents per trimester was around 32. In 2014 this value had fallen to 15,3, a reduction of 50% (with reference to 2009). In 2007, before the introduction of the evaluation system, the average number of incidents was estimated to be around 64 per trimester. Regarding the number of contaminated charges, the impact is also considerable. Despite the high number of loads carried out every year in the scope of SGPU, the percentage of contaminated charges is around 0,23% in 2014. From Table 8.30, we see that this value fell sharply after 2008 (69 in 2008 to 15 in 2014), which coincides with the year of maturation of the evaluation system.

Another issue tested in the simulation experiment was the impact of truckers strike on the performance of the SGPU operators. The simulation model predicted the occurrence of four truckers strike, one in

2009, two in 2013 and one in 2014 (see Table 8.29). However, in the ambit of SGPU, this event does not have a "chaotic" effect as may have in other type of networks where, for example, the companies work in Just in Time (JIT) system or the inventory level are very low. This is because the Managing Entity has a well-implemented mechanism to control the inventory level at Collection Points and Recoveries agents. This mechanism can simply be described as the one where a reference stock is defined for each agent, based on its capacity to store or process used tyres. Every Thursday till 12 am, every Collection Points and Recoveries agents have to communicate the current inventory level. Grounded on this information, the Managing Entity route the flows of tyres for the next week, taking into account the need to ensure enough stock for two months of activities, in the event of the flow of used tyres is interrupted due to some external event, such a truckers strike. This also explains the reason why the charges delivered with delay do not have any impact on the interruption of the activities at recoveries agents.

However, the truckers strike can have a direct impact on the inventory cost at Collection Points as they are constantly receiving new tyres from Distributors and if they do not send tyres to recoveries agents, during for example three days, their reference inventory level can be significantly affected. This would be supported by the Managing Entity, which pays the Collection Points for each ton of tyres stored. Also, the performance of Transporters would be affected as they are only paid by Valorpneu when they carry out charges in the ambit of SGPU.

Before concluding this section, it is also important to analyse the impact of the actions of control and inspection that the Managing Entity has performed, in collaboration with ASAE, to increase the number of SGPU adherents, or in other words, to decrease the number of producers that introduce tyres into the market and do not declare them. Also, the Managing Entity created an area of anonymous denunciations, in the Valorpneu website, where any person can report the existence of tyres importers that do not declare them to Valorpneu. The impacts of these BIDSs were provided in Table 8.25. By analysing this table, it is to highlight the considerable increase of the number of adherent producers, from 703 in 2007 to 1678 in 2014. This increase of adherent producers has an indirect impact on the performance of the SGPU operators in the sense that the more the number of adherent producers the more the monetary value received by Valorpneu, which in turn can have an impact on the value paid to SGPU operators for each ton of tyres processed.

## 8.3 Case Study 2: Dam Baixo Sabor network

### 8.3.1 Characterisation of the network

The Case Study 2 was conducted in a dam construction project (500 Million €) near Douro river, in Northeast of Portugal. This is a major hydraulic project, which includes underground works in the area corresponding to the hydroelectric powerhouse and related hydraulic networks, which will be executed in the shale-greywacke very hard rock (Ordovician) existing in the area. The project involves the construction of an upstream and a downstream dam, the production capacity installed in the two hydroelectric power plants being around 200 MW. The upstream dam comprises the Dam wall (height - 123m, Volume - 700,000 m³), a Spillway with a capacity of 4,800 m³/s, bottom outlet, stilling basin, diversion gallery, upstream cofferdam, water intakes, High Pressure Galleries, Powerhouse, Tailwater, Substation. The downstream dam comprises the Dam (height - 45m, Volume - 170,000 m³), a Spillway Flood with a capacity: 4,800 m³/s, Stilling basin, Bottom outlet, water intake, High pressure Galleries, Powerhouse, Tailwater, and Substation. The network involves a customer (dam owner, an electrical power producer), a contractor, a designer and a supervisor, as shown in Figure 8.9. The objective of the case study is to analyse the impact of the introduction of a cooperative information system trial platform and a RFID system, first on the business interoperability performance, and then on the operational performance of companies. The purpose of the introduction of those two systems, which was done in the scope of the FITMAN project (http://www.fitman-fi.eu), is to help in the better management of the dam construction processes, with the focus on the concrete handling.

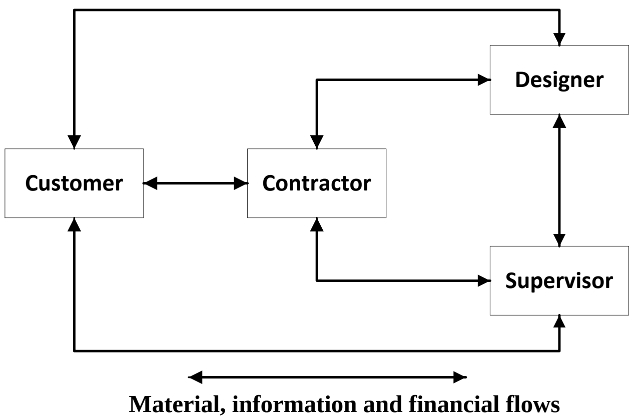



Figure 8.9: Structure of the Dam Baixo Sabor network

Concrete handling and testing is an essential part of any construction project, as concrete is one of the components that ensures resistance and durability of any constructed item. Concrete testing intends to ensure that the design characteristics set for this component and for the item in which it will be applied, are met by each load arriving at the work site. These characteristics are related to structural resistance and durability, structural safety, resistance to environmental conditions, etc. In the specific case of a dam, like the dam Baixo Sabor, the whole structure (the dam wall) is divided into sections and concrete is applied to each section separately, according to a concreting plan defined by the Works Contractor. Each section may involve several truck loads and all of them need to be tested, which means that this is one of the cases that generates thousands of test results.

In such a structure, abnormal results or noncompliance with the design parameters may have tremendous consequences, leading eventually to demolishing noncompliant sections or, in extreme cases, to compromising the dam's structural resistance. It is, therefore, of critical importance to be able to relate, quickly and unequivocally, the test results to specific areas of the dam and to quickly understand the impact of one or more abnormal results in the overall dam wall resistance. The cooperative information system trial platform will thus be implemented for all stakeholders to store and retrieve information and documents generated at different stages of the workflow. With the introduction of such information system trial platform, the stakeholders also aim to automate the process of tracking the physical objects (i.e. the concreting) throughout the network. In this new business scenario, the concreting flow will be tracked at each work stage and integrated to the cooperative information system trial platform with the help of a RFID system.

As various sources of data that produce information regarding concrete class, concreting plan, slum test result, and concrete sample test results will be integrated in the cooperative information system, it is expected that its implementation will bring positive impact on the business interoperability and operational performance of those stakeholders. The following two sections describe in more detail the present and the future scenarios as well as the main expected benefits due to the introduction of the cooperative information system trial platform.

### 8.3.2 Adopted modelling approach

On the basis of what has been explained in Section 5.2 about how to apply the proposed methodology, which depends on whether the cooperative network platform is already implemented or not, this section explains the approach adopted for modelling the Dam Baixo Sabor network. As explained in previous section, the Dam Baixo Sabor construction project is being currently executed, which means that the mechanisms to support the cooperation among the companies involved in its execution construction project are already implemented. In this case, the methodology proposed in Section 5.2 suggests the application, in the first place, of the theoretical ABS model to analyse the "as-is" situation, i.e. to analyse the impact of the identified business interoperability problems on the performance of the companies involved in the Dam Baixo Sabor construction project.

Therefore, the current business scenario of the Dam Baixo Sabor network has been firstly modelled by using the theoretical ABS model. As a result of this analysis, it was concluded that the current business interoperability performance of such network is not satisfactory, resulting in efficiency and productivity losses. Therefore, in second phase, the theoretical Axiomatic Design model has been applied to design a new and more interoperable configuration for the Dam Baixo Sabor network (i.e. the future business scenario), as is demonstrated in Section 8.3.6. Then, the theoretical ABS has been applied again to estimate the impact of the implementation of the new configuration, as explained in Section 5.2. However, it is to notice here that for the purpose of the organisation of this thesis, the application of the theoretical ABS to model both the current and the future business scenarios are demonstrated and discussed in the same section as they have been modelled in the same simulation environment (see Section 8.3.8).

### 8.3.3 Description of the current business scenario

The business scenario under consideration involves several business processes such as concrete planning, concrete sample collection, testing of the samples and analysis of the test results. In each of these steps various stakeholders like Designer, Contractor, and Supervisors are involved directly and Clients are involved indirectly. During each of these phases a number of information are produced and need to be exchanged between various stakeholders involved in the project. The current scenario of the information flow in respect to the workflow of the project is as shown in Figure 8.10.

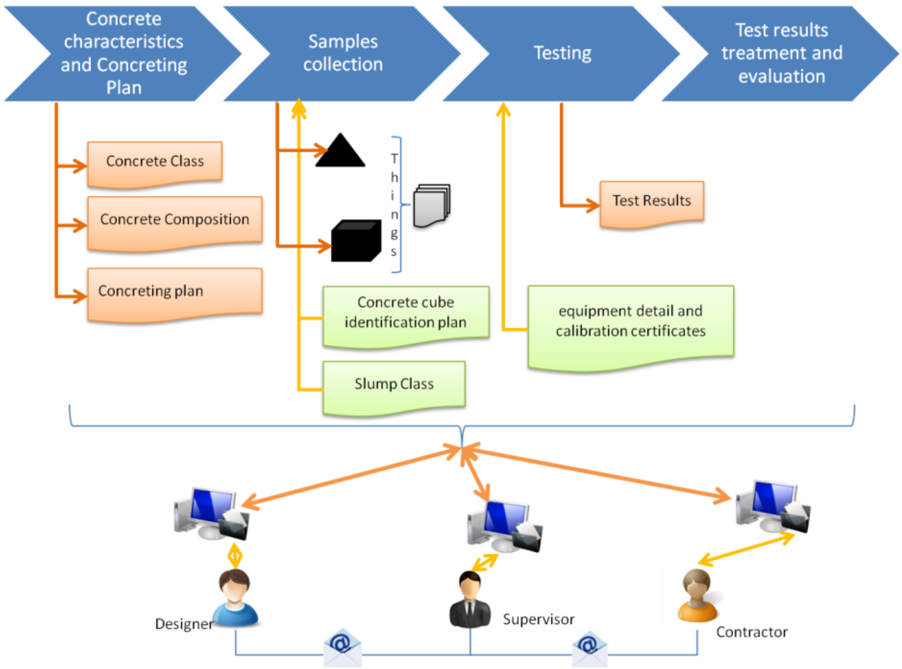



Figure 8.10: Information flow in the present business scenario

Regarding to the way companies interact and how they make decisions, the present scenario is divided into three Business Processes (BPs), which are described as follows:

**BP1 – Identification of concrete characteristics and concreting plan**: the Designer, or the Client, provides the design requirements on what the concrete is concerned. This is done by specifying the required concrete classes and consistency (measured by the slump test). The definition of concrete classes sets the concrete's characteristic stress values. Based on the design requirements, the Works Contractor proposes the concrete composition; each concrete class may correspond to more than one composition. The composition is submitted to Supervision who assesses it and issues a recommendation of approval (or rejection). Additionally, the Designer (or the Client) may have defined a sequence for the concreting operations (Concreting Plan). The Works Contractor may propose a different one or he may define the Concreting Plan from scratch, should the Designer not have previously defined it. The Supervision verifies the Concreting Plan and approves it (or rejects it). This can be represented as shown in Figure 8.11.

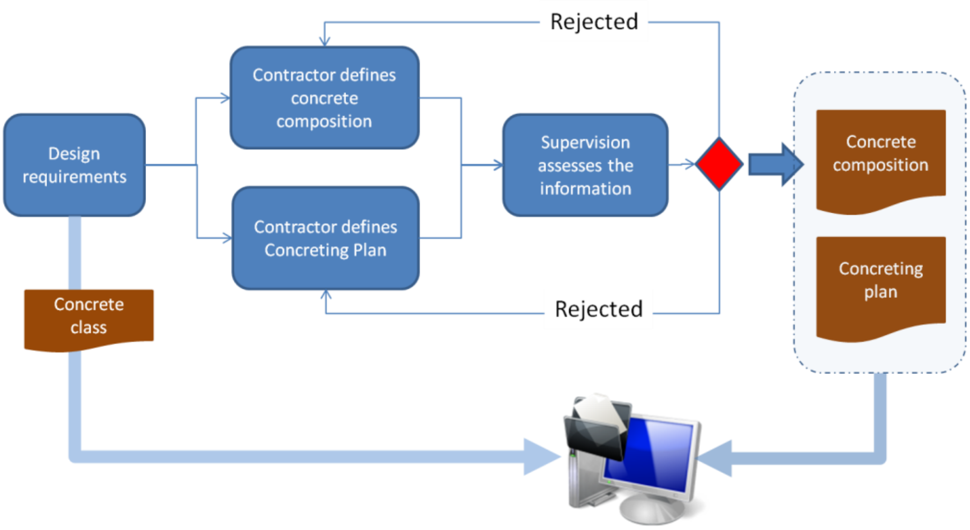



Figure 8.11: Identification of concrete characteristics and concreting plan in the present business scenario

**BP2 – Samples collection and testing**: once the concreting plan is approved, the number of slump tests is also defined (one per truck load). Additionally, the number of samples for the compression tests can be set by the Designer, through the definition of a specific sample plan or by referring to the applicable standards, or may eventually be set by the Contractor and approved by the Supervision. The Contractor also proposes a samples identification system. Upon the arrival of a truck, a sample is collected for the slump test and this is carried out in the presence of an element of the Supervision team. The approval of the slump test by Supervision authorizes the concreting operation. Samples are also taken for the compression test, according to the predefined sampling plan. At least 3 samples (3 cubes of 20 × 20 cm) must be taken for tests after 7 days maturation process (corresponding to 70% of target compression resistance) and another three for tests after 21 days. Eventually, 3 samples may also be taken for tests after 3 days. Samples are identified according to the approved samples identification system, usually in the presence of a Supervision team element. Samples are placed in water at controlled temperature and left for the required time. Test conditions may be checked regularly by Supervision. The cubes are tested (destroyed by compression) at the required time; tests are witnessed randomly by Supervision. The Contractor records the test results and submits them to Supervision, who analyses them and approves/rejects them. This can be represented as illustrated in Figure 8.12.

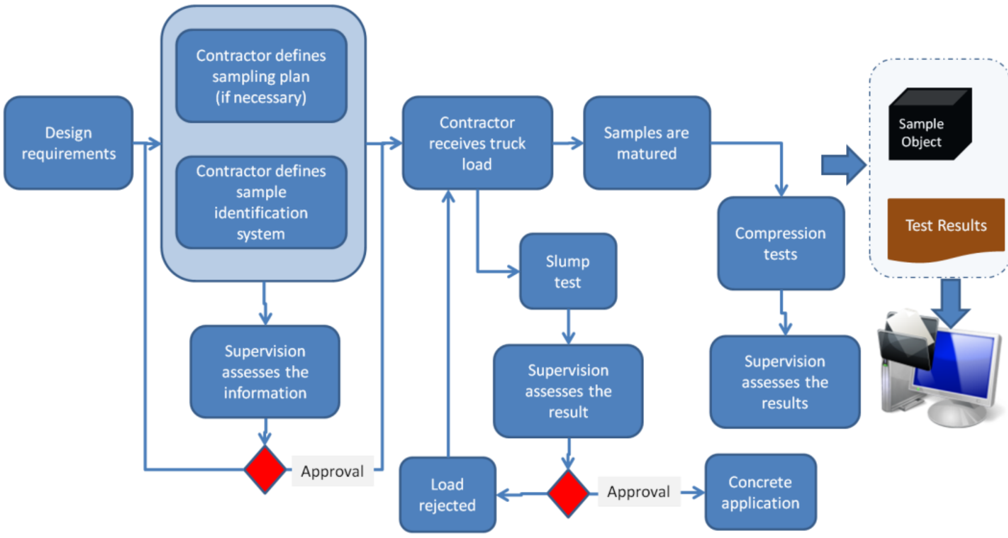



Figure 8.12: Samples collection and testing in the present business scenario

**BP3 – Test results analysis and concrete characteristic stress calculation**: the Works Contractor and Supervision treat the results statistically. Based on this statistical treatment, the Contractor calculates the concrete characteristic stress. Deviations are assessed by Contractor and Supervision; individual non-compliant results may have no or reduced impact on the final characteristic stress calculation. Supervision approves the results. This can be represented in Figure 8.13.

