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Horizontal Collaboration for Sustainable Transport and Logistics

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Foreword

This document presents only the scientific part of the Habilitation thesis of Dr. Shenle Pan, that is defended on 1st December 2017, at Université de Valenciennes et du Hainaut-Cambrésis.

The Habilitation thesis (also called post-doc thesis) has two purposes. The first is to obtain the degree of *Habilitation à Diriger des Recherches* (HDR) in France, which is a degree of accreditation to supervise research. Knowing that it is required for supervising doctoral research (PhD students) and applying for professorship in France. Second, the thesis tends to investigate the research area to which I have been devoted for ten years, i.e. horizontal collaboration in transport and logistics. For that purpose, the thesis will review the recent research works and the state of the art of the research area. Then, my scientific contributions as well as my research program for the next research lines will be discussed under a such context, in order to demonstrate my capacity of supervising and leading doctoral research.

The Habilitation thesis comprises two parts, the first part concerned with my Curriculum Vitae, and the second part devoted to the scientific content of the thesis. With regard to the second part, which is presented in this document, it focuses on recent advances of research on the horizontal collaboration in logistics for sustainable transport and logistics operations. It investigates also scenarios of the future logistics system.

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To my family

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GENERAL INTRODUCTION

This Habilitation thesis aims to investigate the research area of horizontal collaboration in transport and logistics. It will focus on the state of the art, and the trends and future research lines of the research area. Moreover, we will also discuss my research contributions to the area since 2007, and my short-term and long-term research program related to the area.

This Habilitation thesis consisting of 5 chapters is organised as follows:

- Chapter 1 will introduce fundamentals, objectives and challenges, and organisations of logistics. More precisely, the objective of this chapter is threefold: first, to give a consensus definition of logistics and demonstrate its importance, especially with regard to sustainability; second, to summarise and analyse the past, undergoing and emerging evolutions in logistics organisations, then to specify the scope of analysis in this thesis; third, to briefly introduce the scientific issues under the scope that will be discussed in the rest of the part.
- Chapter 2 focuses on the organisation of horizontal collaborative and interconnected logistics (see Type 3 in Figure 6, Chapter 1). An exhaustive survey of all horizontal collaborative transport solutions in the literature, as well as the relevant scientific issues, will be presented. The objective of this chapter is to identify, analyse and position the major international and national contributors to this topic.
- Chapter 3 introduces the research contribution of my own research works since 2007, and the doctoral theses that I have been co-supervising since 2010. The contribution will be discussed solution by solution and issue by issue under the research framework proposed in Chapter 2, in order to position my contributions onto the international and national research community.
- Chapter 4 focusing on the organisation of open, intelligent, decentralised logistics (see Type 4 in Figure 6, Chapter 1). It deals with research prospects for short terms and for long term. First, we will give a theoretical framework of such logistics system, in order to outline its profile. The essential functionalities and requirements, as well as relevant scientific issues will also be discussed. Then, we will give some research lines toward such system, coupling with some research topics (ex supervising or developing Ph.D. theses). The objective of this chapter is to draw a framework for my next research topics.
- Chapter 5 will give a general conclusion.

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LIST OF ABBREVIATIONS

1PL	– First-Party Logistics, see also 2PL, 3PL, etc.
AR/VR	– Augmented Reality/Virtual Reality
B2C	– Business-to-Customer, see also B2B, B2B2C
CLCP	– Collaborative Lane Covering Problem
CPFR	– Collaborative Planning Forecasting and Replenishment
CRC	– Collaborative Routing Centre
CVRP	– Collaborative Vehicle Routing Problem, see also VRP
DC	– Distribution Centre
ECR	– Efficient Consumer Response
EDI	– Electronic Data Interchange
FCE	– Flow-Controlling Entity
FMCG	– Fast Moving Consumer Goods
FTL/LTL	– Full-Truckload/Less-than-Truckload, and TL equal to FTL
HC/VC	– Horizontal Collaboration/Vertical Collaboration
HCT	– Horizontal Collaborative Transport
HDV	– Heavy Duty Vehicle
HMAS	– Holonic Multi-agent System, see also MAS
ICT	– Information and Communications Technology
IoT	– Internet of Things
IT	– Information Technology
JRP	– Joint Route Planning
KPI	– Key Performance Indicator
LLC	– Limited Liability Company
LSP	– Logistics Service Providers
MILP	– Mixed Integer Linear Programming
OTC	– Open Tracing Container
PI	– Physical Internet
PoS	– Point of Sale
RFID	– Radio-Frequency Identification
RTI	– Returnable Transport Item
SC	– Supply Chain
SCM	– Supply Chain Management
SME	– Small-Medium Enterprise
SoLS	– Self-organising Logistics System
SV	– Shapley Value
TSP	– Transport Service Procurement
UCC	– Urban Consolidation Centre
VMI	– Vendor Managed Inventory
WDP	– Winner Determination Problem
WH	– Warehouse
WMS	– Warehouse Management System

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CHAPTER 1

Logistics: Sustainability and Evolution

1.1 Chapter Introduction

This introductory chapter comprises 5 sections. Section 2 presents some fundamentals of logistics and establishes some consensus definitions which will be used throughout the thesis. Section 3 discusses the importance of logistics, especially with regard to sustainability. Section 4 broadly introduces the main challenges and objectives in logistics today, and consequently past, current, and emerging logistics organisations. Finally, Section 5 indicates the scope and limitation of this thesis.

1.2 Fundamentals of Logistics

A variety of definitions exist so it is necessary to provide a widely recognised concept of logistics. Some basic aspects such as definition, activities, and scope are discussed and these concepts will be adopted throughout the rest of this thesis.

1.2.1 General definition and activities

Logistics is a broad discipline in Management Science that consists of many activities. In order to clearly define the scope of this document, it is necessary to define logistics and the activities involved.

A number of definitions can be found in the literature, see Lambert and Cooper (2000), Chopra and Meindl (2004), Christopher (2005), Harrison and van Hoek (2005) and Ballou (2007) for example. In this thesis, we have selected and use the most up-to-date, common definition. Generally speaking, logistics has been considered as a part of Supply Chain Management (SCM) and can be defined as *the management of goods including planning, implementing, and controlling the forward and reverse flows from the production point to the final consumption points to satisfy end-consumer demand*. This definition is adapted from that given by the Council of Supply Chain Management Professionals (CSCMP, 2017).

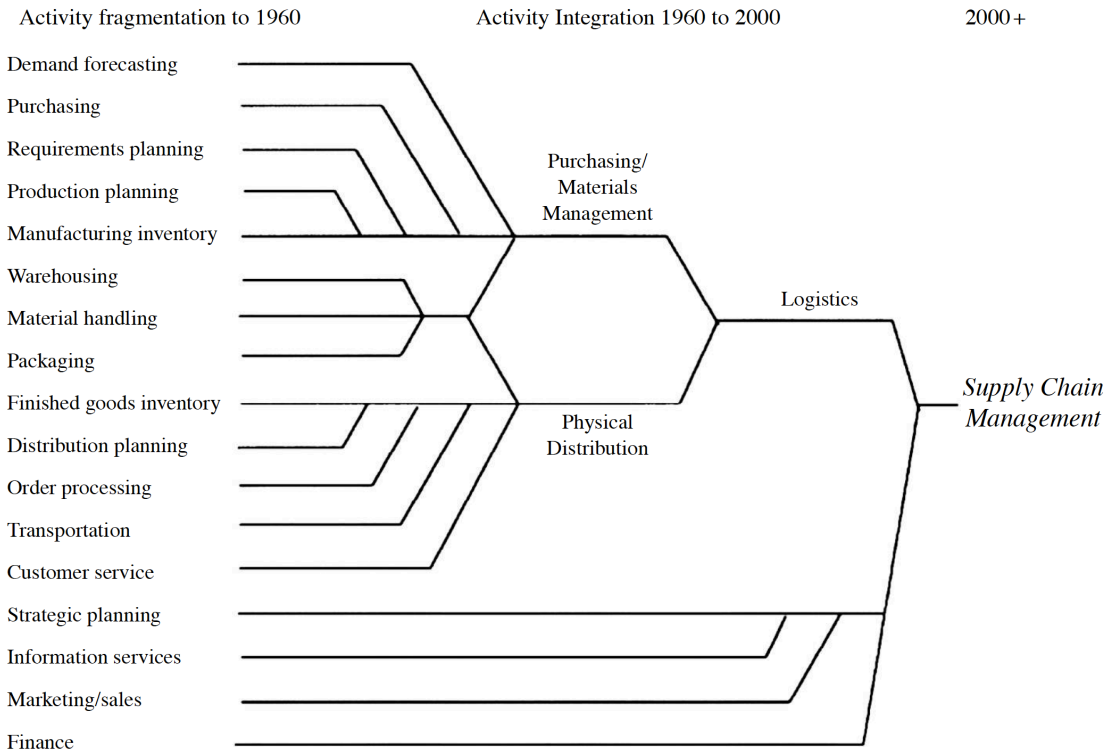


Figure 1. Activities associated with logistics and supply chain management (Ballou, 2007)

More specifically, logistics involves a number of activities from the manufacture (at plant level) to the distribution of goods (at chain or network level). The example presented in Figure 1 adapted from Ballou (2007) defines the scope of logistics and its activities. Generally speaking, logistics focuses on the management of physical and information flows, without compounding IT services, marketing or finance which are usually considered at supply chain management level. Hereinafter, we will use this definition of logistics.

1.2.2 Scope: from individual activity to networks

The meaning and scope of "logistics" has evolved over the past few decades (Jahre and Fabbe-Costes, 2005). Initially, logistics represented the management of *separate activities* such as storage and transport to move physical goods. Then, some began to reorganise and integrate the separate activities to achieve better, more global optimisation. Building on these ideas, companies then introduced *flow* into logistics and organised the related activities as a whole. On a production site, for example, inbound flows involved moving materials from the supplier's site to the production site, internal flows concerned on-site production logistics, and outbound flows concerned distribution from the site to customers. Subsequently, companies working together extended logistics to the *supply chain* with the aim of strengthening coordination and inter-management between companies to ensure global, mutual optimisation. The vision of logistics was thus extended from a single company to a chain of companies. Information flow management plays a vital role in coordinating and managing physical flows in such multi-company organisations, which is why information and physical flows are usually considered together in logistics. Accordingly, the power of "logistics" has been recognised step-by-step, from operational to strategic level.

In this thesis, we consider the most recent vision taking into account multiple chains, namely a *logistics network*. Since 2000, the term *supply network* has been used to define supply chain management in a multiple supply chain and multi-party network (Choi et al., 2001; Harland,

1996; Harland et al., 2001; Jahre and Fabbe-Costes, 2005). The objective is to organise the activities within the network (logistics and supply chain management, as shown in Figure 1) and optimise them as a whole by crossing supply chain borders. The notion of supply network has recently been extended from a set of supply chains to a set of networks, i.e. a network of networks. For example, the concept of *logistics web* (or *supply web*) was introduced by Hakimi (2014) and is defined as "a network of interrelated supply networks, each embedding interlaced supply chains involving multiple organisations with collaborative or competitive supply relationships". Montreuil (2011) and Ballot et al. (2014) propose a similar idea with the concept of the Physical Internet (PI), which is defined as a network of independent networks. The idea is, as a metaphor of the digital internet, to create an open, shared network to interconnect independent logistics networks and services. All resources within the network (distribution centres, assets, information systems, etc.) are standardised and interconnected to provide high interoperability between companies for the optimal use and sharing of a common network – the PI.

In the literature, the difference between *supply network* and *logistics network* is similar to that between supply chain management and logistics, as illustrated in Figure 1. However, the difference is inadequately discussed in the literature, especially due to the lack of definition for logistics network. Knowing that in this thesis we will focus on logistics and then logistics networks, a broad, consensus definition is necessary. We use the term "logistics network" to broadly cover all network-based organisations of logistics activities. Based on the studies discussed above, the following definition is proposed and used in this thesis: *a logistics network consists of a number of companies (manufacturers, forwarders, distributors, service providers, etc.), their physical sites (warehouses, distribution centres, hubs, etc.), physical assets (goods, transport means, pallets, etc.), and working agreements (contracts, charters, rules, etc.), of which the aim is to optimise and mutualise the organisation and management of logistics activities involving physical and information flows within the network as a whole to achieve synergy*. On the basis of this definition, we focus on the management of physical and information flows within a network, without considering other aspects such as finance or marketing.

1.2.3 The objectives of logistics

Logistics should be able to deal with increasing demands for goods while satisfying challenging logistical constraints such as demand uncertainty, lead time, and resource availability. Consequently, logistics organisations are nowadays expected to be efficient, effective, and responsive while respecting other objectives such as sustainability and resilience. Table 1 summarizes the main objectives observed in the literature.

Objectives	Short Description
Effectiveness	How well a goal is adequately met (Mentzer and Konrad, 1991)
Efficiency	How well the resources expended are utilised to meet a goal (Mentzer and Konrad, 1991)
Agility	Ability of a system to rapidly reconfigure (Bernardes and Hanna, 2009)
Flexibility	Ability of a system to change status within an existing configuration (Bernardes and Hanna, 2009)
Resilience	Ability of a system to return to its original state or move to a new, more desirable state after being disturbed (Bhamra et al., 2011)
Sustainability	Ability of a system to protect, sustain and enhance the human and natural resources that will be needed in the future while meeting a desired goal (Labuschagne et al., 2005)

Table 1. Description of the main objectives of logistics today

The five objectives shown in Table 1 can also be considered as criteria to assess the performance of a logistics system. For example, a logistics system may be effective (e.g., all customers are very satisfied) but inefficient (e.g., cost to satisfy customers is too high). Simultaneously meeting all objectives, i.e. good performance on all criteria, is an obvious challenge in logistics today.

Both my research and this thesis focus on sustainability. However, it is worth recalling the objectives in order to further expose the fact that to simultaneously respect sustainability and other criteria is a fundamental challenge for today's logistics systems. We are, therefore, looking for new, innovative organisations to provide solutions. The next part will further explain why it is worth studying sustainability in logistics.

1.3 Sustainability in Logistics

It has been recognised for many years that logistics plays a significant role in economic growth and social development. After 2000 in particular, the environmental impact due to logistics activities such as CO_2 emissions, land use, truck noise, and traffic congestion, also became a major concern. Accordingly, sustainable development has gained much attention from both researchers and practitioners in logistics. In this part, we discuss the significance of logistics according to three aspects: economic impact, environmental impact, and social impact - the three pillars of sustainable development (European Commission, 2001) - in order to illustrate the motivations behind and the importance of the research.

1.3.1 Logistics and economy

The economic importance of logistics can be justified by its cost as a percentage of GDP (Gross domestic product). According to Figure 2, logistics costs in 2013 (mainly transport and inventory) represented approximately 13% of the GDP in Europe and 17% in Asia. Moreover, growth in GPD is correlated with growth in logistics activities, especially freight transport. For several decades, freight transport has seen rapid, sustained growth generally coupled with growth in GDP, as shown in Figure 3. Despite having observed the decoupling of road freight transport and economic growth in some countries, as in the UK over the past decade (McKinnon, 2007), we can assume that freight transport and logistics will remain an important part of the European economy.

As stated in a report issued by the French government (Savy, 2015), logistics costs contributed an estimated 10% to the national GDP, which represents over €200 billion. In terms of volume, inland freight transport in France (excluding pipeline) was an estimated 328 Million tkm (tonne-kilometres) in 2013, of which road transport accounted for almost 88%.

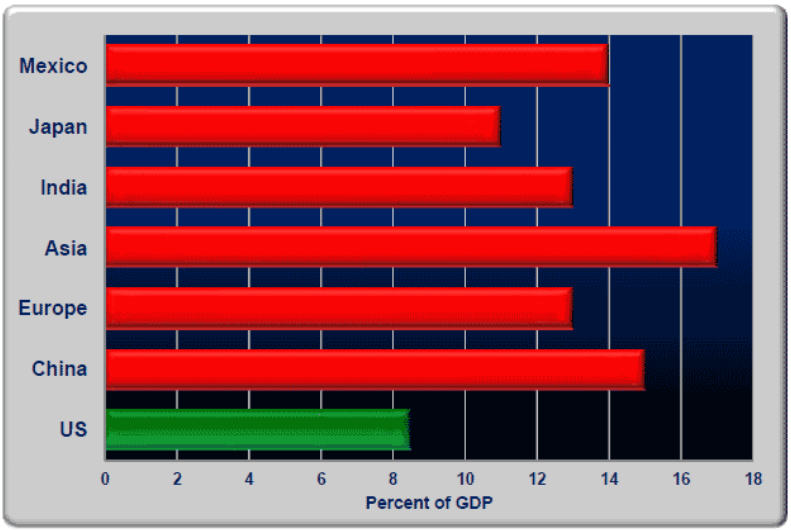


Figure 2. Logistics costs as a percentage of GPD (source: http://www.scdigest.com[1], figure adapted from 2013 CSCMP 'State of Logistics' Report)

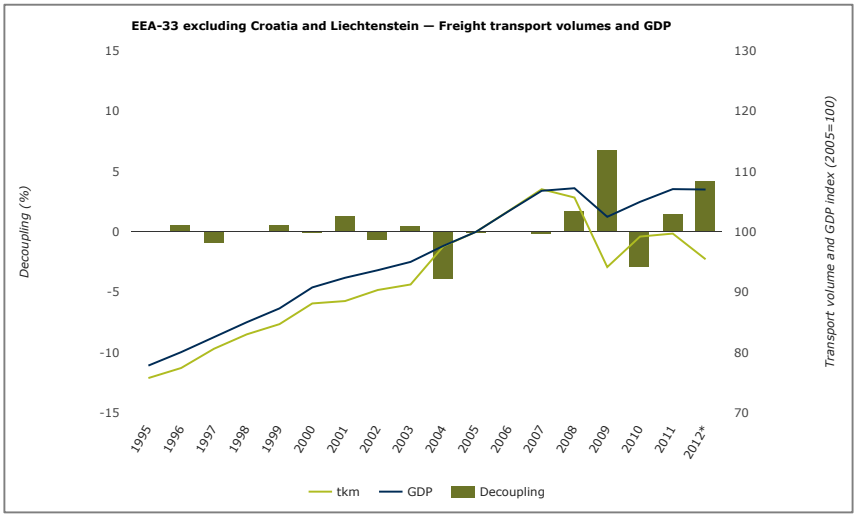


Figure 3. Growth of GDP and freight transport in billion tkm (from European Environment Agency: positive values in the columns indicate higher growth in GDP, while negative values indicate higher growth in freight transport; the data refer to road, rail, and inland waterway transport).

These data show that logistics and freight transport are an important sector for the economy and its growth. ALICE (ALICE, 2016), the European Technology Platform on Logistics, estimated that "*a 10% to 30% improvement in efficiency in the EU logistics sector would potentially equal a €100-300 billion cost relief for the European industry*". In other words, EU logistics is a huge market with significant potential savings.

Logistics also plays an essential role in the economic performance of businesses. Take the e-commerce giant Amazon, for example. Over the past few years, the company has been increasingly recognized as a leading innovator in logistics worldwide. However, one of the pressures came from financial losses on outbound shipping logistics, see Figure 4. From this figure, we can clearly see that Amazon was losing more and more money on outbound logistics, losing $5 billion on shipping costs in 2015. However, thanks to the efforts on innovation, the increase in losses was reduced. The same results can also be observed in other

[1] http://www.scdigest.com/assets/newsviews/13-06-20-2.php?cid=7168

companies and sectors such as manufacturing, traditional retailing, and logistics service providers.

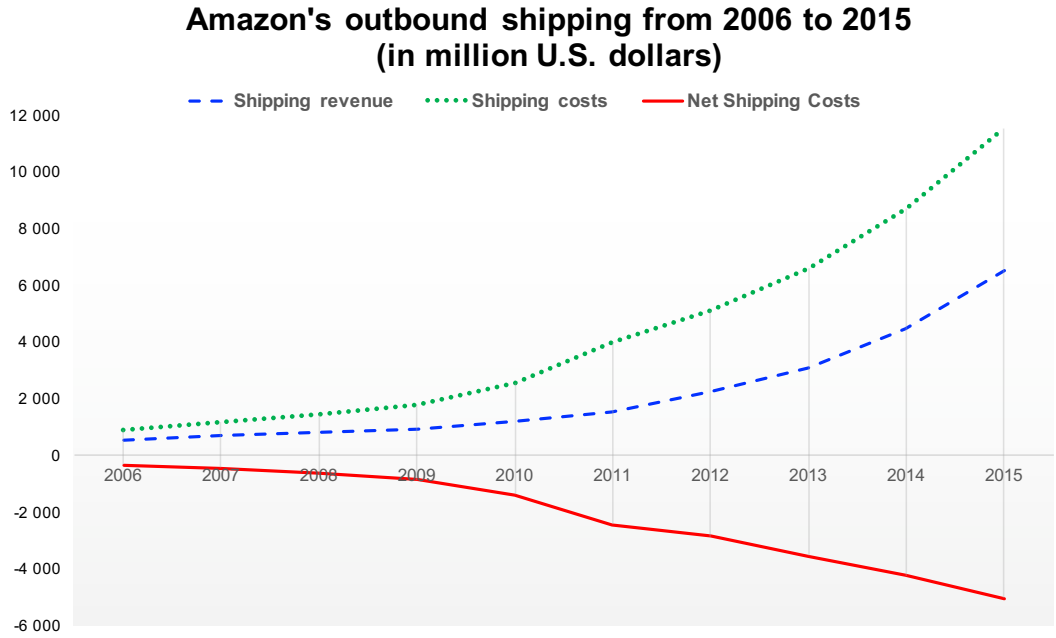


Figure 4. Amazon's shipping revenue and costs 2006-2015 (source Statista.com)

Hence, logistics is of interest to both society and companies in terms of the economy.

1.3.2 Logistics and the environment

One of the major environmental issues of freight transport is greenhouse gas emissions, especially CO_2 (Nouira et al., 2016). In many countries, the freight transport sector is an important contributor to CO_2 emissions. For example, road freight traffic accounts for approximately 6% of total domestic CO_2 emissions in the UK (Piecyk and McKinnon, 2010) and approximately 9% in France (ADEME, 2007). According to Savy (2015), in France in 2012, road freight transport alone produced approximately 33 Mt CO_2. More globally, the World Economic Forum and Accenture reported in 2009 that logistics activities, including freight transport and logistics buildings, accounted for approximately 5.5% of global greenhouse gas emissions (McKinnon et al., 2012). Despite the different time frames and scope, these figures show that the freight transport sector contributes significantly to CO_2 emissions and should, therefore, be aware of the need to reduce emissions.

Some well-known objectives have been established for reducing CO_2 emissions. For example, according to the low-carbon economy roadmap established by the European Commission[2], the EU must cut CO_2 emissions to 20% below 1990 levels by 2020, 40% by 2030, and 60% by 2040, to reach 80% by 2050. All sectors must contribute to these objectives, especially the transport sector, including freight transport. From Figure 5 we can see that since 1990, total emissions have only been increasing in the transport sector. The EU 2050 target in this sector is obviously more ambitious compared to the other sectors. For example, the EU roadmap (Figure 5) envisages reducing emissions from transport to more than 60% below 1990 levels by 2050. Therefore, radical improvements in efficiency in this sector, especially in freight transport, will be required to meet this target.

[2] http://ec.europa.eu/clima/policies/strategies/2050/index_en.htm

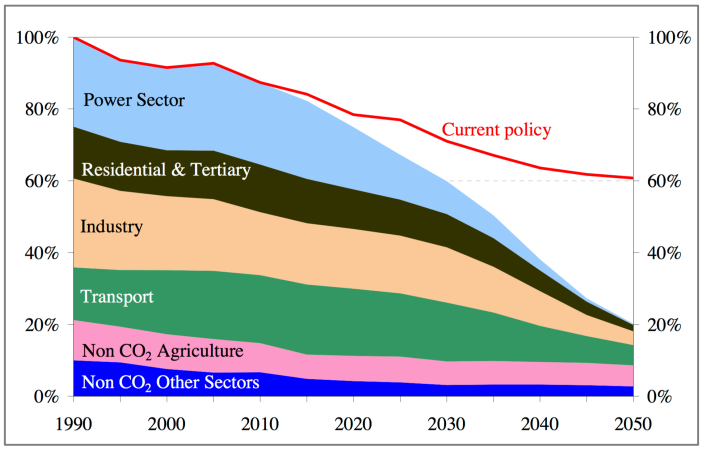


Figure 5. EU GHG emissions towards an 80% domestic reduction by 2050 (100% =1990) (source: http://ec.europa.eu/clima/policies/strategies/2050/index_en.htm)

In addition to emissions, other environmental issues such as energy consumption, noise, land use, and waste are also associated with freight transport and logistics (Goldsby et al., 2014; Korzhenevych et al., 2014; Taniguchi and Thompson, 2014). All these problems can generally be seen as the *negative externalities* of logistics. These externalities can be described as *external costs* that are the costs to society but are not taken into account by transport users unless there are policies dictating otherwise (Maibach et al., 2008). In addition, these external costs are often neglected as they are difficult to justify quantitatively. However, thanks to some econometric approaches, see the handbooks (Korzhenevych et al., 2014; Maibach et al., 2008) for example, the external costs of freight transport can be monetarily estimated, especially external environmental costs. The environmental impact of logistics on our daily lives is thus more concrete and intuitive. Hence, means of reducing all these negative externalities is becoming a major concern in modern logistics for both service providers and users.

1.3.3 Logistics and society

Logistics has both positive and negative impacts on society. Logistics has obviously improved our daily life. For example, effective and efficient logistics can help traditional retailers to reduce logistics costs so as to provide a wide diversity of goods at a low price for end consumers. Shopping is also becoming much easier thanks to recent multi-retailing channels, e.g., online stores, mobile stores, which also rely on strong logistics support. As a result, in China, for instance, the number of packages delivered across the country in 2016 was over 30 billion, which is 53% more than 2015 (National Bureau of Statistics of China). Logistics also contributes to the job market. According to the French government report by Savy (2015) and some statistic reports by INSEE[3], logistics, including transport and warehousing, created 1.3 million jobs in France in 2012, which is approximately 5.7% of all employees within the French economy (all jobs included). These examples show that we all have more or less benefited from the development of logistics.

However, logistics also has a negative impact on society, especially with regards to safety, working conditions, and traffic congestion. According to a report issued by the INRS in France[4], employees in the logistics sector are injured 2 to 3 times more often than employees in other sectors. According to a French government report issued by the SOeS (2013), 2 946

[3] http://www.insee.fr/fr/themes/tableau.asp?ref_id=natnon03146
[4] http://www.inrs.fr/metiers/transport-routier.html

heavy-duty truck accidents occurred in France in 2012 and 486 lives were lost. The same report also indicates that heavy-duty truck drivers in France work more than 45 hours per week on average and spend 65% to 75% of their time driving. Such indecent working conditions may eventually lead to a higher risk of traffic accidents and this must be improved. The contribution of freight transport to traffic congestion is another important concern for our daily lives, either for inter-city or intra-city traffic, as it may increase our waiting time, driving time, and operating costs. In terms of the economy, the handbook in Maibach et al. (2008) (updated by Korzhenevych et al. (2014)) proposes econometric approaches to estimate the external societal costs of traffic accidents and congestion, which may help us to understand the significance of freight transport and logistics from a social perspective.

Supported by the aforementioned figures, it is clear that logistics is of critical significance to society. Improving the efficiency of logistics within the context of sustainable development is a common goal for industrialists, consumers, and policy makers. The main potential for improving logistics efficiency can be found at organisational level rather than operational level. It is in this context that both researchers and practitioners have been looking for more efficient and effective logistics organisations and solutions for many years. The next section presents how logistics organisations have been becoming more sustainable.

1.4 The Evolution of Logistics Organisations

To understand better how logistics organisations have evolved over the past few decades, this section reviews the current logistics organisations. Four organisations are discussed in chronological order. For each type, we will discuss motivations, enablers, main stakeholders, and key features. Figure 6 illustrates the different organisations.

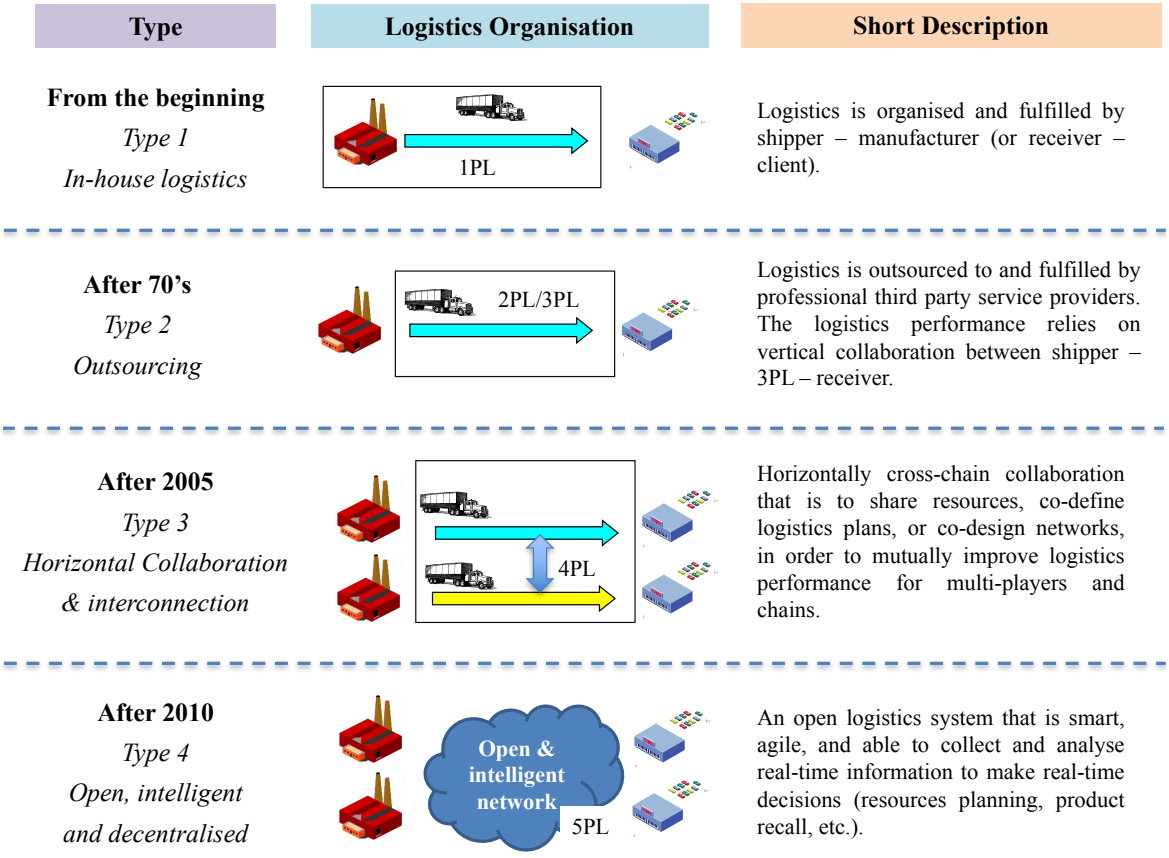


Figure 6. Evolutions of logistics organisations

Table 2 specifies the LSP terms (logistics service providers) used in Figure 6. Despite there being a variety of definitions for 1PL to 4PL in the literature, we have adopted the most widely accepted ones given in the thesis by Cruijssen (2006). However, there is no consensus definition for 5PL. The definition given in Hosie et al. (2012) is cited as it is similar to the idea in this thesis, but in this thesis we do not aim to discuss the concepts and definitions of LSPs in detail. Here, we only cite the definitions from the literature that will help us to clarify the ideas that will be presented in the next section.

LSP	Description
1PL	In a 1PL concept, logistics activities are not outsourced, but performed in-house by the shipper.
2PL	In the 2PL concept, a shipper outsources transport to a carrier company that is expected to perform a number of clear-cut tasks. The planning and organisation remain in the hands of the shipper.
3PL	A 3PL (third party logistics service provider) allows shippers to outsource a whole package of logistics services. This LSP takes the responsibility for the planning and organization and in that role communicates with both the shipper and the receiver(s) of the goods.
4PL	A 4PL concept represents a situation where even the management of logistics activities is outsourced. The 4PL focuses entirely on this management task and therefore generally does not own logistics assets. This concept becomes beneficial if the 4PL manages multiple supply chains amongst which synergies can be exploited.
5PL	A 5PL provider manages at the strategic level by a focus on providing innovative logistics solutions throughout the entire supply chain (or supply network). The major tasks of 5PL companies include mapping and reengineering the supply chain, the 4PL functions (integration and control of transport, handling, warehousing, etc.,) and providing integrated information systems to ensure real-time visibility and control of the entire supply chain. 5PL providers are almost fully virtual.

Table 2. Concept and categories of LSP (1PL to 4PL cited from Cruijssen (2006), and 5PL cited from Hosie et al. (2012))

Below, each type is discussed in succession. Figure 6, supported by Table 2, can be seen as a guiding tool for the discussion.

1.4.1 Type 1 – In-house logistics

Initially, logistics was planned, executed, and controlled by shippers using privately owned resources (including creating own logistics company). This so-called in-house logistics is also called 1PL (first-party logistics) since only one party - shipper is involved in this organisation.

As the primary objective of logistics is customer satisfaction through reliable services, i.e. quality, dependable services, early in-house logistics relied on direct shipment to customers, for example from the shipper's factory (or warehouse) to the customer's address. The main issue with this organisation is the significant increase in logistics costs when customer demands and numbers increase. Shippers are therefore incited to procure logistics services from external providers if they can provide good service at a low price in order to decrease logistics costs.

Nowadays, many companies have maintained their logistics in-house. Some well-known examples can be found in the automobile sector (Manners-Bell, 2014). One of the main reasons is to ensure the reliability of deliveries to customers. For some shippers, keeping logistics in-house may result in better customer service and lower costs than outsourcing[5,6]. In

[5] https://logisticsviewpoints.com/2010/01/13/reasons-why-companies-arent-outsourcing-to-3pls/
[6] http://cmuscm.blogspot.fr/2011/12/transportation-outsourcing-factors.html

reality, outsourcing logistics or not, i.e. *Make or Buy* strategy, is not always obvious, see Abdur Razzaque and Chang (1998), Cánez et al. (2000), Wilding and Juriado (2004) and Kremic et al. (2006). But this question is not within the scope of this thesis.

1.4.2 Type 2 – Outsourced logistics

Once companies (e.g., manufacturers) decide to procure logistics services from external companies who are usually professional logistics service providers, the logistics is outsourced to 3PLs (Third-party logistics providers) (Selviaridis and Spring, 2007). Sometimes the term 2PL is also used to differentiate the degree of outsourcing. Generally speaking, 2PLs can refer to carriers who execute the transport activity without planning or controlling the distribution (inventory control in particular), while 3PLs will ensure all the logistics activities including transport, warehousing, inventory control, distribution planning, etc. Both of them are asset-based companies so as to be able to execute the outsourced logistics activities. Hereinafter they are called 3PL.

At this stage, 3PLs struggled to reduce logistics costs to propose cost-efficient solutions to their clients (shippers) while maintaining effective logistics services. The pressure on logistics costs was thus partially shifted from the shipper (e.g. manufacturing industry) to the 3PL, especially for international 3PLs as a result of globalisation. To this end, 3PLs soon recognised that it was important to collaborate with shippers and receivers. However, shippers and receivers were also incited to collaborate with 3PLs as they would also benefit from lower prices or better services, for example. This is called **vertical collaboration** in a supply chain (Mason et al., 2007). ECR (Efficient Consumer Response) is a measure based on this initiative to optimise the supply chain: "*ECR seeks to optimize the (grocery) supply chain, minimizing inventory levels and optimizing product availability. By taking a holistic approach, time and cost can be stripped from the supply chain. It also addresses product quality*", defined in Wood (1993). ECR then became a joint trade and industry body in many countries and is particularly active in the FMCG (fast moving consumer goods) sector, see ECR France[7], for example. More specifically, companies in a vertical relationship (e.g., suppliers, manufacturers, LSP, retailers) aim to collaborate to build an integrated supply chain (Harrison and van Hoek, 2005; Jayaram and Tan, 2010; Stank and Goldsby, 2000). Well-known solutions developed for this purpose include VMI (vendor managed inventory) models (Marquès et al., 2010; Yao et al., 2007), collaborative transport planning (Stadtler, 2009), and CPFR (Collaborative Planning, Forecasting and Replenishment) (Holmström et al., 2002; Lehoux et al., 2011).

1.4.3 Type 3 – Horizontal collaborative and interconnected logistics

Since the 90's, radical changes have been made to traditional supply chains as a result of new manufacturing and retailing practices aimed at reducing inventory and improving efficiency throughout the entire chain (Dornier, 1997; Pan, 2010). Upstream, LEAN manufacturing practices such as Just-in-time and delayed differentiation were popularized in the manufacturing industry. While considerably reducing stocks in the chain (Tavasszy et al., 2012), these practices upstream (e.g., automotive suppliers) resulted in increasingly demanding logistical constraints – small and accurate shipment size with low delay tolerance. Downstream, retailers strived to reduce inventory levels (both at points of sale and at distribution centres (DC)) by accelerating the inventory turnover rate (Chopra and Meindl, 2004). In the meantime, points of sale (PoS) in cities had also been downsized in order to get closer to end consumers. As a result, shipments to DC and PoS were considerably downsized

[7] http://ecr-france.org

but with shorter delivery times and higher frequencies, see the reports from France (IFSTTAR, 2013) and the U.S. (Bureau of Transportation Statistics, 2006). All these changes resulted in fragmented and accelerated freight flows (Ballot and Fontane, 2010).

Faced with the fragmentation and acceleration of freight flows, better responsiveness and flexibility were necessary in logistics with regard to individual customers. A responsive, flexible logistics system should be able to quickly respond to consumer needs and quickly adjust its status in the current organisation to overcome a diversity of logistical constraints and difficulties, see Bernardes and Hanna (2009), Wilding et al. (2012) and Jafari (2015). In this context, traditional 3PL-based outsourcing was challenged by the fact that it was increasingly difficult to optimise transport for fragmented and accelerated freight flows, and thus inadequate performance could be observed. Considering that transport-related activities can represent more than 60% of total logistics costs (Goldsby et al., 2014), the inefficiencies observed are of critical significance: average truck fill-rates by weight were 60% to 70% and approximately 20% to 25% of trucks were running empty (Department For Transport, 2008; Léonardi and Baumgartner, 2004; McKinnon et al., 2003; PIPAME and CNAM, 2009). As a result, some manufacturing companies quit outsourcing and returned to in-house logistics[8]. Furthermore, logistics-related inefficiencies are also an issue with regard to sustainable development bearing in mind the sustainability challenges discussed in the previous section and the inefficiencies of logistics. Considering all this, we naturally ask the question whether traditional 3PL-based outsourcing is sustainable in the face of these new challenges.

It is in this context that research on logistics **horizontal collaboration** and interconnection of logistics networks began in 2000. Logistics horizontal collaboration describes cross-chain collaboration between two or more firms that operate at the same level of the supply chain to create logistics synergies (Cruijssen, 2006). Examples include lane or request exchange between carriers (Özener et al., 2011), joint route planning between shippers (Cruijssen et al., 2007a), and logistics pooling between SC (Pan et al., 2013). The Physical Internet, another concept of horizontal collaboration, has more recently been introduced and aims to interconnect and integrate logistics networks that are currently independently managed and controlled by different entities based on the modularisation and standardisation of processes and materials within a common network (Ballot et al., 2014). All these concepts and solutions will be discussed exhaustively in the next chapter.

This type of organisation exploits cross-chain or cross-network logistics synergies by sharing logistics resources (means of transport, warehouses, distribution channels, etc.). To this end, a new organisation is necessary, namely 4PL. A 4PL can be described as a non-asset-based company whose job is to manage logistics activities (and assets) for one or several companies, for example, manufacturers or retailers (Cruijssen, 2006). A 4PL or a group of 4PL can coordinate flows of different chains or networks so as to exploit logistics synergies. It can also be called a "trustee", with the additional duty of allocating gain to partners (see Vanovermeire and Sörensen (2014a), and the *Collaboration Concepts for CO-modality (CO^3)* project discussed in Rossi (2012)). A practical example includes the concept of cross-chain collaboration centre (4C). In reality, this is a control tower for managing, executing, and controlling cross-chain logistics activities proposed in Kok et al. (2015). Examples of businesses include *TRI-VIZOR* located in Belgium, claimed as the world's first cross-supply chain orchestrator (TRIVIZOR, 2016); or *CRC® Services* located in France, which is a pooled

[8] https://logisticsviewpoints.com/2010/01/13/reasons-why-companies-arent-outsourcing-to-3pls/

cross-docking platform managed by an independent 4PL for multi-manufacturers and multi-distributors in the FMCG sector (CRC, 2016).

1.4.4 Type 4 – Open, intelligent, decentralised logistics

After 2010, we can observe that customisation and personalisation has become the trend in production and in logistics. It leads to nowadays logistics that is characterised with high deliver frequency, short lead-time, low volume, and multi-distribution channel. Accordingly, new logistics organisation is appealing. New developments in logistics organisations began to emerge making logistics more open, collaborative, and interoperable. This evolution required the sharing of logistical resources and services between companies and decentralised decision-making based on (real-time) data. This type is called an open, intelligent, decentralised logistics system in this thesis. Two reasons have led to this evolution: recent challenges in logistics, i.e. drivers, and recent theoretical and technological developments, i.e. enablers.

Recent challenges in logistics have been **driven** by evolutions in manufacturing and retailing. *From a manufacturing viewpoint*, companies are focusing more and more on product innovation (e.g., developing new products and expanding product range) and customisation (products adapted to specific requirements for every customer), in order to rapidly create new markets or to increase their share in a volatile market. From a logistics standpoint, demands for such new products are very difficult to predict as each request may be different and products may require delayed differentiation. In this context, controlling inventory levels is very important but it is difficult to keep levels to a minimum. However, the time to construct such a supply chain and logistics system is short due to the short time-to-market. Competition is, therefore, fierce in terms of time and cost (Shah, 2009).

From a retail and distribution viewpoint, traditional retailers are striving to develop new channels to distribute products, particularly using internet-based solutions, i.e. e-business or e-commerce. This trend was even more striking with the popularisation of the smartphone in 2010. For example, during the so-called Single's day in China, on 11th November 2016, approximately RMB 120 billion (approximately USD 17 billion) was spent online in 24 hours. Mobile purchases (using smartphones, tablets, etc.) accounted for 82% of purchases, compared to 72% in 2015 and 43% in 2014[9]. This new business approach, called *omni-channel* retailing, uses a variety of channels providing the customer with a fully integrated shopping experience (Dholakia et al., 2005; Verhoef et al., 2015), see Figure 7. It has a significant impact on traditional distribution methods for both manufacturers and retailers. Most of them have to shift from B2B (business to business) to B2C (business to consumer) or to B2b2C (Business to small Business to Consumer), for example. From a logistics standpoint, the distribution chain is shorter so manufacturers or retailers are closer to end consumers. The delivery time - from online payment to delivery to the consumer - is crucial to the success of such a business approach. Same-day delivery, or delivery within a few hours, is becoming one of the most valuable services for e-shoppers. However, fast delivery means that e-retailers must accept cost and reliability constraints (the case of Amazon in Figure 4, for example). In addition, omni-channel retailing also tests the flexibility of the logistics system. Firstly, e-retailers have to cope with highly variable demands, especially due to seasonality and (online) promotions (e.g., cyber Monday, single's day). As current logistics systems often have a fixed warehouse and transport capacity, the variation in demand may

[9] http://www.thedrum.com/industryinsights/2016/11/14/review-alibaba-s-singles-day-2016

result in unused capacity or unmet demands[10]. Secondly, e-retailers are expanding delivery channels and methods to satisfy the consumer's shopping experience and/or to reduce delivery costs. Examples include home delivery, click & collect to stores, pick-up points, collection from depot/warehouse, etc., see Lowe and Rigby (2014). Assuming that purchasers can freely select one of these delivery options, logistics systems have to be more responsive and flexible, i.e. more agile logistics, to cope with unpredictable requests. Therefore, all these new challenges stemming from manufacturing or retailing are compelling logistics to be agile, cost-effective, reliable, and sustainable.

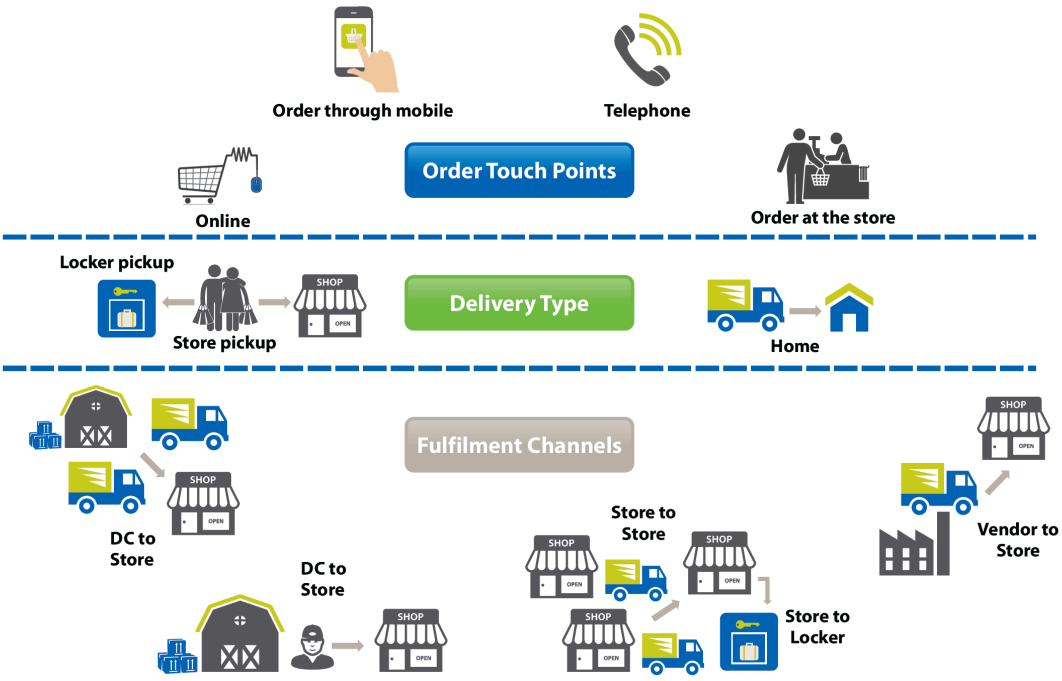


Figure 7. Omni-channel retailing and logistics[11]

Regarding **enablers**, recent theoretical and technological developments and innovations have been stimulating advances in logistics more than ever. Enablers can generally be divided into three categories: new theories, new technologies and new techniques. *New theories* provide new concepts and material to enable innovation in logistics. Examples include the sharing economy (e.g., warehouse sharing such as www.flexe.com), the circular economy (Genovese et al., 2017), crowd shipping (Chen et al., 2017; Mehmann et al., 2015), and horizontal collaboration (e.g., Type 3). Researchers and practitioners rely on these theories to develop new concepts for more efficient logistics systems. *New technologies*, including 3D printers, Internet of Things (IoT), ICT, cloud computing, robotics, drones, self-driving vehicles, virtual reality (VR), augmented reality (AR), etc., can effectively solve technological issues regarding new logistics organisations such as how to capture real-time information (at object level in particular), how to communicate information for decision-making, and how to rapidly execute decisions. *New techniques* are for optimisation and decision-making, e.g., big data analytics, artificial intelligence, complex optimisation methods, and real-time decision-making methods. These techniques could provide adequate support for decision-making involving more dynamic, complex, high-volume information in real-time.

[10] https://www.flexe.com/whitepaper/warehouse-capacity-economics-and-trends
[11] http://www.tcs.com/resources/white_papers/Pages/impact-omni-channel-logistics-retail.aspx

As an example, robotisation and automation is a current, rapidly evolving field and it has already been proved that robotisation and automation may help to improve efficiency and effectiveness in logistics. For example, the Roland Berger Study 2015[12] predicts that, for some positions in logistics, robots will soon be cheaper than human operators, which is also why many companies are now focusing on developing automated sorting systems (e.g., Intralox), or automated shipping devices (e.g., DHL Parcelcopter and SkyPort[13], self-driving vehicles[14]). Based on robotisation and automation, we can imagine that logistics planning and decision making could also be improved using other technological and technical enablers. For example, IoT and ICT technologies could collect and communicate real-time information, then data analytics and decision-making models would help real-time decision-making and planning, in contrast to traditional methods. It is conventionally known as *intelligent logistics* (Crainic et al., 2009; McFarlane et al., 2016).

Furthermore, the intervention and importance of 5PL for future evolutions should be specifically mentioned here. As defined in Table 2, the main task of 5PL is to provide technology- or technique-based innovative solutions to improve SC and logistics performance. Examples include data consulting service providers, IoT solutions providers, and organisations for standardisation of logistics data. Currently, 5PLs already play an import role in logistics. For example, IT, such as RFID for freight traceability, IT-based WMS (warehouse management system), and ICT or EDI for collaboration along or across supply chains, is often used to improve logistics efficiency. Considering an open, intelligent, decentralised logistics environment, 5PL is likely to become increasingly important.

From the aforementioned examples, we can see that recent theoretical and technological developments and innovations contribute to the evolution of logistics systems towards open, intelligent, decentralised systems, which can be briefly described as follows:

- *Open* means users (LSP, shippers, receivers) can join or leave the logistics network relatively easily. The system hinges on high interoperability between LSPs enabled by standardised materials and procedures thus enabling its capacity to be reduced or extended by simply plugging in or unplugging a service. More importantly, thanks to its openness, on-demand transport or storage services can mitigate problems relating to flexibility and agility in today's logistics.

- *Intelligent* means the logistics system is able to forecast subsequent requests for logistics services, then optimise and plan in advance the short-term logistics (McFarlane et al., 2016). This can be achieved using asset-based intelligence, e.g., intelligent containers (Sallez et al., 2016), or organiser-based intelligence, e.g., business intelligence. We assume that intelligence will probably rely on data-based technologies and techniques such as IoT, big data analytics, or machine learning.

- *Decentralised* means decisions in logistics systems are made or updated according to local real-time information instead of centralized advanced planning (Sternberg and Andersson, 2014). It is considered an effective solution to cope with the high dynamic complexity of logistics today. For example, decentralised planning has been investigated in inventory management (Andersson and Marklund, 2000; Shao et al., 2011; Zinn et al., 1989) or in freight transport (Sarraj et al., 2014a; Sternberg and Andersson, 2014). Sometimes,

[12] https://www.rolandberger.com/publications/publication_pdf/of_robots_and_men___in_logistics.pdf
[13] http://www.dpdhl.com/en/media_relations/specials/parcelcopter.html
[14] https://www.wired.com/2016/10/ubers-self-driving-truck-makes-first-delivery-50000-beers/

decentralisation and intelligence are used together for decision making, namely decentralised intelligence in Sternberg and Andersson (2014).

In accordance with recent evolutions in logistics, in this thesis we will propose and discuss a possible scenario for a future logistics system, namely a self-organised logistics system. It can generally be described as "*an open, intelligent, holonic logistics system that aims to harmonise and guide individuals within the system towards a system-wide common goal without significant human intervention from outside*" (Pan et al., 2017c). This system will be discussed in more detail in Chapter 4.

1.5 Limitations and Scope of This Habilitation Thesis

According to the objective of this document, as well as to limit the scope of discussion, not all the logistics activities and organisations introduced above are addressed. The choices made and the reasoning are as follows:

- *Logistics activities*: this thesis focuses on **freight transport**. However, some relevant topics such as ICT, business models or new inventory management models (since re-organising freight transport will have an impact on inventory management) will also be discussed. This choice was made for two reasons. Firstly, transport is an important activity in logistics, especially with regard to sustainability, as discussed above. Secondly, my research activities primarily address freight transport.

- *Logistics objectives*: as stated in Section 1.2.3, this document mainly discusses **sustainability**. It argues that considering sustainability as an objective in addition to the others would fundamentally test current logistics organisations. Hence, further evolutions are appealing.

- *Logistics organisations*: only **Type 3 and Type 4** presented in Figure 6 are discussed in the rest of this thesis so as to focus more on the bleeding edge of research in logistics. It is also because of my own research interest, which is heavily focused on Type 3, as well as the desire to move from Type 3 to Type 4 logistics organisations. More specifically, in this thesis, we will firstly review the literature related to Type 3 horizontal collaborative and interconnected logistics, as it can be seen as the most significant evolution in logistics over the past ten years. Academic and practical contributions to this type over the past decade will also be analysed. The comprehensive literature review will help us to identify key research issues and scientific contributions from the international community and thus enable us to position and discuss our research and contributions. Furthermore, the discussion regarding research prospects will focus on type 4 open, intelligent, decentralised logistics, as it can be seen as the future line of research.

After this introductive chapter, the next chapter will focus on Type 3 Horizontal collaborative and interconnected logistics. We have skipped directly to this type (without taking a close look at Types 1 and 2) for two reasons. Firstly, horizontal collaboration has been the most important and noteworthy evolution in logistics over the past ten years. Secondly, my personal contribution to the field of logistics also started with this type. To help the discussion, we start with an in-depth literature review. Through an analytical positioning framework, we will discuss recent international scientific contributions to this type.

CHAPTER 2

Horizontal Collaborative and Interconnected Logistics: State of the art

2.1 Chapter Introduction

Being aligned with Figure 6 in Chapter 1, from this chapter we will discuss research works devoted to Type 3 - Horizontal collaborative and interconnected logistics. Since the organisation represents the most important and noteworthy evolution in the last ten-year history of logistics - the collaboration extended from vertical to horizontal. In particular, freight transport, being one of the most significant activity to sustainability in logistics, has attracted increasing attention within this organisation. For those reasons, this chapter will focus on freight transport in the context of horizontal collaborative and interconnected logistics. To simplify, we use in this chapter the term "horizontal collaborative transport" (or HCT) for short. It aims to analyse the state of the art and the international scientific contributions to the research topic. A framework is developed to position the most relevant and important research works. By that, we aim to discover the most important research topics and contributions, as well as gaps in the current state-of-the-art.

This chapter is based on a paper (Pan et al., 2017b) submitted to *International Journal of Physical Distribution & Logistics Management*. It is organised as following. First, the context and motivation of the research will be presented. Then, Part 3 introduces a two-axis framework of analyse, one axis of solutions and another of scientific issues. Representative and significant scientific publications will be positioned and discussed under the framework. Part 4 will discuss some key findings from the survey; and Part 5 to discuss further research prospects relevant. Finally, Part 6 d will conclude this chapter.

2.2 Horizontal Collaborative Transport and Sustainability

Over the past decades, sustainability in freight transport has become a major preoccupation in the field of logistics (McKinnon et al., 2015; Touboulic and Walker, 2015). On the one hand, freight transport is a lever for economic growth and on the other hand, it contributes significantly to problems such as CO_2 emissions, road accidents, and congestion in many countries (Goldsby et al., 2014; Piecyk and McKinnon, 2010). More effective and efficient organisation of freight transport has become crucial to succeed in logistics, as well as to deal with sustainability challenges.

Among other solutions for sustainable transport such as new fuels or engines, eco-driving, new regulations, electric vehicle, new logistics schemes, as reported in European Commission (1998), collaboration between logistics parties has been recognised as one of the most effective approaches to improve freight transport efficiency and sustainability at logistics level (Goldsby et al., 2014). Although cooperation, coordination, and collaboration should be differentiated (the partnerships vary from operational to strategic level (Spekman et al., 1998)), the term "collaboration" is used here to broadly cover collaborative partnerships in transport and logistics from operational level to strategic level. As discussed in Mason et al. (2007), there are two types of collaboration in logistics: vertical collaboration (VC) and horizontal collaboration (HC). VC focuses on the beneficial vertical relationships between

parties within a supply chain (SC). It has been widely studied in the literature and several surveys are already available, for example Barratt (2004), Power (2005) and Stadtler (2009).

HC is more recent and concerns collaboration across SCs. Generally speaking, HC refers to "*active cooperation between two or more firms that operate at the same level of the supply chain…*", between shippers, between LSPs, or between receivers for example (Cruijssen, 2006; Mason et al., 2007). Some successful examples of HC can be found in passenger transport with airline alliances such as *Skyteam* and *Star Alliance*.

Specifically, in the field of freight transport, the development of HC can be observed from both industrial and academic viewpoints. From an industrial viewpoint, HC is not a new concept, especially in the trucking industry. Well-known examples include the European carrier association *ASTRE* (ASTRE, 2016) that was created to help independent carriers exchange transport requests. Another example is the well-known collaborative practice *conference* in liner shipping (Agarwal and Ergun, 2010). Over the past decade, companies have been looking for greater synergy in freight transport to mitigate the higher pressure of logistics costs and demanding services (Cruijssen, 2006). As a result, collaboration across independent SCs to consolidate flows, which is more extensive and efficient than simple lane exchange between carriers, has been considered as an innovative freight transport and logistics solution (Cruijssen, 2006; Mason et al., 2007; Schmoltzi and Wallenburg, 2011). The case of four collaborating manufacturers in France (*Mars*, *UB*, *Wrigley* and *Saupiquet*) is one of the success stories (CO3, 2014). More industrial case studies can be found in Saenz et al. (2015). From an academic viewpoint, HC is a relatively young but rapidly evolving stream for which new lines of research can be observed. In recent years, a number of relevant concepts, methods, and models have been initiated and studied (see Section 4). These contributions promote HC in freight transport from carrier to SC level, and more recently at supply network level.

Considering the importance and rapid development of HC in freight transport, this chapter focuses exclusively on this topic, which is termed herein "horizontal collaborative transport" (HCT). As there is currently no collective definition of HCT, this document offers a broad, generic one: *HCT refers to all types of horizontal collaboration in freight transport between parties operating at the same level of the supply chain (carriers, logistics service providers or shippers), between independent supply chains, and between transport networks, from occasional cooperation to long-lasting collaboration, and from operational level to strategic level*. This definition is broad enough to cover the related literature concerning cooperation, coordination, and collaboration in freight transport, and to help provide us with an exhaustive review of the domain. The definition also suggests that HCT can be achieved from various perspectives from transport to supply chain level, and from operational to strategic level. In the survey, we use the term "HCT solutions" to cover all concepts, methods, and models aimed at achieving HCT. Afterwards, the key implementation issues of the solutions will be discussed.

2.3 Analysis of Research Contributions

To provide a structured review of the research on HCT, relevant research works are classified according to two axes: HCT solutions and implementation issues addressed. The classification is proposed to answer to two significant research questions related to the topic. Frist, from industrial perspectives, how should logistics companies (e.g., carriers, LSP, shippers, receivers) adopt effective and efficient HCT solutions, by taking into account their position,

resources, and responsibility in the SC, while being aware of the underlying issues and difficulties when implementing the solutions (called implementation issues in this paper)? Second, from academic perspectives, what are the recent research trends and gaps in HCT, particularly regarding each solution and each issue?

The first axis of classification is called *HCT solutions*. All HCT concepts, methods, and models reported in the papers reviewed could be classified into six classes of solutions: *Single carrier collaboration (S1)*; *Carrier Alliance/Coalition (S2)*; *Transport Marketplace* (*S3)*; *Shipper or LSP collaboration (S4)*; *Logistics pooling (S5)*; *Physical Internet (S6).*

The second axis of classification focuses on the *implementation issues* involved in HCT solutions. Overall, seven classes could be observed from the literature: *Collaborative network design (I1)*; *Transport planning optimisation (I2)*; *Mechanism for exchanging requests (I3)*; *Coalition formation and Gain sharing (I4)*; *Information and communications technology (I5)*; *Organisation (I6)*; *Management and governance (I7)*; *Collaborative and Distributed Inventory Management (I8)*.

2.3.1 Classification of HCT solutions

This section discusses one by one the definitions and collaboration schemes of the six classes of HCT solutions introduced previously.

2.3.1.1 Single carrier collaboration (S1)

Single carrier collaboration is a term used in Hernández et al. (2011) to describe an HCT solution for an autonomous and independent carrier who collaborates with one or more other carriers. It is a bilateral collaboration between carriers motivated by at least three goals, i.e., reduce transport costs (Hernández et al., 2011), acquire external capacity to serve excess requests (Hernández and Peeta, 2014), or improve services for the (same) client (Puettmann and Stadtler, 2010). Practical examples include collaboration between express carriers, for example, *Fedex* (in the US) and *Chronopost* (in France) collaborating to improve local delivery services and efficiency in both countries.

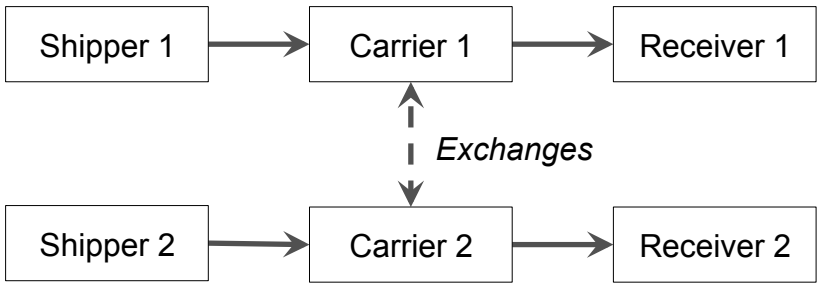


Figure 8. Single carrier collaboration scheme

Figure 8 illustrates the single carrier collaboration scheme. For each SC, shippers will procure transport services from a carrier to ship freight to a receiver. The two carriers serving different SC may exchange on hand requests in order to improve transport efficiency and thus profitability. Moreover, a carrier takes a request from another with the transport constraints given by the shipper and/or the receiver. The constraints can be lane, volume, lead time, delivery time windows, etc. The service undertaken must be maintained in the two SC after the exchange.

2.3.1.2 Carrier alliance and coalition (S2)

In contrast to bilateral exchange, a number of collaborating carriers may form a group for more stable and efficient collaboration. Transport requests can then be exchanged within the group in order to mutually optimise transport for a group of carriers, but not for a single carrier, as shown in Figure 9. This kind of group is generally called a *carrier alliance* or *coalition*. S2 differs mainly from S1 in organisation and management: S2 based on a multilateral alliance agreement, while S1 is based on a bilateral carrier-carrier agreement. The HCT solution is not new in transport industry, but it has been receiving attention in recent research.

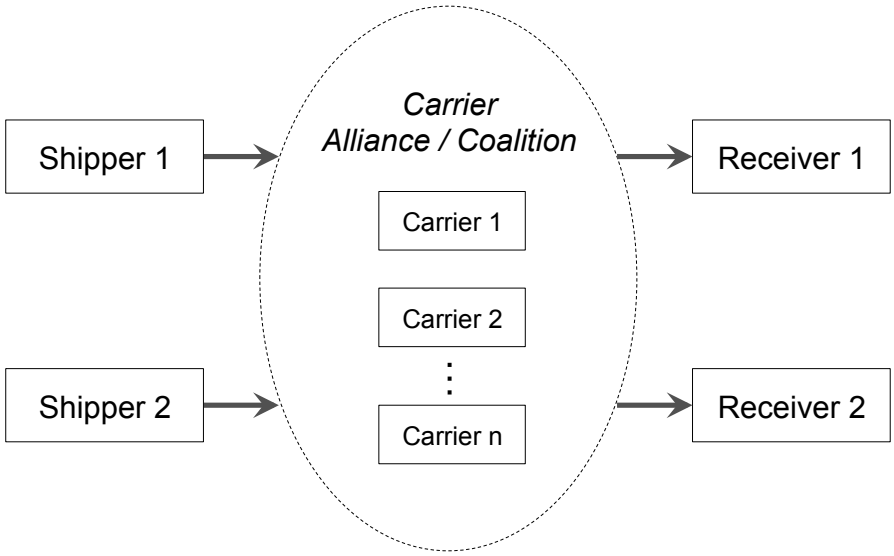


Figure 9. Carrier alliance or coalition collaboration scheme

Alliance and coalition are two distinct forms of organisation but sometimes misused interchangeably. In general, companies in an alliance collaborate with each other but operate as independent units, while companies in a coalition operate in a fully coordinated way and work as a single integrated company (Zhou et al., 2011), and is usually referred to as corporate mode for coalition and cooperative mode for alliance (Klaas-Wissing and Albers, 2010). The two forms also have different collaboration schemes for exchanging requests (Houghtalen et al., 2011; Verdonck et al., 2013). More specifically, carriers in an alliance may choose to outsource their low-profit transport requests that are available to other alliance partners or pick up appropriate requests from alliance partners to improve their vehicle fill rates (Dai and Chen, 2011; Li et al., 2015). However, carriers in coalitions will pool their on-hand requests and transport resources to establish globally optimal transport plans (Dai and Chen, 2012a, b). In other words, an alliance is based on decentralised planning, while a coalition is based on centralised planning. As a result, a coalition normally achieves better global optimality for all partners than an alliance (Agarwal and Ergun, 2008, 2010; Houghtalen et al., 2011; Kuo and Miller-Hooks, 2012; Zhou et al., 2011). In practice, an alliance is more suitable for large groups of trucking companies, while a coalition is better for small groups, as evidenced by the case study involving two real-life companies in Albers and Klaas-Wissing (2012).