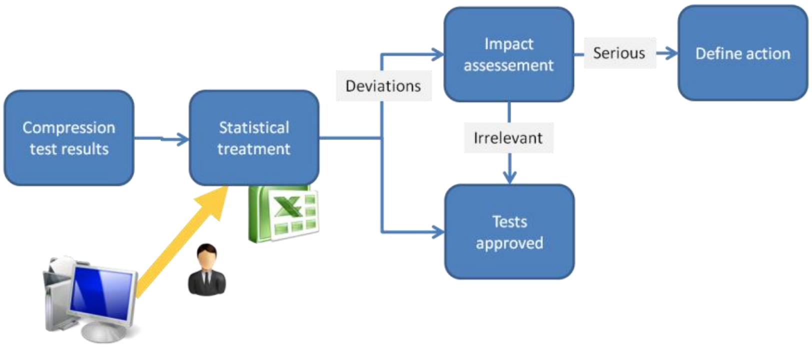



Figure 8.13: Test results analysis and concrete characteristic stress calculation in the present business scenario

### 8.3.4 Description of the future business scenario

The major focus for the future scenario is the automation of the concrete handling procedure with a well-defined information management system. This new scenario describes a situation in which a common web platform will be introduced for all the stakeholders to store and retrieve information and documents generated at different stages of the workflow. At the same time the physical objects, which are important part of the overall workflow (e.g. concrete), are identified and connected to information system and accessed/tracked through a RFID system. The workflow remains the same and the information generated at various phases remains the same. But there will be a significant change in the way the generated information is stored, retrieved, processed and distributed, as illustrated in Figure 8.14.

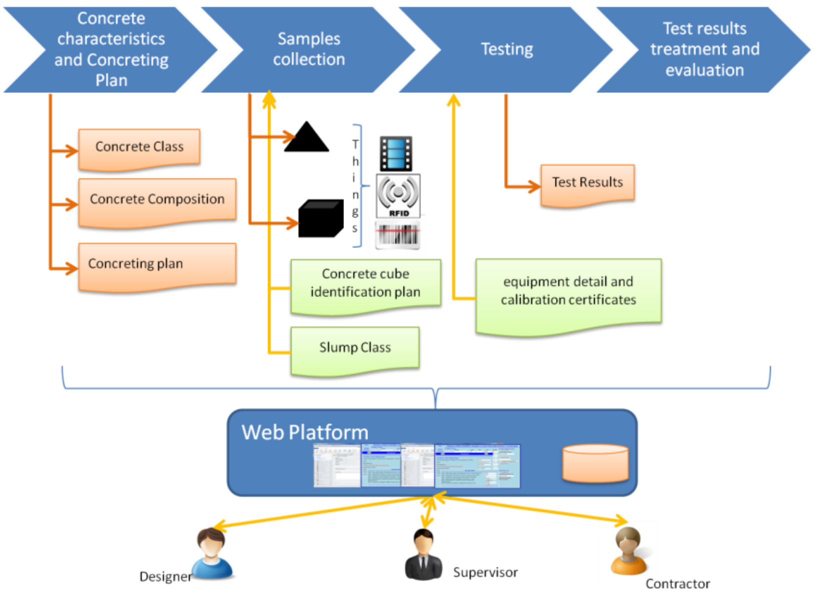



Figure 8.14: Workflow for the future business scenario

Although the sequence of activities to be performed will not be affected in the future scenario, the methodology for the stakeholders to take part in the activities will change. Instead of consisting of three business processes, the future scenario will consist of seven business processes, which are described as follows:

- ***BP1 – Identification of concrete class and concrete composition***: in this process, the designer defines the concrete classes. After that, the contractor submits concrete compositions, for the concrete classes defined. Finally the supervisor checks and approves (or rejects) the information submitted;
- ***BP2 – Concreting plan process***: in this process, the contractor defines the concreting plan. The supervisor verifies the concreting plan and approves it (or rejects it);
- ***BP3 – Identification, collection and classification of concrete samples process***: in this process, the sampling plan is defined according to the quality standards of the concrete, and the designer submits this information to the trial platform;
- ***BP4 – Slump tests results for each concreting operation***: in this process, the concrete is manufactured with the characteristics defined in the previous process and is transported to the dam by truck. Upon the arrival of a truck, a sample is collected for the slump test, which is carried out in the presence of an element of the supervision team. The supervision team employee on site records the slump-test being performed with handled device, eventually adding a photo or video evidence, and send to trial platform, immediately approving or rejecting the test. If, due to unpredictable circumstances, it is not possible for a supervision team employee to be at the test site, then the test can be recorded on video or photographed by another employee, who uploads the test details to the trial platform, allowing the supervision team to access it online and approve or reject the test remotely. The approval of the slump test by supervision authorizes the concreting operation;
- ***BP5 – Testing and test results of samples***: in this process, testing and test results of samples from each concreting operation are carried out. The person performing the test makes use of sample identification to initialize the results entry for the particular sample and enters the test result into the trial platform. Samples are identified according to the approved samples identification system, usually in the presence of a supervision team element. In the dam laboratory, some samples are placed in water at controlled temperature and left for the required time. Test conditions may be checked regularly by supervision. The samples are tested (destroyed by compression) at the required time; tests are witnessed randomly by supervision. The contractor records the tests and submits them to supervision, who analyses them and approves/rejects them;

- ***BP6 – Test results treatment***: in this process, the contractor and the supervisor treat the results statistically. Based on this statistical treatment, the contractor calculates the concrete characteristics stress;
- ***BP7 – Test results evaluation***: in this process, the concrete resistance to compression value will be compared against the class of concrete and concrete characteristics specified in the BP1. Deviations are assessed by contractor and supervisor; individual non-compliant results may have no impact, or reduced impact on the final characteristic stress calculation. Supervisor approves/rejects the results.

The first three business processes are independent and can be executed in parallel. The others are sequential and therefore can only be achieved after achieving the previous ones, as shown in Figure 8.15.

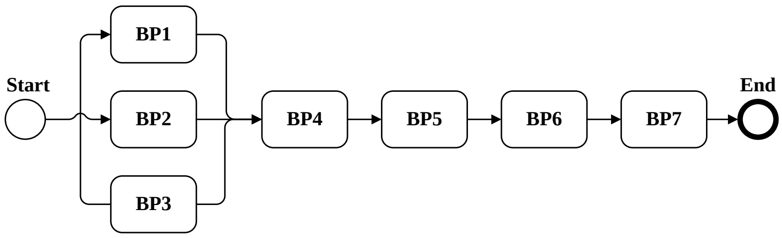



Figure 8.15: Sequence of implementation of business processes in the future business scenario

In order to provide a more detailed picture on the way companies interact and make decisions, Appendix D depicts a BPD that integrates the seven business processes described above, as has been done in the Case Study on the Valorpneu network. Those business processes will be supported by a cooperative information system platform, which will ensure the information management inherent to this complex network, while simultaneously will enable the general customer to control the whole network, in real time. The benefits to be achieved in each BP described above can be summarized by Table 8.35.

Table 8.35: Benefits to be achieved in each business process in the future business scenario

| BP | Expected benefit (s) |
|---|---|
| BP1 | Information is available in "real time" to the stakeholders (faster access to information), eventually with links to specific files containing design details. |
| BP2 | Visual representation of concrete classes distribution and of concreting sequence (information is more easily accessible). |
| BP3 | • Information related to concrete easily processed and available;<br>• Slump test result approval available in "real time" to all stakeholders and, eventually, supported by visual evidence;<br>• Information related to slump characteristics visually available;<br>• Reliable and accurate identification of concrete samples at each work site |
| BP4 | • Information related to samples and samples tracking is systematically available;<br>• Possibility of creating a full sample history, including curing conditions;<br>• Possibility of relating a concreting zone with a sample history, visually;<br>• Early identification of design and technical mistakes, including online detection and real time fixing of incongruences using remote collaboration |
| BP5 | • Information related to tests is more easily accessible and easily relatable to sample history and concreting zones;<br>• Sample history includes information on supervision test attendance;<br>• Results may be fed automatically in the platform by the Contractor or fed by the Supervision based on the information received from the Contractor;<br>• Platform analyses the results automatically, relating them with the concrete characteristics defined in the design for that specifically concrete sample and concreting operation.<br>• Reduction in the time for recoding test result for a particular cube by making use of cube identification technology. Reduction in use of paper for test result recording. |
| BP6 and BP7 | • Statistic treatment is made automatically by the platform; however, it must interact with EXCEL, either for data input or data output;<br>• Platform could eventually predict the effect of a non-compliant result;<br>• Supervisor will have less work to make the validation of the test results. Only critical situation need human intervention. Reduction in the manual labour of test result validation will impact the decision-making procedure;<br>• Reduction in the time to perform statistical analysis, independence from vendor product like Microsoft. Many stakeholders can make use of statistical analysis tools and view results at the same time, and take collaborative actions |
| Other benefits | • Quicker and effective communication of the processing status of the collaborative business processes; it will enable quickly identification of abnormal results or noncompliance;<br>• Improved integration and coordination of the collaborative business processes;<br>• Quicker access to more detailed information and improvement on information processing; Reduction in the decision-making and future risk mitigation process. Faster decision-making will have high beneficial impact on the industry on the whole. Clients can have access to the project status and information much easily. They can manage the project documentations and data for archival as per the way it suits their need. At the same time increases the interactions with the other stakeholders in transparent way, thus building trust among each other. The contractor can work with supervisor in a collaborative way as allowed by the platform. The contractor and supervisor always have access to the relevant information and will be very useful in the time when they need to take critical decisions;<br>• Reduction in the cost of the project management, by allowing remote participation;<br>• Historical data can be easily obtained with visual proof of the activities where applicable. Reduction in the legal conflicts. |

Those business processes will be supported by a cooperative information system platform aimed to ensure the proper management of the information inherent to this complex network, and to simultaneously enable the general customer to control the whole network, in real time.

### 8.3.5 Data for validating the application of the proposed methodology

The data collected to validate the proposed methodology can be grouped according to two categories: qualitative and quantitative data. Qualitative data concern the identification of the BIDSs used in both current and future scenarios, and the description of their corresponding levels of business interoperability, as summarized in Table 8.49 (see Section 8.3.7). Quantitative data are concerned with the numerical quantification of the impact of those BIDSs on the Key Performance Indicators (KPIs), as shown in Table 8.36.

Table 8.36: As-is and to-be values of key performance indicators

| KPI | Designation (Ratio) | Description | Related BIDS | As-is | To-be (reduce by) |
|---|---|---|---|---|---|
| KPI1 | Average lead time to access the information relating to concrete characteristics and concreting plan after/before the DV/AV [23]implementation during the concrete control process (hours) | This is the average time between the emission of the document by Contractor/Designer and the reception of the document by the person responsible for the analysing. | BIDS12 | 4 | 98% |
| KPI2 | Average number of pages used in the test results recording, archival, after/before the DV/AV implementation during one concrete operation (pages) | This is the average number of pages used for recording the test results during one concrete operation. | BIDS7, BIDS10 | 5 | 40% |
| KPI3 | Average lead time needed to perform and record the test results after/before the DV/AV implementation during one concrete operation (minutes) | This is the average time between the manual identification of samples and the time needed to fulfil the forms with tests results. | BIDS6, and BIDS7 | 27,5 | 30% |
| KPI4 | Average lead time needed to analyse the test results after/before the DV/AV implementation during one concrete operation (days) | This is the average time from recording the test results in the forms and the analysis being made by the responsible. | BIDS13 | 39 | 98% |
| KPI5 | Time for data exchange between stakeholders after/before the DV/AV implementation during the concrete control process (hours) | This is the average time for data exchange between the designer, the Contractor and the supervisor. | BIDS5 | 8 | 98% |
| KPI6 | Average cost needed to perform and record the test result after/before the DV/AV implementation during one concrete operation (€) | This is the average cost of human resources involved in the process. | BIDS6, and BIDS7 | 2,04 | 30% |
| KPI7 | Average cost needed to analyse the test result after/before the DV/AV implementation during one concrete operation (€) | This is the average cost of human resources involved in the process. | BIDS13 | 1,41 | 65% |

[23] DV – Decision Variables; AV – Action Variables

### 8.3.6 Demonstration and validation of the theoretical Axiomatic Design model

Grounded on what has been explained in Section 5.4 about how to apply the theoretical Axiomatic Design model to design configurations of interoperable cooperative industrial network platforms (see Figure 5.6), this section presents the design of the new configuration for the Dam Baixo Sabor construction network. The first step in this design is to set the top level FR and its corresponding DP, i.e. the main design goal and the solution to achieve it. Thus, at this level, to achieve the goal of the new design, the $FR_0$ is set as follows:

***$FR_0$: Improve interoperability between the companies involved in the Dam Baixo Sabor construction project as well as all the systems used by them to interoperate.***

To achieve this FR, the top level in the physical domain is set as follows:

$DP_0$: ***Design and implementation of a new interoperable configuration for the Dam Baixo Sabor cooperative network platform.***

As can be easily stated, $FR_0$ is broad and only represents the design intent. Therefore, the first level decomposition is needed to incorporate the most relevant dimensions of business interoperability (see Section 5.3) into the design of the new configuration for the Dam Baixo Sabor network. Thereby, it was considered that the most relevant dimensions of business interoperability to be incorporated in the design of the new configuration are business strategy, management of external relationships, collaborative business processes, employees and work culture, business semantic, information systems, information quality and network minute details. The dimensions related to products and services and knowledge management were not incorporated because it was assumed that they are not relevant for this design. Thus, $FR_0$ and $DP_0$ are decomposed into the seven level 1 FRs and DPs provided in Table 8.37.

Table 8.37: Decomposition of the top level FR to the level 1 FRs

| ***$FR_0$: Improve interoperability between the companies involved in the Dam Baixo Sabor construction project as well as all the systems used by them to interoperate*** | ***$DP_0$: Design and implementation of a new interoperable configuration for the Dam Baixo Sabor cooperative network platform*** | ***$PV_0$: Defining the process, steps, or methods necessary to create or implement the $DP_0$*** |
|---|---|---|
| $FR_1$: Set the strategic cooperation goals for the Dam construction project | $DP_1$: List of strategic cooperation goals | $PV_1$: Process, steps or methods needed to create or implement $DP_1$ |
| $FR_2$: Manage the inter-organisational relationships between the companies involved in the Dam construction project | $DP_2$: Mechanisms to manage the inter-organisational relationships between the companies involved in the Dam construction project | $PV_2$: Process, steps or methods needed to create or implement $DP_2$ |
| $FR_3$: Ensure interoperability between the Dam cooperative business processes | $DP_3$: Redesign of the Dam cooperative business processes | $PV_3$: Process, steps or methods needed to create or implement $DP_3$ |
| $FR_4$: Manage the human resources involved in the Dam construction project operations | $DP_4$: Strategies to manage the human resources involved in the Dam operations | $PV_4$: Process, steps or methods needed to create or implement $DP_4$ |
| $FR_5$: Understand the structure and meaning of the information to be exchanged between in the ambit of the Dam construction project | $DP_5$: Strategies and approaches to address semantic problems (e.g. ontological models, shared metadata repositories) | $PV_5$: Process, steps or methods needed to create or implement $DP_5$ |
| $FR_6$: Ensure interoperability between the systems and applications used to manage the Dam information flows | $DP_6$: Implementation of a common information systems platform | $PV_6$: Process, steps or methods needed to create or implement $DP_6$ |
| $FR_7$: Deal with the minute details imposed by the environment to the Dam construction project | $DP_7$: Mechanisms to deal with minute details imposed by the environment in which the companies involved in the Dam construction project operate | $PV_7$: Process, steps or methods needed to create or implement $DP_7$ |

Having decomposed the top level FR to the level 1 FRs, a design matrix that represents the relationships between the level 1 FRs and DPs must be generated to evaluate the Axiom 1 – Independence Axiom, as discussed in Section 4.2.3. This design matrix, which provides the independence between the level 1 FRs and DPs and sequence of implementation of the level 1 DPs, is illustrated by Figure 8.16.

| | **$DP_1$** | **$DP_2$** | **$DP_3$** | **$DP_4$** | **$DP_5$** | **$DP_6$** | **$DP_7$** |
|---|---|---|---|---|---|---|---|
| **$FR_1$** | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_2$** | X | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_3$** | X | 0 | X | 0 | 0 | 0 | 0 |
| **$FR_4$** | 0 | 0 | X | X | 0 | 0 | 0 |
| **$FR_5$** | 0 | 0 | X | 0 | X | 0 | 0 |
| **$FR_6$** | X | X | X | X | X | X | 0 |
| **$FR_7$** | X | X | X | X | 0 | X | X |

Figure 8.16: Design matrix for level 1 FRs (Dam Baixo Sabor construction project)

Taking a look at the configuration of the design matrix above, it is possible to state that it is decoupled, as all upper triangular elements are equal to zero and some lower triangular elements are different from zero. As a result, the independence of FRs can be ensured if and only if the DPs are implemented in a proper sequence, as discussed in Section 4.2.3. For example, to achieve the ensure greater interoperability between the systems and applications used to manage the information flows of the Dam Baixo Sabor network ($FR_6$), $DP_1$, $DP_2$, $DP_3$, $DP_4$ and $DP_5$ must be meet before of $DP_6$. $FR_7$ needs to be achieved after implementing $DP_1$, $DP_2$, $DP_3$, $DP_4$ and $DP_6$. $FR_2$ and $FR_3$ need to be fulfilled after achieving $DP_1$ because they are dependent on $FR_1$. $FR_4$ and $FR_5$ must be fulfilled after achieving $DP_3$ because they are dependent on $FR_3$.