2.3.1.3 Transport marketplace (S3)

A transport marketplace, also called freight marketplace or shipping marketplace, is a place where shippers (manufacturers or retailers) procure transport services from carriers or LSPs.

It is known as a transport service procurement (TSP) problem (Huang and Xu, 2013; Xu and Huang, 2013). It can also be an online platform (Caplice, 2007; Huang and Xu, 2013). Typically, in a transport marketplace, the buyers (of a transport service) are shippers and the sellers are carriers. In this context, there is no collaboration but competition (on bidding price) between carriers. Nevertheless, in some cases, carriers can be simultaneously buyers and sellers, for example, marketplaces that are open to carriers for exchanging requests (Berger and Bierwirth, 2010; Caplice, 2007; Dai and Chen, 2011). Marketplaces become collaborative transport marketplaces for carriers, in other words, an HCT solution, as shown in **Figure 10**.

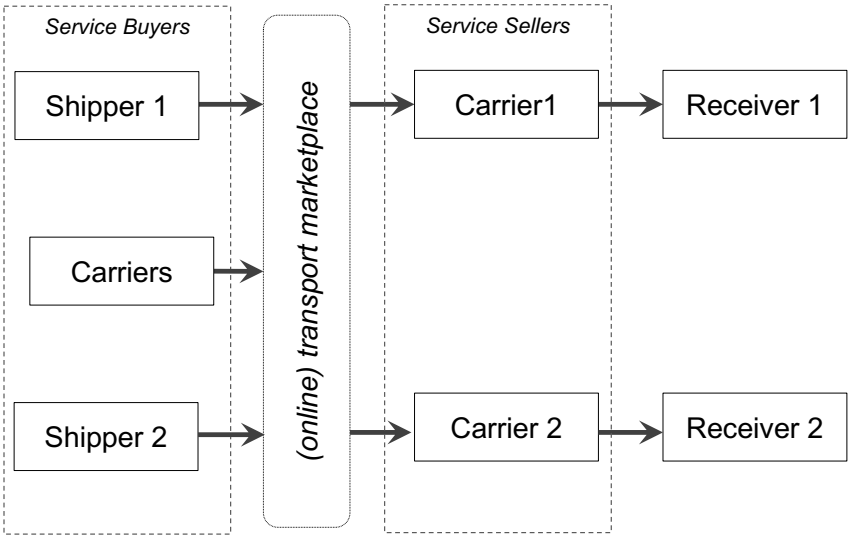


Figure 10. Carrier collaboration via transport marketplace

A marketplace collaboration scheme differs from solutions S1 and S2 in the openness of the exchange system. A carrier can simply enter his request in the system without seeking partners himself. Then, any carrier offering an attractive price can respond to the request via the system. Sometimes, online platforms – logistics intermediations play also the role of coordinator who matches supplies and demands, for example *Click&Truck* in France (www.clickandtruck.com). In all cases, no long-term contract or alliance agreement is required in the exchange, contrary to S1 and S2. The openness enhances the flexibility and the agility of HCT, which are particularly important for on-demand transport requests (spot markets) (Caplice, 2007). However, cost optimisation is opportunistic compared to S1 and S2, since it depends on the bid prices submitted by carriers. Auction mechanism has been popularly proposed to mitigate the loss of cost efficiency (see discussion in Section 5.3).

2.3.1.4 Shipper or LSP collaboration (S4)

Further to collaboration between carriers, HCT may also arise between shippers at SC level. Collaborating shippers can collectively and mutually define or revise logistics and transport constraints (e.g., lane, volume, lead time, delivery time windows), for the sake of transport synergy (Ergun et al., 2007b). This kind of solution is fundamentally different to carrier-based HCT solutions (S1, S2, and S3) since in the latter carriers are not allowed to modify transport constraints imposed by the shipper, thus limiting transport synergy (Vanovermeire et al., 2014). In particular, for shippers who have outsourced logistics and transport activities to LSP, collaboration between shippers is practically collaboration between LSPs (Soysal et al., 2016). We must clarify that the term LSP used here stands for 3PL/4PL that manage shipper's logistics tasks, but it does not include carriers who only execute transport tasks. The reason is that an LSP should be able to revise the shipper's logistics and transport constraints for LSP collaboration.

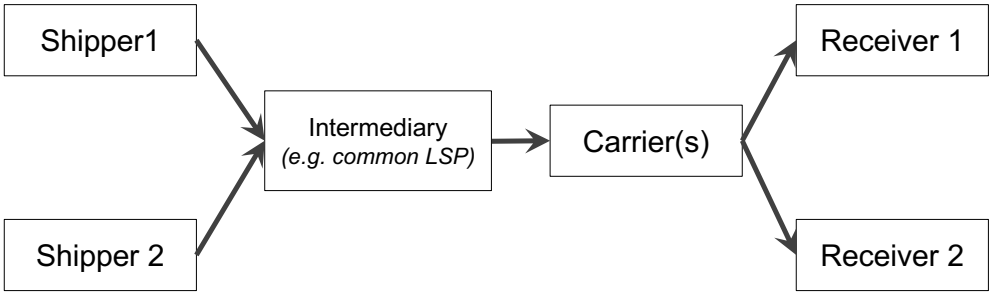


Figure 11. Shipper or LSP collaboration scheme

Figure 11 illustrates the collaboration scheme of two shippers via a common LSP. In such a scheme, the LSP will establish mutual transport plans for the shippers and sends transport requests to carriers. The elaboration of mutual transport plans is called Joint route planning (JRP), or joint distribution, in Cruijssen et al. (2007a), Cruijssen et al. (2007b), and Verstrepen et al. (2009). The authors argue that JRP works on the basis of collaboration between flow-controlling entities (FCE) such as shippers, LSPs, or receivers of goods who have direct control over the flow of goods, and between those who have a joint distribution centre or whose vehicle depots are located "sufficiently close" to each other.

Many famous examples of S4 can be found in practice, including Amazon marketplace. For many companies, especially the SME (small-medium enterprises), they are allowed to sell their products through the Amazon's website (the marketplace), and take the advantage of Amazon's logistics service to deliver the products to clients. In such context, Amazon is indeed a common LSP for the companies and for himself as well. Tus, all shipments are pooled and managed by Amazon, for optimisation sake.

2.3.1.5 Logistics pooling (S5)

Logistics pooling, or supply chain pooling, can be described as a solution to exploit synergies between supply chains by combining vertical and horizontal collaboration (Mason et al., 2007; Rodrigues et al., 2015). Ballot and Fontane (2008), Pan et al. (2013) and Pan et al. (2014a) further proposed a definition of pooling as a solution for co-designing and sharing a common logistics network by partners (suppliers, clients, carriers, etc.) with a common objective. And the resources (warehouses, platforms, transport resources, etc.) are pooled and shared by the partners. According to this definition, S5 differs from S4 in that the former aims to coordinate all SC stakeholders and integrate their common interests into the solution in order to optimise and maximise transport synergy, while S4 only concerns shippers. In other words, S5 may outperform S4 in terms of transport synergy exploitation, but the organisation and management of S5 could be more complex and complicated.

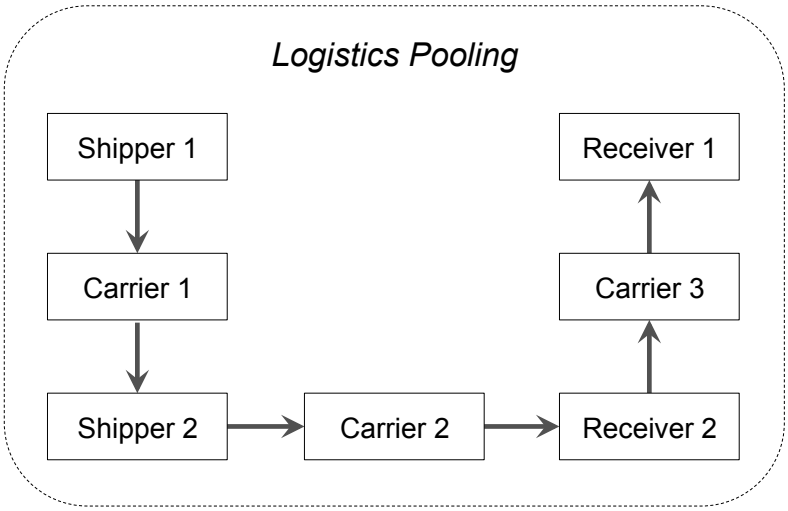


Figure 12. Logistics pooling scheme

Figure 12 illustrates an example of SC pooling adapted from Pan et al. (2013). Before pooling, shipper 1 and shipper 2 independently ship goods to both receiver 1 and receiver 2. After pooling, the shippers can share a warehouse (that of shipper 2, for example) to consolidate their flows to be dispatched; meanwhile, the receivers can also share a distribution centre (that of receiver 2, for example) to consolidate their flows to be received. In this way, both upstream and downstream flows are consolidated so that carrier 2 carries all the flows. The interests and constraints of all stakeholders (shippers, LSP, and receivers) should be considered when designing mutual transport plans.

A practical example is the pooling case led by *FM Logistic* in France, which comprises 7 manufacturers, 6 retailers, and 10 LSP (FM Logistic, 2016; Gapska and Rutkowski, 2009). Case studies can also be found in Ballot and Fontane (2010), Pan et al. (2013), and Pan et al. (2014a) in the fast moving consumer goods (FMCG) sector, or in Hingley et al. (2011) in the grocery sector.

2.3.1.6 Physical internet (S6)

The Physical Internet (PI) is an HCT solution that has been developed since 2010. It is proposed for the purpose of developing a shared, highly modularised, standardised, and interoperable collaborative transport network of which the aim is to interconnect currently independent transport networks, as a metaphor of the digital internet (Ballot et al., 2014; Montreuil, 2011; Sarraj et al., 2014b). It is also called “the network of independent logistics networks” in Ballot et al. (2014). Modularisation and standardisation of physical, informational, and managerial materials are key factors in the success of such a network, as they play a vital role in seamless interoperability between networks (Lin et al., 2014; Montreuil, 2011; Sallez et al., 2016).

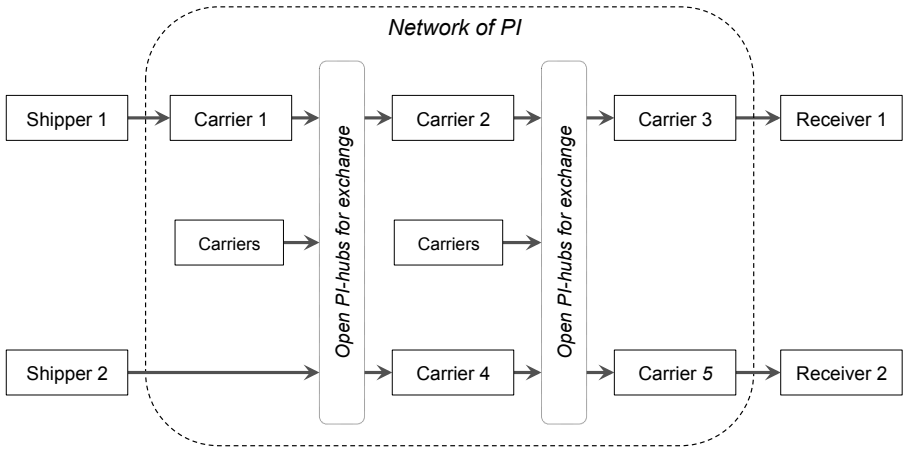


Figure 13. Physical Internet collaboration scheme

Figure 13 illustrates an example of PI. Within the PI network, carriers can exchange requests through an open PI-hub to optimise truck fill rates or reduce empty runs. It is similar to the way that data packets are routed via routers in the digital internet (packets and routers are respectively freight and PI-hubs in PI). In this way, a request can be reallocated to the most competitive carrier every time it arrives at a hub, and each reallocation is considered as a local optimisation. The particularity in PI is that transport is organised and optimised in a decentralised way. This means that for a given request its optimal route from the origin to the final destination will be updated every time it arrives at a PI-hub according to real-time, local information. To manage such decentralised systems, transport protocols and collaborative protocols are necessary for the level of service and global optimality of the network (Ballot et al., 2014; Xu, 2013). Besides, some studies have proven that such an interconnected and decentralised transport network can also help reduce inventory levels (Pan et al., 2015b; Yang et al., 2017b, c).

2.3.2 Classification of implementation issues

This section discusses one by one the seven implementation issues raised by the HCT solutions.

2.3.2.1 Collaborative network design (I1)

In the context of HCT, collaborative network design aims at reorganising or designing a common, shared collaborative logistics and transport network for SC stakeholders. The objective of a collaborative network is to consolidate logistics flows as regards the origin and the destination. One example is to set up warehouse shared by multi-shippers, or distribution centre shared by multi-receivers. In terms of modelling, it is very similar to the traditional network design problem (Campbell et al., 2005) and has therefore been rarely studied alone in the literature. According to the papers devoted to the issue, optimisation approaches, especially Mixed integer linear programming, are the most common methods used to investigate the issue, for example, collaborative Hub-and-Spoke network design (Hernández et al., 2012; Wang et al., 2014a), pooled network design for multi-suppliers and multi-retailers (Pan et al., 2013), location of collaborative hubs for regional small and medium-sized food suppliers (Pan et al., 2014a), and a collaborative network for the inventory routing problem (Soysal et al., 2016). These experimental studies aimed to demonstrate the potential of collaborative networks in transport synergy.

2.3.2.2 Transport planning optimisation (I2)

In the literature, much attention is devoted to the collaborative transport planning optimisation issue. Under a given transport network, it consists of all collaborating actors – shippers or carriers – establishing optimal transport plans collectively and mutually. Two objectives are often considered in the optimisation, i.e., improve transport fill rate especially for LTL (less-than-truckload) shipments (Adenso-Díaz et al., 2014b; Cruijssen et al., 2007a; Dai and Chen, 2012a), and reduce empty runs of repositioning especially for TL (truckload) shipments (Adenso-Díaz et al., 2014a; Bailey et al., 2011; Ergun et al., 2007b; Lin and Ng, 2012; Liu et al., 2010a; Liu et al., 2010b; Pérez-Bernabeu et al., 2015). The effects are called, respectively, economies of scale (Wang and Kopfer, 2015) and economies of scope (Özener et al., 2011) in transport.

Two modelling approaches are often used for collaborative transport planning: the collaborative vehicle routing problem (CVRP) and the collaborative lane covering problem (CLCP). CVRP is an extension of VRP from single to multiple carriers. Classic VRP aims to minimise the total cost (or time, distance, etc.) of delivering n requests assigned to a single carrier, while CVRP aims to maximise the total profit of delivering n requests assigned to m collaborating carriers. More specifically, the cost of fulfilling a request can be different for each collaborating carrier, so it is possible to establish a mutual routing plan to maximise the total profit for all carriers. As with VRP, CVRP should consider some constraints, such as carrier capacity (Fernández et al., 2016; Hernández and Peeta, 2011; Hernández et al., 2011; Montoya-Torres et al., 2016; Wang et al., 2014a; Wang et al., 2014b), time windows of requests (Caballini et al., 2016), availability of information for planning (static, dynamic or real-time information) (Dahl and Derigs, 2011; Dai and Chen, 2012a; Hernández and Peeta, 2014; Wang and Kopfer, 2014, 2015). The second approach, CLCP, is often used in shipper/LSP collaboration (Ergun et al., 2007a; Ergun et al., 2007b; Kuyzu, 2016). Technically, CLCP aims to find a set of transport plans covering all lanes (from multi-shippers) such that the total cost to serve the lanes is minimised. For example, all three studies reviewed focused on TL shipments to minimise total asset repositioning. As discussed in Kuyzu (2016), the main difference between CVRP and CLCP is that the former focuses on tour optimisation, while the latter focuses more on lane exchange optimisation without considering vehicle tours.

2.3.2.3 Mechanism for exchanging requests (I3)

This issue deals with incentives and methods to exchange requests, and mechanism design is a popular approach. Two main mechanisms were studied in the literature: side payment and auction. Side payment refers to monetary transfer between two carriers when requests (or capacity) are exchanged (Agarwal and Ergun, 2008, 2010; Özener et al., 2011). It is also called collaborative price in Zhou et al. (2011), or capacity exchange price in Houghtalen et al. (2011). Basically, it can be seen as the price fixed by a carrier for the extra-capacity he wants to sell. The crucial decision is fixing the right price with a dual objective: effectiveness to encourage carriers to exchange requests, and efficiency to reach an optimal exchange solution (Houghtalen et al., 2011). In other words, the price is leverage to optimise transport. Two main methods are proposed to solve the problem: the inverse optimisation method in Agarwal and Ergun (2008) and Houghtalen et al. (2011), and price sensitivity simulation in Zhou et al. (2011).

The auction mechanism is also proposed for exchanging requests. In this context, the auction can be seen as a transport procurement process where carriers submit (to the auctioneer) a price for a transport request placed by a shipper or other carrier. Then, the auctioneer will

decide the winner for each request according to the prices submitted. The process concerns two main problems: the bidding price setting problem and the winner determination problem (WDP). The former consists of determining the optimal bidding price for a request (or for a bundle of requests), whereby the carrier's expected revenue is maximised (Ağralı et al., 2008; Dai et al., 2014; Gansterer and Hartl, 2016; Kuyzu et al., 2015; Qiao et al., 2016a). The latter consists of assigning many requests to many bidding carriers in an optimal way, usually solved using linear programming (Berger and Bierwirth, 2010; Chen, 2016; Dai and Chen, 2011; Huang and Xu, 2013; Kuo and Miller-Hooks, 2012; Xu and Huang, 2013; Xu and Huang, 2014; Xu et al., 2016). Moreover, auctions may have different mechanisms depending on the actual problem to be solved (see van Duin et al. (2007) and Verdonck et al. (2013) for a comparison of the mechanisms). The literature revealed that second price or double auction was effective and efficient to exchange requests, and combinatorial auction was efficient to exploit transport synergies in-between requests.

Compared to the side payment mechanism, the auction mechanism is more suitable for decentralised HCT solutions due to its real-time, local optimisation capability. That is why it has been greatly studied for the (online) freight marketplace (Caplice, 2007). Nevertheless, the disadvantage is that the auction mechanism might not ensure global optimality for all carriers as a whole since it does not rely on centralised planning (Berger and Bierwirth, 2010).

2.3.2.4 Gain sharing (I4)

The gain sharing (or cost allocation) issue concerns how to fairly allocate the common gain (or cost) to collaborating players. A number of papers have investigated the issue, and cooperative game theory is the dominant approach (see the two reviews by Nagarajan and Sošić (2008) and Guajardo and Rönnqvist (2016)). With the same goal that is to develop fair rules or models to allocate gain, the papers differ from each other in the constraints or criteria of fairness taken into account, for example additional desirable properties in collaboration (Özener and Ergun, 2008), satisfying the coalition budgetary balance (Yilmaz and Savasaneril, 2012), the player's stand-alone cost before collaboration (Audy et al., 2011) or bargaining power (Guajardo et al., 2016; Yang et al., 2015a), the player's flow characteristics (Palhazi Cuervo et al., 2016) or flexibility in transport (Vanovermeire and Sörensen, 2014b; Vanovermeire et al., 2014), or the cost of unvisited customers in collaborative routing (Defryn et al., 2016). In particular, the Shapley Value based on the player's contribution to the gain is the model most often proposed in the studies due to its validity and convenience of implementation (Cruijssen et al., 2010a; Dai and Chen, 2012b; Krajewska et al., 2008; Vanovermeire and Sörensen, 2014a). Some studies also used the Shapley Value to compare the proposed methods (Frisk et al., 2010; Hezarkhani et al., 2015; Li et al., 2016; Lozano et al., 2013; Verdonck et al., 2016).

The gain sharing problem can be extended to the coalition stability problem since the sharing scheme is crucial to coalition stability (Audy et al., 2012a). Most of the studies cited above only consider grand coalition including all players. However, in some cases, some players may be more interested in joining sub-coalitions that contain only a subset of players but provide higher profit for each (see the case in Cruijssen et al. (2010a)). Then, the problem is finding the most profitable and stable sub-coalitions, if there are any. This is called the coalition formation game (Audy et al., 2012a; Ben Jouida et al., 2016). The problem has received less attention in this survey.

Not all HCT solutions involve the gain sharing or coalition formation issues. These issues are implicated more in solutions that are usually employed within a coalition/alliance

organisation, S1, S2, S4, and S5, for example. Other solutions like S3 and S6 are less concerned since they do not necessarily rely on this kind of organisation.

2.3.2.5 Communications technology (I5)

Previous studies have proven that information sharing is crucial to improve collaboration efficiency, see Berger and Bierwirth (2010) and Özener et al. (2011) for example. How partners effectively and efficiently communicate with others to share information becomes an issue and impediment of HCT (Cruijssen et al., 2007b). But surprisingly, in this survey we were able to find only two papers that focus on the issue of information communication technology (ICT). At carrier level, Buijs and Wortmann (2014) investigated how ICT can help carriers establish optimal transport plans in a dynamic way by sharing real-time information. They found that the practicability and performance of dynamic planning depend on the harmonisation of different IT applications used by collaborating carriers. At supply chain and network level, Wang et al. (2015) investigated how ICT employed between collaborating shippers can help reduce CO_2 emissions from freight transport in the grocery retail industry in the UK. According to this case study, ICT solutions exist at transport and supply chain level, but there is a lack of ICT provision and usage at network level.

As sharing real-time information plays a vital role in HCT, it is foreseeable that ICT will attract more attention. This is particularly important for solutions at supply chain and network level, S4, S5, and S6, for example, because monitoring, tracing, and tracking freight from end to end will be more complicated in such shared, open systems for multi-carriers and shippers.

2.3.2.6 Organisation (I6)

Organisation issues examine how to build and organise HCT. They relate to the organisation, motives, and organisational concepts (facilitators) of HCT. The organisation of each of the six HCT solutions has already been discussed in Section 4. Motives often include cost reduction, better service, and better competitiveness to protect market positioning (Cruijssen et al., 2007b). Shippers are mostly attracted by cost and service improvement. However, market-oriented motives, that is, improving the quality of service to enhance the market share, are of primary importance for LPS (Cruijssen et al., 2010b; Schmoltzi and Wallenburg, 2011; Verstrepen et al., 2009). Recently, SC stakeholders also expected sustainability and resilience from HCT solutions (Ballot and Fontane, 2010; Czerny et al., 2016; Montreuil, 2011; Pérez-Bernabeu et al., 2015; Yang et al., 2017c).

Despite strong motives, HCT solutions may fail due to some organisational impediments (Cruijssen et al., 2007b; Rodrigues et al., 2015). To overcome the latter, some organisational concepts have been proposed. For carrier collaboration (S2 for example), a limited liability company (LLC) is usually formed to organise and manage an alliance (or a coalition) (Albers and Klaas-Wissing, 2012). LLC can be economically independent (owned by someone outside the alliance) or dependent (owned by the partners in the alliance). The former is more autocratic – members can either accept the board's decision or leave the alliance – while the latter is more democratic - members make strategic decisions together (see the study of two cases in Albers and Klaas-Wissing (2012)). For cross supply chain collaboration (S4 and S5 for example), orchestrator is a concept to be highlighted. A cross supply chain orchestrator can be considered as an impartial coordinator who manages and coordinates multiple supply chains to create horizontal collaboration and value (Zacharia et al., 2011). It can be a 3PL or 4PL managing multiple supply chains (Hingley et al., 2011; Rodrigues et al., 2015). It can also be a "trustee", adding the duty of allocating gain to patterns (see Vanovermeire and Sörensen (2014a), and the project *Collaboration Concepts for CO-modality (CO^3)* discussed

in Rossi (2012)). Likewise, Kok et al. (2015) proposed the cross-chain collaboration centre (4C) concept that, concretely, is a control tower aimed at managing, executing, and controlling cross-chain logistics activities. An example is *TRI-VIZOR* located in Belgium, claimed as the world's first cross supply chain orchestrator (TRIVIZOR, 2016). Another example is *CRC® Services* located in France, which is a pooled cross-docking platform managed by an independent 4PL for multi-manufacturers and multi-distributors in the FMCG sector (CRC, 2016).

2.3.2.7 Management and Governance (I7)

Management and governance issues deal with the question of how to manage and maintain an HCT solution. Management framework development and operational governance modes are the two main problems covered by the survey. A management framework for HCT can be considered as a stepwise framework to manage key decisions and influencing factors involved in HCT (Audy et al., 2012b; Brekalo et al., 2013; Leitner et al., 2011; Verstrepen et al., 2009). For example, a framework can involve three stages. The first stage concerns partner selection (Cheikhrouhou et al., 2010; Raue and Wallenburg, 2013) and developing trust between partners (Pomponi et al., 2015). The studies indicated that market position, common objectives and motives, structure, and similarity of flows influenced partner selection. The second stage is devoted to implementation, including defining the partner's responsibilities, leadership, and benefits (Audy et al., 2012b). Finally, the third stage concerns the long-term evolution and growth of the collaboration (Verstrepen et al., 2009).

Operational governance mode, which is sometimes part of the management framework (Verstrepen et al., 2009), relates to the selection of an adequate governance model for HCT. Governance mode plays a vital role in the efficacy of a collaboration (Schmoltzi and Wallenburg, 2012). There are two major governance models commonly used in practice: corporate and cooperative. These models are compared in Klaas-Wissing and Albers (2010) who indicate that with the former model, partners act as one single integrated company, while with the latter partners act as independent collaborating companies based on an alliance agreement (see also Agrell et al. (2016) for a practical example of the cooperative model). In both models, conflict management is one of the most prominent issues, see Wallenburg and Raue (2011) and Verstrepen et al. (2009), for example.

2.3.2.8 Collaborative and distributed inventory management (I8)

The issue concerns collaborative inventory control strategies or models based on HCT. The research is motivated by the fact that HCT will enable shared transport service between SCs. The service would further stimulate innovative collaborative inventory control models that may generate economic gain (e.g., decreasing inventory level, improving service level, etc.) Two main new models are studied in the literature. The first model is called inventory pooling as a centralised model. Under horizontal collaboration, companies may ask a common 3PL to manage their inventory as a whole so as to create the synergy in orders, transport and inventory holding, i.e., inventory pooling for multi-companies (Wong et al., 2005; Wong et al., 2007). The second model is called decentralised and distributed inventory management, which is the opposite of centralised inventory management. In an interconnected and decentralised network like PI, companies are allowed to store their products in shared logistics platforms that are closer to the market (Pan et al., 2015b). The interconnectivity also allows companies store their products in different locations for each short period. As a result, orders from clients can be satisfied by different or multiple sources for each time. The high dynamicity and flexibility enabled by the interconnected and shared network provide research opportunities for developing new inventory control models, for example that are studied in

Yang et al. (2017c) and in Yang et al. (2017b). For both models, the relevant literature mainly addresses inventory strategies and parameters optimisation problem, through optimisation or simulation approach.

2.4 Research Trends and Gaps

This section discusses the research trends and gaps derived from the literature. The discussion will follow the two axes of the framework.

2.4.1 HCT solutions

With regard to HCT solutions, several remarks can be given here. Firstly, the spectrum of HCT solutions has been extended from carrier level (S1, S2, and S3) to supply chain level (S4 and S5), and to supply network level (S6), see Figure 14. The main reason is that both carriers and other SC stakeholders are now interested in HCT. Specific solutions should be developed for each according to their own interests and convenience. For example, S1 and S3 would be adequate for big trucking companies who prefer to maintain their independence and autonomy with regard to transport organisation. However, for small or self-employed trucking companies, S2 would be a better solution, since it would provide much greater possibilities to exchange requests and thus to reduce the transport cost. S4 is proposed for shippers who have compatible flows and who are geographically close to each other, while S5 and S6 are not proposed for one specific SC stakeholder but for all those with common interests. For companies who are seeking opportunities in HCT, the current broad spectrum of HCT solutions can provide sufficient support to choose a solution.

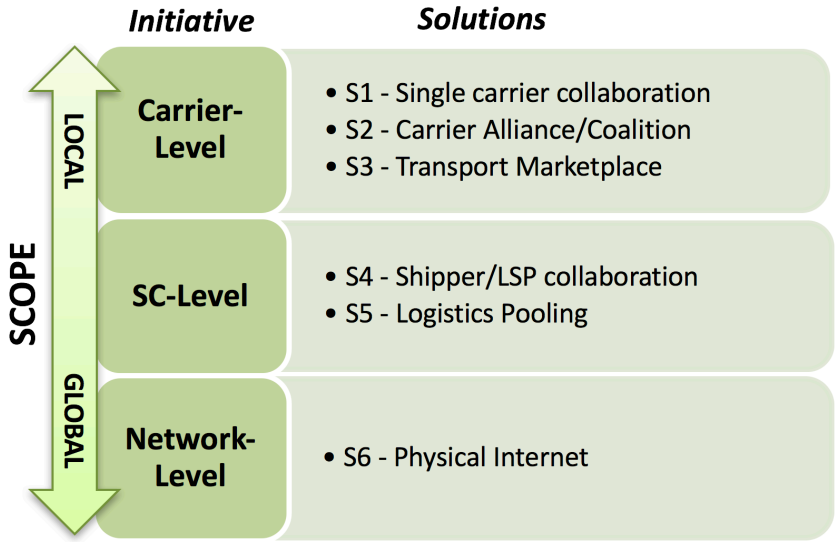


Figure 14. Level of initiative of HCT solutions

Secondly, the number of papers per solution is aligned with the mutation of HCT. Over the past ten years, the focus of research has clearly been on S2 and S4, since both solutions were considered valuable for both researchers and practitioners. Apparently, they are also the most advanced and applied HCT solutions within the chosen time frame. In contrast, S1 and S3, which are not new, have received little attention for different reasons. S1 concerns bilateral collaboration between large companies. The organisation is therefore relatively simple and only two implementation issues have been studied: transport planning and lane exchange mechanism. For S3, the marketplace is not always considered as an HCT solution. Although there are a number of papers that have studied the auction theory in the transport marketplace, not all are included in the survey since they focus on shipper-carrier rather than carrier-carrier

relationships. This can be seen as a limitation of the survey. S5 and S6 are relatively young but are rapidly developing as most of the related papers were published after 2013. They could be the next hot trend in HCT research. In particular, S6 has been considered as the central European 2030-2050 vision for supply chain and logistics by the European technology platform *ALICE* (ALICE, 2016). A comprehensive research and innovation roadmap to attain the Physical Internet by 2050 is also proposed highlighting extensive research and industrial prospects.

2.4.2 Implementation issues

Regarding implementation issues, our first remark is that the most important and significant issues, from strategic level to operational level, have been covered by the literature surveyed. It reflects the maturity of horizontal collaboration in logistics and transport which has moved on from proof of concept to implementation. Experience with regard to implementation has also been discussed in some case studies (see Hingley et al. (2011), Buijs and Wortmann (2014), Rodrigues et al. (2015), for example). The scientific literature thus provides solid support for implementing HCT solutions.

Secondly, in the literature, the focus has been on the development of decision-making models, specifically for I2, I3, and I4. Most of the studies concern experimental research using mathematical models. This can be explained by the operational requirements for the implementation of HCT solutions, and by the interests of researchers. In addition, I4 is apparently one of the most fertile research fields in HCT since 17 studies are devoted to the issue of gain sharing in shipper/LSP collaboration (plus 2 literature review papers). Indeed, gain sharing plays a crucial role in maintaining collaboration in practice, as witnessed in the aforementioned project CO3. I1 has been studied a lot less in the context of HCT since it is mathematically extremely close to the classical network design problem.

Thirdly, we were very surprised by the fact that only two studies were devoted to I5 considering the importance of information exchange in HCT solutions. In the literature, this scarcity has not been discussed and explained. One of the reasons might be that, since communication between collaborators is an issue equally important for vertical collaboration, it had been already previously and widely studied in this stage, see El Kadiri et al. (2016) for example. Consequently, less contribution has been made for horizontal collaboration, in which the issue is very similar. However, it is reasonable to expect more research on this issue, particularly for solutions based on real-time decisions, such as S3 and S6.

Finally, from a practical point of view, I7, the management and governance issue, has gained insufficient attention. Currently, this issue has only been considered for S2 and S4, and only two papers were devoted to S2. More particularly, for the more recent solutions S5 and S6, the development of management and governance operating models has never been investigated.

2.5 Research Prospects

This part discusses several prospective lines of research derived from the survey but not limited to the solutions and implementation issues discussed. Firstly, further investigation is necessary to compare and contrast centralised and decentralised organisation for HCT, see Figure 15. Klaas-Wissing and Albers (2010) gave an example comparing carrier alliance with coalition. However, current solutions are all based on centralised organisation at SC level (S4 and S5) and decentralised organisation at network level (S6). These solutions have not been

compared. It is certain that centralised organisation may offer globally optimal solutions for all collaborating companies, but the companies may lose some of their independence and flexibility (Li et al., 2015). Moreover, significant change by any collaborator (e.g., flow, market size) would also destroy the existing collaboration (Rodrigues et al., 2015). In contrast, decentralised organisation offers greater independence and flexibility for collaborators, but not necessarily global optimality. Knowing that companies are looking not only for efficiency but also flexibility and dynamics in HCT solutions (Saenz et al., 2015), the possibility of developing a hybrid organisation model remains a research topic. Furthermore, management and governance operating models for decentralised organisation solutions also merit further investigation.

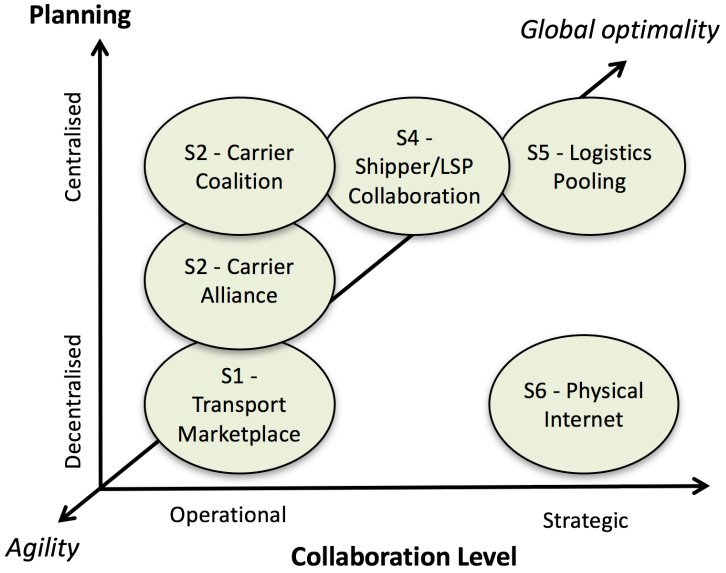


Figure 15. Planning and collaboration level of HCT solutions

Secondly, developing real-time information communication processes is becoming urgent. Real-time communication is doubly important for HCT. Firstly, it enables real-time information sharing to make real-time decisions involving cross chain collaborators (truck sharing, routing optimisation, actual lead time, etc.). Secondly, it enhances real-time traceability and visibility of freight in a collaborative transport network. Thanks to modern technologies such as Internet of Things and RFID, it is easier to acquire real-time information related to logistics and transport. Nevertheless, information exchange still relies mostly on some traditional means such as e-mails or telephone calls, which seem inadequate to satisfy real-time communication. One solution is to interconnect the heterogeneous (cross chain) information systems via collaborative digital platforms with standardised API (application programming interface) and EDI (Electronic Data Interchange) messages. System architecture and process standardisation then become research problems. Furthermore, the subject can be extended to data governance and privacy, whose aim is to effectively and efficiently share real-time information.

Thirdly, evaluation criteria and metrics for HCT solutions need to be enhanced in view of sustainability. In the survey, the main performance criterion of HCT solutions was economic, i.e., the reduction of logistics and transport costs. Only a few studies considered the environmental aspect (CO_2 emissions), and even fewer considered the social aspects. The assessment of HCT solutions is biased towards a single (economic) criterion, as also evidenced by the case study in Keseru et al. (2016). Due to this bias, the advantages of HCT might be underestimated and the disadvantages ignored. To improve reporting on the

sustainability performance of HCT, accurate and comprehensive logistics metrics are necessary for further investigation.

Fourthly, not many studies focus on horizontal collaboration for intermodal transport, with only a few of the papers reviewed being devoted to this issue (see Puettmann and Stadtler (2010), Kuo and Miller-Hooks (2012), Pan et al. (2013) and Sarraj et al. (2014a)). This line of research should be enhanced for the sake of sustainability in logistics. The studies have proven that, for inland transport, high-volume modes of transport (like railways or waterways) are environmentally friendly, but are only cost-effective with high-volume flows. Companies (shippers or receivers) may collaborate to consolidate flows by sharing means of transport. But collaborative planning could be long and complex due to booking means of transport in advance and lack of flexibility. More effective planning methods are necessary to overcome this impediment. Indeed, the problem relates to a current trend in supply chain and transport called synchromodality. The concept emphasises ad-hoc modal shifts (to more effective or efficient means of transport), even during execution of the transport plan (Kok et al., 2015). In this context, it is predictable that HCT and synchromodality play complementary roles in logistics sustainability.

Fifthly, HCT solutions for urban freight transport are appealing. Along with the development of e-commerce and home deliveries, urban freight transport has been rapidly increasing along with sustainable problems. As has been proven, HCT could be an effective and efficient approach to reduce the negative externalities of freight transport in cities. Currently, only a few studies are looking into the issue (Montoya-Torres et al., 2016). It should be emphasised that the problematic of urban freight transport is different to long-haul transport since the former is much closer to our daily life in the city. Specific HCT solutions for urban freight transport should thus be developed. For example, an urban consolidation centre (UCC) is one of the most studied solutions (Allen et al., 2014). However, the solution can also fail for various reasons. One of the main reasons is that, as it is often imposed by the government, the additional transhipment at a UCC sometimes increases the transport cost for the shipper or the carrier and so they need to rethink their logistics to adapt to the solution. More research is still required for UCC, as well as for other HCT solutions with regard to urban freight transport.

2.6 Conclusion of the Chapter

This chapter provides a comprehensive survey of horizontal collaborative transport (HCT) solutions. A survey framework has been proposed under which the studies were classified according to two axes: HCT solutions and implementation issues. This framework can be used efficiently by researchers in HCT to position their work and their future research, as well as by practitioners to implement HCT solutions. This study has also set out some significant findings regarding emerging lines of research and gaps in the literature and provides some prospective lines of research.

CHAPTER 3

My Scientific Contributions to Horizontal Collaborative and Interconnected Logistics in FMCG Sector

3.1 Chapter Introduction

This chapter discusses my scientific contributions from 2007 to 2017 to the development of *Type 3* introduced in Chapter 1, i.e. horizontal collaboration and interconnection of logistics services. My main research activities were devoted to this type of logistics organisation, precisely to the solutions of *logistics pooling* and *physical internet* (*S5* and *S6* presented in Chapter 2), and the applications in the sector of FMCG. Two categories of scientific contributions are discussed here: research projects and publications (journal articles, peer reviewed conference papers and book chapters). The discussion follows the literature review framework developed in Chapter 2, in order to analyse and position my scientific contributions aligned with the relevant international and national research communities. In other words, my contributions are classified here by the first axis of solutions (pooling and physical internet), then by the second axis of scientific issues involved in each solution (among the 8 issues discussed in Chapter 2). The applications of research results will be discussed through research projects.

Issues	**HCT Solutions** S5 Pooling	 S6 Physical Internet
I1 Network	*3 articles (IJPE, FSM, RFGI)* *2 projects (Demeter, FEEF)* *1 thesis (S. Pan)*	*1 article (JIM)* *1 project (OpenFret)* *1 thesis[§] (R. Sarraj)*
I2 Transport plan		*2 articles (2 IJPR)* *1 book chapter (SOHOMA)* *1 conference paper[#]* *3 projects (PI Simu, Crowdshipping[*], PI-nuts[*])* *3 theses (R. Sarraj, Y. Yang, B. Qiao[*])*
I3 Exchange Mechanism		*1 article (JIM)* *3 conference papers[#]* *1 project (PI-co-mod[*])* *3 theses (X. Xu, B. Qiao[*], M. Lafkihi[*])*
I4 Gain Sharing	*3 conference papers[#]* *2 projects (VegeSupply, CO3)* *1 thesis (X. Xu)*	
I5 ICT	*1 book chapter (SOHOMA)* *1 project (Kaypal)*	*1 article (CII)*
I6 Organisation	*1 project (CRC)*	*1 book chapter (SOHOMA)* *2 projects (Modolushca, Clusters 2.0[*])*
I7 Management		
I8 Inventory		*3 articles (2 IJPR, CIE)* *1 thesis (Y. Yang)*

[*] *Works in progress*
[#] *Full conference papers with peer-review not extended for journal article or book chapter*
[§] *Doctoral theses, of which each may be concerned with multiple issues*

Table 3: Summary of my publications and research projects (2007-2017)

Table 3 sums up of my contributions according to the two axes. Reader may refer to Appendix A for more details. In particular, all projects are not discussed in this chapter in order to focus on publication contributions, due to the purpose of the document.

In the following paragraphs, each issue will be discussed from 3 aspects: research problem(s) description, results and impacts on the industry, and summary of theoretical contributions to the literature and limitation.

3.2 Contributions to Logistics Pooling

Logistics pooling – the S5 introduced in Chapter 2 – has been the core research actives for my doctoral thesis from 2007 to 2010, under the supervision of Prof. Eric Ballot and Prof. Frédéric Fontane. After my thesis, the research has been extended through some projects and as part of a doctoral thesis that I have co-supervised (Xu, 2013). My contribution has been focused on some of the implementation issues and applications (issues and number aligned with the issues introduced in Chapter 2), they are (I1) Collaborative network design; (I4) Coalition formation and gain sharing; (I5) Information and communications technology.

3.2.1 Collaborative network design

Considering logistics pooling as a solution to sustainable logistics, my first contribution was to design a pooled network compromising all partners' interests with respect to sustainability constraints. The issue was tackled in my thesis (Pan, 2010) and in the publications (Pan et al., 2009a, b, 2010a, b, 2011, 2013; Pan et al., 2014a).

3.2.1.1 Problem description

Among the sustainability criteria, we had been focused on optimising logistics activities to minimise CO_2 emissions from freight transport, with respect to logistics costs and logistics services. To this end, the first step was to model an accurate emission equation. One of the most popular ways to compute CO_2 emissions of a shipment is to employ a linear function as: Emissions of a shipment = emission factor in *kg* CO_2*/ton-km* multiplied by weight *ton* and distance *km* of the shipment, see ADEME (2014) or Igl and Kellner (2017) for example. The emission factor is given based on studies of diesel consumption per type of vehicle per 100km, and of electricity consumption of train per 100km. The advantage of such linear function is that it may considerably reduce the complexity as it is a purely linear function. Nevertheless, one main drawback to it is that neither the number of trucks for a shipment, nor the fill rate of each truck is taken into account. The drawback is particularly obvious with regard to reduce CO_2 emissions by pooling logistics networks, since it is expected that pooling will improve the average fill rate of trucks and then reduce the number of trucks. We therefore must construct a more accurate function, which is a piece-wise linear function to compute the CO_2 emission from transport by HDV truck or train, as shown in Figure 16.

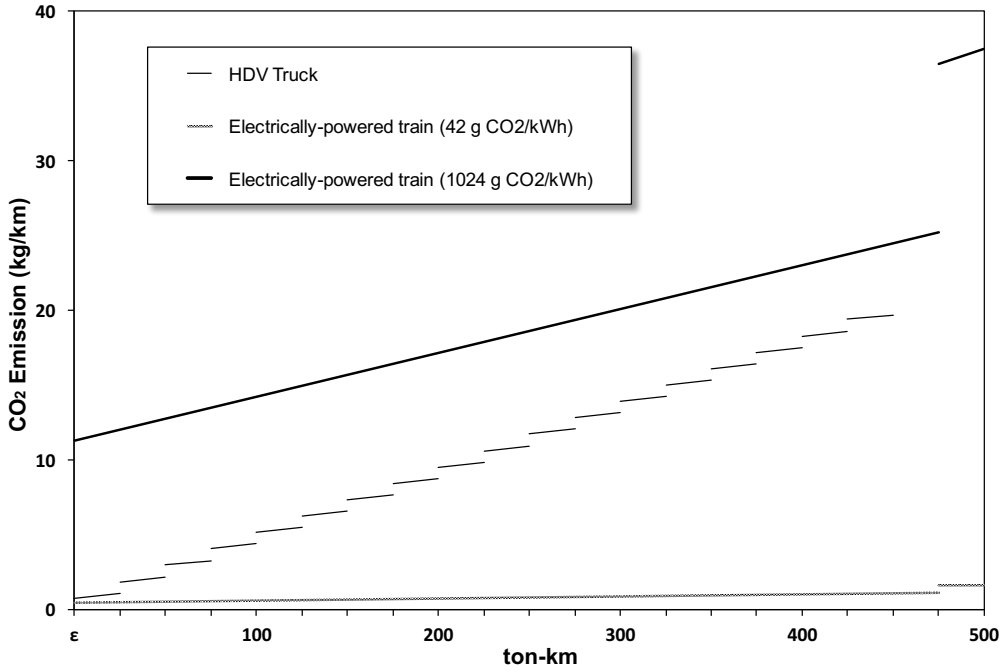


Figure 16. CO_2 emission function from road or rail transport (from Pan (2010))

In Figure 16, each segment represents the emission (kg/km) of a transport means (a truck or a train). For example, for a shipment of 30 ton, two HDV trucks are necessary (the first fully charged by 25 ton and the second charged by 5 ton, as example); and the CO_2 emission is approximately 2.2 kg/km for the shipment. We can see that the emission function is more accurate comparing to a purely linear function, since both the number of transport means and fill rate are taken into account now. Besides, we can also see that rail transport by electrical train emits much less than road transport by HDV truck, when electricity is generated by clean sources, for example unclear power in France. On the opposite, if electricity is produced from unclean sources, for example coal, rail transport by electrical train could be even more polluting (the emission factor of energy produced by coal is 2014 g CO_2/kWh, according to Jancovici (2007)). One can refer to the doctoral thesis (Pan, 2010) for more information.

Once the emission function is determined, it is integrated into an optimisation model as part of the objective function that minimises CO_2 emission in a pooled logistics network. Figure 17 gives a scheme example of logistics pooling (in FMCG sector). In such example, after pooling, upstream flows of suppliers *i* and *j* are consolidated at an upstream hub which is the WH of supplier *j* for example. In the same way, retail *m* and *n* can use a downstream hub to consolidate their flows, for example, the DC of retailer *n*. Moreover, supplier *k* alone would also benefit from the downstream hub to consolidate the flows. Intuitively, after pooling, both upstream and downstream flows are consolidated to improve transport productivity. Meanwhile, the solution generates additional flows between hubs – midstream flows. The location of hubs – the pooled network – and flows should be further optimised. To qualitatively and quantitatively assess the potential of such solution an optimisation model is necessary.

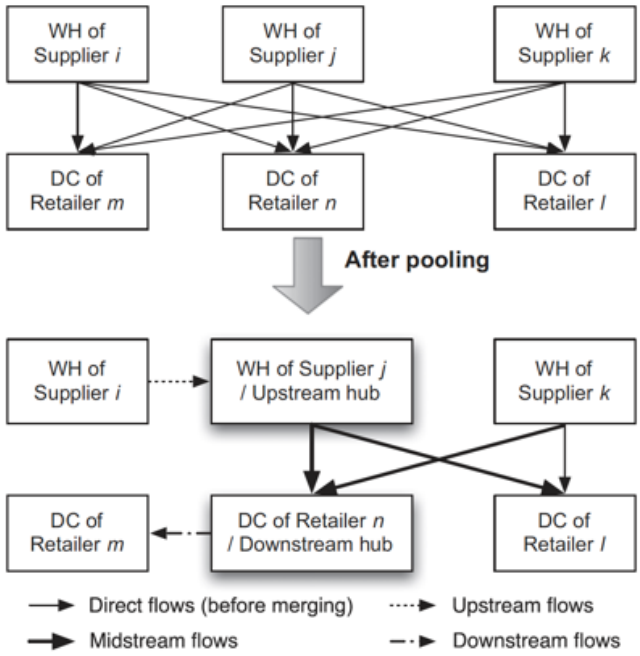


Figure 17. Scheme example of logistics pooling in FMCG sector

We developed a Mixed Integer Linear Programming (MILP) optimisation model to design pooled network which is a three-echelon multi commodity network. The MILP model aims to minimise the total emissions (or total transport cost) of the three echelons - up, mi and downstream. See Pan et al. (2013) for the entire model.

3.2.1.2 Results and impacts

Experimental studies have been realised based on two real world databases in FMCG sector, one for national major suppliers with high volumes, and another for regional SME suppliers with low to medium volumes. The studies have been done in collaboration with FMCG companies through research projects. All results and impacts are validated by both academia and industry.

In the first study, published in Pan et al. (2013), the database mentioned above comprises two major retail chains in France and their most important 106 common suppliers, with the transport record over a timeframe of 13 weeks in 2006. In total, there are 4451 flows, 211167 orders, and 2.5 million pallets. The database contains 303 Plants and 57 WH as source points, and 58 DC as destination points (point of sales level is not considered). In terms of optimisation, the original database generates more than 10 million variables; and it is too complex for the MILP model proposed. To reduce the complexity, the 106 suppliers are subdivided into three classes: Group A with less than 200 pallets per week, Group B with between 200 and 600 pallets per week, and Group C with more than 600 pallets per week. Moreover, 702 product types present in the database and they are subdivided into three categories: CARE (pharmaceuticals, cosmetics, perfume and hygiene), GRO (grocery) and LIQ (liquids). In other words, the original database is divided into 9 subsets. The performance of pooling in reducing CO_2 emissions is illustrated in Figure 18, from which we can see that pooling is an efficient and effective solution to reduce CO_2 emissions, a relative reduction of CO_2 emissions of 14% exclusively with road transport and of 52% with joint road and rail transport. Making an assumption that all flows are shipped only by FLT, we may also compute the minima of emissions in road, as a value of reference. Figure 19 gives an example of network and flows movement before and after pooling, from which we can observe that

flows are consolidated after pooling and trains are used for the most important transport corridors.

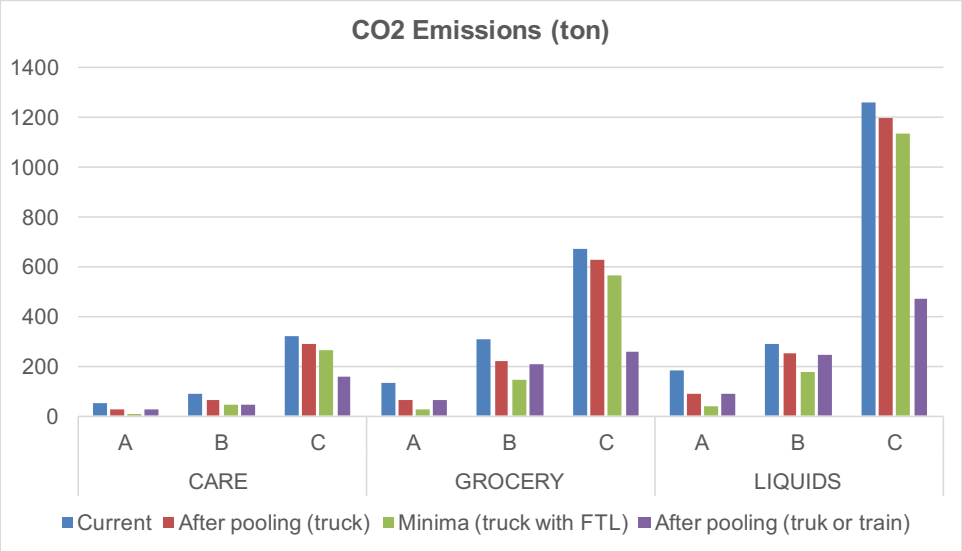


Figure 18. Performance of pooling in reducing CO_2 emissions

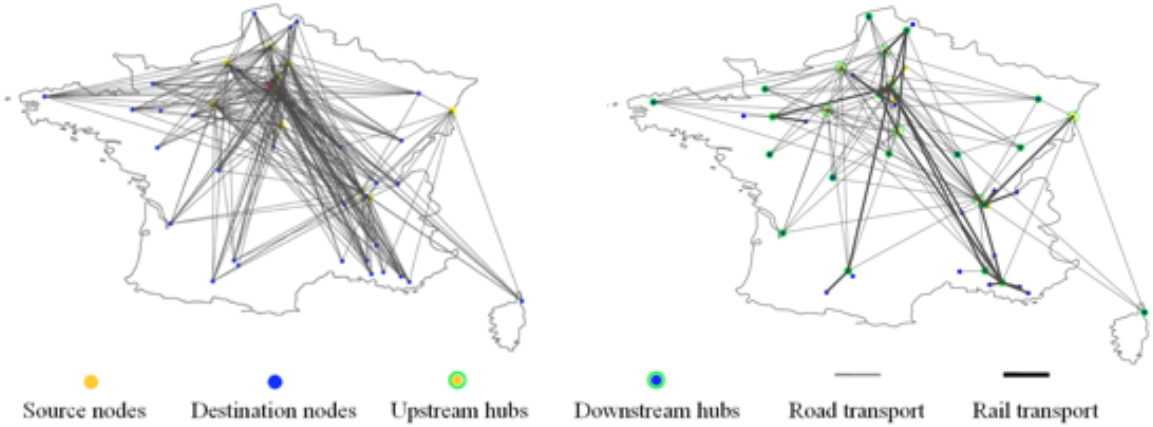


Figure 19. Example of network and flows movement before and pooling (by multimodal transport in group C of CARE product)

In the second study, published in Pan et al. (2014a), we investigate a major French retailer with its 154 SMEs suppliers of grocery products located in the same region in western France (see Figure 20). We were able to construct a database that contains the deliveries made between the suppliers (from regional factories or warehouses) and the 5 DCs of the retailer over a time frame of 33 weeks. As the case concerns only SME suppliers, the average weekly shipment per O-D pair varies from 5 to 11 pallets, which is much lower than a FTL shipment of 33 pallets. Therefore, three organisational pooling strategies have been proposed and studied in this study. The first strategy (S1) is that suppliers send only direct FTL shipments to a pooled warehouse, then products are shipped form the warehouse to the 5 DCs (mostly in FTL). This strategy is efficient in transport, meanwhile generates a very high inventory level at the warehouse. The second strategy (S2) proposes to use a pooled cross-docking centre, in which suppliers send direct (but not necessary in FTL) consolidated flows to the pooled cross-docking centre which serves the 5 DCs. Comparing to S1, S2 does not generate a high inventory level, but is less efficient in transport. The third strategy (S3) is based on S2 but proposes pooled vehicle routings to collect very small shipments from multiple suppliers. Figure 21 give a comparison of the three strategies comparing to S0 the status quo, in terms of

CO_2 emissions and logistics costs including transport and inventory costs. We can see that the pooling scenarios achieve a reduction between 18 and 44 % in CO_2 emissions but show different performances in terms of logistical costs. Nevertheless, S2 is the only one strategy outperforming the current situation in both criteria.

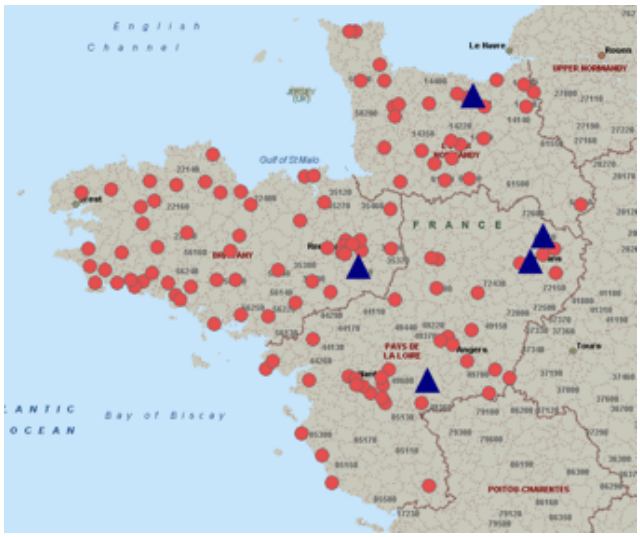


Figure 20. Suppliers' sites (point) and retailer's distribution centres (triangle) location

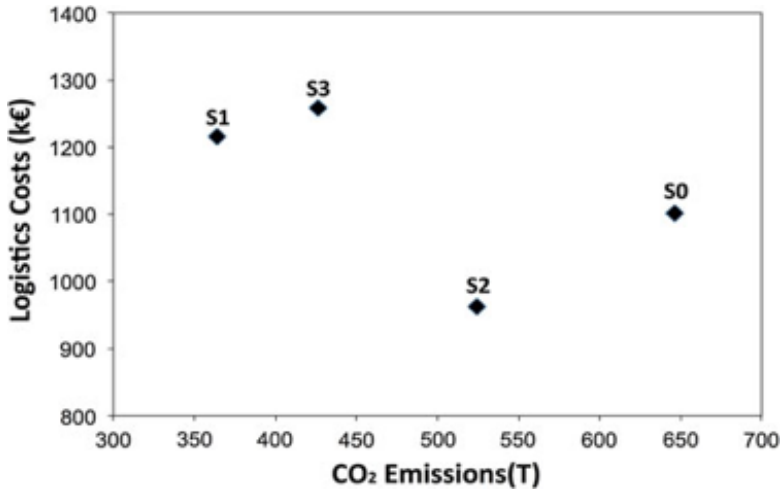


Figure 21. Scenario-based trade-off analysis between CO_2 emissions and logistics costs

3.2.1.3 Conclusion and limitations

The studies discussed above have made several signification contributions. First, the works are among the first who propose a piece wise linear function to accurately model CO2 emission from transport. As clarified, the emission function proposed is more adequate for assessing the performance of logistics pooling in transport. Second, the studies are among the first who initiate the concept of pooling and assess its performance of sustainability. The works prove that pooling is an effective and efficient solution to improve logistics performance, among all horizontal collaborative transport discussed in Chapter 2. Third, the works show possible implementation of the concept in real life FMCG chains. The concept has been further developed from theory to application in real world.

Several limitations exit in the works. First, all operational constraints are not taken into account in the optimisation models. For example, the capacity of pooled hubs or warehouse, on-site fleet management, investment budget. These operational constraints should be further

studied, especially at transport planning level. Second, the pooled network is optimised based on available datasets. Even in the first study having a large amount of data, the flows studied counts for approximately 20% of the national FMCG flows in France. It is plausible that a more comprehensive dataset would help to better illustrate the potential of pooling. However, computational complexity would also become more challenged.

3.2.2 Coalition formation and gain sharing

The next issue that we investigated are how to fairly share the common gains and how to build a stable coalition for the long-lasting collaboration. These research questions have been a part of a doctoral thesis that I have co-supervised (Xu, 2013), and have led to three publications (Xu et al., 2012a, b, 2013) and two research projects.

3.2.2.1 Problem description

The gain sharing problem, as well as the coalition formation and coalition stability problem is crucial to the success of pooling. It has been substantially studied via the approach of Cooperative Game Theory in the literature (see Chapter 2). However, dynamic collaborative environments have rarely been studied in games. Considering that the collaborative environments may vary during a long-lasting collaborative relationship like logistics pooling, we argue that the dynamicity should be investigated before establishing the collaboration. According to our expertise on the domain, there are at least two factors of high importance, i.e., coordination costs and collaborating actors' bargaining power. In general, coordination costs are extra costs that occur in a collaboration and which are required to start and ensure the collaboration (such as investment on information system, employees who manage the collaboration). Bargaining power stands for the power of every collaborator when negotiating gain sharing. Both factors can vary overtime in a collaboration.

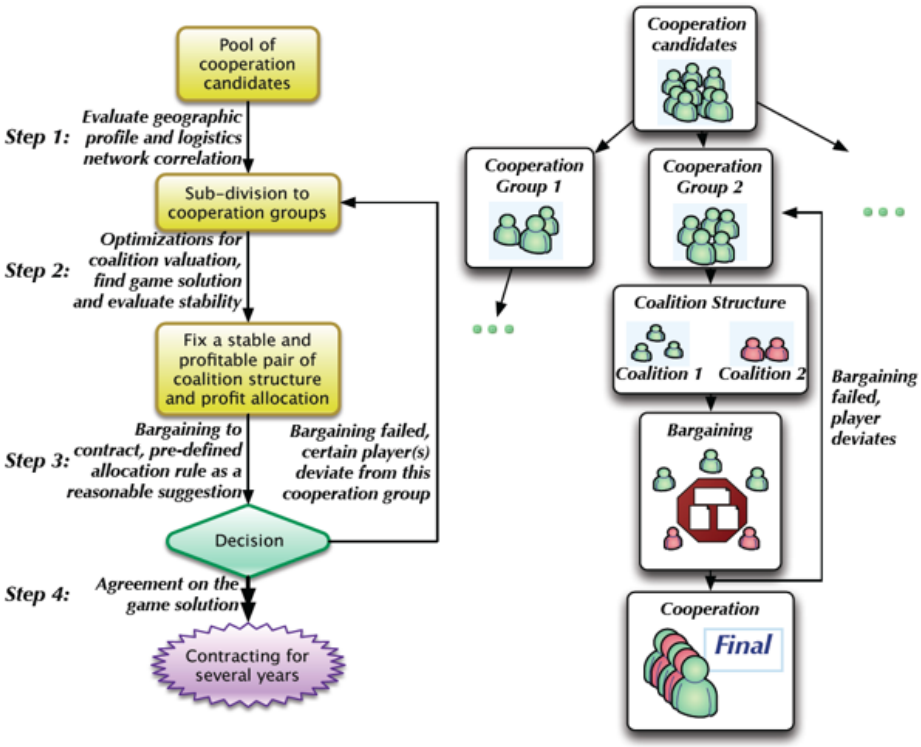


Figure 22. Cooperation model for logistics pooling

A new cooperation model is proposed in our research, taking into account the two factors (see Figure 22). The model is especially developed for supply chains pooling and it differs from

others in two aspects: consider sub-coalitions and multi-round negotiation. First, we assume that coordination costs would vary, for example from low to high. Assume that coordination costs are negligible, players are always willing join the coalition as it costs next to nothing. Thus, the grand coalition is always the reasonable and optimal coalition, i.e., a supper-additive game. However, significant coordination costs may turn a game from being super-additive to non-super additive if the increased savings cannot cover the extra costs of having new partners. Accordingly, the grand coalition could no longer be the optimal. Thus, finding the optimal partition of coalitions, i.e., grand coalition or a set of sub-coalitions, is necessary. We use coalition structure game to formulate the problem (Step 1 and 2 in the cooperation model). Second, we assume that the final sharing scheme would be set after serval rounds of negotiation; and it could be modified via renegotiation afterwards (Step 3). The reason is that the power of each play could vary overtime; and flexibility is necessary to cope with the dynamicity.