Although the design matrix generated from the relationships between the level 1 FRs and DPs satisfies the Independence Axiom, the level 1 FRs only express abstract requirements of ensuring greater business interoperability between the companies involved in the Dam Baixo Sabor construction project as well as all the systems used by them to interoperate. In other words, they are not detailed enough to be easily managed. Therefore, the designer went back to the functional domain and decomposed those FRs to the level 2 FRs, in order to incorporate the most relevant sub-dimensions of business interoperability related to each level 1 FR set above. It is important to refer here that for the purpose of this thesis, this design will focus on only the decomposition of $FR_3$ (collaborative business processes) and $FR_6$ (information systems) as only the last level DPs related to them will be used as input in the demonstration and validation of the theoretical ABS model (see Section 8.3.8). Accordingly, the decomposition of these two level 1 FRs to the level 2 FRs is presented following.

**Decomposition of $FR_3$ to the level 2 FRs**

As mentioned above, "$FR_3$ – Improve the interoperability between the business processes of the companies involved in the Dam Baixo Sabor construction project" is one of the level 1 FRs that does not provide sufficient detail to ensure greater business interoperability between the companies involved in the Dam Baixo Sabor construction project and all the systems used by them to interoperate. Requirements such as clear division of responsibilities and roles, clear definition, easy understanding, visibility, integration and flexibility of inter-organisational business processes must be incorporated in order to facilitate decision-making regarding the level of business interoperability needed as well as the type of mechanism to be implemented. Accordingly, $FR_3$ has been decomposed into the eight level 2 FRs, as shown in Table 8.38.

Table 8.38: Decomposition of $FR_3$ to the level 2 FRs

| ***$FR_3$: Ensure interoperability between the Dam cooperative business processes*** | ***$DP_3$: Redesign of the Dam Baixo Sabor cooperative business processes*** | ***$PV_3$: Process, steps or methods needed to create or implement $DP_3$*** |
|---|---|---|
| $FR_{3.1}$: Define the Dam cooperative business processes | $DP_{3.1}$: A document that describes the Dam cooperative business processes (see Section 8.3.4) | $PV_{3.1}$: Using the office tools (e.g. word file) |
| $FR_{3.2}$: Specify companies responsibilities for cooperative works | $DP_{3.2}$: Description of the responsibilities of each company involved in Dam construction project (who does what) | $PV_{3.2}$: Using the office tools (e.g. word file) |
| $FR_{3.3}$: Understand the Dam workflow | $DP_{3.3}$: Graphical modelling of the Dam cooperative business processes (a BPD – see Appendix D) | $PV_{3.3}$: Applying the standard business process modelling notation (BPMN) |
| $FR_{3.4}$: Perform the Dam cooperative business processes | $DP_{3.4}$: Mechanisms to perform the Dam cooperative business processes | $PV_{3.4}$: Process, steps or methods needed to perform the Dam cooperative business processes |
| $FR_{3.5}$: Ensure the continuity of concreting during a concrete operation | $DP_{3.5}$: Rules and procedures for the concreting (e.g. having present an element of the supervision team) | $PV_{3.5}$: Using the office tools (e.g. word file) |
| $FR_{3.6}$: Communicate the status of processing within each company to cooperating partners | $DP_{3.6}$: Mechanism to communicate the status of processing within each company | $PV_{3.6}$: Through online information systems |
| $FR_{3.7}$: Coordinate the Dam cooperative business processes | $DP_{3.7}$: Mechanism to coordinate the Dam cooperative business processes (e.g. coordination by planning – the processes are mainly sequential) | $PV_{3.7}$: Software for planning construction processes |
| $FR_{3.8}$: Identify the concreting flow throughout the Dam | $DP_{3.8}$: Mechanism to identify the concreting flow (computerised tracking of the concreting flow) | $PV_{3.8}$: The concreting flow will be tracked at each work stage and integrated to the cooperative information system trial platform with the help of a RFID system |

In order to evaluate the independence of the above FRs and DPs as well as to define the sequence of implementation of the DPs, the design matrix illustrated by Figure 8.17 has been developed.

| | **$DP_{3.1}$** | **$DP_{3.2}$** | **$DP_{3.3}$** | **$DP_{3.4}$** | **$DP_{3.5}$** | **$DP_{3.6}$** | **$DP_{3.7}$** | **$DP_{3.8}$** |
|---|---|---|---|---|---|---|---|---|
| **$FR_{3.1}$** | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.2}$** | X | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.3}$** | X | X | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.4}$** | X | X | X | X | 0 | 0 | 0 | 0 |
| **$FR_{3.5}$** | 0 | 0 | 0 | X | X | 0 | 0 | 0 |
| **$FR_{3.6}$** | 0 | 0 | 0 | X | 0 | X | 0 | 0 |
| **$FR_{3.7}$** | 0 | 0 | 0 | X | 0 | X | X | 0 |
| **$FR_{3.8}$** | 0 | 0 | 0 | X | 0 | 0 | 0 | X |

Figure 8.17: Design matrix for level 2 $FR_3$

From the design matrix provided above, it is possible to state that the Independence Axiom is satisfied, though the matrix is decoupled. In this case, the Independence Axiom is achieved only and only if the DPs are implemented in a proper sequence. For example, to achieve $FR_{3.4}$, $DP_{3.1}$, $DP_{3.2}$ and $DP_{3.3}$ must be implemented earlier. To achieve $FR_{3.5}$, $DP_{3.4}$ has to be implemented first. It is also possible to state that FRs such as $FR_{3.1}$ and $FR_{3.4}$ did not achieve sufficient level of detail. Therefore, a third level of decomposition for these two FRs shall be performed further in this section.

**Decomposition of $FR_6$ to the level 2 FRs**

Similarly to $FR_3$, "$FR_6$: Ensure interoperability between the systems and applications used to manage the Dam information flows" also does not provide sufficient detail to achieve information systems interoperability. As explained in Section 5.3.8, there is a set of requirements that must be fulfilled in order to make an information system platform interoperable. In the specific case of the Dam Baixo Sabor construction project, requirements such as information systems model, type of connectivity and interaction, security and privacy, access to data, information exchange, etc., have to be incorporated in order to make the design more manageable and to facilitate decision-making regarding the type of mechanisms to be implemented. For instance, as mentioned in Table 8.49, in the current business scenario, the data and documents generated at each stage of the workflow are stored by the stakeholders in their own system, and later used in the other stages of the workflow with manual integration of the previous results. Therefore, it is important in the future scenario to have these data and documents integrated into a common information system platform. It is also important to integrate the legacy systems of the end-users with the new information system platform. Regarding the accessibility to information, currently this is low and highly manual. Thus, in the future scenario it is proposed that the access to information will be provided by means of standard technologies for accessing information.

The risk of unauthorized access to information is also critical in the future business scenario, which involves confidential information regarding construction project. Since the trial is focused on generation and utilization of large amount of information produced and accessed by various stakeholders, it is very important to keep the information secure from unwanted access. Some information should be kept confidential as it may compromise concurrency if the companies' own information is not protected. It is also important to protect the personal information of the users of the platform. So security is an important aspect for the scenario of the trial. Privacy is another important aspect over the access rights of the users. The information has to be classified and is to be disseminated based on the roles of the users. It is also necessary to increase the level of security and confidentiality for the operations conducted over the Internet, i.e. it is necessary to ensure that the information exchanged between companies is transmitted in an illegible, secure and confidential way.

Development and maintenance of strong access management framework is important for the successful implementation of the new business scenario.

Data produced during the activities of each of these steps are of great importance for the project execution, future reference and legal proceedings (if necessary). So, loss of data is of very high risk in this business scenario. It implies that the system must be safeguarded against cyber attacks in order to avoid the access, changes or elimination of the data stored in the system. In addition, there is a need to ensure that the user interface of the new cooperative information system platform is intuitive and easy enough and to ensure an efficient interaction between the user and the system. Also, there is a need to ensure a continuous functioning of the information system platform.

All these issues are critical as a failure in their definition and operationalization can result in tremendous efficiency losses to the involved companies. For example, if the likelihood of information system breakdown is high, the communication among the companies may be frequently interrupted, which may result several perturbations along the network. The impact on cost and time may be significant.

Grounded on the issues discussed above, $FR_6$ has been decomposed into the twelve level 2 FRs, as illustrated by Table 8.39.

Table 8.39: Decomposition of $FR_6$ to the level 2 FRs

| ***$FR_6$: Ensure interoperability between the systems and applications used to manage the information generated at the various stage of the Dam workflow*** | ***$DP_6$: Implementation of a common information systems network platform*** | ***$PV_6$: Process, steps or methods needed to create or implement $DP_6$*** |
|---|---|---|
| $FR_{6.1}$: Ensure that the common information system platform matches the needs of the companies involved in the Dam construction project | $DP_{6.1}$: Design of the information system architecture for the Dam construction project operations | $PV_{6.1}$: Using information systems modelling tools (e.g. use cases, and class diagram) |
| $FR_{6.2}$: Set the type of connectivity between the systems and applications used to manage the information generated at the various stage of the Dam workflow | $DP_{6.2}$: Establishment of electronic business relationships (also referred to as m:n connectivity) | $PV_{6.2}$: IT consulting |
| $FR_{6.3}$: Allow communication between the systems and applications used to manage the information generated at the various stage of the Dam workflow | $DP_{6.3}$: Mechanisms of ICTs integration (Web services) | $PV_{6.3}$: IT consulting |
| $FR_{6.4}$: Ensure security of the systems and applications used to manage the information generated at the various stage of the Dam workflow | $DP_{6.4}$: Mechanisms of ICTs security | $PV_{6.4}$: ICTs security providers |
| $FR_{6.5}$: Ensure privacy to transmit confidential information and conduct secure operations over the Internet | $DP_{6.5}$: Encryption technologies (e.g. Secure Sockets Layer – SSL, with 128-bit encryption key) | $PV_{6.5}$: IT consulting |

| | | |
|---|---|---|
| $FR_{6.6}$: Integrate data generated at the various stage of the Dam workflow | $DP_{6.6}$: Mechanism to integrate data coming from multiple sources (e.g. distributed database) | $PV_{6.6}$: Database developers |
| $FR_{6.7}$: Manage the access to data | $DP_{6.7}$: Mechanisms to manage the access to data | $PV_{6.7}$: The information systems network platform administrator |
| $FR_{6.8}$: Allow interaction between the information systems and applications and their users | $DP_{6.8}$: Establishment of user-friendly interface | $PV_{6.8}$: Grounding on standards for user interface development |
| $FR_{6.9}$: Allow synchronous exchange of information between the companies involved in the Dam construction project | $DP_{6.9}$: Mechanism to exchange information (e.g. EDI systems) | $PV_{6.9}$: IT providers |
| $FR_{6.10}$: Store data | $DP_{6.10}$: Mechanism to store data (electronic system to store data in a database) | $PV_{6.10}$: IT consulting |
| $FR_{6.11}$: Retrieve data | $DP_{6.11}$: Mechanism to retrieve data (electronic system to retrieve data from a database) | $PV_{6.11}$: IT consulting |
| $FR_{6.12}$: Archive historical data | $DP_{6.12}$: Mechanism to archive historical data (electronic system to archive historical data in a database) | $PV_{6.12}$: IT consulting |

To evaluate the independence of the above FRs and DPs and to determine the sequence of implementation of the DPs, a design matrix has been developed, as illustrated in Figure 8.18.

| | **$DP_{6.1}$** | **$DP_{6.2}$** | **$DP_{6.3}$** | **$DP_{6.4}$** | **$DP_{6.5}$** | **$DP_{6.6}$** | **$DP_{6.7}$** | **$DP_{6.8}$** | **$DP_{6.9}$** | **$DP_{6.10}$** | **$DP_{6.11}$** | **$DP_{6.12}$** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$FR_{6.1}$** | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{6.2}$** | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{6.3}$** | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{6.4}$** | X | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{6.5}$** | X | X | X | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{6.6}$** | X | X | X | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{6.7}$** | 0 | 0 | 0 | 0 | 0 | X | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{6.8}$** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | | 0 | 0 | 0 |
| **$FR_{6.9}$** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 |
| **$FR_{6.10}$** | X | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | X | 0 | 0 |
| **$FR_{6.11}$** | X | 0 | 0 | 0 | 0 | X | 0 | X | 0 | 0 | X | 0 |
| **$FR_{6.12}$** | X | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 | X |

Figure 8.18: Design matrix for level 2 $FR_6$

Taking a look at the design matrix above, one can conclude that it is decoupled, meaning that the Independence Axiom is satisfied only and only if the DPs are implemented in a proper sequence. For example, to fulfil $FR_{6.4}$, $FR_{6.5}$ and $FR_{6.6}$, $DP_{6.1}$, $DP_{6.2}$ and $DP_{6.3}$ must be achieved earlier. To satisfy $FR_{6.11}$, $DP_{6.1}$, $DP_{6.6}$ and $DP_{6.8}$ have to be achieved first. It is also important to refer that some FRs such as $FR_{6.4}$ and $FR_{6.7}$ did not reach sufficient level of detail. As a result, a third level of decomposition for these two FRs will be performed further in this section.

**Decomposition of $FR_{3.1}$ to the level 3 FRs**

The purpose of this decomposition is to provide more detail to $FR_{3.1}$, i.e. to set the FRs that characterise each of the seven business processes described in Section 8.3.4 as well as the DPs to achieve them. By performing this decomposition, the evaluation on the extent to which a given business process is well-defined or not will be easier. Accordingly, Table 8.40 shows how $FR_{3.1}$ was decomposed.