3.2.2.2 Results and impacts

Serving as decision making tool, a robust gain-sharing model is developed in our research, called contribution-and-power weighted value (CPWV) model. The model is at two steps. First, we allocate the gain based on players' contribution. The allocation vector is computed by Shapley value (SV), which is commonly proposed in the literature. Second, the vector of SV is modified by a bargaining power vector of player. Briefly speaking, a player with higher power could negotiate for more shared parts. Furthermore, the allocation scheme after modification should also respect the stability of the game. Accordingly, the CPWV is computed by a Mixed Integer Linear Programming model, see Xu et al. (2013).

Then, we integrate the coordination costs into the MIP model. We model the actual gain of a given coalition as $Gain_{actual}=Gain_{theoretic}-coordination\ costs$, where $Gain_{theoretic}$ is the transport costs saving after pooling, and coordination costs is a linear function in which a fix cost (cc) is multiplied by the number of players in the coalition. By that, we are able to vary the fix marginal cost to assess the impact of coordination costs on coalition stability. Figure 23 illustrates the simulation results when cc increases from 0 to 4000 (sufficiently high). As we can see, when $cc\leq530$, the grand coalition is always the optimal coalition structure, which is stable and the most profitable. The situation changes when $cc>530$ and player S1 has left the grand coalition, then when $cc>1854$ player S4 has also left to work alone. In the end, when cc>3929, no collaboration can be maintained, and the optimal structure is therefore singleton. From such example, we can see that coordination costs are not always negligible.

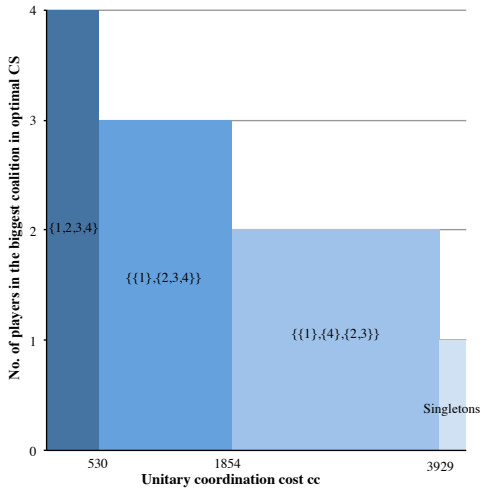


Figure 23. Optimal coalition structure submitted to variable coordination cost

The proposed model and methodology have been studied in two research projects: *Vegesupply* supported by F.U.I (*Fonds Unique Interministériel*) in France, and CO3 (collaboration concepts for co-modality in logistics) supported by the European program FP7. The cooperative model and the gain sharing model have well contributed to the success of the projects.

3.2.2.3 Conclusion and limitations

Our main contribution to this scientific issue is that we aim to develop cooperative modal including a robust gain-sharing model. The model takes into account the dynamicity of the collaborative environment in pooling which is long-lasting horizontal logistics collaboration, and provides solutions that are faire and stable, thus acceptable for players. The dynamicity investigated includes coordination costs and collaborating actors' bargaining power. The results reveal that the consideration of these factors may significantly influence the decision on coalition formation and gain sharing.

The main limitation of the proposed model, as the other similar ones, is the computation time. Since the proposed methods is based on Shapley Value, it is necessary to compute first the gain of every possible coalitions and the Shapley Value for the grand coalition. The problem is NP-hard. In the projects of application, the number of players is limited to 4. But for some experimentations with more than 15 players, the computational time becomes unacceptable.

3.2.3 Information and communications technology

In this research, we are interested in the question how IoT and ICT can help improve tractability or decision makings in collaborative logistics network. Our contribution (Pan and Ballot, 2015) to the issue is based on a research project concerning an experimentation of IoT-based solution in FMCG chains.

3.2.3.1 Problem description

In the project called *OTC KayPal®MR*, we aim to study how the concept Open Tracing Container (OTC) can help to improve the traceability of item in open supply chain like pooling, so as to facilitate the solution. OTC is pallet-like innovative returnable transport item. It can be thought of as two innovations. First, it is made from cardboard and can be easily recycled. This product has the advantage of being lightweight, eco-friendly, and low-cost. Second, for the sake of product real-time traceability, all OTC is equipped with a passive RFID tag and the information is published in a computing cloud environment according to GS1 EPCglobal standard. The EPCglobal standard enables direct publication to the cloud of all events captured from operations in a context enriched and a protected framework. The concept can thus be seen as an example of the application of IoT in logistics.

The concept has been experimented upon a pooled national FMCG network, having one factory of OTC that is the source of new OTC, 5 concentrators where OTC are repositioned to and stocked at, 23 collectors that regularly collect and consolidate OTC from retailers (without stock), and 6 warehouses (WH) of suppliers that serve 43 distribution centres (DC) of retailers with the use of OTC, as shown in Figure 24. In other words, OTC is only used between WH and DC with freight loaded. The rest of the network is to collect, stock, and recycle the OTC.

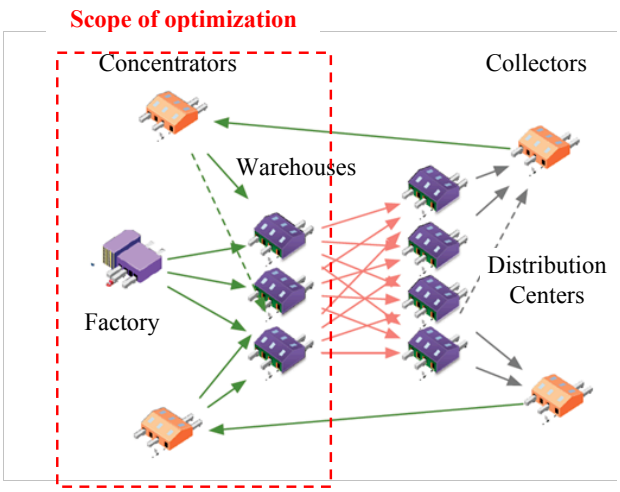


Figure 24. Illustration of pooled network with the use of OTC

Knowing that OTC are tracked and traceable on real-time within the network, and the information are shared between stakeholders, we assume that decision making on inventory or transport for example, could be more dynamic. One of decision making problem was studied in our work, which is the OTC repositioning problem that can be descripted as follows. At the beginning of each week, the quantity of OTC required for the freight flows between WH and DC should be determined. The quantity to be shipped depends on two factors: the freight flows, the remaining OTC on the site from last week. It is also assumed that an OTC used more than 6 times should be discarded to recycle. If there is not enough OTC at the concentrator level, requests should be placed to the factory. As a result, the repositioning problem is very complex for two reasons. First, the supply quantity is determined according to real-time information, for example the OTC stock level at the end of each week and the freight flows during a week. Second, for each week a WH can be served by any concentrator or factory. The decision depends on transport optimisation results. To tackle the decision-making problem, we have developed a closed-loop continuous time simulation optimisation model (see Figure 25).

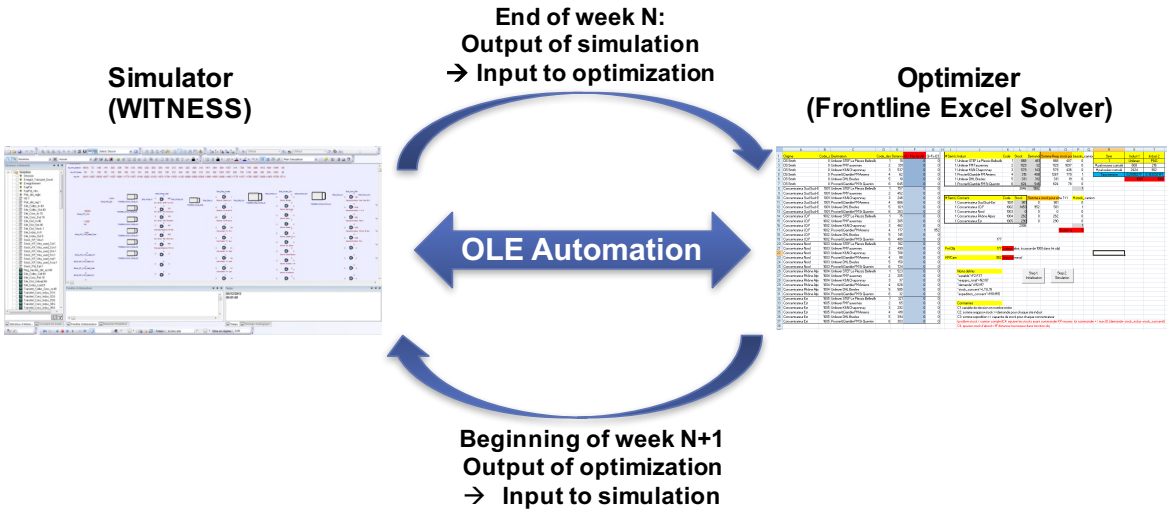


Figure 25. The proposed closed-loop continuous time simulation optimisation model

Basically, the model comprises two coupled models. On the one hand, we develop a simulator (upon Witness) to simulate the movement of OTC in the network, during the week n, with respect to the actual rules and behaviour of the network (e.g., OTC scrap rate, waiting time on site, etc.). The movements are recorded in order to compute some Key Performance Indicators

(KPI). On the other hand, an MILP optimisation model (upon Frontline Solvers) is developed to make decisions on the supply and repositioning plan (quantity and path) at the beginning of each week, according to the hebdomadal demands of OTC and the OTC inventory level at the end of last week. The simulator and optimiser are connected via OLE Automation, so that the model can be run continuously for any desired length of time. See Pan and Ballot (2015) for more information.

3.2.3.2 Results and impacts

As a work package of the project, my work was focusing on the decision-making tool development for OTC repositioning. With the use of the proposed simulation optimisation coupled model, two repositioning strategies were investigated through two scenarios, they are Sc1 - optimising transport distance only, and Sc2 - optimising transport distance and global inventory level (for faster turnover). Several KPI are computed to compared the two strategies, see for example.

KPI	No. Sc	Average	Max	Min
1. Average weekly transport distance (KM)	Sc1	64 943	98 606	36 522
	Sc2	65 034	98 495	36 576
2. Average number of rotation per OTC	Sc1	1,6	6	1
	Sc2	2,38	8	1
3. Average days per rotation of OTC	Sc1	57,35	119	7
	Sc2	26,17	91	7
4. Average KM per rotation	Sc1	665	1 894	30
	Sc2	719	2 024	40
5. Average weekly scrap rate	Sc1	1,77%	3,88%	0,48%
	Sc2	3,81%	9,80%	0,67%
6. Average daily global inventory level	Sc1	22 600	31 658	11 018
	Sc2	11 957	13 793	10 477
7. Average daily inventory level of WH	Sc1	3 971	6 968	1 642
	Sc2	3 921	6 968	1 642
8. Average daily inventory level of DC	Sc1	3 161	4 778	1 340
	Sc2	3 168	4 778	1 441
9. Average daily inventory level of collectors	Sc1	719	4 485	0
	Sc2	708	4 485	0
10. Average daily inventory level of concentrators	Sc1	14 750	26 320	2 803
	Sc2	4 160	7 261	1 116

Table 4. KPI comparison of repositioning strategies

Overall, we can see that the two strategies have comparative performance in terms of transport, see the transport-related KPI_1 and 4. However, strategy 2 clearly outperforms strategy 1 with regard to inventory level and turnover, see others KPI. The model and the results can therefore give instructive and practical guideline to the decisions on OTC flow management in the network.

3.2.3.3 Conclusion and limitations

In general, our contribution to the issue is that we have experimented the OTC, i.e., an IoT-based innovative RTI, upon a pooled FMCG network. The feedback is instructive and meaningful to the application of this kind of solution. Differing form theoretical research, our work was based on a research project closed to real-life application field. The industrial impact is thus significant. On the academic side, we also contribute to the modelling approach of coupling simulation optimisation model. The practicability of such methodology has been further shown and proved.

The main limitation of the work is that my personal contribution was limited to a work package concerning the modelling problem. Other constraints or technical issues, e.g. system architecture, information reliability, etc., have not been considering in my work, even though they have been studied within the scope of the project.

3.3 Contributions to Physical Internet

Since 2009, our research team including myself have been working on a breakthrough concept in logistics organisation, namely the Physical Internet (PI hereinafter) – the S6 introduced in Chapter 2. Our team has been taking the leadership of the research theme in Europe, in collaboration with other teams, mainly in US, China mainland and Hong Kong, and UK. We investigated the PI from definition to proof of concept, and from design to implementation. The topic has also been my core interest and main research activities over the last six years. Within our team, the research theme has yielded 5 doctoral theses that I have co-supervised with Prof. Eric Ballot (three of them defended in 2013 and in 2016, and two undergoing), as well as publications and research projects. The output and impacts of the research are significant.

To be aligned with the analytic framework (defined in Chapter 2), and to position my work, till now five scientific issues related to PI have been investigated by our team. The most representative related publications and projects in which I have been involved will be discussed here.

3.3.1 Collaborative network design

As the PI consists of a new topology of transport network that is collaborative, interconnected and decentralised, one of the first steps was to design a network prototype for exploration. The network design problem was mainly investigated through the thesis of Sarraj (2013), then published in Sarraj et al. (2014b) and in Ballot et al. (2012). Two international projects *Openfret* (Ballot et al., 2010) and PI simulation (Ballot, 2012) were also devoted to the problem. The project was leaded by our team in collaboration with Université Laval in Canada and EPFL in Switzerland.

3.3.1.1 Problem description

Aiming to build an interconnected logistics network, we firstly studied the digital internet which is a good example of interconnection of networks. According to a further analogy study, digital internet and PI have some strong similarities and some significant differences. With regard to similarity, both of them work on the basis of a network composed by open and shared nodes where flows are routed (network packets in digital internet or freight containers in PI). The nodes are namely router in digital internet and PI-hub in PI, respectively. Both of the networks provide good interoperability for multi-operator, since they rely on standards and protocols at system and network wide. As a result, they could have a very similar logical topology, see Figure 26 for example. As an illustration, each round in the figure can be considered as a subnetwork for a country (or for a region) for example. Within each subnetwork all nodes are interconnected (fully or not); and subnetworks are connected through some border nodes. The links stand for the routes to exchange flows between nodes or between subnetworks. On the other hand, digital internet and PI obviously have some differences, especially in terms of physical topology. The first one to be noticed is the time of transporting flows. In contrast to digital world, the time of transporting freight plays more significant, even crucial role in the physical world. Therefore, the location of PI-hubs will

have significant impact on the efficiency of the PI. Moreover, the reliability and traceability of transport is not an important issue in digital internet but in PI, since the latter deals with freight of value. Reader may refer to Sarraj et al. (2014b) for more details about the analogy study.

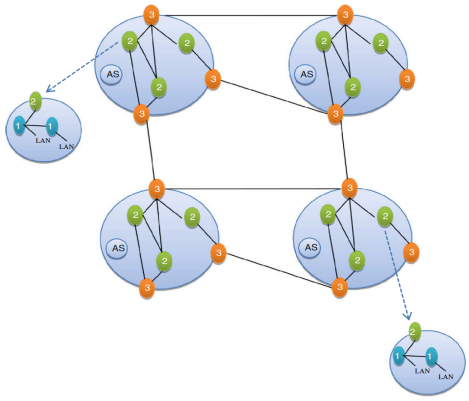


Figure 26. Topology of hierarchical interconnected network

After investigated the topology of PI network, the next step is to design a concrete one. To be aligned with the actual demands of transport, we employed the same database of two big retail chains in France used in 3.2.1 logistic pooling network design. The objective is to design an optimal network to connect source points (plants or WH) and destination points (WH or DC).

3.3.1.2 Results and impacts

Design an optimal PI network is indeed an optimisation problem. The number and location of PI-hubs – the decision variables – are to be optimised and determined, according to criterion of optimisation like KM, time or costs – the objective function. Since the dataset is very large and it is too complex to use a MILP model with exact algorithm, the optimisation problem was solved by a metaheuristic approach with evolutionary algorithm. More specifically, the PI network is optimised according to a cost function (of transport) and with the most important operational constraints such as maximum length of truck trips to avoid round trip in more than one driver shift. For details on the optimisation process, hub location and arcs determination, refer to Ballot et al. (2012) and Ballot (2012). Finally, a network of 47 hubs for road transport and 19 hubs for road-rail transport is designed, as illustrated in Figure 27. The network will serve as a transport network for the further research for example for transport planning, hub design, resilience of PI.

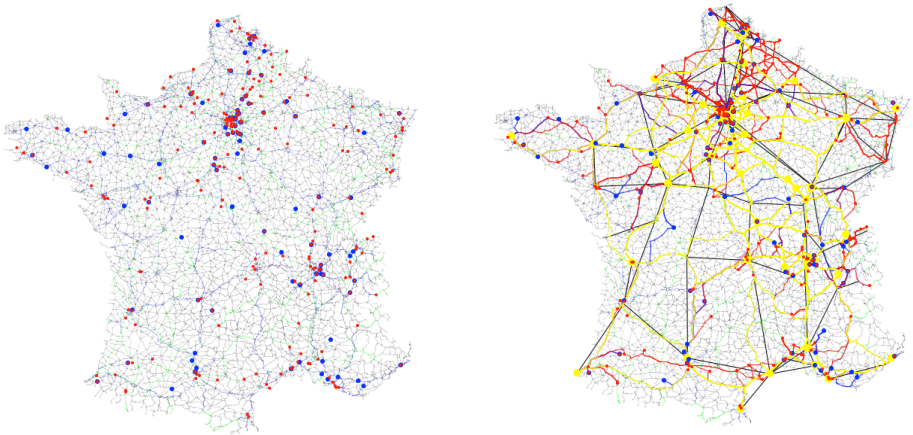


Figure 27. Left: location of plants/WH (blue) and DC (red); Right: network of PI with 47 hubs for road transport (hubs and arcs in yellow) and 19 hubs for road-rail transport (hubs and arcs in black) (from Ballot (2012) and Ballot et al. (2012))

As shown in Figure 27, every plant/WH/DC is connected to at least one PI-hub, and all PI-hubs are interconnected. The whole network contains over 13,000 arcs (road and rail) and 500 nodes.

3.3.1.3 Conclusion and limitations

This research work made two contributions to the development of PI. First, it envisions the topology of PI via an in-depth analogy between the digital internet and the PI. Second, it provides the first national-wide PI network for the next step of transport planning. Most importantly, this work for the first time demonstrates how a PI can be formed and how it looks like.

Nevertheless, the work has some limitations. First of all, the flows considered in the study represent only for two big retail chains in France, which approximately count for 20% of the national FMCG flows in France. Without mentioning the flows from other sectors such as automotive industry, construction, the flows considered are far from enough to construct an adequate PI to meet actual transport demands. The result, and the contribution is thus limited (to the two chains). Second, all operational constraints are not taken into account, such as infrastructure of sites, road capacity, land occupation.

3.3.2 Transport planning optimisation

Transport planning was one of the main topics in my research. Over the past 6 years I have mainly contributed to three research problems, they are freight routing problem in PI, resilient transport strategies in PI, and PI-inspired crowdsourced delivery for city logistics. This part discusses one by one the three problems and my contributions according to the framework in Chapter 2.

3.3.2.1 Problem description

Research Problem I – Freight routing in PI (Sarraj et al., 2014a)

Under the framework of PI, it is defined that freight is not conventionally transported directly from *A* to *B*, but encapsulated in standard containers and transported through a hub-based network in-between. The transport problem is thus very similar to network packets routing problem in digital internet. It is called freight (or container) routing problem in PI. There are two key optimisation problems here: routing path determination and freight consolidation.

Routing path determination consists of determining the optimal route from A to B through PI (if they are not geographically very close to each other). The criteria of transport optimisation could be time, costs, or CO_2 emissions. The problem can be generally termed as the shortest path problem. The is well known problem and finding the optimal solution needs a polynomial computation time that becomes long in a large-scale graph, for example in the PI network in Figure 27. The fact that the number of freight (containers) is over a million increases also considerably the computational complexity. For those reasons, we used the heuristic method A* for the shortest path problem in PI, which is the most popular among all heuristic algorithms for this problem.

Freight consolidation problem deals with consolidating freights (containers) to improve outbound transport means' fill rate at PI-hub. At each hub, freights are arriving asynchronously and continuously overtime. They can wait at hub for other arrivals to share transport means so to improve the fill rate. However, freights have different features of size, allowed waiting time (urgency), or next destination. Maximise transport means' fill rate is

indeed an optimisation problem (see Figure 28). In our work the problem is formulated as bin-packing problem and solved by greedy algorithm. In complementary, some protocols are also proposed to manage the priority of freight, for example, for a container the waiting time at a hub is limited to 3 hours.

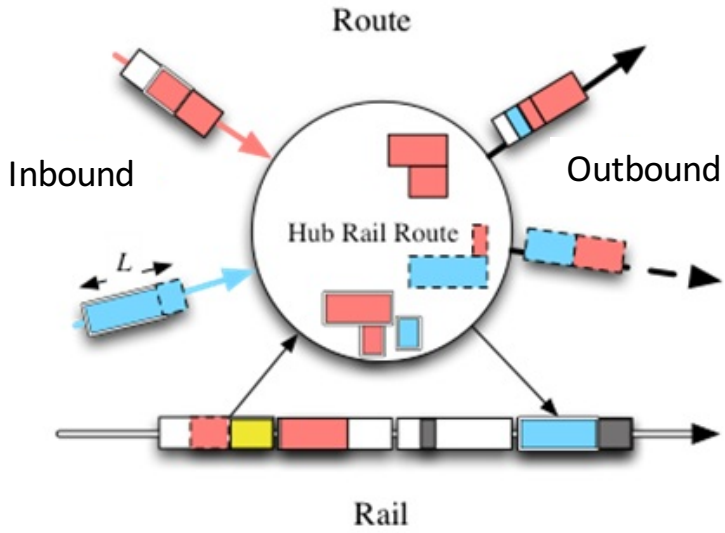


Figure 28. Freight consolidation optimisation problem in multimodal PI-hub

The two optimisations were investigated conjointly in the transport planning issue in PI. A multi-agent simulation model was developed and coded on the software *Anylogic*. Simulation results will be resented in the next section.

Research Problem II – Resilient transport strategies in PI (Yang et al., 2017a)

As an extension of the previous research problem, the research about resilient transport strategies is interested in taking the use of PI as a solution to enhance logistics networks resilience. We explored the PI network designed above as example. Then, on top of the simulation model and transport planning solutions developed in *Problem I* above, we further consider disruptions at hub level, such as earthquake, inundation, fire, strikes. Disruptions at hubs (the 47 hubs for road and 19 hubs for road-rail) are considered and formulated by a two-state Markov process, with a probability of breakdown α_i and a probability of repair β_i. However, the impact of disruption could be different according to cause. A set of disruption profiles is designed for investigation, as summarised in Table 5.

#	Probability of breakdown	Probability of repair	Av. During (hour)	Lost capacity of PI	Description
0	0%	100%	0	0%	No disruptions
1	1%	30%	3,2	3%	Rare, very long
2	5%	50%	1,9	9%	Rare, long
3	5%	70%	1,4	7%	Rare, mi-long
4	10%	50%	1,9	17%	Less frequent, long
5	10%	70%	1,4	13%	Less frequent, mi-long
6	20%	50%	1,9	29%	Frequent, long
7	20%	70%	1,4	22%	Frequent, mi-long
8	20%	90%	1,1	18%	Frequent, short

Table 5. Scenarios of different disruption profiles

Faced with the disruptions, two resilient routing protocols are proposed to mitigate disruption:

Risk avoidance - which avoids all the disrupted hubs for the routing. That is, if there is disrupted hubs in the path of the container, the container will route with another path without disruptions. This strategy may mitigate the delay caused by disruptions but may augment logistics costs.

Risk-taking - under this strategy, the disrupted hubs will be considered with an estimated penalty time for the path finding. If the routing agent finds that disrupted path remains to be the best path according optimization criteria, then the containers will continue using the disrupted path and take risks. From the analysis, the strategy enables the routing agent to find global optimal routes but may also results in possible delay because of unpredictable long disruptions.

Then, both disruption profiles and resilient routing protocols are integrated into the multi-agent simulation model introduced above. The results are presented in the next.

Research Problem III – PI-inspired crowdsourced delivery (Chen et al., 2017)

In this research work, we tackled the transport planning problem at city logistics level. In particular, we were interested in the problem of reverse logistics in E-commerce context. The stake and significance of the problem was argued in Pan et al. (2015a) and in Chen et al. (2017). We studied the reverse flows collection problem which is part of reverse logistics, as shown in Figure 29. Comparing with the forward flows, the collection problem of reverse flows (returned goods) has its own characteristics: low-added value, same destination for items from the same retailer, flexible delivery time and so on. Moreover, it is believed that the returned goods collection problem is becoming a more and more notable issue of sustainable development to city logistics. This problem is particularly observable in metropolitan areas, not only due to the economical preoccupations such as pick-up costs, but also the environmental footprints such as CO_2 emissions, energy consumption, traffic congestion and the social impacts such as the wastes of the impulse buying and reducing the incitation of online shopping. In such context, this work seeks to propose an alternative sustainable solution to the problem, especially at large cities.

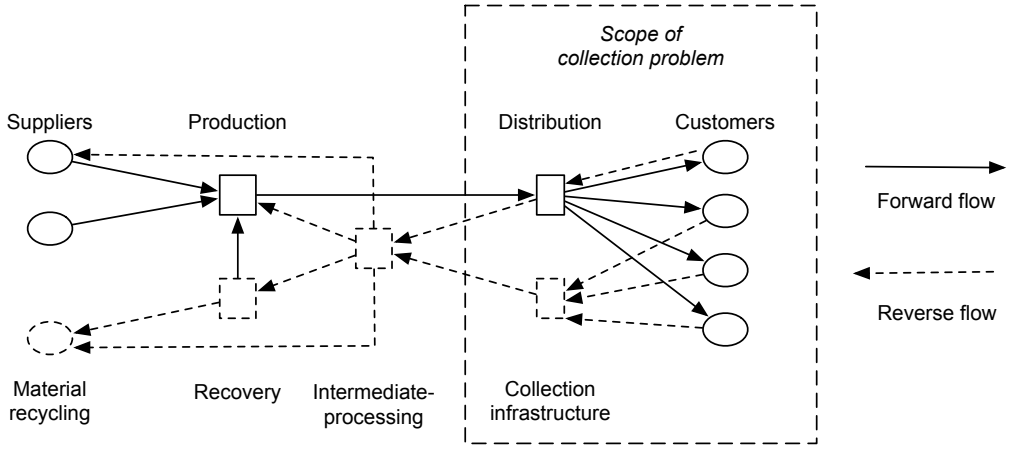


Figure 29. Example of the logistic network with forward and reverse flows (Bostel et al., 2005)

The solution proposed is to use taxi (with passenger only) in city to collect reverse flows at the same time, by using shops as collection points. It namely is a crowdsourcing solution (Carbone et al., 2016). We selected only taxi with passenger because, on the one hand it would barely generate extra externality to collect flows; on the other hand, it would not influence the drivers' behaviour (ex passenger-hunting strategies etc.). Motivations are detailed in Chen et al. (2017). At the first step, we wanted to investigate the performance of

such solution. A data mining based simulation model is developed for that purposed. Results will be presented later.

3.3.2.2 Results and impacts

Research Problem I – Transport planning in PI

To assess the performance of PI on transport, a multi-agent simulation model is developed to simulate the transport with or without PI. We used the network defined above as an example of PI, and the flows of the two retails chains in France introduced above as input data for the simulation. Further, some scenarios of simulation are defined as follows:

- S0: the current logistic network without PI;
- S1: the current logistic network with PI of road-only transport;
- S2: the current logistic network with PI of multi-modal transport. Road and rail are the two transport modes studied, knowing that in France electrical trains are much less polluting than trucks.
- S3: logistic network with direct flow from plant to DC (removing WH). It is assumed that PI would enable adequate transport services so that WH would be no more necessary as upstream consolidation point.

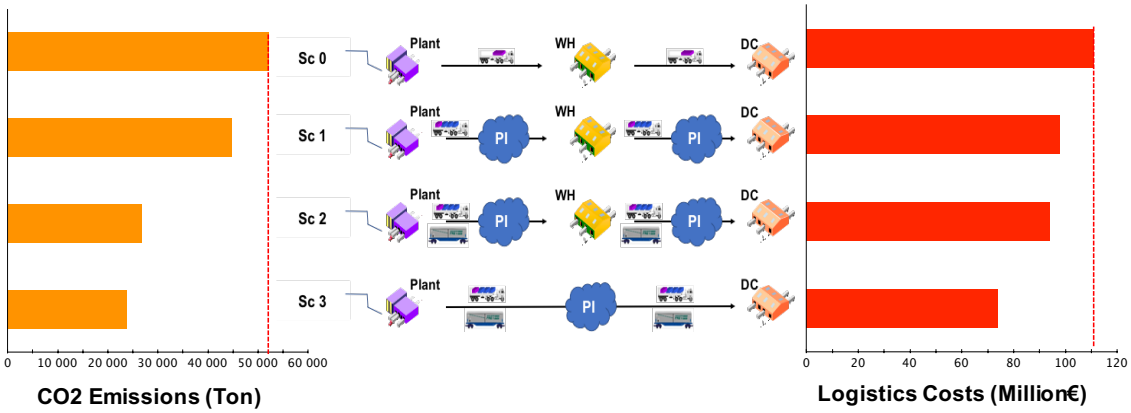


Figure 30. Scenario-based simulation results

Figure 30 illustrates and compares the simulation results of all scenarios. Here we briefly display logistics costs and CO_2 emission (other KPIs such as transport time, waiting time in hub, containers used, fill rate of containers or transport means etc., are also computed and compared in Sarraj et al. (2014a) and in Sarraj (2013)). According to the results, PI is an efficient and effective solution to reduce logistics costs and CO2 emissions. Its advantage is even greater with multi-modal transport, since PI enables the possibility to consolidate freights to mobilise high-volume but eco-friendly transport means like train. The last scenario Sc3 without WH envisions a future evolution of the current logistics network, enabled by PI.

Research Problem II – Resilient transport strategies in PI

We aim to demonstrate how PI can improve resilience for logistics networks faced with divers disruptions. We used the performance ratio to illustrate the performance, which is calculated by (A-B)/B to compare scenario A to scenario B. All scenarios are simulated based on PI network. Each scenario is defined as (routing criteria, resilient protocol, disruption profile). In other words, we have totally 32 scenarios with disruption. All of them is compared with the corresponding scenario without disruption, for example, scenario (minimise distance, Risk avoidance, disruption profile 1) compared with (minimise distance, Risk avoidance, disruption profile 0). Moreover, performance ratio can be compared in terms of different KPI,

such as total logistics costs, CO_2 emissions, and total time. All results are presented in Figure 31.



Figure 31. Performance ratios of PI with disruptions to PI without disruptions (top: total logistics costs; middle: total CO_2 emissions; down: total lead time)

First, the results show that, thanks to the dynamic and resilient protocols, the performance of PI is slightly perturbed compared to the significant loss of capacity caused by disruptions. Even in the worst case where PI lost 29% of its capacity (percentage of unserviceable time of the whole network), the disruptions will cause maximum 4.3% additional total logistic cost, 9.6% additional total CO_2 emission and 1,83 over 8 hours' delay of delivery of containers. That is, if customers accept 1.83 hours' delay, the performance of PI on transport is barely perturbed by the disruptions. Second, we can see that there exists no dominant strategy for all scenarios. It depends on the nature of disruptions as well as the objectives of services. For example, if customers expect shorter lead times, it would be better to adapt risk avoidance strategy and minimisation of time as the routing criteria. If the network is exposed with frequent random disruptions at hubs such as machine breakdowns, the transport protocols with risk-taking strategy may result in less expenses and emission.

Research Problem III – PI-inspired crowdsourced delivery

To simulate the proposed crowdsourcing solution, we first conduct the qualitative and quantitative study, and further investigate the feasibility and viability of the solution based on

three real-world datasets. There are three datasets needed for the simulation. The first one is the actual taxi mobility. For that, we model taxi mobility by mining taxi GPS trajectory data to plan citywide delivery routes. We were able to find and work on an open dataset of one-month taxi GPS data (January in 2010 in Hangzhou in China), having more than 7000 taxi fleet and over millions of trajectories. Then data mining techniques were employed to find out the most reliable routes for collecting flows (only trajectories with passenger). The second dataset required is the collection network, which basically consists of locations of shops and a road network. To be aligned with the taxi dataset, we selected Hangzhou city in China (15km*30km). From Google and Baidu, it was possible to create a map of all roads and shops (>3000) in the city, from which we can pick one for each driven direction of each road. Accordingly, 852 shops were selected (2 shops by segment) and 1 DC as the destination of flows nearby the airport (see Figure 32). Finally, the third dataset required is the reverse flows. Knowing that we were not able to find any real-life dataset, random package service demands were generated for the simulation. As one month simulation has been run in Matlab, 2000 packages (demands) were generated during a month (2,8 requests / hour). Each demand is defined as <*origin, destination, time of birth*>.

Inspired from the freight routing problem in PI, we assumed that a package can be delivered by one or several taxis in sequence to reach its destination, i.e., package is routing at city by relay between drivers. Three routing strategies were proposed:

- Destination-Orientated Spreading Strategy (*DesSpreading*), that contains two phases, including Offline Routing Path Identification – *determine the optimal path according to historical data* – and Online Taxi Scheduling – *assign the optimal taxi for a package according to real-time information*.
- First-Come-First-Service (*FCFS*) Strategy. FCFS strategy assigns the package to the first taxi that will pick up a passenger near the package collection station that the package locates, regardless of its destination.
- Destination-Closer (*DesCloser*) Strategy. DesCloser strategy assigns the package to the first taxi heading to somewhere closer to the destination of the package, compared to the current station of the package.

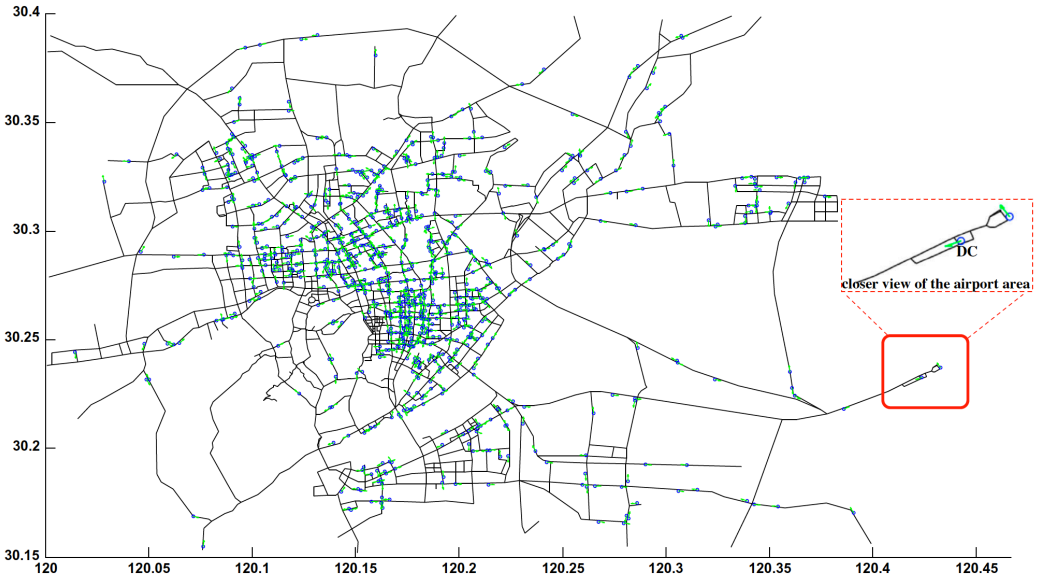


Figure 32. 852 shops and the selected DC near the airport located in the city of Hangzhou (x =latitude and y =longitude)

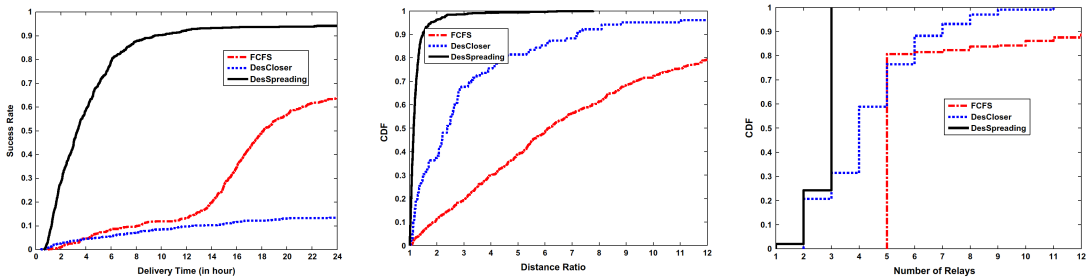


Figure 33. Simulation results of the three strategies (left: success delivery rate in terms of delivery time; middle: cumulative distribution function of delivery distance ratio; right: cumulative distribution function of the number of relays)

Simulation results of the three routing strategies are presented in Figure 33. Overall, we can see that *DesSpreading* strategy (black line) outperforms others in all terms. Regarding success rate, with *DesSpreading* collection strategy, almost 80% of packages can be delivered to the DC within 6 h, and over 90% delivered within 24h. For *FCFS* strategy, we observed that most of packages cannot be delivered within 14 h. For *DesCloser* strategy, the success rate is no more than 15%, even if the given time duration is set to 24 h. Regarding distance ratio that is the ratio of routing distance on direct distance, with *DesSpreading* strategy most of packages travelled around 1.3x longer than the direct distance; and only less than 5%, travelled more than 3x longer than the direct distance. It obviously outperforms other strategies. Looking at the number of relays, we can find that the number of relays for *DesSpreading* strategy is always less than 3, thanks to the offline-online algorithm. As a comparison, *FCFS* strategy needs the biggest number of relays, and even around 10% of packages need more than 12 relays. This is because *FCFS* strategy assigns the package delivery task to the first coming taxi and does not consider its heading destination, thus the package can move back and forth towards the destination, resulting in many unnecessary relays.

Following this work and the results, we are now studying on using taxi, or private passenger cars for freight delivery. An international project called Crowd-delivery in collaboration with Chongqing University in China is funded by China NSFC. Further research outputs and impacts are highly expected.

3.3.2.3 Conclusion and limitations

Research Problem I – Transport planning in PI

Our main contribution to Problem I is twofold: first we firstly identify a new transport planning problem, i.e., container routing problem, upon an innovative logistic organisation of PI. Second, we propose transport protocols to deal with the problem, and investigate the performance through a multi-agent simulation model.

There exist some limits in this work. For example, the simulation study does not consider fleet management issue at hubs. The operational problems, like availability of transport means, vehicle types, scheduling problem etc., were not considered. Second, the repositioning problem is not studied. How the proposed protocols impact on backhauling should be further studied.

Research Problem II – Resilient transport strategies in PI

Close to the Problem I, this research contributed to the PI by quantitatively investigating its resilience performance in transport. By that, we also aim to indicate a novel approach to build a resilient distribution system.

The major limit of this work is that all important real-world practices are not taken into account, for example, priority in transport or inventory management (not always FIFO), freight traceability at disrupted hubs, sourcing strategies. The proposed resilient protocols should be shaped to more adapt to the reality before application.

Research Problem III – PI-inspired crowdsourced delivery in city

Different to the former works, the Research Problem III deals with transport planning at city logistic level. One of the current challenges to city logistics is to create the synergy between freight flow and passenger flow. Motived by this problem, we propose a taxi-based crowdsourcing solution for collecting reverse flows in large cities, with routing strategies and planning algorithms proposed. The work provides the first quantitative study demonstrating the performance of such solution, as well as a valid methodology for the next steps.

The work is concerned with some limits. First of all, the solution proposed is only for the large cities with large fleet of taxi. Otherwise, we should consider another type of crowds. Second, in the simulation study, the size of package and the place available in the taxi are not considered. Besides, it is assumed that each taxi can take only one package, due to the second limit.

3.3.3 Mechanism for exchanging request

Under the framework of PI, transport requests can be exchanged (subcontracted) from one carrier to another at hubs for being exchange points. By that, PI hub can be thought of a spot marketplace of transport requests, where (shippers or) carriers place on-hand requests to which other carriers answer. By such setting, the mechanism of the marketplace plays vital role for the functioning of the PI system. Because if the mechanism is not adequately deigned, the exchanging of requests may lead to the loss of efficiency, then the loss of incentive to collaboration. The request exchange mechanism design problem has been part of our research topics since 2010, and there theses were devoted to the research problem (one (Xu, 2013) defended in 2013 and two undergoing). The research also led to several publications (Pan et al., 2014b; Qiao et al., 2016a, b) and a research project called *PI-comodality* funded by ANR in France from 2016.

3.3.3.1 Problem description

In a PI hub or in a spot transport marketplace, there are two main questions concerned in the transport service procurement problem (TSPP): how to procure and at what price. The former is investigated via mechanism design approach, and the latter via dynamic pricing approach.

Research Problem I – Rules based auction mechanism in PI-hub

For transport service procurement, the literature resume that there exist three main procurement mechanisms: catalogue, negotiation, and auction (Caplice, 2007). As in PI the TSPP is in short term and relying on real time information, auction mechanism has been seen as an adequate mechanism for that. However, traditional auction mechanism deals with local decision-making problems without respecting system-wide objectives. It is particularly an issue to request exchanging between carriers, i.e., collaborative TTP. Our work argued that, to ensure transport effectiveness and efficiency of all shipments in PI, network-wide common objectives have to be respected when making local decisions on request exchange, for example ensuring promised service to shippers, improving global transport efficiency, and finding individually and collectively desirable solutions. The common objectives are

formulated and called *collaborative rules* of PI in our work. Four collaborative rules are designed:

- Rule 1: Allow the reallocation of requests and enable the co-delivery of requests.
- Rule 2: No halfway drop-outs. A bidder should submit a price (for allocation or reallocation) that covers the entire route from the point of auction to the final destination. If no reallocation is possible, the carrier must be able to deliver the shipment to its final destination at the proposed price.
- Rule 3: Maximize individual and global profit. If there is more than one carrier offering a better price, the shipment should be allocated to the lowest price. Once a price is promised to a shipper, it cannot be increased while shifting the request(s) from one carrier to another.
- Rule 4: Incentive for reallocation. Collaborating carriers may share common gain generated by the collaboration.

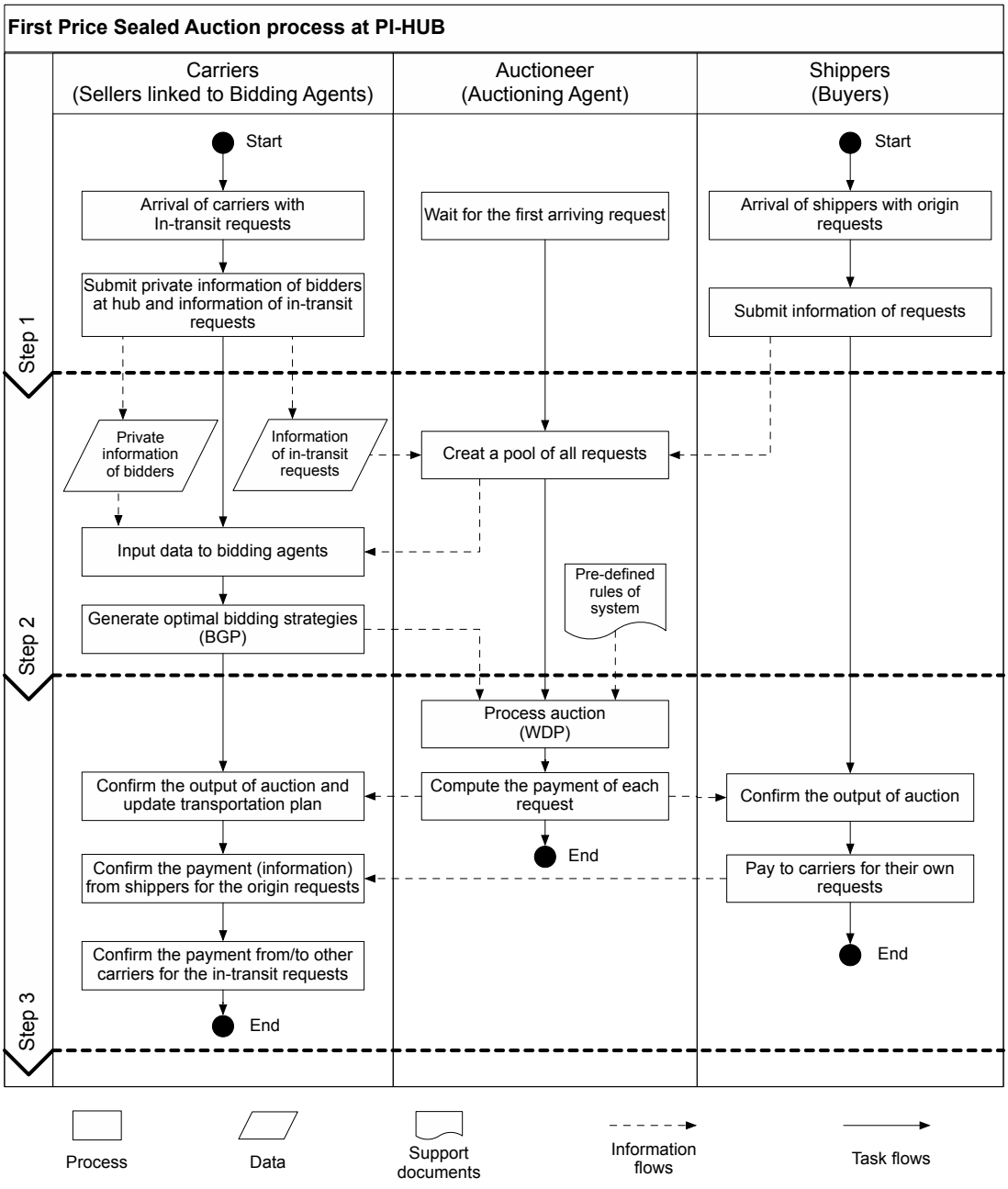


Figure 34. Cross-functional flowchart of the auction process at PI-hub

Then, the four rules are integrated into a first-price combinatorial auctions for the collaborative TSPP (see Pan et al. (2014b)). Figure 34 explains how auction process happen at hub. An optimisation-simulation model has been developed on Mathematica to assess the practicability of the proposed solutions. Results will be presented later.

Research Problem II – Carrier pricing strategies at PI-hub

The second problem investigated is pricing. From the point of view of carriers, their concern could be how to propose prices for requests to maximise their revenue that is determined by the proposed price and the probability of winning the request at that price (see Figure 35 for example). The particularity here is that the transport requests in PI-hubs are highly dynamic and stochastic: they are mostly in LTL (containers) with stochastic features such as arrival or departure time, size, destination, and scheduled lane (routing). Meanwhile, carriers also have some dynamic and stochastic features such as capacity, departure time (waiting time), predefined destination. The current pricing practice of fix price list is therefore challenged. In our works, we propose a dynamic pricing model based on an auction mechanism to optimise the carrier's bid price (Qiao et al., 2016a, b).

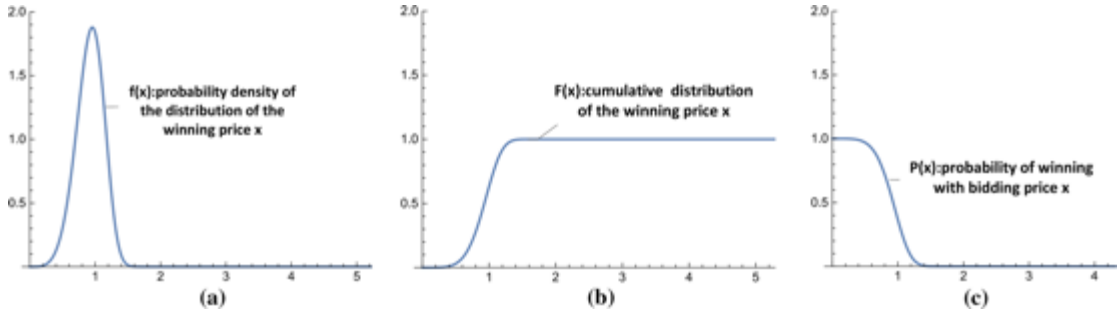


Figure 35. Probability of winning expressed as a Weibull Distribution (a: Probability density of the distribution of the winning price x; b: Cumulative distribution of the winning price x; c: Probability of winning with bidding price x)

3.3.3.2 Results and impacts

Research Problem I – Rules based auction mechanism in PI-hub

Four scenarios are designed for the study, as shown in Table 6. As the same setting to each scenario, we consider a simple network of 6 connected hubs. We set 10 rounds of auction, for each 5 new requests with different size are entered to be auctioned (see Pan et al. (2014b) for more details). The requests will be re-auctioned when arrived at the next hub. The four scenarios are defined as:

- S1: this scenario aims to compute the theoretical minimum transport cost to fulfil all requests in the study, called the *MiniCost*. This theatrical lowest cost can help us to define the bottom line of the case and to assess the performance of our model.
- S2: the second one, called the Auction without PI scenario, is to simulate the auctioning scenario without transhipment - without the PI. We therefore use S1 as the lower bound and S2 as the upper bound in the case to assess the performance of the PI with the proposed Combinatorial Auction models.
- S3: that focuses on a situation in which carriers may reallocate their on-hand requests to someone who submits a lower price for the requests. Accordingly, requests will be assigned or reassigned to achieve the global optimal solution via auction. Nevertheless, the payment rate of a single request may be increased during reassignment.

- S4: the only different between S3 and S4 is the consideration of the constraint of payment rate superiority (i.e., rule 3). When the rule is valid, carriers are allowed to sub-contract their on-hand request(s) to other carriers only if the payment rate of the request(s) is not increased after being reassigned.

Scenario	Assignment	Presence of PI	Reallocation of request	Payment Rate Superiority	Cost (€)	Difference to S2
S1. MiniCost	Lowest cost	No	No	No	41345	-7.6%
S2. Auction without PI	Auction	No	No	No	44751	/
S3. Without Payment Rate Superiority	Auction	Yes	Yes	No	43226	-3.4%
S4. With Payment Rate Superiority	Auction	Yes	Yes	Yes	43398	-3.0%

Table 6. Scenarios of collaborative rules and results of transport cost

Results are presented in Table 6, Several elements require our attention. First, S1 and S2 together may identify the maximum reduction of cost in our case, which is 7.6%. Second, with the use of the PI, S3 and S4 provide, respectively, a reduction of 3.4% and 3%, that are approximately being half of the maximum. Third, S3 has slightly higher reduction of cost than S4, which is a 0.5% difference, due to the violation of the constraint of payment rate superiority. However, in S4 transport cost of every request is never increased at reallocation, while in S3 this is not guaranteed.

Research Problem II – Carrier pricing strategies at PI-hub

To solve the pricing decision-making problem to carriers in PI-hub, we proposed dynamic programing optimisation model. The model is based on recursive functions that calculate the carrier's expected maximum profit, by determining the optimal price for each request. Two pricing strategies were also tested in the experimental study, they are: (1) Unique Price, in which it is assumed that the carrier bids the same price for each request. The optimisation result is the optimal bidding price x^* for all requests; (2) Variable Price, in which the carrier bids different prices for each request according to their status, i.e. the remaining capacity or the remaining number of requests. The optimisation result is a set of optimal bidding prices $\{x_i\}^*$ for each request r for each status. Then, an experimental study of one-leg transport (from *A* to *B*) is conducted to test the proposed model and investigate the strategies. Moreover, the impact of three influencing factors on pricing decision is also studied: quantity of requests, carrier capacity, and carrier transport cost.

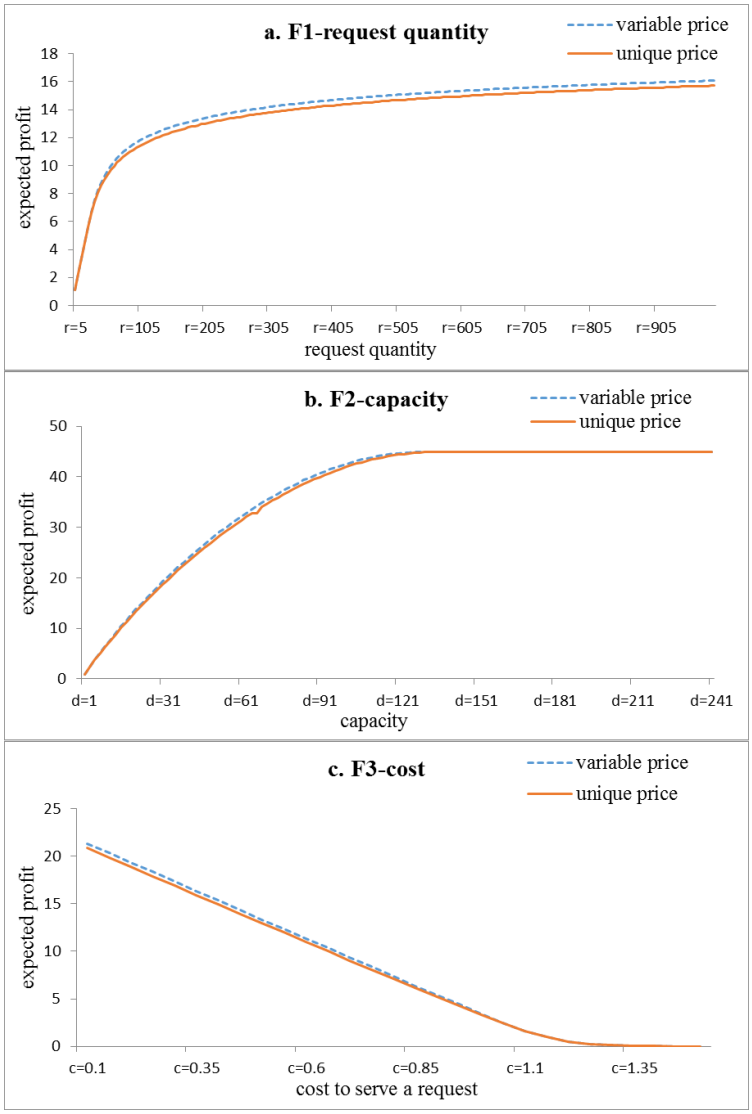


Figure 36. Expected profit of strategy Unique price vs strategy Variable price

Figure 36 demonstrates how the two strategies perform under the variation of the three factors, as part of the experimental results from Qiao et al. (2016a). The first remark is that the two strategies have very similar performance on expected profit. Regarding the quantity of requests, carrier's expected profit increases with the number of requests. However, the rate of increase decreases, dropping dramatically after request number > 125. This result is helpful for carriers with a fixed capacity. If they knew (or could estimate) the number of requests in each PI-hub, they would be able to select the PI-hubs with the highest rate of profit increase. Regarding carrier capacity, when the capacity increases, the profit increases as well. However, beyond a critical point that was always close to the quantity of requests, the profit is almost stable. This can be explained by the fact that if request number is greater than carrier capacity, the dynamic program will stop once all the requests have been auctioned. Regarding transport cost, as expected, the profit decreases concomitantly toward to zero with the increase of transport cost. The results can help carriers analyse the impact of the variation in their actual costs on the expected profits and pricing strategy.

The first results are very insightful for a trucking company who is thinking to improve their pricing strategy, especially for their online spot transport platform. The research work is undergoing through a research project with the company. More industrial impacts are highly expected.

3.3.3.3 Conclusion and limitations

Research Problem I – Rules based auction mechanism in PI-hub

The main contribution of this work is that it was the first one who advocated to design collaborative rules for PI that is thought of as a collaborative transport network. The result proved that the rules could have significant impact on global or individual efficiency of the transport requests in PI. The work also contributed to the development of auction mechanism in transport. We extended the traditional auction models by taking into account system-wide rules, so that they can be used for local decision making with respect to common global objectives of all participants.

Some improvements related to the model can be expected in the next steps. For example, only transport cost is considered in the current model. Other aspects, such as the reputation of carriers, the expected delivery time or other hidden costs, can also be complementary criteria in the auction model. Moreover, the collaborative mechanism between carriers or shippers, such as side payments or gain sharing mechanisms should also be refined. Who takes charge of the extract costs of reallocation (handling, loading/unloading etc.) is also a relevant issue.

Research Problem II – Carrier pricing strategies at PI-hub

This work contributed significantly to research on pricing in freight transport, as well as to research on the PI. Firstly, the research introduced and defined a new dynamic pricing decision problem in PI environment, which is different to and more complex than the traditional pricing problem in the freight transport industry, and so a new problem has been identified and investigated. Secondly, we also contributed to research relating to pricing policies in the LTL transport industry, for which the literature is currently very limited. Finally, the works provided the first research on the pricing problem of transport in the Physical Internet. The decision-making tool proposed, as well as the conclusions from the experimental study, will provide some useful guidelines for future research.

This work has a main limitation that there is no real-world auction data available. Therefore, an assumption was made regarding the distribution of the winning price. This assumption should be validated once real-data become available. Also, the work dealt with a simple situation of one-leg transport. The model could be extended to other problems of multi-echelons, or of destination selection for example.

3.3.4 Collaborative distributed inventory management

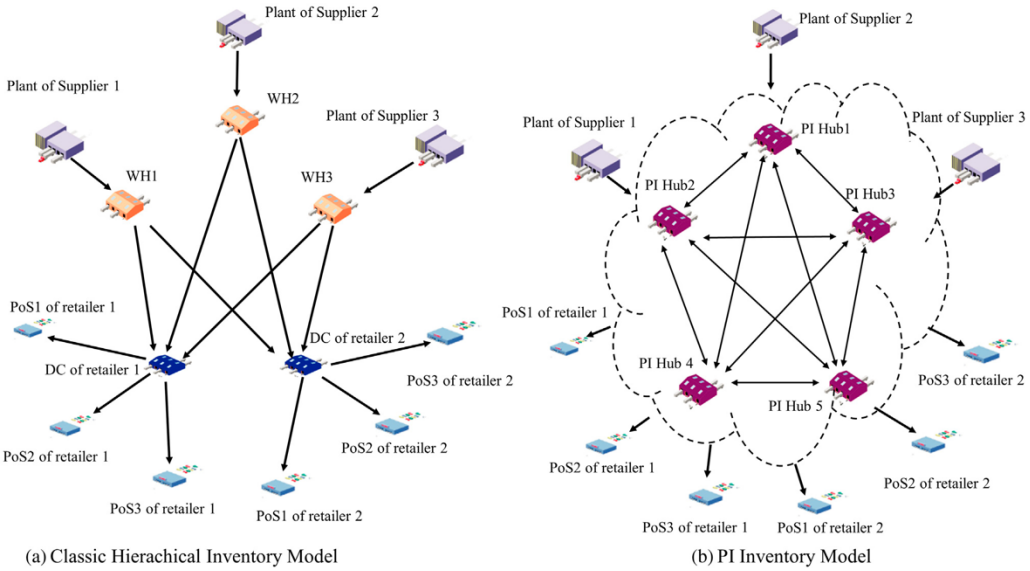
Transport and inventory are the two most important parts in logistics, and they are usually jointly studied. The former research works have proven that PI may improve transport service. We were then interested in the question that whether the interconnection of networks might also improve inventory management. The research works started at 2014, through a doctoral thesis defended in 2016 (Yang, 2016), co-supervised by Prof. Ballot and myself.

3.3.4.1 Problem description

Two problems of inventory management in PI have been studied: innovative inventory control model (Pan et al., 2015b; Yang et al., 2015b, 2017b) and resilience of PI in inventory control (Yang et al., 2017c).

Research Problem I – Innovative inventory control model in PI

Thanks to the openness and interconnectivity, it is assumed that PI would allow users to position stock anywhere in the network and also provides open multi-sourcing options for orders with on-demand warehousing services within PI. Taking FCMG as example, Figure 37 compares the current classic hierarchal distribution network and PI-base distribution network. Within the classic network, once the network has been defined, the storage points (WH or DC) as well as replenishment schemes are fixed and dedicated, resulting in the current predetermined hierarchical multi-echelon inventory systems. In contrast, within PI order can be placed to any storage points (PI-hubs) as inventory repositioning between hubs is allowed. Moreover, the stocking locations of a given product are alterable according to replenishment plans for a given time horizon. Because all sites in PI are open and shared, users can select the best stocking location according to the variation of demands from time to time. Consequently, replenishment schemes in PI are highly dynamic; and inventory decisions in PI thus become very complex.



(a) Classic Hierachical Inventory Model (b) PI Inventory Model

Figure 37. Comparing of FMCG distribution system in current classic network and in PI

Our work investigated the PI-enabled vendor-managed inventory (VMI) problem and aimed to propose innovative inventory control model. In traditional VMI problem (and under uncertainty (Marquès et al., 2012)), once the network as well as replenishment scheme is defined, vendor should determine the optimal replenish strategy, for example to determine the optimal *(R,Q)* value that means a replenishment order Q is placed when the inventory level drops below a reorder point R. The value of *(R,Q)* are often fixed for long time. Differently in PI-based VMI, as for every order the sourcing point is not preassigned, vendor should simultaneously determine the value of *(R,Q)* and sourcing point. And the value of *(R,Q)* could be different according to the sourcing point selected. The optimisation problem is thus much more complex. A non-linear simulation-based optimisation model is thus proposed to solve the problem. *(R,Q)* and sourcing point for each order are the decision variables to the model, and the objective function is to minimise the total logistics cost composed by inventory holding cost, transport cost, handling cost, ordering cost, and penalty cost (if shortage of inventory). Experimental results will be presented later. Refer to Yang et al. (2017b) for more details about the model.

Research Problem II – Resilient inventory control in PI

We further studied whether PI could also improve resilience of inventory models. Based on the model for Problem I above, we further considered disruptions at PI-hubs. The

methodology is given by Figure 38, which is very closed to that for the study of resilient transport strategies presented previously.

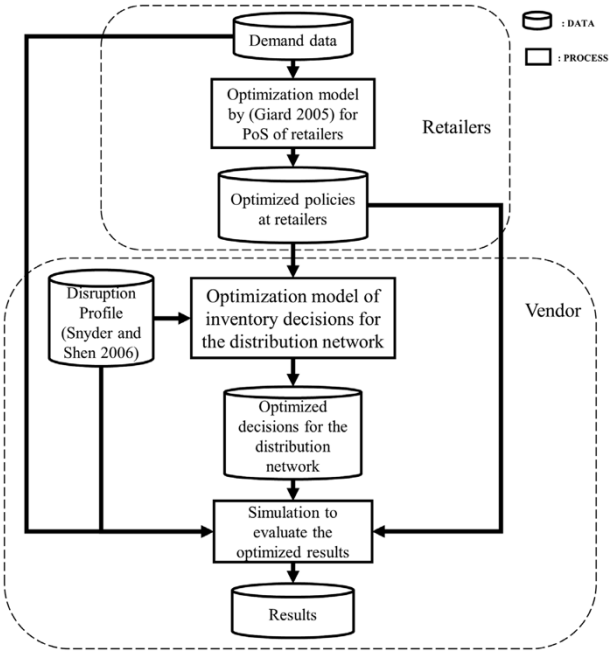


Figure 38. Methodology of PI resilience study

We assume that the disruption profile used mainly corresponds to disruption events without destroying in-site stocks, for example equipment failures, labour strikes. The disrupted facility cannot place, receive and deliver orders until the disruption ends.