Table 8.40: Decomposition of $FR_{3.1}$ to the level 3 FRs

| ***$FR_{3.1}$: Define the Dam cooperative business processes*** | ***$DP_{3.1}$: A document that describes the Dam cooperative business processes (see Section 8.3.4)*** | ***$PV_{3.1}$: Using the office tools (e.g. word file)*** |
|---|---|---|
| $FR_{3.1.1}$: Define the identification of concrete class and concrete composition process | $DP_{3.1.1}$: The text of the definition of Business Process 1 | $PV_{3.1.1}$: Using the office tools (e.g. word file) |
| $FR_{3.1.2}$: Define the concreting plan process | $DP_{3.1.2}$: The text of the definition of Business Process 2 | $PV_{3.1.2}$: Using the office tools (e.g. word file) |
| $FR_{3.1.3}$: Define the process of identification, collection and classification of concrete samples | $DP_{3.1.3}$: The text of the definition of Business Process 3 | $PV_{3.1.3}$: Using the office tools (e.g. word file) |
| $FR_{3.1.4}$: Define the process of performing the slump tests | $DP_{3.1.4}$: The text of the definition of Business Process 4 | $PV_{3.1.4}$: Using the office tools (e.g. word file) |
| $FR_{3.1.5}$: Define the process of performing the compression tests | $DP_{3.1.5}$: The text of the definition of Business Process 5 | $PV_{3.1.5}$: Using the office tools (e.g. word file) |
| $FR_{3.1.6}$: Define the process of processing the compression test results | $DP_{3.1.6}$: The text of the definition of Business Process 6 | $PV_{3.1.6}$: Using the office tools (e.g. word file) |
| $FR_{3.1.7}$: Define the process of evaluating the compression test results | $DP_{3.1.7}$: The text of the definition of Business Process 7 | $PV_{3.1.7}$: Using the office tools (e.g. word file) |

Having decomposed $FR_{3.1}$, a design matrix that explores the relationships between its sub-FRs and sub-DPs has been developed, as shown in Figure 8.19. The configuration of the design matrix generated, which is decoupled, suggests that the seven business processes should be defined in ascendant order, i.e. from Business Process 1 to Business Process 7. This will help to avoid redundancy in the definition of the business processes.

| | **$DP_{3.1.1}$** | **$DP_{3.1.2}$** | **$DP_{3.1.3}$** | **$DP_{3.1.4}$** | **$DP_{3.1.5}$** | **$DP_{3.1.6}$** | **$DP_{3.1.7}$** |
|---|---|---|---|---|---|---|---|
| **$FR_{3.1.1}$** | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.1.2}$** | X | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.1.3}$** | X | X | X | 0 | 0 | 0 | 0 |
| **$FR_{3.1.4}$** | X | X | X | X | 0 | 0 | 0 |
| **$FR_{3.1.5}$** | X | X | X | X | X | 0 | 0 |
| **$FR_{3.1.6}$** | X | X | X | X | X | X | 0 |
| **$FR_{3.1.7}$** | X | X | X | X | X | X | X |

Figure 8.19: Design matrix for level 3 $FR_{3.1}$

**Decomposition of $FR_{3.4}$ to the level 3 FRs**

Similarly to $FR_{3.1}$, the aim of this decomposition is to provide more detail to $FR_{3.4}$, i.e. to set the FRs that represent the execution of each of the seven business processes described in Section 8.3.4 as well as the DPs to achieve them. Also, by performing this decomposition, the evaluation on the extent to which a given business process is well performed or not will be easier. Accordingly, Table 8.41 shows how $FR_{3.4}$ has been decomposed.

Table 8.41: Decomposition of $FR_{3.4}$ to the level 3 FRs

| ***$FR_{3.4}$: Perform the Dam cooperative business processes*** | ***$DP_{3.4}$: Mechanisms to perform the Dam cooperative business processes*** | ***$PV_{3.4}$: Process, steps or methods needed to create or implement $DP_{3.4}$*** |
|---|---|---|
| $FR_{3.4.1}$: Identify the concrete classes and concrete composition (BP1) | $DP_{3.4.1}$: Mechanisms to identify the concrete classes and concrete composition | $PV_{3.4.1}$: Process, steps or methods needed to create or implement $DP_{3.4.1}$ |
| $FR_{3.4.2}$: Identify the concreting plan (BP2) | $DP_{3.4.2}$: Mechanisms to identify the concreting plan | $PV_{3.4.2}$: Process, steps or methods needed to create or implement $DP_{3.4.2}$ |
| $FR_{3.4.3}$: Identify the concrete samples (BP3) | $DP_{3.4.3}$: Mechanisms to identify the concrete samples | $PV_{3.4.3}$: Process, steps or methods needed to create or implement $DP_{3.4.3}$ |
| $FR_{3.4.4}$: Perform the slump test for each concreting operation (BP4) | $DP_{3.4.4}$: Rules and procedures to perform the slump test for each concreting operation | $PV_{3.4.4}$: Process, steps or methods needed to create or implement $DP_{3.4.4}$ |
| $FR_{3.4.5}$: Perform the compression test for each concreting operation (BP5) | $DP_{3.4.5}$: Rules and procedures to perform the compression test for each concreting operation | $PV_{3.4.5}$: Process, steps or methods needed to create or implement $DP_{3.4.5}$ |
| $FR_{3.4.6}$: Treat the compression test results statistically (BP6) | $DP_{3.4.6}$: Mechanism to treat the compression test results statistically (a software for statistical treatment of the compression test results) | $PV_{3.4.6}$: Sub-contracting a software developer |
| $FR_{3.4.7}$: Evaluate the compression test results (BP7) | $DP_{3.4.7}$: Procedures to evaluate the compression test results | $PV_{3.4.7}$: Using the office tools (e.g. word file) |

Figure 8.20 illustrates the relationships among the level 3 $FR_{3.4}$ and $DP_{3.4}$. The independence axiom can be fulfilled as the design matrix is decoupled. However, the DPs must be implemented in a proper

sequence. As explained in Section 8.3.4, the first three business processes are independent and therefore they can be performed in parallel. The others are sequential and therefore can only be achieved after achieving the previous ones, i.e. $DP_{3.4.4}$, $DP_{3.4.5}$, $DP_{3.4.5}$ and $DP_{3.4.7}$ must be implemented after achieving $FR_{3.4.1}$, $FR_{3.4.2}$ and $FR_{3.4.3}$. $DP_{3.4.5}$ has to be implemented after achieving $FR_{3.4.4}$, $DP_{3.4.6}$ must be implemented after achieving $FR_{3.4.5}$, and so on.

| | **$DP_{3.4.1}$** | **$DP_{3.4.2}$** | **$DP_{3.4.3}$** | **$DP_{3.4.4}$** | **$DP_{3.4.5}$** | **$DP_{3.4.6}$** | **$DP_{3.4.7}$** |
|---|---|---|---|---|---|---|---|
| **$FR_{3.4.1}$** | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.4.2}$** | 0 | X | 0 | 0 | 0 | 0 | 0 |
| **$FR_{3.4.3}$** | 0 | 0 | X | 0 | 0 | 0 | 0 |
| **$FR_{3.4.4}$** | X | X | X | X | 0 | 0 | 0 |
| **$FR_{3.4.5}$** | X | X | X | X | X | 0 | 0 |
| **$FR_{3.4.6}$** | X | X | X | X | X | X | 0 |
| **$FR_{3.4.7}$** | X | X | X | X | X | X | X |

Figure 8.20: Design matrix for level 3 $FR_{3.4}$

### Decomposition of $FR_{6.4}$ to the level 3 FRs

As mentioned elsewhere in this section, $FR_{6.4}$, which is concerned with the security of the security issues, did not reach enough level of detail. Thus, this decomposition intends to overcome this gap and make the design easily manageable and comprehensible by decision-makers. Based on this goal, $FR_{6.4}$ has been decomposed into eleven level 3 FRs, as illustrated by Table 8.42.

Table 8.42: Decomposition of $FR_{6.4}$ to the level 3 FRs

| ***$FR_{6.4}$: Ensure security of the systems and applications used to manage the information generated at the various stage of the Dam workflow*** | ***$DP_{6.4}$: Mechanisms of ICTs security*** | ***$PV_{6.4}$: ICTs security providers*** |
|---|---|---|
| $FR_{6.4.1}$: Allow access to the systems and applications | $DP_{6.4.1}$: Creation of users profile (with password) | $PV_{6.4.1}$: System administrator |
| $FR_{6.4.2}$: Deny access of unauthorised users to the systems and applications | $DP_{6.4.2}$: Password request function | $PV_{6.4.2}$: Process, steps or methods needed to create or implement $DP_{6.4.2}$ |
| $FR_{6.4.3}$: Allow access to the user workspace | $DP_{6.4.3}$: Creation of users credentials (user id and password) | $PV_{6.4.3}$: The information systems network platform administrator |
| $FR_{6.4.4}$: Deny access of unauthorised users to the users workspace | $DP_{6.4.4'}$: User id and password request functions<br>$DP_{6.4.4''}$: System of traffic control | $PV_{6.4.4}$: IT providers |
| $FR_{6.4.5}$: Validate the identity of users | $DP_{6.4.5}$: Mechanisms of authentication and identification | $PV_{6.4.5}$: The information systems network platform administrator |
| $FR_{6.4.6}$: Minimise the risk of a session to remain open due to logout oblivion | $DP_{6.4.6}$: Mechanism for automatic logout (e.g. after 5 minutes) | $PV_{6.4.6}$: Process, steps or methods needed to create or implement $DP_{6.4.6}$ |
| $FR_{6.4.7}$: Control the access to the information system platform | $DP_{6.4.7}$: Mechanism of access control (date and hour of last access) | $PV_{6.4.7}$: Process, steps or methods needed to create or implement $DP_{6.4.7}$ |
| $FR_{6.4.8}$: Confirm the validity of the websites used by users to perform operations in the ambit of the Dam construction project | $DP_{6.4.8}$: Digital certificates (making sure that the URL begins with https://, and verifying the existence of a padlock symbol on the browser URL) | $PV_{6.4.8}$: Provided by a certifying and independent authority |
| $FR_{6.4.9}$: Detect online suspicious activities | $DP_{6.4.9}$: Online activities monitoring systems | $PV_{6.4.9}$: Software developers |
| $FR_{6.4.10}$: Ensure that users use Internet in a secure way | $DP_{6.4.10}$: List of advices and procedures for the safe use of Internet | $PV_{6.4.10}$: Available in the Dam website |
| $FR_{6.4.11}$: Safeguard the information system platform against Internet virus | $DP_{6.4.11}$: Installation of antivirus software (e.g. ESET NOD32 Antivirus$^{TM}$) | $PV_{6.4.11}$: Antivirus software providers |
| $FR_{6.4.12}$: Safeguard the information system platform against breakdown | $DP_{6.4.12}$: A maintenance plan for the information system platform | $PV_{6.4.12}$: Sub-contracting an IT provider |
| $FR_{6.4.13}$: Safeguard the information system platform against cyber attacks | $DP_{6.4.13}$: Security mechanism against cyber attacks | $PV_{6.4.13}$: IT consulting |

Having decomposed $FR_{6.4}$, the next step is to generate the design matrix, evaluate the Independence Axiom and determine the sequence of implementation of DPs. As can be seen in Figure 8.21, the design matrix is decoupled and therefore the Independence Axiom is satisfied only and only if the DPs are determined in a proper sequence. For example, to achieve $FR_{6.4.5}$, $DP_{6.4.1}$, $DP_{6.4.2}$, $DP_{6.4.3}$ and $DP_{6.4.4}$ must be implemented earlier. To achieve $FR_{6.4.13}$, $DP_{6.4.7}$, $DP_{6.4.8}$ and $DP_{6.4.9}$ have to be implemented first.

| | $DP_{6.4.1}$ | $DP_{6.4.2}$ | $DP_{6.4.3}$ | $DP_{6.4.4}$ | $DP_{6.4.5}$ | $DP_{6.4.6}$ | $DP_{6.4.7}$ | $DP_{6.4.8}$ | $DP_{6.4.9}$ | $DP_{6.4.10}$ | $DP_{6.4.11}$ | $DP_{6.4.12}$ | $DP_{6.4.13}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $FR_{6.4.1}$ | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.2}$ | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.3}$ | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.4}$ | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.5}$ | X | X | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.6}$ | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.7}$ | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.8}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 | 0 |
| $FR_{6.4.9}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 | 0 |
| $FR_{6.4.10}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 |
| $FR_{6.4.11}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 |
| $FR_{6.4.12}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 |
| $FR_{6.4.13}$ | 0 | 0 | 0 | 0 | 0 | 0 | X | X | X | 0 | 0 | 0 | X |

Figure 8.21: Design matrix for level 3 $FR_{6.4}$

**Decomposition $FR_{6.7}$ to the level 3 FRs**

The aim of $FR_{6.7}$ decomposition is to provide more detail to the design in order to facilitate decision-making regarding the type of mechanisms used to manage the access to data. In the context of … it is important to define the conditions to access data, i.e. what can be accessed by whom. It is also important to eliminate the physical barriers to access data, i.e. to provide access of data regardless of the hardware, software, network infrastructure or geographical localization of users. This is important, for example, in the process of validating the slump test procedures and results, carried out by the Supervisor. Last, it is essential to provide access to authorised users and deny access to unauthorised ones, as shown in Table 8.43.

Table 8.43: Decomposition of $FR_{6.7}$ to the level 3 FRs

| ***$FR_{6.7}$: Manage the access to data*** | ***$DP_{6.7}$: Mechanisms to manage the access to data*** | ***$PV_{6.7}$: The information systems network platform administrator*** |
|---|---|---|
| $FR_{6.7.1}$: Set the conditions for data access | $DP_{6.7.1}$: Rules to access data (e.g. based on the roles and permissions of users) | $PV_{6.7.1}$: The information systems network platform administrator |
| $FR_{6.7.2}$: Eliminate the barriers to access data | $DP_{6.7.2}$: Access in mobile Apps such as tablets and smartphones | $PV_{6.7.2}$: IT providers |
| $FR_{6.7.3}$: Allow data access to authorised users | $DP_{6.7.3}$: Standards tools for accessing data (access to data regardless of the hardware, software, network infrastructure or geographical localization of users) | $PV_{6.7.3}$: Access to information will be provided by means of standard tools for accessing information, eventually with links to specific files containing design details |
| $FR_{6.7.4}$: Deny access to data to unauthorised users | $DP_{6.7.4}$: Mechanisms to deny access of data to unauthorised users | $PV_{6.7.4}$: IT providers |

The design matrix resulting from the decomposition of $FR_{6.7}$ is decoupled, as can be seen in Figure 8.22. This implies that the Independence Axiom can be satisfied only and only if the DPs are implemented in a proper sequence. For instance, to achieve $FR_{6.7.3}$ and $FR_{6.7.4}$, $DP_{6.7.1}$ and $DP_{6.7.2}$ must be achieved earlier. To achieve $FR_{6.7.2}$, $DP_{6.7.1}$ has to be implemented earlier, as the acquisition of the tablets and smartphones shall depends on the established rules to access data.

| | **$DP_{6.7.1}$** | **$DP_{6.7.2}$** | **$DP_{6.7.3}$** | **$DP_{6.7.4}$** |
|---|---|---|---|---|
| **$FR_{6.7.1}$** | X | 0 | 0 | 0 |
| **$FR_{6.7.2}$** | X | X | 0 | 0 |
| **$FR_{6.7.3}$** | X | X | X | 0 |
| **$FR_{6.7.4}$** | X | X | X | X |

Figure 8.22: Design matrix for level 3 $FR_{6.7}$

**Decomposition of $FR_{3.4.1}$ to the level 4 FRs**

On the basis of what has been explained in the decomposition of $FR_{3.4}$, this decomposition intends to provide more detail to the "Business Process 1 – Identify the concrete classes and concrete compositions". In short, this process consists of four main tasks, as shown in Table 8.44. With this decomposition we ensure that each sub-FR is achieved by its sub-DP rather than having a single DP to satisfy $FR_{3.4.1}$.

Table 8.44: Decomposition of $FR_{3.4.1}$ to the level 4 FRs

| ***$FR_{3.4.1}$: Identify the concrete classes and concrete composition*** | ***$DP_{3.4.1}$: Mechanisms to identify the concrete classes and concrete composition*** | ***$PV_{3.4.1}$: Process, steps or methods needed to create or implement $DP_{3.4.1}$*** |
|---|---|---|
| $FR_{3.4.1.1}$: Submit the concrete classes from Designer to Contractor and Supervisor | $DP_{3.4.1.1}$: Mechanism to submit the concrete classes from Designer to Contractor and Supervisor | $PV_{3.4.1.1}$: Process, steps or methods needed to create or implement $DP_{3.4.1.1}$ |
| $FR_{3.4.1.2}$: Submit the concrete compositions for the concrete classes defined (from Contractor to Supervisor) | $DP_{3.4.1.2}$: Mechanism to submit the concrete compositions for the concrete classes defined (from Contractor to Supervisor) | $PV_{3.4.1.2}$: Process, steps or methods needed to create or implement $DP_{3.4.1.2}$ |
| $FR_{3.4.1.3}$: Validate the concrete compositions submitted (Designer) | $DP_{3.4.1.3}$: Procedures to validate the concrete compositions submitted | $PV_{3.4.1.3}$: Using the office tools (e.g. word file) |
| $FR_{3.4.1.4}$: Communicate the decision on the validation of the concrete compositions, from Supervisor to the sender | $DP_{3.4.1.4}$: Mechanism to communicate the decision on the validation of the concrete compositions, from Supervisor to the sender | $PV_{3.4.1.4}$: Process, steps or methods needed to create or implement $DP_{3.4.1.4}$ |

To evaluate the Independence Axiom and determine the sequence of implementation of DPs, the design matrix illustrated in Figure 8.23 has been generated. The configuration of this design matrix indicates that it is decoupled, which means that the Independence Axiom can be satisfied only and only if the DPs are implemented in a proper sequence. For instance, to achieve $FR_{3.4.1.3}$, $DP_{3.4.1.1}$ and $DP_{3.4.1.2}$ must be achieved earlier. To achieve $FR_{3.4.1.4}$, $DP_{3.4.1.3}$ has to be implemented first.

| | **$DP_{3.4.1.1}$** | **$DP_{3.4.1.2}$** | **$DP_{3.4.1.3}$** | **$DP_{3.4.1.4}$** |
|---|---|---|---|---|
| **$FR_{3.4.1.1}$** | X | 0 | 0 | 0 |
| **$FR_{3.4.1.2}$** | X | X | 0 | 0 |
| **$FR_{3.4.1.3}$** | X | X | X | 0 |
| **$FR_{3.4.1.4}$** | 0 | 0 | X | X |

Figure 8.23: Design matrix for level 4 $FR_{3.4.1}$

**Decomposition of $FR_{3.4.2}$ to the level 4 FRs**

Similar to the Business Process 1, $FR_{3.4.2}$, which is concerned with the Business Process 2, needs to be decomposed in order to incorporate the tasks carried out in this process. As illustrated in Table 8.45, this process incorporates four FRs.