3.3.4.2 Results and impacts

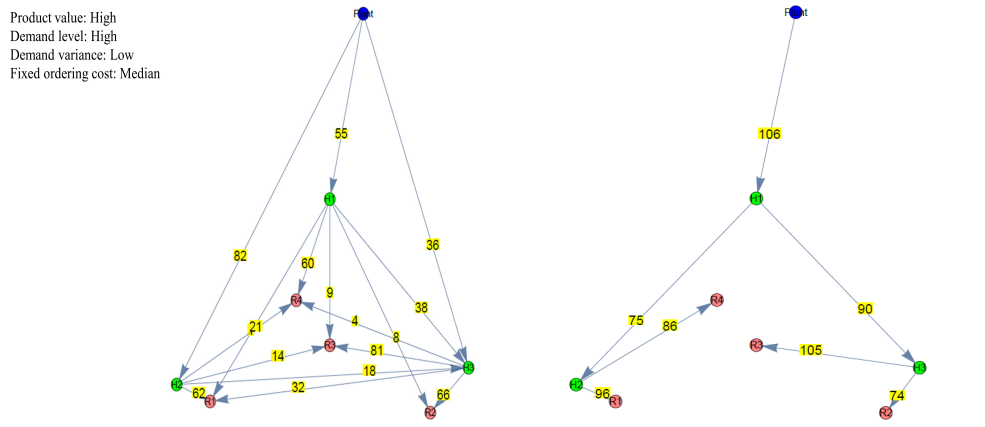
Research Problem I – Innovative inventory control model in PI

An experimental study has been conducted to study the performance of PI on inventory control. We compare the performance of the proposed PI inventory model with that of the classic inventory model and investigated the differences in performance for different configurations of a typical supply network. In the study, we considered a single product network with a supplier holding one plant and one WH who supplies two regional retail companies holding one DC and two points of sales for each. In the scenario of classic network, products are distributed from plant to WH to DC to point of sales. Meanwhile, in the scenario of PI, the WH and the two DC are presumed to be PI-hubs, so that products are shipped from the plant to one of them. And, the points of sales can be serviced by one of them as well. At each points of sale, we assumed that the daily demands from final customers are stochastic.

Using the developed simulation-based optimisation model, we simulated one year with stochastic demands. We setup four parameters to analyse the sensibility of the model and results. They are demand of the product (average level and variable), value of the product, handling cost, and ordering cost. Then, we varied the value of the parameters, from low to high for example, and simulated each scenario. The performance ratio is used to compare the scenarios, which is computed by (A – B)/B if we compare scenario A to scenario B for example. The classic inventory model is considered as the baseline and the performance ratio with other instances is the relative variation. Table 7 summarises the simulation results. Figure 39 illustrates one of the scenario as an example of supply scheme and flows.

Parameters	Average demand level		Demand standard deviation		Handling cost		Product value		Ordering cost	
Value	High	Low	High	Low	Low	High	Low	High	Low	High
Total costs	-36%	-56%	-48%	-44%	-46%	-46%	-45%	-47%	-42%	-54%
Service level	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Holding cost	-25%	-51%	-40%	-36%	-41%	-36%	-36%	-40%	-32%	-51%
Transport cost	-4%	1%	-2%	-1%	-2%	-1%	-2%	-1%	-4%	1%
Penalty cost	-1%	0%	0%	0%	0%	0%	0%	0%	-1%	1%
Ordering cost	-2%	-4%	-3%	-4%	-3%	-3%	-2%	-4%	-3%	-3%
Handling cost	-3%	-2%	-2%	-3%	0%	-5%	-4%	-1%	-3%	-2%

Table 7. Average performance ratios PI vs Actual



a. Annual distribution flows in Physical Internet b. Annual distribution flows in classic network

Figure 39. Annual distribution flows simulated in PI and in Classic network

In the simulation study, compared with classic network, PI can reduce total logistics costs from 36% to 56%. As expected, the gain mostly is coming from inventory holding cost reduction. Besides, the variation of parameters has impact on the gain but the impact is not always significant. The results can prove that PI is an adequate solution to deal with highly dynamic and heterogenic environment.

Research Problem II – Resilient inventory control in PI

The resilience study is an extension of the Problem I above. The same input data and simulation-based optimisation model are used here again. The main difference is the consideration of disruption at hubs and the corresponding strategies. To formulate disruption profile, we adopted a disruption process of two-state Markov chain (Normal/Fail) with a probability of disruption α_i (the node becomes unserviceable) and a probability of repair β_i (the node becomes normal). For example, the pair $(\alpha_i, \beta_i) = (0, 1)$ represents the network with no disruptions; $(\alpha_i, \beta_i) = (0.001, 0.1)$ indicates infrequent and long disruptions; $(\alpha_i, \beta_i) = (0.2, 0.9)$ describes short-term, frequent disruptions. Finally, the following three pairs of disruption profiles were applied to the simulation: (0.001, 0.1), (0.05, 0.5) and (0.2, 0.9).

Moreover, two disruption management strategies are adapted and compared: passive acceptance and inventory mitigation. The former indicates that the company passively accepts the disruption risks; the latter refers to the inventory redundancy strategy in the literature which involves increasing inventory levels to reduce disruption risks.

Parameter	Value	Total Costs	Service Level	Holding	Transport	Penalty
Product value	Low	-24%	0%	-41%	-6%	-34%
	Medium	-31%	1%	-40%	-3%	-64%
	High	-40%	3%	-35%	6%	-67%
Penalty rate	Low	-31%	1%	-40%	-1%	-55%
	High	-33%	1%	-37%	-1%	-52%
Disruption	(0.001, 0.1)	-24%	0%	-41%	-6%	-34%
	(0.05, 0.5)	-31%	1%	-40%	-3%	-64%
	(0.2, 0.9)	-40%	3%	-35%	6%	-65%

Table 8. Performance ratios of passive acceptance strategy: PI vs Classic network

Parameter	Value	Total Costs	Service Level	Holding	Transport	Penalty
Product value	Low	-11%	1%	-36%	-2%	-42%
	Medium	-37%	1%	-39%	-5%	-82%
	High	-56%	1%	-43%	-5%	-81%
Penalty rate	Low	-27%	0%	-43%	-6%	-66%
	High	-42%	1%	-36%	-2%	-71%
Disruption	(0.001, 0.1)	-25%	0%	-43%	-6%	-58%
	(0.05, 0.5)	-34%	1%	-40%	-5%	-76%
	(0.2, 0.9)	-45%	2%	-35%	-1%	-71%

Table 9. Performance ratios of inventory mitigation strategy: PI *vs* Classic network

Two simulation studies have been done to demonstrate the performance of the two strategies. The results are shown in Table 8 and Table 9, in which the performance ratios are computed by (PI – Classic network)/Classic network. Overall, we can see that both strategies under PI can help to improve logistics performance, especially in reducing totals costs and reducing penalty cost (improving service level). As expected, their advantage is even better with higher disruption. Comparing the two strategies, inventory mitigation slightly outperforms passive acceptance strategy.

3.3.4.3 Conclusion and limitations

Research Problem I – Innovative inventory control model in PI

Several contributions are made by this work. First, we define a new research problem related to inventory management in PI, and provide a view of how the PI affects traditional inventory control policies. Second, we propose a simulation-based optimisation model for inventory decision-making problems in PI. The first results are very encouraging to demonstrate that PI could lead to a new research chapter in Inventory management. This work can be further extended to other related problems, such as the production inventory problem in (Hammami et al., 2015), or inventory routing problem (Soysal et al., 2016), taking into account sustainability criterion.

Research Problem II – Resilient inventory control in PI

The work studied how inventory models using PI respond to SC facility disruptions and their resilience. A simulation-based optimisation model has been proposed to investigate the question through an experimental numerical study. The experimental results show that the PI inventory model outperforms current pre-determined inventory control models for demand uncertainties and SC disruptions. Moreover, the difference in performance increases when the product value, penalty costs and disruption frequency increase. We conclude that the benefits result mainly from increased agility, flexibility and delivery options enabled by the interconnected logistics services in PI. As one of the first studies investigating PI inventory

control and resilience problems, this study may provide some qualitative and quantitative results that could be useful guidelines for the next steps. By that, this work indicates a novel approach to build a resilient supply network that rests on PI.

There exist some limits in the both studies. For example, future research is needed to investigate the optimality of inventory control decisions and sourcing methods for the distribution network, as here we used a simple heuristic to obtain near-optimal results in order to compare performances. Further studies are also required to examine a network with more suppliers and consignees that is closer to a real case of interconnected supply networks. Furthermore, some studies are also necessary regarding the application of the inventory control models studied such as developing operational models and decision-making tools, studying managerial issues, and the adaptability of the models to different systems.

3.4 Conclusion of the Chapter

The objective of this chapter is to briefly discuss my scientific contributions to the research topic of horizontal collaboration in logistics, from 2007 to 2017. All work discussed are originally done by myself, or in collaboration with the colleagues form our research team or from other partners. The discussion was in alignment with the framework of international contribution analysis presented in Chapter 2. However, all solutions and issues are not concerned in my research activities. My contribution is devoted to the development and application of the two solutions - logistics pooling and Physical Internet - to the sector of FMCG. I mainly investigated the scientific issues of collaborative network design, transport planning, gain sharing, mechanism of exchanging request, and collaborative distributed inventory management. Research results, as well as scientific contribution and limits are well discussed for each research problem.

CHAPTER 4

Towards a New Era of Open, Intelligent, Decentralised Logistics Systems

4.1 Chapter Introduction

Logistics is advancing faster than ever before and is likely to continue to in the future. Logistics systems, as well as companies, have to cope with demanding requests driven by new business environments such as omni-channel retailing (Verhoef et al., 2015). Innovations to achieve powerful logistics systems are thus appealing. However, the new wave of disruptive technologies such as IoT, big data analytics, automated facilities, and autonomous vehicles, have considerably stimulated advances in logistics. These technologies provide solid, reliable solutions for the design and development of new systems. From a research perspective, in addition to current developments in horizontal collaborative and interconnected logistics, we are also interested in investigating future logistics scenarios to explore more efficient and powerful logistics systems. This chapter discusses an emerging scenario.

The objective of this chapter is threefold. Firstly, we aim to introduce an emerging new era of open, intelligent, decentralised logistics systems, i.e. the Type 4 organisation introduced in Chapter 1 (see Figure 6 in Chapter 1). Secondly, we endeavour to provide a comprehensive, in-depth discussion supported by some recent emerging concepts and technologies to specify the expected advantages and functionalities of such systems. Finally, we intend to provide a theoretical framework for such systems, indicating future lines of research. Concerning my research activities, my research programme will also be closely related to this topic, particularly focusing on the transition from Stage 3 horizontal collaborative, interconnected logistics to Stage 4 open, intelligent, decentralised logistics. Accordingly, the short, medium and long term research prospects will be discussed.

Firstly, this chapter briefly discusses the context and motivations of the research questions. Then, we briefly review the relevant literature. Part 4 provides definitions and describes the most important functionalities of self-organised logistics systems. Part 5 aims to identify the research gaps and opportunities. Part 6 concludes this chapter.

4.2 Context and Motivation

As argued in Chapter 1, the motivation to devise a new organisation of logistics beyond horizontal collaborative and interconnected logistics can be justified by the disruptive drivers and enablers. The drivers are mainly the demanding logistics requests provoked by radically changing business environments such as the omni-channel approach. The change has led to the current upheaval in logistics including fragmented flows, short lead times, and multi-distribution channels, for example. In addition to other constraints such as sustainability, logistics is currently very complex and needs to be more efficient, responsive, and sustainable than ever before. Manufacturers and distributors, as well as logistics service providers, have to rethink current logistics organisation to cope with this upheaval. However, new organisations become possible and feasible thanks to some enablers. The enablers are basically the benefits of advances in research in other areas, e.g., new theories in economics or organisation, computing technologies and techniques, IT, and ICT that are being increasingly studied and applied in logistics. As the drivers were discussed in detail in

Chapter 1 (see Section 1.4.4), here we focus on the enablers in terms of the literature and practices.

Logistics systems are now much larger and more complex than ever before and, therefore, difficult to manage as a whole. Emerging disruptive technologies, concepts, and paradigms are being widely studied as solutions to address this difficulty, e.g., widespread application of IoT or ICT technology in logistics, intelligent products or intelligent logistics (McFarlane et al., 2016), Holonic and Multi-Agents System control and modelling (Barbosa et al., 2015), Cyber-physical Systems (Lee, 2008), or the Physical Internet (Ballot et al., 2014; Montreuil, 2011). Manufacturing has already witnessed the impacts of this wave of innovation with new concepts and paradigms such as Industry 4.0 and intelligent or smart manufacturing (Zheng et al., 2017). With regard to logistics, one may be interested in the following question: what could the next era of logistics be if all these state-of-the-art concepts and technologies contribute jointly to the development of logistics?

Different scenarios of future logistics system can be envisaged. But to deal with the logistics flows that are more and more fast, fragmented, down-sized, and disruptive, one of the crucial levers is to reduce human inappropriate decisions and the related decision time, i.e., human intervention. Based on this assumption, here we focus on one of the emerging scenarios, namely self-organising logistics systems (SoLS hereinafter). We are interested in how SoLS can deal with new challenges in logistics and what are the essential functionalities required. It is envisageable that in a such system human intervention will be limited at operational level (e.g.., taken over by automation), and importantly moved to strategic level (e.g., system design, algorithm development and applications, continual improvement, monitoring).

As suggested in Bartholdi III et al. (2010), an SoLS is a logistics system that "*can function without significant intervention by managers, engineers or software control*". The definition proposed implies a number of potential advantages of such systems for today's large-scale, complex logistics. Based on this research, we attempt to provide a wider, deeper vision to define SoLS by determining the primary functionalities desired and analysing the advantages in the context of logistics organisation. The advantages are discussed qualitatively from a logistics performance and sustainability perspective to illustrate that SoLS could make logistics more autonomous, efficient, and effective, i.e., more sustainable.

4.3 A Brief Review of the SoLS-related Literature

Self-organisation is a popular term in many research fields including computer science, human society and behaviour, and biology (Aliu et al., 2013; Mamei et al., 2006; Serugendo et al., 2003; Serugendo et al., 2006). Manufacturing and logistics are primarily concerned in operations management. The literature related to both areas will be discussed in this section. But before that, consensus definitions of the popular terms used in the discussion need to be provided.

4.3.1 Relevant emerging concepts, paradigms, technologies

Firstly, it is necessary to provide consensus definitions for the state-of-the-art concepts, paradigms, and technologies that are widely studied and applied in manufacturing and logistics. Consensus definitions regarding these terms are important for the rest of the chapter to avoid any ambiguity. The related concepts and paradigms are classified here according to their objective: conceptual criteria, technical paradigm, technology, and application. They are also the SoLS enablers.

Conceptual Criteria:

- *Openness*: the system boundary is not fixed but variable and flexible (Ballot et al., 2014).
- *Adaptation*: objects adapt to each other to coordinate activities resulting in more efficient processes (Jahre and Fabbe-Costes, 2005).
- *Reconfiguration*: add, remove and modify logistics activities and functions (Koren et al., 1999).
- *Self-organising system*: a system that can function without significant intervention by managers, engineers, or software control (Bartholdi III et al., 2010).

Technical Paradigm:

- *Cyber-Physical System*: integrations of computation with physical processes (Lee, 2008).
- *Intelligent and active products*: a product can self-identify its state, and able to send information once certain pre-conditions are met (Sallez, 2012; Sallez et al., 2016; Trentesaux et al., 2013).
- *Multi-agent system*: a system that coordinates intelligent behaviour among a group of agents which are autonomous and flexible computational systems (Botti and Boggino, 2008).
- *Holonic System*: a system composed of holons. Holons are autonomous, cooperating, and potentially recursive decisional entities which can simultaneously be a part or sub-whole of the system. A holon is generally composed of a physical part and a digital part (Giret and Botti, 2004).
- *Complex Adaptive System*: a system that develops over time into a coherent form and adapts and organises itself without any singular entity deliberately managing or controlling it (Choi et al., 2001).
- *Intelligent logistics*: a desire to plan, manage or control logistics activities in a more intelligent way (McFarlane et al., 2016). It may rely on intelligent products, data techniques, etc.
- *Physical Internet*: the network of logistics networks using the internet analogy (Ballot et al., 2014). The essential idea is to interconnect the logistics network to create a common network providing common logistics services, based on the standardisation and modularisation of resources and systems.

Technology:

- *IoT*: Internet of Things is the network of physical objects that are connected via the Internet and technologies providing unique addressing schemes such as RFID tags or sensors (Atzori et al., 2010).
- *ICT*: Information and communications technology for the communication between objects or systems (El Kadiri et al., 2016; Shen et al., 2006)
- *Embedded systems*: a combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function inside a single identified system (Barr, 2007).
- *Blockchain technology*: Blockchains are open, distributed ledgers that can record transactions between two parties efficiently and in a verifiable and permanent way. The ledger itself can also be programmed to trigger transactions automatically. By design, blockchains are inherently resistant to data modification - once recorded, the data in a block cannot be altered retroactively (Lansiti and Lakhani, 2017). This

technology is now being increasingly used in the fields of finance, product tracing, smart contracts, etc.

4.3.2 Self-organisation in Manufacturing

Similar to the situation in logistics, the manufacturing (and production) industry has also been facing increasing international competition and radical changes in business environments over the last few decades. A number of innovative concepts and paradigms have been proposed and developed for manufacturing system optimisation. For example, motivated by the development of IoT and ICT, intelligent (or smart) manufacturing was proposed as a revolutionary paradigm to significantly improve manufacturing system efficiency (Cardin et al., 2017; Trentesaux et al., 2016). Based on the paradigm, advanced concepts with a concrete roadmap have been proposed at national strategic level in some countries such as *Industry 4.0* in Germany, *Future Industrial Systems* (*Usine du Future* in French) in France (Cardin et al., 2017), or *Made in China 2025* in China (Tao et al., 2017). Generally speaking, all these concepts comprise the most advanced practices and technologies (cyber-physical systems, IoT, cloud computing, ambient intelligence, etc.) to improve manufacturing efficiency. Some important principles and abilities such as Machine-to-Machine communication (Atzori et al., 2010), Plug and Play (McFarlane and Bussmann, 2000), or activeness and self-acting (Sallez et al., 2016) are also proposed for this purpose.

Under the paradigm of intelligent manufacturing systems, self-organisation is often considered as a system-wide ability. It has sometimes been considered from different perspectives and also called a system property, principle, or mechanism (Barbosa et al., 2015; Bousbia and Trentesaux, 2002). However, the basic idea is the same: the ability of a system to self-decide and self-act without significant intervention from outside. For example, Barbosa et al. (2015) recently proposed to integrate the self-organisation principle into ADACOR (ADAptive holonic COntrol aRchitecture for distributed manufacturing systems), in order to improve the system's self-evolvable and self-reconfigurable performance resulting in an innovative control architecture named ADACOR^2. They modelled the principle at two levels in the architecture: behavioural self-organisation at micro level to respond smoothly to perturbations, and structural self-organisation at macro level to enable the system to react more drastically. With a similar idea, Zhang et al. (2017) argued that self-organization as a mechanism in manufacturing systems can increase system responsiveness, flexibility, reconfigurability, and autonomy. They investigated how self-organisation can maximise system autonomy and resource-task matching.

With regards to a modelling approach, self-organising systems are often modelled as holonic multi-agent systems (Serugendo et al., 2003; Trentesaux et al., 2016; Wycisk et al., 2008). Most of the research focuses on the development of control architectures and proof-of concepts via simulation models.

4.3.3 Self-organisation and intelligence in Logistics

In the field of logistics, self-organisation can also be seen as the ability of logistics systems to self-decide and self-act, which is similar to manufacturing systems. From a different perspective, self-organisation can be considered as a prerequisite function of intelligent systems (Choi et al., 2001), or an extension of the capabilities of intelligent systems (Barbosa et al., 2015). Generally speaking, an intelligent logistics system with the ability to self-organise can be called a self-organised logistics system (SoLS). But unlike in the field of manufacturing, the literature related to the research problem is scarce in the field of logistics; only a few papers can be found. For example, references (Choi et al., 2001; Hülsmann et al.,

2008; Wycisk et al., 2008) proposed considering a supply network as a complex adaptive system where self-organisation is considered as an internal mechanism between agents. Contrastingly, (Bartholdi III et al., 2010) considered self-organisation as an organisational paradigm to cope with complex assembly lines using "bucket brigade'' assembly lines as an illustration. Belle et al. (2011) provided an example of use in logistics. The research considers self-organisation as a mechanism or a paradigm for logistic systems. However, prerequisites and functionalities of such systems have rarely been studied.

The scarcity of the literature focusing on self-organisation in logistics is probably due to the novelty of the concept and the characteristics of the field, particularly compared to manufacturing. *Firstly, logistics systems are much more complex* than manufacturing systems, often involving short or long-term large-scale operations. For example, in terms of facilities, rather than focusing on a single site, the aim of logistics is to coordinate multiple sites and internal/external operations. The context is much more complex with a broader vision. Another example is transport. An operation could rely on multi-modality so that the lead-time is dependent on the selected modal (transport time, sorting, handling, transfer time, etc.). *Secondly, logistics systems often involve multiple companies* (collaboration among stakeholders and parties is either vertical or horizontal) so the objectives of the decisions may vary. A number of parties may be concerned within a system or with a decision, i.e. shippers, receivers, carriers and other service providers, society or intermediaries. They may have different objectives or priorities such as service rate, cost or sustainability, which are extremely difficult for a decision or a system to take into account simultaneously. *Finally, uncertainties, e.g., disruptions in logistics systems, could be significant and extremely difficult to predict*. One of the objectives of self-organisation is to cope with disruptions responsively and autonomously. However, disruptions in logistics systems often vary in time, category or severity. For example, disruptions in transport could be unavailable resources (means, drivers' strike, etc.), infrastructural problems, congestion, etc. At supply chain level, disruptions could be disasters, facility failures, accidents, etc.

Considering the great complexity and uncertainty of logistics, self-organisation is expected to play a more significant role in logistics systems with regard to efficiency, sustainability, and resilience. However, designing an SoLS is also very challenging due to the large-scale operations, decisions, and parties involved. We, therefore, argue that a framework of essential functionalities should be defined in the initial stages.

To contribute to the literature and to the development of the concept, this chapter discusses an SoLS framework in which the main functionalities will be defined and investigated. The framework covers most of the research problems concerning SoLS research. The research programme can thus be further developed in relation to this framework.

4.4 Functionalities of SoLS

This chapter can be seen as an extension of the previous research (Bartholdi III et al. (2010) and (Belle et al., 2011), for example). It focuses on investigating SoLS functionalities with regard to effectiveness and efficiency, which is particularly important to cope with current and future challenges in logistics. From our point of view, an SoLS can be thought of as

"an open, intelligent, holonic logistics system that aims to harmonise and guide individuals within the system towards a system-wide common goal, without significant human intervention from outside."

An individual within an SoLS can be an object (e.g., a truck), a manufacturer, a service provider (e.g., 3PL), a receiver (e.g., a customer), even a supply chain or an entire supply network, i.e. a holon. Assuming that individuals may have different constraints and objectives, e.g., improvement in service rate or cost reduction, we argue that an SoLS should have the ability to respect individual constraints and objectives while guiding them towards a common goal - sustainability, for example. To this end, individuals should be coordinated by system-wide design rules, i.e. system environment (Narahari et al., 2009).

In this work, we argue that an effective and efficient SoLS must rely on a set of well-defined functionalities to ensure its performance, and in particular to avoid any unexpected or undesirable outputs. Initially, the three most important and crucial functionalities are discussed here: openness, intelligence, and decentralised control.

4.4.1 Openness

Openness in SoLS means the boundary of the system is not fixed but open so individuals (actors, assets, supply chain, etc.) can easily join and leave the system. As an illustrative example, it is like connecting a computer to the Internet from all over the world for different purposes such as searching for information or communicating with others. Individuals join the SoLS to provide, procure or share logistics assets (truck, facilities, etc.) and logistics services (delivery, operational planning, etc.). SoLS thus become fast extendable and reducible to fulfil highly flexible logistics requirements, as shown in Figure 40. Here we discuss several functions that are essential to this end.

- *Function 1.1 Connectivity and interoperability*: This function means that individuals can easily connect with others and/or the environment. For example, in Figure 40, individuals outside can easily connect to the system or other individuals inside if rules and standards are respected. System-wide modularisation and standardisation of physical assets (e.g., Physical Internet Container (Sallez et al., 2016)), information systems (e.g., ICT), and organisation models is crucial to enable good connectivity. The Physical Internet (Ballot et al., 2014; Montreuil, 2011) is an example. Notions of interoperability must equally be considered to allow adequate communication between the different actors.
- *Function 1.2 Reconfiguration*: Once the system receives new logistics requests (transport, storage, etc.), it should be able to add or change current internal functions to fulfil the requests. The reconfiguration function, i.e. the system can rapidly self-reconfigure, is particularly important to cope with disruptions (Kim et al., 2015).
- *Function 1.3 Adaptation*: Individuals should adapt to each other and to the environment in order to rapidly build effective and efficient coordination (Choi et al., 2001).

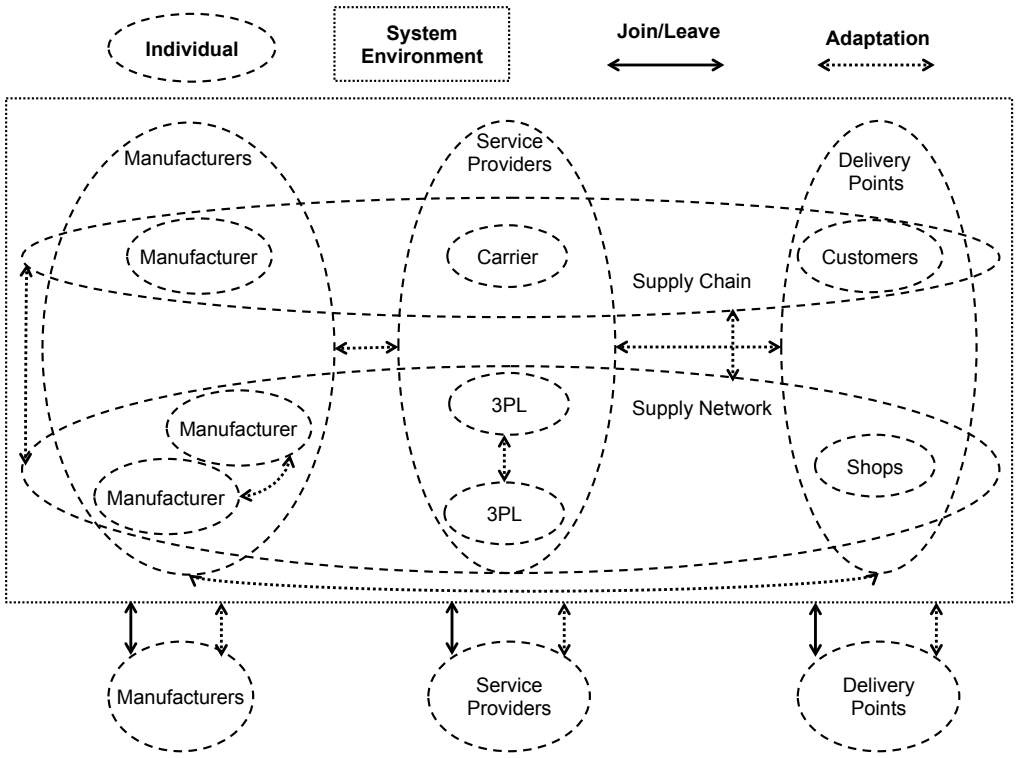


Figure 40. Open logistics system

4.4.2 Intelligence

Intelligence in SoLS means that every individual within the system can make and execute autonomous decisions and interact with other individuals and with the environment. For that, they should have the ability to collect, store, and process information from other individuals (their state and decision) and from the environment (rule modification). IoT and ICT technologies will provide fundamental support for such abilities. Furthermore, at least two important functions can be identified for the intelligence function.

- *Function 2.1 Activeness*: Individuals should have the ability to collect or receive information from other individuals (e.g., state, decisions made, alerts) and from the environment (rules and any modifications), then to store and process the information for autonomous decision-making. In other words, it concerns the decision making of individuals, collectively or not. Moreover, they should also be able to send information to others, to advertise any changes in their state, i.e. send alerts to the system or other individuals. A change in state can be seen as an event that has occurred in the system, e.g., a warehouse is disrupted, a truck is full or an order is cancelled. Activeness is clearly an important functionality for SoLS.
- *Function 2.2 Autonomous acting*: Once a decision has been made, systems should also be able to apply and execute the decision. This function may rely on embedded systems of autonomous operating assets, autonomous supply chains or autonomous networks, including sensors and actuators inside decisional loops.

Figure 41 illustrates some existing and emerging examples of intelligence in logistics. It is obvious that some of these functions are questionable with regard to current logistics organisations and technologies. However, emerging innovative technologies may help us to anticipate the future of intelligence in SoLS, e.g., drones, autonomous operating trucks or Kiva.

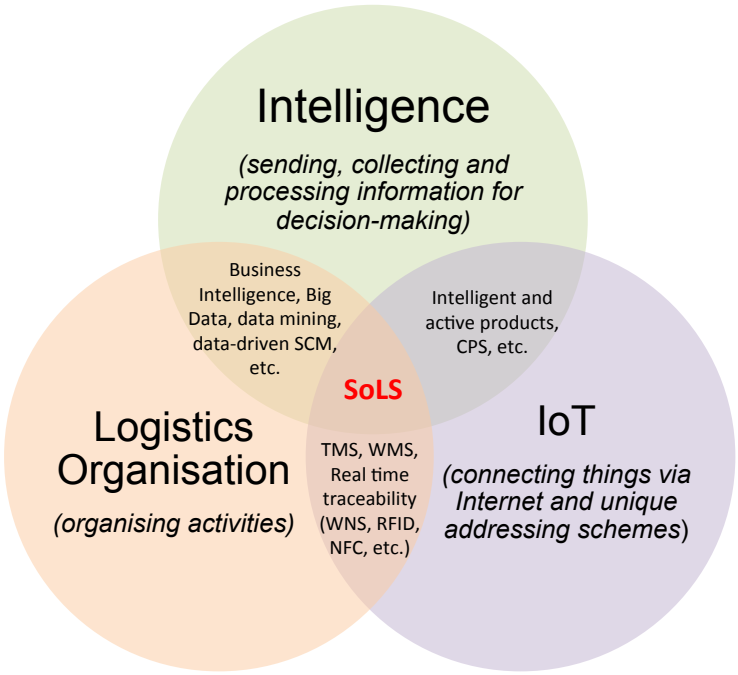


Figure 41. Technologies and Techniques of intelligence applied in logistics

4.4.3 Decentralised Control

As stated in Choi et al. (2001), "imposing too much control in a complex system detracts from innovation and flexibility; conversely, allowing too much emergence can undermine managerial predictability and work routines". Here we propose specifying SoLS as rule-based decentralised control systems with effectiveness and efficiency in mind (Bakule, 2008). More precisely, rule-based decentralised control in SoLS aims to help autonomous decision making of individuals within the system and the objective is twofold: to avoid unpredictable and undesirable outcomes and to guide individuals towards a system-wide common goal. We propose that decentralised control should rely on well-designed system-wide rules and individual-wide protocols which should be respected when local autonomous decisions occur (Bakule, 2008). In this context, we propose that decentralised control in SoLS should be modelled as a holonic multi-agent system (Botti and Boggino, 2008; Serugendo et al., 2006), with the following functions:

- *Function 3.1 Holonic multi-agent system*: we propose modelling SoLS as holonic multi-agent systems (HMAS) as they must be controlled at individual level, i.e. holon level (whole, part, or sub-whole). Each holon is composed of a physical part mirrored by an agent in the model. Each agent is self-controlling so no controlling agent is required in HMAS
- *Function 3.2 Rule- and protocol-based*: rules here represent the common regulations of the system that every individual must respect; and protocols are communication protocols that allow individuals to communicate with each other, i.e. interoperability. Take the digital internet, for example, in which there are rules and protocols such as TCP/IP. The same idea can also be found in the protocols associated with the Open Systems Interconnection (OSI) model. In other words, rules are designed to achieve a common goal and protocols for effective, efficient communication.