Table 8.45: Decomposition of $FR_{3.4.2}$ to the level 4 FRs

| ***$FR_{3.4.2}$: Identify the concreting plan*** | ***$DP_{3.4.2}$: Mechanisms to identify the concreting plan*** | ***$PV_{3.4.2}$: Process, steps or methods needed to create or implement $DP_{3.4.2}$*** |
|---|---|---|
| $FR_{3.4.2.1}$: Submit the contract concreting plan from Designer to Contractor | $DP_{3.4.2.1}$: Mechanism to submit the contract concreting plan (workspace to upload the contract concreting plan) | $PV_{3.4.2.1}$: IT consulting |
| $FR_{3.4.2.2}$: Submit the concreting plan from Contractor to Supervisor | $DP_{3.4.2.2}$: Mechanism to submit concreting plan (workspace to upload the concreting plan) | $PV_{3.4.2.2}$: IT consulting |
| $FR_{3.4.2.3}$: Validate the concreting plan submitted by Contractor (Designer) | $DP_{3.4.2.3}$: Procedures to validate the concreting plan | $PV_{3.4.2.3}$: Using the office tools (e.g. word file) |
| $FR_{3.4.2.4}$: Communicate the decision on the validation of the concreting plan, from Supervisor to Contractor | $DP_{3.4.2.4}$: Mechanism to communicate the decision on the validation of the concreting plan | $PV_{3.4.2.4}$: IT consulting |

As can be seen in Figure 8.24, the design matrix resulting from the decomposition above is decoupled. This implies that the Independence Axiom can be satisfied only and only if the DPs are implemented in a proper sequence. As example, $DP_{3.4.2.2}$ must be achieved before $DP_{3.4.2.3}$, and $FR_{3.4.2.4}$ must be fulfilled after implementing $DP_{3.4.2.3}$.

| | **$DP_{3.4.2.1}$** | **$DP_{3.4.2.2}$** | **$DP_{3.4.2.3}$** | **$DP_{3.4.2.4}$** |
|---|---|---|---|---|
| **$FR_{3.4.2.1}$** | X | 0 | 0 | 0 |
| **$FR_{3.4.2.2}$** | X | X | 0 | 0 |
| **$FR_{3.4.2.3}$** | 0 | X | X | 0 |
| **$FR_{3.4.2.4}$** | 0 | 0 | X | X |

Figure 8.24: Design matrix for level 4 $FR_{3.4.2}$

**Decomposition of $FR_{3.4.3}$ to the level 4 FRs**

The Business Process 3 is another one that did not achieve enough level of detail. Thus, a fourth level of decomposition has been carried out, as shown in Table 8.46.

Table 8.46: Decomposition of $FR_{3.4.3}$ to the level 4 FRs

| ***$FR_{3.4.3}$: Identify the concrete samples*** | ***$DP_{3.4.3}$: Mechanisms to identify the concrete samples*** | ***$PV_{3.4.3}$: Process, steps or methods needed to create or implement $DP_{3.4.3}$*** |
|---|---|---|
| $FR_{3.4.3.1}$: Submit the sampling plan, from Designer to Contractor | $DP_{3.4.3.1}$: Mechanism to submit the sampling plan (workspace to upload the sampling plan) | $PV_{3.4.3.1}$: IT consulting |
| $FR_{3.4.3.2}$: Propose the sampling identification scheme, from Contractor to Supervisor | $DP_{3.4.3.2}$: Mechanism to propose the sampling identification scheme (workspace to upload the sampling identification scheme) | $PV_{3.4.3.2}$: IT consulting |
| $FR_{3.4.3.3}$: Validate the sampling identification scheme submitted (Designer) | $DP_{3.4.3.3}$: Procedures to validate the sampling identification scheme submitted | $PV_{3.4.3.3}$: Using the office tools (e.g. word file) |
| $FR_{3.4.3.4}$: Communicate the decision on the validation of the sampling identification scheme, from Supervisor to Contractor | $DP_{3.4.3.4}$: Mechanism to communicate the decision on the validation of the sampling identification scheme | $PV_{3.4.3.4}$: IT consulting |

Again, the design matrix resulting from the decomposition of $FR_{3.4.3}$ is decoupled, as can be stated in Figure 8.25. In this case, to satisfy the Independence Axiom, the sequence of implementation of DPs must be determined in a proper sequence. For example, to achieve $FR_{3.4.3.3}$, $DP_{3.4.3.2}$ and $DP_{3.4.3.1}$ must be achieved earlier.

| | **$DP_{3.4.3.1}$** | **$DP_{3.4.3.2}$** | **$DP_{3.4.3.3}$** | **$DP_{3.4.3.4}$** |
|---|---|---|---|---|
| **$FR_{3.4.3.1}$** | X | 0 | 0 | 0 |
| **$FR_{3.4.3.2}$** | X | X | 0 | 0 |
| **$FR_{3.4.3.3}$** | X | X | X | 0 |
| **$FR_{3.4.3.4}$** | 0 | 0 | X | X |

Figure 8.25: Design matrix for level 4 $FR_{3.4.3}$

**Decomposition of $FR_{3.4.4}$ to the level 4 FRs**

$FR_{3.4.4}$, which is regarded with the process of performing the slump test for each concreting operation, also did not reach enough level of detail. Therefore, the decomposition provided by Table 8.47 has been carried out.

Table 8.47: Decomposition of $FR_{3.4.4}$ to the level 4 FRs

| ***$FR_{3.4.4}$: Perform the slump test for each concreting operation*** | ***$DP_{3.4.4}$: Rules and procedures to perform the slump test for each concreting operation*** | ***$PV_{3.4.4}$: Process, steps or methods needed to create or implement $DP_{3.4.4}$*** |
|---|---|---|
| $FR_{3.4.4.1}$: Collect samples for slump tests | $DP_{3.4.4.1}$: Rules and procedures to collect samples for slump tests | $PV_{3.4.4.1}$: Upon the arrival of a truck, a sample is collected for the slump test |
| $FR_{3.4.4.2}$: Perform the slump tests | $DP_{3.4.4.2}$: Rules and procedures to perform slump tests | $PV_{3.4.4.2}$: The slump test is carried out in the presence of an element of the supervision team |
| $FR_{3.4.4.3}$: Record the slump test procedures | $DP_{3.4.4.3}$: Handled device to record the slump test procedures | $PV_{3.4.4.3}$: The supervision team employee on site records the slump-test being performed, eventually adding a photo or video evidence |
| $FR_{3.4.4.4}$: Communicate the slump test procedures | $DP_{3.4.4.4}$: Mechanism to communicate the slump test procedures (using a mobile application – a tablet with access to Internet, for example) | $PV_{3.4.4.4'}$: The supervision team employee on site send a digital proof of the slump test procedures to the to trial platform<br>$PV_{3.4.4.4''}$: If, due to unpredictable circumstances, it is not possible for a supervision team employee to be at the test site, then the test can be recorded on video or photographed by another employee, who uploads the test details to the trial platform |
| $FR_{3.4.4.5}$: Validate the slump test procedures | $DP_{3.4.4.5}$: Mechanism to validate the slump test procedures (remote validation) | $PV_{3.4.4.5}$: The supervision team accesses the test procedures online and approve or reject the test remotely |
| $FR_{3.4.4.6}$: Communicate the decision on the validation of the slump test procedures | $DP_{3.4.4.6}$: Mechanism to communicate the decision on the validation of the slump test procedures | $PV_{3.4.4.6}$: The remote approval of the slump test by supervision authorizes the concreting operation |
| $FR_{3.4.4.7}$: Record the slump test results | $DP_{3.4.4.7}$: Mobile application to record the slump test results (e.g. tablet or smartphone) | $PV_{3.4.4.7}$: Process, steps or methods needed to create or implement $DP_{3.4.4.7}$ |
| $FR_{3.4.4.8}$: Communicate the slump test results | $DP_{3.4.4.8}$: Mechanism to communicate the slump test results | $PV_{3.4.4.8}$: Process, steps or methods needed to create or implement $DP_{3.4.4.8}$ |
| $FR_{3.4.4.9}$: Validate the slump test results | $DP_{3.4.4.9}$: Mechanism to validate the slump test results | $PV_{3.4.4.9}$: Process, steps or methods needed to create or implement $DP_{3.4.4.9}$ |
| $FR_{3.4.4.10}$: Communicate the decision on the validation of the slump test results | $DP_{3.4.4.10}$: Mechanism to communicate the decision on the validation of the slump test results | $PV_{3.4.4.10}$: Process, steps or methods needed to create or implement $DP_{3.4.4.10}$ |

To assess the Independence Axiom and to determine the sequence of implementation of DPs, a design matrix that explores the relationships among the above FRs and DPs has been generated, as shown in Figure 8.26.

| | $DP_{3.4.4.1}$ | $DP_{3.4.4.2}$ | $DP_{3.4.4.3}$ | $DP_{3.4.4.4}$ | $DP_{3.4.4.5}$ | $DP_{3.4.4.6}$ | $DP_{3.4.4.7}$ | $DP_{3.4.4.8}$ | $DP_{3.4.4.9}$ | $DP_{3.4.4.10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $FR_{3.4.4.1}$ | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{3.4.4.2}$ | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{3.4.4.3}$ | 0 | X | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{3.4.4.4}$ | 0 | X | X | X | 0 | 0 | 0 | 0 | 0 | 0 |
| $FR_{3.4.4.5}$ | 0 | X | X | X | X | 0 | 0 | 0 | 0 | 0 |
| $FR_{3.4.4.6}$ | 0 | X | X | X | X | X | 0 | 0 | 0 | 0 |
| $FR_{3.4.4.7}$ | 0 | X | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 |
| $FR_{3.4.4.8}$ | 0 | X | 0 | 0 | 0 | 0 | X | X | 0 | 0 |
| $FR_{3.4.4.9}$ | 0 | X | 0 | 0 | 0 | 0 | X | X | X | 0 |
| $FR_{3.4.4.10}$ | 0 | X | 0 | 0 | 0 | 0 | X | X | X | X |

Figure 8.26: Design matrix for level 4 $FR_{3.4.4}$

As can be seen, the design matrix above is decoupled. In this case, the Independence Axiom can be satisfied only and only if the DPs are implemented in a proper sequence. For instance, to achieve $FR_{3.4.4.6}$, $DP_{3.4.4.5}$, $DP_{3.4.4.4}$, $DP_{3.4.4.3}$ and $DP_{3.4.4.2}$ must be implemented first. To achieve $FR_{3.4.4.2}$, $DP_{3.4.4.1}$ has to be implemented first. To achieve $FR_{3.4.4.9}$, $DP_{3.4.4.8}$, $DP_{3.4.4.7}$ and $DP_{3.4.4.2}$ have to be implemented earlier.

**Decomposition of $FR_{3.4.5}$ to the level 4 FRs**

Similar to the process of performing the slump tests, $FR_{3.4.5}$, which is regarded with the process of performing the compression tests for each concreting operation, also did not achieve sufficient level of detail. Accordingly, the decomposition illustrated by Table 8.48 has been made.

Table 8.48: Decomposition of $FR_{3.4.5}$ to the level 4 FRs

| ***$FR_{3.4.5}$*: Perform the compression test for each concreting operation** | ***$DP_{3.4.5}$*: Rules and procedures to perform the compression test for each concreting operation** | ***$PV_{3.4.5}$*: Process, steps or methods needed to create or implement $DP_{3.4.5}$** |
|---|---|---|
| $FR_{3.4.5.1}$: Collect samples for compression tests | $DP_{3.4.5.1}$: Rules and procedures to collect samples for compression tests | $PV_{3.4.5.1}$: Samples are identified according to the approved samples identification system, usually in the presence of a supervision team element |
| $FR_{3.4.5.2}$: Perform the compression tests | $DP_{3.4.5.2}$: Procedures to perform the compression tests | $PV_{3.4.5.2}$: In the dam laboratory, some samples are placed in water at controlled temperature and left for the required time |
| $FR_{3.4.5.3}$: Check the compression test conditions | $DP_{3.4.5.3}$: Monitoring of the compression test conditions | $PV_{3.4.5.3}$: Test conditions may be checked regularly by supervision |
| $FR_{3.4.5.4}$: Record the compression test results | $DP_{3.4.5.4}$: Mechanism to record the compression test results | $PV_{3.4.5.4}$: The contractor records the tests |
| $FR_{3.4.5.5}$: Communicate the compression test results | $DP_{3.4.5.5}$: Mechanism to communicate the compression test results | $PV_{3.4.5.5}$: After recording the tests, the contractor submits them to supervision, who analyses them and approves/rejects them |

To evaluate the Independence Axiom and to determine the sequence of implementation of DPs, a design matrix shown in Figure 8.27 has been generated. Similar to the process of performing the slump test, the design matrix FRs and DPs concerned with the process of performing the compression tests is decoupled, meaning that the Independence Axiom can be satisfied only and only if the DPs are implemented in a proper sequence. For example, to achieve $FR_{3.4.5.2}$, $DP_{3.4.5.1}$ must be implemented first. To fulfil $FR_{3.4.5.5}$, $DP_{3.4.5.4}$ and $DP_{3.4.5.2}$ have to be implemented earlier.

| | $DP_{3.4.5.1}$ | $DP_{3.4.5.2}$ | $DP_{3.4.5.3}$ | $DP_{3.4.5.4}$ | $DP_{3.4.5.5}$ |
|---|---|---|---|---|---|
| $FR_{3.4.5.1}$ | X | 0 | 0 | 0 | 0 |
| $FR_{3.4.5.2}$ | X | X | 0 | 0 | 0 |
| $FR_{3.4.5.3}$ | 0 | X | X | 0 | 0 |
| $FR_{3.4.5.4}$ | 0 | X | 0 | X | 0 |
| $FR_{3.4.5.5}$ | 0 | X | 0 | X | X |

Figure 8.27: Design matrix for level 4 $FR_{3.4.5}$

The last levels of decomposition carried out in this section are considered appropriate to be used in the validation of the theoretical ABS model, performed in Section 8.3.8. In other words, by decomposing the FRs to level 3 and level 4, the extent to which their corresponding DPs are well implemented/defined or not can be adequately evaluated using the theoretical business interoperability maturity model, proposed in Section 6.3. On this basis, the next section consists of choosing the DPs or BIDSs to be used in the demonstration of the theoretical ABS model and the evaluation of their level of business interoperability, according to the theoretical business interoperability maturity model.

### 8.3.7 Demonstration of the theoretical business interoperability maturity model

The purpose of this section is to choose the BIDSs that may be used as decision variables in the validation of the theoretical ABS model. The criteria to choose the BIDSs are the existence of documents that describe the level of business interoperability in both current and future scenario and the relationship that may exist between them and the impact on the performance, i.e. to choose the BIDSs that have evident relationships to the KPIs provided in Table 8.36. The chosen BIDSs and their corresponding levels of business interoperability in both present and future scenarios are summarised in Table 8.49.

Table 8.49: BIDSs and corresponding levels of business interoperability

| BIDSs | Present scenario (as-is) | ALBI | Future scenario (to-be) | RLBI |
|---|---|---|---|---|
| $DP_{3.1}$: Design of the Dam cooperative business processes | Currently, there is a poor design of Dam cooperative business processes | 1 | Well-defined business processes with easy to use information system platform. IT Provider will work in close contact with End-User to define the correct business workflow that takes in account of all the single activities and actors involved | 4 |
| $DP_{3.4.4.3}$: Mechanism to record the slump test procedures | Currently, there are no mechanisms for recording the slump test procedure | 0 | The employee at the slump test site will take a digital proof (video or photography) of the slump test procedure, which will be sent immediately to the supervisor at remote place, so that he can validate the procedure | 4 |
| $DP_{3.4.4.7}$: Mechanism to record the slump test results | Currently, the test results are recorded and circulated in paper | 1 | Test result recording for a particular cube will be carried out by making use of cube identification technology | 4 |
| $DP_{3.4.4.9}$: Procedures to validate the slump test results | Currently, there are no mechanisms for automatic validation of test results. They are validated by human intervention (supervisor) | 1 | Platform will support the automatic validation of the test results based on the concrete class definition | 4 |
| $DP_{3.4.6}$: Mechanism to treat the compression test results statistically | Currently, standard tools for statistical analysis and deviation assessment is missing. The test results are treated statistically, using Microsoft EXCEL | 2 | Platform will support automatic statistical analysis. Statistical analysis and deviation assessment will be carried out in an automatic way with customizable business logics (using standard tools) | 4 |
| $DP_{3.7}$: Mechanism to coordinate the Dam cooperative business processes | Currently, there is a poor coordination of the Dam cooperative business processes | 1 | Well-coordinated business processes by sharing information (on planning) in real-time, via easy to use information system platform | 4 |
| $DP_{3.8}$: Mechanism to identify the concreting flow | Currently there is no use of technology for integrating things (or objects) into the information system. The objects like slump, and concrete cubes are not connected to the information system | 0 | Objects involved at various activities will be tagged and integrated to the central system with the help of RFID readers | 4 |
| $DP_{6.6}$: Mechanism to integrate data coming from multiple sources | Currently, the data and documents produced at each state of the workflow are stored by the stakeholders in their own system. They are used in the other stages of the workflow with manual integration of the previous results | 1 | In the future scenario, the various sources of data that produce information regarding concrete class, concreting plan, slum test result, and concrete sample test results are integrated in the central information system | 4 |
| $DP_{6.7.3}$: Tools for accessing data | Currently, the accessibility of information is low and highly manual | 1 | Access to information will be provided by means of standard tools for accessing information (information will be available in "real time" to the stakeholders), | 4 |

| | | | | |
|---|---|---|---|---|
| | | | eventually with links to specific files containing design details | |
| $DP_{6.9}$: Mechanism to exchange information | Currently, all the involved stakeholders (including client) exchange information with tradition means via emails or hard copies | 1 | Information between stakeholders will be exchanged electronically and in real time, using the common platform | 4 |
| $DP_{6.10}$: Mechanism to store data | Currently, all the data (storage in standard files) is stored in the file system (windows standard) | 1 | With the implementation of the new business scenario the data storage will be done with well-defined standard technologies. Users will have standard way to store information | 4 |
| $DP_{6.11}$: Mechanism to retrieve data | Currently, all the data (storage in standard files) is retrieved manually | 1 | With the implementation of the new business scenario the retrieval of data will be done with well-defined standard technologies. Users will have standard way retrieve information | 4 |
| $DP_{6.12}$: Mechanism to archive historical data | The record regarding the objects like slump and concrete cubes are created and archived making use of the paper documents. There is no specific network software/platform to archive and manage data | 0 | Platform will provide efficient way for data archival historical data will be archived in digital format and can be easily obtained with visual proof of the activities where applicable | 4 |

### 8.3.8 Demonstration and validation of theoretical Agent-Based Simulation model

As in the Case Study 1, the theoretical ABS model was implemented in *NetLogo* software (Wilensky 1999). A simulation environment was developed to support the modelling of the interactions among the agents involved in the Dam construction project and the analysis of the impact of the BIDSs described above on the performance of these agents. The steps to implement the simulation model were the same that were used in the Case Study 1 (see Figure 8.5). Each company involved in the Dam construction project was modelled as an independent agent with autonomous decision making abilities and characterised by a set of attributes. The interaction and decision rules were modelled based on the description of the business processes carried out in Section 8.3.3 and 8.3.4, and according to the BPD provided in Appendix D. The specific BIDSs or DPs that were used as decision variables in the model implementation are: $DP_{3.4.4.3}$, $DP_{3.4.4.7}$, $DP_{3.4.4.9}$, $DP_{3.4.6}$, $DP_{6.7.3}$, $DP_{6.9}$, $DP_{6.10}$ and $DP_{6.11}$. As mentioned in previous section, the reason behind the choice of these BIDSs is that their links to the KPIs provided in Table 8.36 are more evident. For instance, "$DP_{6.7.3}$ – Tools for accessing data" has a direct impact on the "KPI1 – Average lead time to access the information relating to concrete characteristics and concreting plan after/before the DV/AV implementation during the concrete control process". For each tested BIDS, a distance has been calculated based on Equation 10 (as explained in Section 5.5), and based on the achieved distance, the impact was estimated by triangulating it with the quantitative impact provided in Table 8.36. To help in the modelling of the interactions among the agents, a set of assumptions was made, as illustrated in Table 8.50. Note that, as in the Case Study 1, these assumptions were made grounded on the interviews the author had with the managers interviewed.

Table 8.50: Assumptions made for Case Study 2

| A | Designation | Present scenario | Future scenario |
|---|---|---|---|
| A1 | Probability of the concreting compositions to be submitted by Designer | 0,70 | 0,70 |
| A2 | Probability of concreting compositions to be rejected | 0,15 | 0,05 |
| A3 | Probability of the sampling plan to be rejected | 0,10 | 0,03 |
| A4 | Probability of the concreting plan to be rejected | 0,15 | 0,05 |
| A5 | Probability of the sampling identification scheme to be rejected | 0,11 | 0,04 |
| A6 | Probability of a sample to be collected at the arrival of truck | 0,70 | 0,70 |
| A7 | Probability of slump test to be made | 0,60 | 0,50 |
| A8 | Probability of a supervision team employee to be at the slump test site, during a slump test | 0,00 | 0,90 |
| A9 | Probability of a supervision team employee to be at the compression test site, during a compression test | 0,00 | 30 |
| A10 | Probability of the slump test results to be rejected | 0,15 | 0,04 |
| A11 | Probability of the compression test results to be rejected | 0,12 | 0,03 |
| A12 | Number of working days a year | 255 | 255 |
| A13 | RLBI (for all BIDSs) | 4 | 4 |

The duration of the cooperation is of two years (510 days) and the trial platform will be introduced at the beginning of the second year (t = 256). Daily time steps were used as the aim is to understand how companies interact with each other and how business interoperability can impact their operational performance in a daily basis.

### 8.3.9 Simulation experiment and results

The KPIs tested in the ambit of this case study as well as their mean and standard deviation, are provided in Table 8.51 – 8.52. Those KPIs were derived from the aggregate KPIs provided in Table 8.36. The model was replicated hundred times using *NetLogo*'s BehaviourSpace tool (Wilensky 1999), although, for example, Rand and Rust (2011) suggest that 30 runs are acceptable.

Table 8.51: Simulation results (t < 256)

| KPI | t < 256 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | D | | CTT | | S | | CTM | |
| | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| Time needed to access concrete classes (hours) | - | - | 4,04 | 0,51 | 4,04 | 0,51 | - | - |
| Time needed to access concreting plan (hours) | - | - | - | - | 4,03 | 0,56 | - | - |
| Time needed to access the sampling plan (hours) | - | - | 4,03 | 0,56 | - | - | - | - |
| Time needed to access concrete compositions (hours) | - | - | - | - | 4,03 | 0,56 | - | - |
| Lead time to receive concrete compositions (hours) | - | - | - | - | 7,50 | 0,68 | - | - |
| Lead time to receive concrete classes (hours) | - | - | 7,48 | 0,72 | 7,48 | 0,72 | - | - |
| Lead time to receive concreting plan (hours) | - | - | - | - | 7,50 | 0,68 | - | - |
| Lead time to receive the record of the slump test (hours) | - | - | - | - | N.Ap. | N.Ap. | - | - |
| Time needed to perform the slump test (minutes) | - | - | 27,03 | 3,39 | N.Ap. | N.Ap. | - | - |
| Time needed to perform compression test (minutes) | - | - | 27,10 | 3,39 | - | - | - | - |
| Cost needed to perform the slump test (€) | - | - | 2,02 | 0,48 | - | - | - | - |
| Cost needed to perform compression test (€) | - | - | 2,01 | 0,45 | - | - | - | - |
| Time needed to record the slump test results (minutes) | - | - | 27,03 | 3,39 | - | - | - | - |
| Time needed to record compression tests results (minutes) | - | - | 27,15 | 3,24 | - | - | - | - |
| Cost needed to record the slump test results (€) | - | - | 2,02 | 0,48 | - | - | - | - |
| Cost needed to record compression tests results (€) | - | - | 2,09 | 0,42 | - | - | - | - |
| Number of pages used to define concrete compositions | 5,00 | 0,69 | 4,93 | 0,68 | - | - | - | - |
| Number of pages used to define concrete classes | 4,91 | 0,72 | - | - | - | - | - | - |
| Number of pages used to define concreting plan | - | - | 5,02 | 0,65 | - | - | - | - |
| Number of pages used to define the sampling plan | 4,99 | 0,57 | - | - | - | - | - | - |
| Time needed to analyse the slump test results (days) | - | - | - | - | 38,14 | 4,26 | - | - |
| Time needed to evaluate compression test results (days) | - | - | - | - | 38,33 | 4,51 | - | - |
| Cost needed to analyse the slump test results (€) | - | - | - | - | 1,30 | 0,17 | - | - |
| Cost needed to evaluate compression test results (€) | - | - | 1,30 | 0,17 | - | - | - | - |
| Number of pages used to record the slump test results | - | - | 4,95 | 0,75 | - | - | - | - |
| Number of pages used to record compression tests results | - | - | 4,98 | 0,79 | - | - | - | - |
| Lead time needed to receive the compression test results (hours) | - | - | - | - | - | - | 7,44 | 0,95 |
| Time needed to treat compression test results statistically (days) | - | - | 38,04 | 4,26 | 38,04 | 4,26 | - | - |
| Cost needed to treat compression test results statistically (€) | - | - | 1,30 | 0,17 | 1,30 | 0,17 | - | - |

D – Designer, CTT – Contractor, S – Supervisor, CTM – Customer

Table 8.52: Simulation results (255 < t < 511)

| KPI | 255 < t < 511 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | D | | CTT | | S | | CTM | |
| | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| Time needed to access concrete classes (hours) | - | - | 0,09 | 0,06 | - | - | - | - |
| Time needed to access concreting plan (hours) | - | - | - | - | 0,08 | 0,01 | - | - |
| Time needed to access the sampling plan (hours) | - | - | 0,08 | 0,01 | - | - | - | - |
| Time needed to access concrete compositions (hours) | - | - | - | - | 0,08 | 0,01 | - | - |
| Lead time to receive concrete compositions (hours) | - | - | - | - | 0,15 | 0,01 | - | - |
| Lead time to receive concrete classes (hours) | - | - | 0,16 | 0,12 | 0,16 | 0,12 | - | - |
| Lead time to receive concreting plan (hours) | - | - | - | - | 0,15 | 0,01 | - | - |
| Lead time to receive the record of the slump test (hours) | - | - | - | - | 0,19 | 0,03 | - | - |
| Time needed to perform the slump test (minutes) | - | - | 19,18 | 1,25 | 19,18 | 1,25 | - | - |
| Time needed to perform compression test (minutes) | - | - | 19,24 | 1,15 | - | - | - | - |
| Cost needed to perform the slump test (€) | - | - | 1,47 | 0,30 | - | - | - | - |
| Cost needed to perform compression test (€) | - | - | 1,41 | 0,30 | - | - | - | - |
| Time needed to record the slump test results (minutes) | - | - | 19,01 | 1,13 | - | - | - | - |
| Time needed to record compression tests results (minutes) | - | - | 19,22 | 1,17 | - | - | - | - |
| Cost needed to record the slump test results (€) | - | - | 1,65 | 0,16 | - | - | - | - |
| Cost needed to record compression tests results (€) | - | - | 1,51 | 0,22 | - | - | - | - |
| Number of pages used to define concrete compositions | 2,83 | 0,38 | 2,85 | 0,37 | - | - | - | - |
| Number of pages used to define concrete classes | 2,95 | 0,26 | - | - | - | - | - | - |
| Number of pages used to define concreting plan | - | - | 2,85 | 0,36 | - | - | - | - |
| Number of pages used to define the sampling plan | 2,79 | 0,31 | - | - | - | - | - | - |
| Time needed to analyse the slump test results (days) | - | - | - | - | 0,92 | 0,23 | - | - |
| Time needed to evaluate compression test results (days) | - | - | - | - | 0,98 | 0,31 | - | - |
| Cost needed to analyse the slump test results (€) | - | - | - | - | 0,46 | 0,04 | - | - |
| Cost needed to evaluate compression test results (€) | - | - | 0,46 | 0,03 | - | - | - | - |
| Number of pages used to record the slump test results | - | - | 2,92 | 0,28 | - | - | - | - |
| Number of pages used to record compression tests results | - | - | 2,85 | 0,36 | - | - | - | - |
| Lead time needed to receive the compression test results (hours) | - | - | - | - | - | - | 0,15 | 0,01 |
| Time needed to treat compression test results statistically (days) | - | - | 0,77 | 0,02 | 0,77 | 0,02 | - | - |
| Cost needed to treat compression test results statistically (€) | - | - | 0,46 | 0,03 | 0,46 | 0,03 | - | - |

Next, it is presented a brief analysis on the case study results and the main rationales supporting the results reported here.

### 8.3.10 Analysis of the case

The simulation results provided in Table 8.51 – 8.52 illustrate that the introduction of the trial platform will enable the cooperative networked companies to improve their operational performance. The main benefits are time saving and reduction of paperwork. For instance, the time needed to treat the compression test results statistically can be reduced from 38,04 days to 0,77 days, which represent a reduction of 97,97%. The main BIDS that contributes to achieve this reduction is the introduction of a software for automatic statistical treatment of the compression test results rather than Excel and paperwork. Another relevant impact is on the time for data exchange between stakeholders during the concrete control process. For instance, the lead time for the Customer to receive the compression test results can be reduced from 7,44 hours to 0,15 hours. This is because in the future business scenario this information will be exchanged through the online information system platform rather than emails and hard copies as is currently made. The time to access information/data is also affected. For example, the time needed to access the concrete compositions can be reduced from 4,03 hours to 0,08 hours. The introduction of standards tools for accessing data rather than the use of manual process will contribute to achieve this improvement.

## 8.4 Cross-case analysis

Once analysed each case individually, this section makes a cross-case analysis, i.e. a comparative analysis on the appropriateness of the proposed methodology to model the two cooperative networks analysed in this thesis. Regarding the Case Study 1 (Valorpneu network), the proposed methodology contributed to simulate the interactions between the SGPU operators and most importantly, to understand how the impacts business interoperability on the performance of these companies spread over the Valorpneu network. With regard to the Case Study 2 (Dam Baixo Sabor network), the methodology contributed to perform a systematic modelling by interplaying between the application of ABS and the Axiomatic Design Theory. Specifically, ABS has been applied in a first place to analyse the performance of the current business scenario, following the application of the Axiomatic Design Theory to design new configuration for the Dam construction project, and last, ABS was once again used to estimate the impact of the implementation of the new designed configuration.

In short, the main difference in the modelling of the two cases lies in the use of the two proposed theoretical models or not. As explained in Section 5.2, for existing cooperative industrial networks one should first apply the theoretical ABS model, then the theoretical Axiomatic Design model, and then the theoretical ABS model. This modelling approach was entirely employed in the Case Study 2, while in the Case Study 1 the theoretical Axiomatic Design has not been used as the simulation results were considered satisfactory. However, it is to refer that as both the application scenario presented in

Chapter 6 and the Case Study 1 are concerned with cooperative RL network, some of the last level DPs achieved in the first have been used as reference to identify the BIDSs to be used as input in the validation of the theoretical ABS model (Case Study 1). This means that there is another relevant difference in the way how the decision variables (last level DPs or BIDSs) used in simulation of both networks were obtained, i.e. while the BIDSs used in the simulation of the Dam Baixo Sabor network were gathered directly from the design of a new configuration, the ones used in simulation of the Valorpneu network were obtained by triangulating the last level DPs achieved in the application scenario presented in Chapter 6 and the cooperation mechanisms that have been implemented in the Valorpneu network over the years.

Regarding the appropriateness of the theoretical ABS model to analyse the impact of business interoperability on the performance of cooperative industrial networks, it is to refer that the results achieved in both case studies reinforced the Proposition 2, which states that ABS is appropriate for analysing the impact of business interoperability on the performance of cooperative industrial networks. In other words, these results suggest that the way how the impacts of business interoperability spread over a business network (network effect), which is implicitly related to the Research Question 2, can be properly addressed through the ABM method.

## 8.5 Summary

This chapter started with an overview on the two case studies presented in this thesis. The purpose of the case studies has been stated as being the demonstration of the applicability of the proposed methodology rather than the achievement of generalisation about the application of the methods. In this sense, data have been collected from two the Portuguese cooperative industrial network mentioned previously to demonstrate how such methodology can be applied. In the first case study, the one concerned with the Valorpneu network, the methodology has been applied only to validate the theoretical ABS model while in the second case study regarding the Dam Baixo Sabor network it has been applied to validate both the theoretical Axiomatic Design model and the theoretical ABS model. Based on the results achieved in each case study, a within-case analysis was carried out to discuss how the analysed BIDSs affect the impact of the companies belonging to the network studied. Last, a cross-case analysis has been made to discuss the importance of the proposed methodology to model both the Valorpneu network and the Dam Baixo Sabor network. The main conclusion was that indeed, the two theoretical models proposed in this thesis can be applied in an integrated way as has been done in the Case Study 2, or separately as shown in Case Study 1.

# Chapter 9 Conclusions

This chapter summarises and discusses the main findings of this research. First, it will be discussed how these findings address the research questions and propositions identified in Section 1.3. Then, the theoretical and managerial implications are discussed. Finally, guidelines for future research to extend this work will be suggested, based on the identified limitations.

## 9.1 Conclusions about the research questions and propositions

This thesis proposed a novel approach for modelling business interoperability in a context of complex cooperative industrial networks. The thesis addressed two research questions, defined on the basis of two important gaps in business interoperability and OM:

1. Existing works do not explain how to design interoperable cooperative industrial network platforms, taking into account all relevant dimensions of business interoperability;
2. Existing works do not explain how to analyse the impact of business interoperability on the performance of networked companies, taking into account the network effect (e.g. how a business interoperability problem between two companies of a dyad can affect the performance of the other companies in the network).

To explore the first research gap a first research question has been set (see Section 1.3): *How can we design business platforms that are able to deliver business interoperability, in a context of complex cooperative industrial networks?* The second research gap has been explored through the definition of the following research question: *How can we analyse the impact of business interoperability on the performance of companies, in a context of complex cooperative industrial networks?* To explore these two research questions, two propositions have been set, regarding the most appropriate tool to address each research question. First, it has been assumed that the Axiomatic Design Theory can effectively contribute to address the research question related to the issue of how to design interoperable cooperative industrial networks. Then, ABS has been assumed to provide an effective set of tools for addressing the Research Question 2, i.e. to explore how the impacts of business interoperability spread over a cooperative industrial network.

Regarding the first research question and its corresponding proposition, it is to refer that the application of the theoretical Axiomatic Design model to different application scenarios (see Chapter 6) and mainly to the case study regarding the Dam Baixo Sabor network suggested that indeed configurations of interoperable cooperative industrial network platforms can be properly designed using the Axiomatic Design Theory because it enables the designer to:

1. Organise or separate in three different domains what are the business interoperability requirements, the business interoperability solutions and the way how each business interoperability solution should be implemented;
2. Interplay between two different domains and relate each business interoperability requirement to its corresponding business interoperability solution, and then each business interoperability solution to each process or method of implementation;
3. Evaluate the quality of design by applying two design axioms (Independence Axiom and Information Axiom), and then choose the best configuration for interoperable industrial network platforms – by applying the Independence Axiom, the designer will be able to ensure a proper sequence of implementation of the business interoperability solution, and to ensure that each FR is satisfied independently of each other;
4. Decompose the dimensions of business interoperability into a more detailed level, i.e. to a level where the business interoperability solutions can be easily understood, managed and measured through a business interoperability maturity model – this facilitates the decision-making process regarding the level of business interoperability to be achieved in each business interoperability solution and not a dimension of business interoperability as a whole. This is one of the limitations of the existing maturity models, i.e. they try to evaluate the level of business interoperability for a concrete dimension (i.e. information system) instead of decomposing it into different sub-dimensions (e.g. mechanism to ensure confidentiality and privacy, mechanism to ensure secure exchange of information, mechanism to integrate information coming from different sources of data, etc.).

With regard to the Research Question 2, the application of the theoretical ABS model in two different cooperative industrial networks resulted in a valuable tool that can be effectively used in the analysis of the impact of business interoperability on the performance of companies, in a context of cooperative industrial networks. It means that ABS is indeed appropriate for addressing the second research question as enabled the researcher to:

1. Model the interaction among the companies in each of the networks analysed (e.g. make companies exchange information, deliver products, celebrate contracts, etc.);
2. Model the way that each business interoperability design solution can affect the interaction among the companies by relating each interaction process to specific business interoperability variables;

3. Model the probability of occurrence of business interoperability problems based on the distance between the ALBI and RLBI for each business interoperability design solution, as proposed in Section 5.5;
4. Model the occurrence of business interoperability problems when companies interact with each other and spread the impact of such problems to other members of the network;
5. Estimate the impact of the business interoperability problems, first on the performance of the companies belonging to the relationship(s) in which the problem occurred, and then on the performance of the companies belonging to the neighbours relationships;
6. Model the impact of external events such as truckers strike, introduction of new legislations, economic crisis, etc.;
7. The impact of business interoperability problems emerged from the interaction at the dyadic level can be effectively assigned to each individual agent or to the network as a whole.

Summarising, the main research gap related to the Research Question 2 (the network effect) can be effectively captured using the proposed theoretical ABS model. For example, in the Case Study 1, a situation was modelled in which a charge sent by a Collection Point to a Recycler or a Energy Recovery is rejected due to contamination and/or non-conformity. The impact of this rejection was first assigned to the Collection Point responsible for sending the rejected charge and then spread to Transporters and the Managing Entity. The transporter benefits from the transportation cost paid by the Collection Point (round trip transportation cost) and the Managing Entity charges a penalty to the Collection Point due to the rejected charge. This situation could have a considerable impact on the performance of the Recycler or Energy Recovery that rejected the charge if its current inventory level is not enough to ensure that its production is not interrupted. In short, the conclusions obtained in both case studies provided insights that they address the Research Question 2. However, more case studies are needed to in order to make this generalisation.

## 9.2 Conclusions on the case study results

The application of the theoretical ABS model in two different industrial network contexts showed that indeed the implementation of appropriate levels of business interoperability can contribute to reduce several non-value-adding activities and consequently improve the operational performance of cooperative networked companies. For example, in the Case Study 1 (Valorpneu network), the implementation of a system for evaluating and rewarding the quality of the service provided by the SGPU operators, which was introduced in 2008, has helped to reduce year after year the percentage of charges delivered with delay (from 30,71% in 2007 to 0,83% in 2014), the percentage of receptions registered with delay (from 40,37% in 2007 to 3,98% in 2014), and the percentage of contaminated charges sent from Collection Points to Recyclers and Energy Recoveries (from 0,38% in 2009 to 0,27% in 2014). Also, the existence of a well-defined and well-documented system for sorting used tyres at Collection Points, helps to maintain the percentage of non-conforming charges sent from these agents to recoveries agents at values relatively low (0,18% in 2009, 0,03% in 2010, 0,08% in 2011, 0,04% in 2012, 0,10% in 2013 and 0,10% in 2014).

Another relevant impact of having appropriate level of business interoperability, in the ambit of the Valorpneu network, is the increase of the number of adherent Producers, which had a significant increase from 609 in 2007 to 1787 in 2014. This increase was achieved due to the various diligences that the Managing Entity has taken to bring the freeriders into the SGPU, such as: characterisation of the origin at the delivery of tyres at Collection Points with the identification whether the tyres have been imported or not, providing an area in the Valorpneu website for anonymous denunciations, collaboration with oversight entities (namely ASAE) by providing them periodic lists of suspected importer of tyres without contract with Valorpneu.

Regarding the Case Study 2 (Dam Baixo Sabor), the results indicated that the design of a new and more interoperable configuration for the cooperative platform (e.g. implementation of a cooperative information system platform and a RFID system) can bring significant improvements on the business interoperability and operational performance of the companies involved in the construction dam project. The main benefits are time saving and reduction of paperwork. For instance, the time needed to treat the compression test results statistically can be reduced from 38,04 days to 0,77 days, which represent a reduction of 97,97%. This reduction is mainly motivated by the introduction of a software for automatic statistical treatment of the compression test results rather than Excel and paperwork.

Another relevant impact is on the time for data exchange between stakeholders during the concrete control process. For instance, the lead time for the Customer to receive the compression test results can be reduced from 7,44 hours to 0,15 hours, and the time needed to access the concrete compositions can be reduced from 4,03 hours to 0,08 hours. This is because with the implementation of the new configuration, the compression test results will be directly uploaded into the common information system platform and accessed by the Customer in an easier and quicker way.

## 9.3 Theoretical implications

As discussed in Section 9.1, this thesis addresses two important research gaps in business interoperability and OM literature. By defining the two research questions, this thesis proposes a methodology that can be used by researchers from different areas such as business interoperability, SCM, and OM in general to design configurations of interoperable cooperative industrial network platforms and to analyse how companies interact in business networks and how business interoperability can affect the performance of these companies. As explained in previous sections, the application of the proposed methodology in two cooperative industrial networks suggested that such methodology can result in a valuable tool for modelling business interoperability, in a context of business networks in general. For example, researchers can use this methodology to systematically design, analyse and redesign configurations of interoperable business network platforms, and understand better the complexity of business relationships, in different business contexts.

In terms of relevance to theory, this is the first time that a holistic approach that integrates all dimensions of business interoperability is proposed to design configurations of interoperable business network platforms, and also the first time that the network effect is taken into account in the analysis of the impact of business interoperability on the performance of networked companies. In short, the main difference regarding the existing approaches is that this research addresses an important problem in business networks, that is: how dyad organisational relationships affect the network of companies to which the two companies in the dyads belong. For example, the bullwhip effect, a well-known problem in SCs, could be effectively addressed by researchers using the approach proposed here.

## 9.4 Managerial implications

With regard to the practical contribution of this research, the methodology proposed in this thesis is intended to support industrial managers in decision-making processes regarding the business relationships their companies have with their business partners. In other words, it is intended to provide a methodology that can guide them easily, and in practical way, on how to design of configurations of interoperable cooperative industrial network platforms and/or how to analyse the impact of business interoperability on the performance of their companies and the networks in which their companies operate. In a more detailed way, the methodology seeks to help managers to:

1. Better understand the complex nature of the business networks in which their companies operate and identify points where improvements in terms of business interoperability and operational performance can be achieved;
2. Better understand how the business relationships between their companies and their partners, and the whole network in which they operate, evolve over time;
3. Make informed decisions on the mechanisms of business interoperability that can be used by their companies and their partners to ensure an effective interaction with their business partners, and achieve such improvements in terms of business interoperability and operational performance;

4. Analyse which level of business interoperability is needed for each mechanism of business interoperability being implemented, thereby avoiding unnecessary investments;
5. Better analyse the impact of the implementation of a given mechanism of business interoperability and/or a given level of business interoperability;
6. Predict the occurrence of business interoperability problems, not only between their companies and their partners, but also between their partners and other elements of the network, and implement preventive actions rather than mitigation plans;
7. Better understand how internal events such as cooperation breakdown, entrance of new partners, and information system breakdown can impact the performance of their companies;
8. Better understand how external events such as economic crisis, strikes, introduction of new technologies and/or legislations, new competitors, etc., can affect the performance of their companies and the network of companies in which they operate;
9. Identify the dyad(s) in which the levels of business interoperability are inappropriate and make informed decisions on behalf of the whole network;
10. Improve competitiveness and sustainability of the whole network where their companies operate, in order to compete against other business networks – as the competition between companies has been increasingly replaced by competition between business networks.

## 9.5 Limitations

Although the findings of this research suggest that the proposed methodology is appropriate for designing configurations of interoperable cooperative industrial network platforms and to analyse the impact of business interoperability on the performance of networked companies, this research is subject to a number of limitations.

First, the Information Axiom, which is one of the relevant axioms of the Axiomatic Design Theory, was not evaluated in the validation of the theoretical Axiomatic Design model. Second, only two case studies were conducted, which implies that conclusions on the findings cannot be generalised. Third, the data collected in both case studies were not enough to fully explain the network effect, as in most cases the managers interviewed recognised that the network effect is a real “phenomenon” in their business networks, but were unable to quantify its impact. Fourth, the lack of quantitative data regarding the impact of business interoperability, mainly in terms of the network effect, led the investigator to make several assumptions, meaning that some results of the case studies presented are not reliable. As a result, conclusions may be biased. Fifth, the two industrial networks analysed in this thesis do not involve companies from other countries. Therefore, issues such as cultural and linguistic differences, misaligned legislations and regulations could not be explored.

## 9.6 Future research

Taking into account the limitations discussed in the section above, there are many ways to extend this work in the future. First, the proposed theoretical Axiomatic Design model must be validated in a situation in which the cooperative industrial network does not exist and in which is necessary to design several configurations and select the best one by applying the theoretical ABS model to predict their business interoperability and operational performance. Second, more empirical data need to be collected in order to better explain the network effect. Third, both the theoretical Axiomatic Design and ABS models must be applied to other types of business networks (e.g. automotive and aircraft industries) in order to compare the results with those reported here. Also, more case studies need to be conducted in order to better decide on the appropriateness of the Axiomatic Design Theory to design configurations of interoperable industrial network platforms and ABS to analyse the impact of business interoperability on the performance of companies in a context of cooperative industrial networks. Another interesting future work, which is already being developed, is to use the results of the levels of business interoperability achieved in the ambit of the case study on the Valorpneu network to develop a business interoperability index for each dyad also for the whole network.

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# Appendices

## Appendix A – Case study protocol

**Protocolo de Estudo de Caso**

Este protocolo tem como objectivo definir os procedimentos para a realização do estudo de caso na rede Valorpneu. Assim, define-se a seguinte ordem:

### 1. Apresentação do investigador e do entrevistado

O estudo de caso será conduzido pelo investigador Izunildo Cabral, no âmbito da sua tese de doutoramento em Engenharia Industrial, especialidade de Gestão de Operações em Redes Industriais, da Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa.

### 2. Descrição do projecto de investigação e dos objectivos do estudo

Este trabalho de investigação está a ser desenvolvido na Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, através da Unidade de Investigação e Desenvolvimento em Engenharia Mecânica e Industrial (UNIDEMI), no âmbito de um projecto de investigação intitulado 'Business Interoperability for Collaborative Platforms with Axiomatic Design Theory for Lean, Agile, Resilient and Green Industrial Ecosystems', PTDC/EME-GIN/115617/2009, financiado pela Fundação para a Ciência e a Tecnologia. O projecto tem uma duração de três anos e uma equipa de investigação de 5 elementos.

O objectivo da investigação é desenvolver uma metodologia que permita estudar a forma como as empresas de uma rede industrial implementam práticas de cooperação (logística inversa, desenvolvimento de novos produtos, etc.), através da utilização de plataformas digitais de negócio capazes de garantir interoperabilidade entre as empresas da rede. Interoperabilidade pode ser definida como a capacidade dos sistemas das empresas em trabalhar em conjunto de uma forma efetiva. A metodologia contempla um modelo de simulação baseado em agentes para analisar o impacto da interoperabilidade na performance das empresas e um modelo baseado na teoria axiomática do projecto para desenhar configurações de plataformas de negócio interoperáveis.

## 3. Descrição dos dados pretendidos

Os dados pretendidos para a validação da metodologia descrita anteriormente dizem respeito à: caracterização da rede de empresas (Valorpneu – Sede, distribuidor retentor, pontos de recolha, recauchutador, reciclador, valorizador energético, parceiros externos e operadores logísticos); descrição geral da forma como as empresas operam em ambientes de redes industrias de cooperação; caracterização da forma como as empresas implementam as práticas de cooperação; caracterização dos potenciais problemas de interoperabilidade entre as empresas, na implementação das práticas de cooperação; caracterização dos potenciais impactos em termos de custo, tempo, nível de serviço, e impacto ambiental devido aos problemas de interoperabilidade; e caracterização das potenciais soluções que permitam minimizar os problemas e os impactos.

## 4. Definição do acordo de confidencialidade

Os dados recolhidos durante a realização do estudo de caso serão estritamente mantidos confidenciais por parte da equipa de investigação e apenas serão utilizados para a validação da metodologia desenvolvida no âmbito deste projecto de investigação. No entanto, os resultados e os dados associados ao estudo poderão ser publicados na tese de doutoramento do investigador Izunildo Cabral, em revistas científicas, e conferências, de acordo com o acordo com o consentimento dos entrevistados.

## 5. Procedimento para a recolha e análise de dados

- A recolha de dados será realizada através de entrevistas, consulta de documentos e arquivos;
- As entrevistas serão gravadas, caso haja permissão dos entrevistados;
- Em caso de não ser possível a gravação das entrevistas, serão tomadas notas;
- O investigador compromete-se a não influenciar as respostas dos entrevistados, abstendo-se de emitir opiniões ou indicar os documentos a analisar;
- O investigador pode formular novas perguntas à medida que vão surgindo novas evidências;
- Os entrevistados têm o direito de não responderem às questões que considerarem não pertinentes ou que por motivos confidenciais não podem ser respondidos;
- As gravações/notas serão transcritas e sintetizadas pelo investigador. As sínteses serão posteriormente enviadas para os entrevistados para aprovação;
- As entrevistas serão planeadas de acordo com a disponibilidade dos entrevistados e terão uma duração máxima de uma hora.

## 6. Questionário

As questões serão colocadas de acordo com a seguinte ordem:

1. Informações gerais sobre os entrevistados e as empresas;
2. Avaliação do nível interoperabilidade atual e necessário;
3. Caracterização dos potenciais problemas de interoperabilidade na implementação das práticas de cooperação;
4. Caracterização dos potenciais impactos devido aos problemas de interoperabilidade;
5. Caracterização das potenciais soluções de interoperabilidade para minimizar os problemas e os respectivos impactos.

Muito obrigado pela sua colaboração, a sua contribuição é um ingrediente muito importante para o desenvolvimento de novos conhecimentos em interoperabilidade de negócio!

Lisboa, Data O entrevistado O entrevistador

## Appendix B – A fragment of the interview guide

**Questionário**

*Recebeu um convite especial para participar num estudo de caso desenhado para analisar a capacidade das empresas da rede Valorpneu de trabalhar em conjunto e o impacto dessa capacidade na performance dessas empresas!*

### 1. Introdução

**a. Enquadramento e objectivo:** Pretende-se com este questionário recolher evidências empíricas para a validação de um trabalho de investigação sobre a forma como as redes industriais implementam práticas de cooperação (e.g. logística inversa) através de plataformas de negócio baseadas em tecnologias de informação. O objectivo é desenvolver uma metodologia que permite analisar o impacto dos problemas de interação na performance das empresas e desenhar configurações de plataformas de negócio que sejam capazes de garantir às empresas uma melhor capacidade de trabalhar em conjunto.

**b. Confidencialidade:** A sua resposta a este questionário é muito importante para o desenvolvimento de novos conhecimentos sobre a forma como as empresas operam em redes industrias de cooperação. Neste sentido, agradecíamos a sua cooperação para o seu preenchimento. As suas respostas serão mantidas estritamente confidenciais.

**c. Obrigado** por participar neste projeto de investigação.

***Esta entrevista terá uma duração aproximada 45 minutos.***

### 2. Contexto do projeto

**a. Descrição do problema:** As redes industriais estão cada vez mais complexas, envolvendo relações não lineares entre empresas. Problemas de interação entre duas ou mais empresas de uma rede podem ter impactos unilaterais, bilaterais ou multilaterais a nível de custo, tempo, nível de serviço, impacto ambiental, etc. Assim, é essencial que essas empresas tenham um conhecimento claro das suas capacidades de trabalhar em conjunto com os parceiros de negócio de forma a implementarem de forma proactiva os mecanismos de interação que atuam como facilitadores para um melhor desempenho e maior vantagem competitiva.

**b. A solução:** Baseado em uma investigação multidisciplinar em estratégia de negócio, relações externas, processos colaborativos, semântica de negócio, recursos humanos, sistemas de informação, gestão do conhecimento e complexidade das redes de negócio, o conceito de ‘capacidade de trabalhar em conjunto' surgiu como uma propriedade crítica de sistemas complexos e dinâmicos, como as redes industriais.

**c. A metodologia**: A nossa metodologia contempla dois modelos. Um modelo de simulação baseado em agentes para a análise do impacto e um modelo baseado na teoria axiomática do projeto para o desenho de configurações de plataformas de negócio. Consideramos que a combinação desses dois modelos permitirá às empresas efetuar uma avaliação contínua do impacto dos problemas de interação e identificar pontos onde melhorias podem ser alcançadas.

***Your contribution today is a first step on the journey toward enhanced business interoperability!***

**Parte 1 – Caracterização da Empresa**

**Em primeiro lugar**, solicitamos que caracterize a sua empresa e o respondente deste questionário. Para cada um dos seguintes pontos, indique, caso seja possível, a informação solicitada.

1.0 Nome da empresa:
1.1 País:
1.2 Sector de atividade:
1.3 Número de empregados:
1.4 Serviço principal prestado pela empresa:
1.5 Volume de negócio:
1.6 Cargo da pessoa que preenche o questionário:
1.7 Experiência da pessoa que preenche o questionário:
1.8 Nome da pessoa que preenche o questionário (facultativo):
1.9 Contacto (e-mail) da pessoa que preenche o questionário (facultativo):
1.10 Como posiciona a sua empresa na rede Valorpneu? (assinale a sua resposta com um X)

| Valorpneu (Sede) | Produtor | Distribuidor | Ponto de Recolha | Recauchutador | Reciclador | Valorizador Energético | Transportador |
|---|---|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

1.11 Com quais das seguintes empresas da rede Valorpneu mantém uma relação de negócio (fluxo de material, de informação ou monetário)? (assinale a sua resposta com um X)

| Tipo de empresa | Tipo de Fluxo | | |
|---|---|---|---|
| | Material | Informação | Monetário |
| **Valorpneu (Sede)** | ☐ | ☐ | ☐ |
| **Produtores** | ☐ | ☐ | ☐ |
| **Distribuidores** | ☐ | ☐ | ☐ |
| **Pontos de Recolha** | ☐ | ☐ | ☐ |
| **Transportadores** | ☐ | ☐ | ☐ |
| **Recauchutadores** | ☐ | ☐ | ☐ |
| **Recicladores** | ☐ | ☐ | ☐ |
| **Valorizadores Energético** | ☐ | ☐ | ☐ |

## Parte 2 – Descrição da forma como os objectivos de cooperação são definidos e potenciais impactos

**Em segundo lugar**, será solicitado para descrever como os objectivos de cooperação da rede Valorpneu estão definidos e como deveriam estar, tendo em conta a clareza e o alinhamento.

Começamos com uma breve definição para cada fator que caracteriza os objectivos da cooperação, seguido de algumas perguntas relacionadas com os potenciais problemas e impactos.

**Clareza dos objectivos de cooperação (COC)** – considera se os objectivos de cooperação são claros, bem definidos e fáceis de compreender.

**COC1** Em que medida os objectivos de cooperação da rede Valorpneu são claros, bem definidos e fáceis de compreender? Qual deverá ser a melhor opção para as necessidades atuais da sua empresa? (assinale com um X a opção que melhor descreve a sua percepção)

| | | Resposta | |
|---|---|---|---|
| **Descrição** | **Nível** | **Atual** | **Necessário** |
| Os objectivos de cooperação da rede não são definidos e não existe interesse em defini-los. | 0 - Isolado | ☐ | ☐ |
| Os parceiros reconhecem a importância da definição dos objectivos da cooperação mas os objectivos estão por definir. | 1 - Inicial | ☐ | ☐ |
| Existem objectivos genéricos de cooperação mas metas e prazos específicos não estão definidos nem documentados. | 2 - Funcional | ☐ | ☐ |
| Os objectivos de cooperação da rede são claros, bem definidos e documentados; no entanto os prazos para alcançá-los não são (bem) definidos. | 3 - Conectável | ☐ | ☐ |
| Os objectivos de cooperação da rede e os prazos para alcançá-los são claros, bem definidos e bem documentados. | 4 - Interoperável | ☐ | ☐ |

**COC1.1** Existe algum problema entre a sua empresa e os parceiros da rede Valorpneu, em relação à clareza na definição dos objectivos de cooperação? Por exemplo, existem dificuldades em compreender os objectivos definidos?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

**COC1.2** Caso tenha respondido 'Sim' à pergunta anterior, qual é o impacto desse(s) problema(s) para a Valorpneu? Os parceiros da rede Valorpneu são afectados? De que forma? (caso tenha respondido 'Não', passe para a pergunta seguinte)

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**COC1.3** Ter os objectivos de cooperação claros e bem definidos, traz algum benefício para a sua empresa? Os parceiros da Valorpneu também são beneficiados? De que forma? Por exemplo, permite prevenir os conflitos entre os parceiros da rede? Permite motivar os parceiros da rede? (caso tenha respondido 'Não', escreva 'Não Aplicável' e passe para à pergunta seguinte)

______________________________________________________________________________
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______________________________________________________________________________

**Alinhamento dos objectivos de cooperação e interesses individuais (AOCII)** – considera se os objetivos de cooperação da rede satisfazem ou estão alinhados com os interesses individuais dos parceiros da rede.

**AOCII1** Em que medida os objectivos de cooperação da Valorpneu estão alinhados com os interesses individuais da sua empresa? Qual deverá ser a melhor opção para as necessidades atuais da sua empresa? (assinale com um X a opção que melhor descreve a sua percepção)

| | | **Resposta** | |
|---|---|---|---|
| **Descrição** | **Nível** | **Atual** | **Necessário** |
| Os objectivos de cooperação da rede são diferentes dos interesses individuais dos parceiros da rede e não existe nenhum interesse em alinhá-los. | 0 - Isolado | ☐ | ☐ |
| Os objectivos de cooperação são diferentes dos interesses individuais dos parceiros da rede mas o alinhamento está planeado. | 1 - Inicial | ☐ | ☐ |
| Os objectivos de cooperação são definidos em conformidade com os interesses individuais dos parceiros mas por imposição de um parceiro dominante. | 2 - Funcional | ☐ | ☐ |
| Os objectivos de cooperação são definidos, de forma livre, em conformidade com os interesses individuais dos parceiros; no entanto, existem ainda objectivos e interesses a serem alinhados. | 3 - Conectável | ☐ | ☐ |
| Os objectivos de cooperação são os mesmos que os interesses individuais dos parceiros; são definidos por consenso e refletem acordos multilaterais. | 4 - Interoperável | ☐ | ☐ |

**AOCII1.1** Existe algum problema entre a sua empresa e os parceiros da rede Valorpneu, relacionado com o alinhamento dos objectivos da rede de cooperação aos interesses individuais dos parceiros da rede? Por exemplo, existem conflitos de interesse entre a sua empresa e os parceiros da rede?

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

**AOCII1.2** Caso tenha respondido 'Sim' à pergunta anterior, qual é o impacto desse(s) problema(s) para a sua empresa? Os parceiros da rede Valorpneu são afectados? De que forma? (caso tenha respondido 'Não', passe para a pergunta seguinte)

______________________________________________________________________________
______________________________________________________________________________
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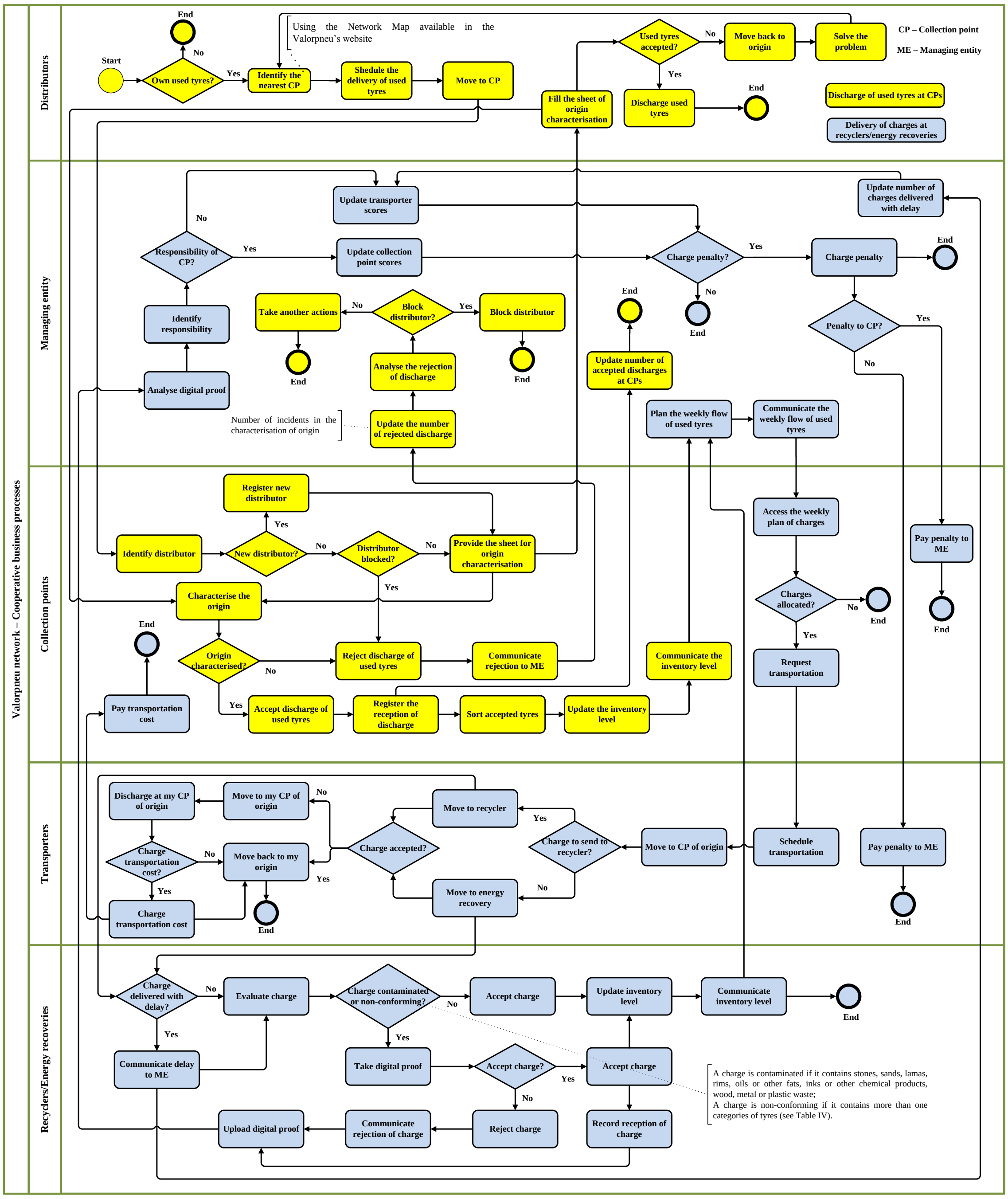
**AOCII1.3** O alinhamento dos objectivos de cooperação da rede aos interesses individuais dos parceiros traz algum benefício para a sua empresa? Os parceiros da Valorpneu também são beneficiados? De que forma? Por exemplo, permite evitar conflitos de interesse entre os parceiros da rede? (caso tenha respondido 'Não', escreva 'Não Aplicável')

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

**Fim! (Muito) Obrigado pela sua cooperação.**

**Data: ___/___/_____**

# Appendix C – Valorpneu Network Business Process Diagram



# Appendix D – Dam Baixo Sabor Network Business Process Diagram (Future Business Scenario)