Figure 42 presents the system architecture of a rule- and protocol-based HMAS. We consider here a transport request as an example of a logistics activity, i.e. L1. As per the current organisation, the driver (P1) and the means of transport (P2) are the essential physical objects. In the SoLS scenario, an HMAS model is employed to help P1 and P2 make decisions. More precisely, P1 and P2 are each mirrored by a virtual agent in the MAS model, V1 and V2, respectively. Rules regarding logistics organisation (e.g., speed limit, recommendation of multi-modal transport) and protocols between objects (e.g., driving instruction, autonomous driving control) are translated as the environment of the MAS model. By that, P1 (or V1) and P2 (or V2) must respect the environment when they make autonomous decisions. The MAS model here thus aims to coordinate and ensure cooperation between agents and physical objects, but not to control them.

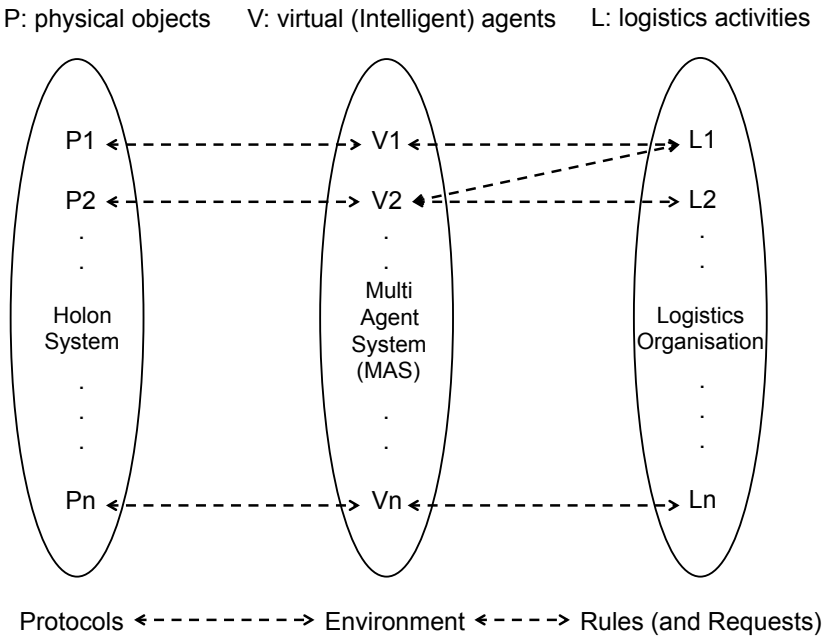


Figure 42. Modelling an SoLS as a rule- and protocol-based holonic multi-agent system

4.5 Research Prospects

This section presents some research prospects based on the proposed SoLS framework. Firstly, we discuss a wide range of research topics related to the framework to demonstrate that it could become a fertile field of research. Then, considering the goal of this thesis, I will introduce some research topics as examples of my interests in order to illustrate my future research programme.

4.5.1 Research Opportunities

Based on the SoLS theoretical framework, some research prospects can be further identified. Here, we briefly discuss some emerging lines of research.

- *F1.1 Connectivity*: Seamless connectivity in logistics activities relies on connection, digitalisation, and standardisation of physical, informational, and managerial systems. Connection means logistics systems are (fully) connected to each other by physical infrastructures (rail, road, warehouse, etc.) and digital links (phones, internet, digital platform, etc.). Based on this, digitalisation, which is basically the process of converting information into a digital format, helps improve seamless connectivity by

reducing communication time and costs while improving information accuracy. As claimed by the European Commission[15] "*in transport, digitalisation can significantly improve traffic and transport management through more accurate information on traffic and infrastructure conditions and on the location of vehicles and/or goods…*" The advantage is also valid for other logistics activities such as warehousing management or material handling (Charpentier et al., 2015; Tran-Dang et al., 2017). Along with digitalisation, the standardisation of information flows is another key issue of seamless connectivity. Many companies provide IT solutions for inter-firm connectivity such as *GS1*, an international organisation that develops and provides global standards and services to manage information flows in logistics including Electronic Product Code (EPC) and EPCIS (Electronic Product Code Information Services), for example. For seamless connectivity, it is foreseeable that demands for standards will become broader and more specific, from product ID to product description, for example. The development of standards and the relevant technologies and services is clearly of considerable significance and offers huge potential. For that, the current state of the art of horizontal collaborative and interconnected logistics would provide a solid base for SoLS.

- *F1.2 Reconfigurability*: IT/IS development and data availability play a key role in good reconfigurability in logistics. To be able to fulfil a request immediately or to react to an unexpected change, the system (or the objects within the system) should have good, real-time visibility of the resources (location, state, availability, etc.). It is expected that currently rapidly developing IoT technologies will provide solutions. Low cost solutions, in particular, are expected considering the huge demand and use in logistics. Moreover, how to make decisions based on large decentralised data sets would be a big challenge with regard to the computational complexity. Big data analytics and cloud computing thus offer huge potential with regard to the decision-making problem.

- *F1.3 Adaptation*: One example of adaptation in logistics is the modularisation of logistics units. Take, for example, shipping containers. The modular sizes are perfectly adapted to each other as well as to the means of transport and handling equipment. For land and inter-site transport, modular boxes are a similar idea but the stakes are higher, see Lin et al. (2014) and Landschützer et al. (2015). Adaptation should be considered from informational and managerial aspects as well as the physical aspect, like the adaptive product storage strategy studied in Tsamis et al. (2015) which showed that the storage location of products in a warehouse should take product matching into consideration to improve order-picking efficiency.

- *F2.1 Activeness*: In SoLS, some decisions must be made at object level (micro level) based on real-time information. As the information is requested for every object in real time, there will be at least two key challenges to be investigated: information collection and storage, and decision making. The challenges concern the embedded system or embedded intelligence, generally known as active or intelligent products (McFarlane et al., 2012; Sallez, 2012; Sallez et al., 2016), or smart parts (Wycisk et al., 2008). Moreover, decisions could be made collectively, which means individuals should interact with each other when making decisions. This implies a considerable research problem in operational research and computer science. The literature has

[15] https://ec.europa.eu/transport/themes/logistics-and-multimodal-transport/digitalisation-transport-and-logistics-and-digital-transport-and_en

already shown an interest in Swarm Intelligence (Serugendo et al., 2003; Serugendo et al., 2006), data analytics for decision making and large-scale real-time optimisation, etc. to investigate the issue.

- *F2.2 Autonomous acting*: Once a decision has been made, the next step is action. Take, for example, a self-driving car which should know when and how to accelerate or stop. This functionality relies primarily on robotisation and automation in logistics activities. Another example includes automated cross-docking centres (Walha et al., 2016).

- *F3.1 Holonic multi-agent system*: On the basis of the framework, SoLS is defined as a holonic multi-agent system. This functionality offers huge potential in research on multi-agent control systems (Barbosa et al., 2015). Advances in the latter will also help the development of SoLS, particularly control system architectures.

- *F3.2 Rule- and protocol-based*: Two lines of research can be identified for this functionality. The first is the development of IoT protocols for device-to-device communication. IoT-wide communication protocols is an emerging topic in many fields, for example, vehicle-to-vehicle wireless communication protocols for autonomous vehicles (Biswas et al., 2006). In logistics, devices/objects will have different functions, for example, from transport to storage or to packing, and communication protocols between different object categories will become more complex and complicated. Moreover, as there are several criteria and goals in terms of logistics performance, rules to be respected by all objects should also be further developed. The rules could be integrated into communication protocols or not according to the function of the objects. It is believed that the theory of mechanism design could contribute significantly to the investigation of rule and protocol design for SoLS.

4.5.2 My Research Interests

Regarding my research activities and interests, some of the research topics mentioned above will be investigated within my research programme. In the short term, I will continue the ongoing research focusing mainly on (Stage 3) horizontal, collaborative, interconnected logistics. Then, in the mid-to-long term, I will contribute to research on the transition from horizontal, collaborative, interconnected logistics to (Stage 4) open, intelligent, decentralised logistics, as well as real industrial applications. As examples, I am interested in the following research topics. However, it is worth noting that my research should not be limited to these examples in the future.

Topic 1: Fundamental interconnection and interoperability of logistics networks. Regarding the framework proposed, network openness is a prerequisite for SoLS. My current research, which focuses on the interconnection and interoperability of logistics networks, e.g., horizontal collaboration or the Physical Internet, is in line with the topic. It mainly concerns the standardisation and modularisation of physical and informational resources in logistics. *In terms of physical resources*, research problems include designing standard and modular logistics supports (pallet, box, trolley, etc.), facilities (multi-modal platforms, warehouses, lockers, etc.) or logistics schemes (open network, freight routing optimisation, etc.). *In terms of information resources*, I am very interested in the question of interconnection and synchronisation of information systems, and standardisation of information flows and operations. Currently, logistics companies have heterogeneous information systems. Existing solutions such as *EPCglobal* and EPCIS still seem to be limited with regard to seamless

sharing and information synchronisation. It is thus worth studying new solutions or models. On the one hand, we can interconnect information systems, for example, via a centralised system that is a single system used jointly by all the companies, or via a decentralised system that aims to interconnect the systems of each company, see Figure 43. The former is probably more adequate for small-scale collaborations such as logistics pooling, while the latter appears to be appropriate for large-scale collaborations such as the Physical Internet and other open networks. In this way, information can be synchronised through intermediate platforms or channels. On the other hand, communication technologies to interconnect objects and/or systems should also be further explored as a solution for information synchronisation, particularly new technologies (Wi-Fi, Sigfox, LoRa, NB-IoT, etc.) and new paradigms (intelligent product, smart part, etc.).

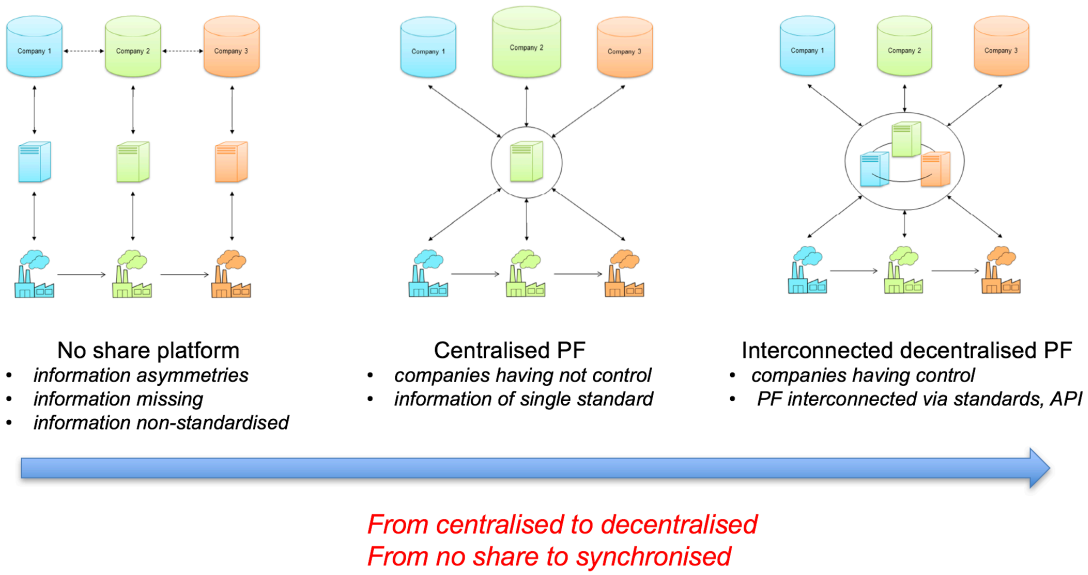


Figure 43. Interconnection of information systems (based on Mattila et al. (2016))

Topic 2: Intermediaries in open networks. Interconnected, open networks rely on intermediaries such as (online) platforms matching service supply and demand (e.g., click&truck, flexe.com) or orchestrators ensuring cross-chain coordination (e.g., TRIVIZOR, CRC® Services). These intermediaries are new to logistics and thus some research questions still need to be investigated. My research will focus on questions about their business models and decision support models. Take, for example, online platforms matching supply and demand of logistics services. The platforms normally set a fixed rate (x% of the deal, for example) for each one-shot service; they match the service provider and the buyer. This kind of business model is similar to that of *Uber*. This type of model has raised many questions such as who decides or optimises the trading price, should the buyer pay the intermediary or directly the providers, or what trading mechanism should be adopted. The advantages or disadvantages of different business models vary according to the different kinds of market and service. For example, orchestrators prefer fixed-term contracts rather than a fixed rate for each service as they are looking to develop long-term collaborations with their partners. Moreover, some intermediaries may also be concerned with decision support models. For example, they can optimise their service pricing decisions, optimise transport planning or inventory control for the service buyers, or even help service providers improve revenue. These functionalities rely on powerful decision-support and decision-making models that are mainly based on Operational Research. These research problems and questions should be further investigated.

Topic 3: Collaborative mechanisms in open networks. If we consider an SoLS as an open, decentralised system, an important question would be how parties can optimally and fairly collaborate with each other. As said previously, logistics systems often involve large-scale operations and parties, so achieving optimal decision-making for all would be unrealistic. I am interested in the research problem of designing collaborative mechanisms for such systems. More specifically, I am interested in designing rule-based mechanisms to which the parties' decisions should be submitted. It means the parties are free to make their own decisions while respecting some pre-defined rules. The rules are designed to guide self-interest decisions to achieve outcomes of global interest. Take, for example, transport. In an open network, carriers are allowed to exchange freight to optimise transport efficiency. However, the exchange should rely on a mechanism and rules for two reasons: to maximise total efficiency and to avoid chaotic results. In my research, auction mechanisms are proposed for that. Some rules are also proposed to be integrated into the mechanisms such as rules to protect shipper's interests, rules to harmonise services and costs, rules for modal-shifting or rules for gain sharing. To investigate the problem, we use the Mechanism Design theory (Narahari et al., 2009). The research is in its early stages and further work is necessary.

Topic 4: Data collection and analytics for decision making. This topic refers to the advances in research in data sciences and possible applications in logistics. In my recent research, I have been investigating how to use data and data analytics to improve decision making in logistics operations. More specifically, I am interested in developing a methodology to couple a data analytics approach with an operational research approach for decision making. Examples include the study by (Ferreira et al., 2016) who propose mining online retailing data to adjust dynamic pricing decisions of products for sale, or our study in (Pan et al., 2017a) that aims to mine e-customer-related data (electricity consumption data to improve home delivery success rate, see Figure 44. In both studies, the output of the data mining process serves as an input for the optimisation model. This methodology could generate huge potential in SoLS or in other open networks, especially for real-time decision-making problems. However, there are several questions that require further investigation. For example, what data should be collected and using what technology, or which optimisation model should be used for real-time decision making in large–scale, complex systems, or what is the impact of data privacy on optimisation results.

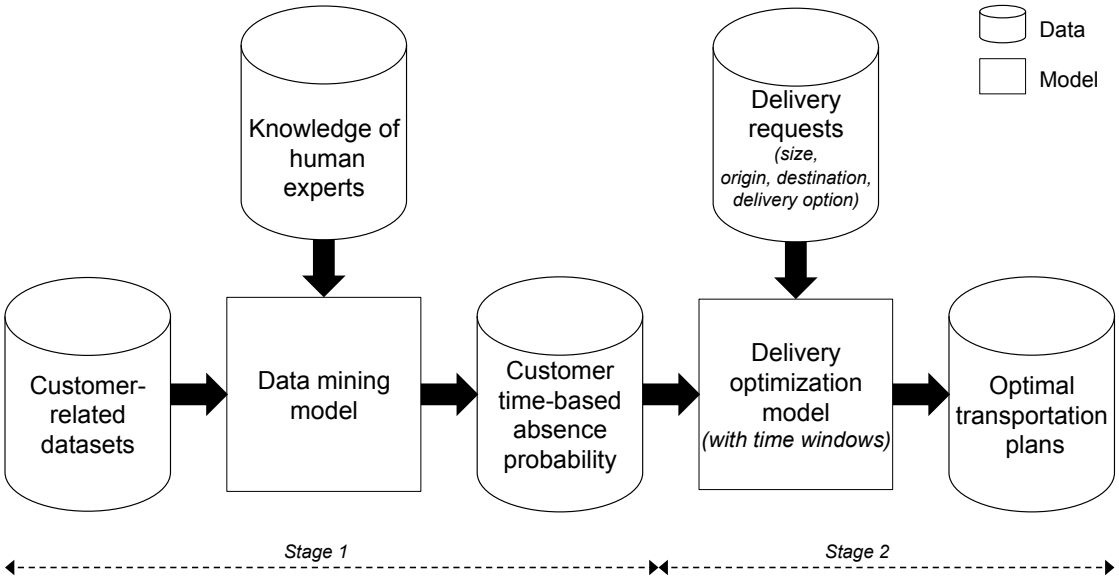


Figure 44. Example of a two-stage methodology coupling a data analytics approach and an operational research approach (Pan et al., 2017a)

Topic 5: New solutions for sustainable urban logistics. My previous and current research focuses mainly on the upstream side (B2B) of FMCG chains. I have been thinking about how to extend the research to the downstream side (B2C). Sustainable urban logistics, especially last-mile delivery problems, are one of my research interests. The booming e-commerce and omni-channel market have led to developments and innovations in urban logistics. The wide variety of delivery channels makes e-shopping more convenient, but also results in negative externalities for our society, e.g., congestion, emissions, traffic accidents. It is, therefore, necessary to seek innovative models for sustainable urban logistics. Interconnecting urban logistics networks could be a solution. It is expected that, through interconnected networks, urban freight can be shipped from the (closest) source to clients, rather than being systematically shipped via intermediate storage points (e.g., warehouse, 3PL platform such as Amazon). The number of stops per product in the supply chain can be reduced to improve efficiency. These new logistics schemes will probably challenge the current organisation, see Crainic and Montreuil (2016), for example, and could lead to a new research topic in urban logistics. Subjects could include the urban logistics network design problem, performance assessment, decision support model development or development of new technologies or applications, e.g., hyperloop, delivery robot, drone or flexible auto locker (Faugere and Montreuil, 2017).

Topic 6: Sustainability metrics and intelligent logistics. As a future logistics system, it is expected that intelligent logistics, or more specifically SoLS in this study, will improve sustainability in logistics. However, recent relevant research is mostly interested in assessing system efficiency and effectiveness such as service rate, flexibility, and cost-effectiveness (McFarlane et al., 2016). Sustainability is still rarely studied and considered as a performance assessment criterion, except for a few papers investigating CO_2 emissions and ICT (Wang et al., 2015). In my future research, I am interested in contributing to sustainability performance assessment for intelligent logistics by investigating topics such as the impact of intelligent logistics on logistics policies and carbon footprint, life-cycle assessment of intelligent logistical resources (intelligent containers, automated vehicles, automated platforms, etc.), social impacts of intelligent logistics (job markets, security and safety, congestion in cities, etc.). Qualitative and quantitative studies should be further developed for performance assessment.

4.5.2 Examples of Applications

Some real-life industrial examples of SoLS can be observed. Real world examples in transport include the recent DHL research project Parcelcopter SkyPort [16] (see Figure 45). Basically, the idea is to simultaneously use autonomous drones (Parcelcopter) and automated parcel stations (Packstations) to cope with challenging logistics demands such as "same day delivery", especially in rural zones. Drones and Packstations together can be seen as an SoLS. Once a package to be delivered with known constraints (volume, delivery location and time, etc.), arrives at a Packstation, the system will autonomously plan and optimise the delivery. Only monitoring is necessary from outside. Other examples in transport also exist such as Uber's Self-Driving Truck[17], Amazon's autonomous delivery robots tested in Seattle[18], the self-driving boat "Roboat" to be tested in Amsterdam[19], or Mercedes-Benz's drone delivery system tested in Zurich[20]. Some other indoor examples can also be found. For example, the

[16] http://www.dpdhl.com/en/media_relations/specials/parcelcopter.html
[17] https://www.uber.com/info/atg/truck/
[18] http://www.geekwire.com/2016/watch-amazon-autonomous-delivery-robots-may-come-seattle-thanks-skype-co-founders/
[19] http://edition.cnn.com/2016/10/12/design/self-driving-boats-mit/
[20] https://techcrunch.com/2017/09/28/mercedes-benz-kicks-off-drone-delivery-pilot-in-zurich/

self-organising and self-charging sorting system recently implemented by STO Express in China[21], see Figure 46, or the smart warehouse by Cainiao in China[22]. Supported by emerging technologies and techniques, we can assume that more and more examples of SoLS will be discovered and implemented. However, how to interconnect SoLS remains a significant research problem.



Figure 45. DHL Parcelcopter SkyPort (photo from the website)



Figure 46. Self-organising and self-charging package sorting system

4.6 Conclusion of the Chapter

This chapter contributes to the detailed discussion on the advantages and functionalities of self-organising logistics systems (SoLS), a novel paradigm in logistics. Openness, intelligence, and decentralised control are the three main functionalities proposed and discussed as vital functionalities of SoLS to cope with current and future challenges in logistics. Real world examples are also illustrated.

The work also provides an insightful overview and theoretical framework for future work. For example, organisational and technical issues related to SoLS such as protocol design, coordination or security issues can be investigated using the mechanism design theory for example. Quantitative research through simulation and optimisation approaches is also necessary to investigate the performance and viability of SoLS in real-life cases.

[21] http://metro.co.uk/2017/04/12/hypnotic-video-shows-robots-sort-parcels-in-a-huge-warehouse-6571436/
[22] http://www.dailymail.co.uk/news/article-4754078/China-s-largest-smart-warehouse-manned-60-robots.html

CHAPTER 5

General Conclusion

The research objective of this Habilitation thesis is threefold. Firstly, past and recent challenges and evolutionary organisations in logistics are discussed. These challenges have resulted from changes in business environments and sustainability constraints. Evolutionary organisations are then proposed to deal with the challenges and constraints, e.g., from in-house logistics to outsourced logistics, and horizontal collaborative and interconnected logistics. Nowadays, in new business environments such as omni-channel retailing, logistics is characterised by high frequency, fragmented flows, short delivery times, omni-channel distribution, and uncertainty and is thus inefficient and unsustainable. In this context, new logistics systems need to be more efficient, responsive, sustainable, and resilient.

Secondly, my research and contributions to evolutionary organisations in logistics, more precisely horizontal collaborative and interconnected logistics, are discussed. For this purpose, a state of the art review of the organisations has been conducted. A dual-axis analysis framework is proposed to position and analyse the contributions from international and national research communities. Then, the most significant publications and projects which I have led or contributed to regarding the framework are also presented.

Finally, research perspectives and research program for the future logistics are outlined, as well as my future research career. To cope with the new challenges and constraints, we argue that the future logistics system should have the ability of self-organisation, based on some essential functionalities, that are openness, intelligence, and decentralised control. This kind of system is so-called Self-organising logistics system (SoLS). In a such system, human intervention is limited at operational level, but importantly moved to strategic level, e.g., system design, algorithm development and applications, control and monitoring, or others solutions development at strategic level. Inappropriate decisions by human can thus be reduced, as well as the decision time. A theoretical framework is given to descript the system, as well as to point out some research perspectives. From the point of view of my future research, in the short term, I will continue my research on horizontal collaborative and interconnected logistics. Further, I am interested in the next evolution towards SoLS, and the evolutionary transition. Next research topics can be identified on the basis of the theoretical framework proposed.

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Appendix A: Summary and positioning of my research works under the framework of HCT solutions and implementation issues

Issues	**HCT Solutions**	
	S5 Pooling	**S6 Physical Internet**
I1 Network	***Journal articles (3)*** 1. *Pan, S., Ballot, E., Fontane, F., 2013a. The reduction of greenhouse gas emissions from freight transport by pooling supply chains. International Journal of Production Economics 143, 86-94.http://dx.doi.org/10.1016/j.ijpe.2010.10.023* 2. *Pan, S., Ballot, E., Fontane, F., Hakimi, D., 2014a. Environmental and economic issues arising from the pooling of SMEs' supply chains: case study of the food industry in western France. Flexible Services and Manufacturing Journal 26, 92-118.10.1007/s10696-012-9162-3* 3. *Pan, S., Ballot, E., Fontane, F., 2011. Enjeux environnemental et économique de la mutualisation logistique pour les PME : le cas de l'alimentaire dans l'Ouest de la France. Revue Française de Gestion Industrielle Vol. 20, p. 79-100* ***Projects (2)*** 1. *Ballot, E., Fonatne, F., Pan, S., 2010. La mutualisation : un moyen de réduction des émissions du transport de marchandises, R2DS Eclairages. Programme R2DS Ile-de-France Paris* 2. *Badoc, I., Ballot, E., Barraud, M., Bellone, N., Courtois, S., Feruglio, V., Fontane, F., Pan, S., 2009. Etude de Mutualisation Logistique (étude de cas FEEF)* ***Thesis (1)*** 1. *Pan, S., 2010. Contribution à la définition et à l'évaluation de la mutualisation de chaînes logistiques pour réduire les émissions de CO_2 du transport : application au cas de la grande distribution, Centre de Gestion Scientifique. Mines ParisTech, Paris, France, p. 250.*	***Journal article (1)*** 1. *Sarraj, R., Ballot, E., Pan, S., Montreuil, B., 2014b. Analogies between Internet network and logistics service networks: challenges involved in the interconnection. Journal of Intelligent Manufacturing 25, 1207-1219.10.1007/s10845-012-0697-7* ***Project (1)*** 1. *Ballot, E., R. Glardon and B. Montreuil (2010). OPENFRET : contribution à la conceptualisation et à la réalisation d'un hub rail-route de l'Internet Physique. Paris, PREDIT.* ***Thesis (1)*** 1. *Sarraj, R. (2013). Interconnexion des réseaux logistiques: éléments de définition et potentiel. Ph.D., Ecole Nationale Supérieure des Mines de Paris (co-supervised).*

I2 **Transport plan**		***Journal articles (2)*** 1. *Chen C, Pan S, Wang Z. and Zhong R. (2016). "Using Taxis to Collect City-wide E-commerce Reverse Flows: A Crowdsourcing Solution". International Journal of Production Research. 55(7): 1833-1844* 2. *Sarraj R, Ballot E, Pan S, Montreuil B. and Hakimi D. (2014). "Interconnected logistic networks and protocols: simulation-based efficiency assessment." International Journal of Production Research. 52(11): 3185-3208* ***Book chapter (1)*** 1. *Chen, C. and S. Pan (2016). Using the Crowd of Taxis to Last Mile Delivery in E-Commerce: a methodological research. Service Orientation in Holonic and Multi-Agent Manufacturing, Springer: 61-70.* ***Conference paper[#] (1)*** 1. *Yang, Y., S. Pan and E. Ballot (2017). Freight Transportation Resilience Enabled by Physical Internet. The 20th World Congress of the International Federation of Automatic Control (IFAC 2017 World Congress), Toulouse, France.* ***Projects (3)*** 1. *Ballot, E., 2012. Simulation de l'Internet Physique : contribution à la mesure des enjeux et à sa définition. MEDDAT* 2. *Chen, C., and Pan, S[*]. 2016. Crowdshipping for last mile delivery (in collaboration with Chongqing University)* 3. *PI-Nuts[*] (2013) - a Physical InterNet crossdocking hUb conTrol System (ANR project)* ***Theses (3)*** 1. *Sarraj, R. (2013). Interconnexion des réseaux logistiques: éléments de définition et potentiel. Ph.D., Ecole Nationale Supérieure des Mines de Paris (co-supervised)* 2. *Yang, Y. (2016). Towards more efficient and resilient supply chain management through interconnection of logistics networks. Ph.D., MINES ParisTech. (co-supervised)* 3. *Qiao B[*]. Logistics Service Provider Revenue Management in Physical Internet (In progress). Ph.D., MINES ParisTech (co-supervised)*

I3 Exchange Mechanism		***Journal article (1)*** 1. *Qiao, B., Pan, S., Ballot, E., 2016a. Dynamic pricing model for less-than-truckload carriers in the Physical Internet. Journal of Intelligent Manufacturing (in press), 1-13.10.1007/s10845-016-1289-8* ***Conference papers[#] (3)*** 1. *Mariam LAFKIHI, Shenle PAN, Eric BALLOT (2017). "Mechanisms for freight transportation service procurement: a literature-based analysis". CIE47, Lisbon, Portugal.* 2. *Shenle Pan, Xiaozhou Xu and Eric Ballot (2014). "Auction-based transport services allocation in Physical Inter-net: a simulation framework". 5th International Conference on Information Systems, Logistics and Supply Chain (ILS2014). Breda, Netherlands* 3. *Bin Qiao, Shenle Pan and Eric Ballot (2017). "Optimization of Less-than-truckload request pricing and selection for carrier in physical internet". CIE47, Lisbon, Portugal* ***Projects (2)*** 1. *PI-Comodality[*] (2016) - Co-modal freight transportation chains: an approach based on physical internet (ANR Project)* ***Theses (3)*** 1. *Xu, X. (2013). Collaboration Mechanism in the Horizontal Logistics Collaboration. Ph.D., MINES ParisTech. (co-supervised)* 2. *Qiao B[*]. Logistics Service Provider Revenue Management in Physical Internet (In progress). Ph.D., MINES ParisTech (co-supervised)* 3. *LAFKIHI M[*]. Transport service procurement mechanisms in Physical Internet (In progress). Ph.D., MINES ParisTech. (co-supervised)*

I4 **Gain Sharing**	***Conference papers*[#] *(3)*** 1. *Xiaozhou Xu, Shenle Pan and Eric Ballot (2012). "Allocation of transportation cost & CO_2 emission in pooled supply chains using cooperative game theory." 14th Information Control Problems in Manufacturing (INCOM12). Bucharest, Romania* 2. *Xiaozhou Xu, Eric Ballot and Shenle Pan (2012). "Game theoretic approaches to a horizontal logistic cooperation model." 4th International Conference on Information Systems, Logistics and Supply Chain (ILS2012). Québec, Canada.* 3. *Xiaozhou Xu, Shenle Pan and Eric Ballot (2013). "A sharing mechanism for superadditive and non-superadditive logistics cooperation." International Conference on Industrial Engineering and Systems Management (IESM2013). Rabat, Morocco.* ***Projects (2)*** 1. *VegeSupply (2013): Collaborative deliveries in plant industry (ADEME Project)* 2. *CO3 (2013): Collaboration Concepts for Co-modality in logistics (EU FP7 Project)* ***Thesis (1)*** 1. *Xu, X. (2013). Collaboration Mechanism in the Horizontal Logistics Collaboration. Ph.D., MINES ParisTech. (co-supervised)*	
I5 **ICT**	***Book chapter (1)*** 1. *Pan S and Ballot E. (2015). "Open tracing container repositioning simulation optimization: a case study of FMCG supply chain" in: Borangiu, T., Thomas, A., Trentesaux, D. Service Orientation in Holonic and Multi-Agent Manufacturing Control, Springer, 2014, Studies in Computational Intelligence* ***Project (1)*** 1. *OTC-Kaypal (2011): Open Tracing container in open loop cross-supply chains*	***Article (1)*** 1. *Sallez S, Pan S, Montreuil B, Berger T. and Ballot E. (2016). "On the Activeness of Intelligent Physical Internet Containers". Computers in Industry. 81: 96-104*

I6 Organisation	***Project (1)*** *1. CRC Service (2014): Collaborative Routing Centre for logistics flows in city*	***Book chapter (1)*** *1. Pan, S., Trentesaux, D. & Sallez, Y. (2017) Specifying Self-organising Logistics System: openness, intelligence, and decentralised control. in: Borangiu, T., Thomas, A., Trentesaux, D. (Eds.), Service Orientation in Holonic and Multi-agent Manufacturing. Springer International Publishing* ***Projects (2)*** *1. Clusters 2.0[*] (2017): Open network of hyper connected logistics clusters towards Physical Internet (Project H2020 EU)* *2. MODULUSHCA (2013): Modular Logistics Units in Shared Co-modal Networks based on Physical Internet (Project FP7 EU)*
I7 Management		
I8 Inventory		***Journal articles (3)*** *1. Pan S, Nigrelli M, Ballot E, Sarraj R. and Yang Y. (2015). "Perspectives of inventory control models in the Physical Internet: A simulation study." Computers & Industrial Engineering. 84(0): 122-132.* *2. Yang Y, Pan S, and Ballot E (2016). "Mitigating supply chain disruptions through interconnected logistics services in the Physical Internet". International Journal of Production Research, 55(14): 3970-3983.* *3. Yang Y, Pan S and Ballot E (2016). "Innovative vendor managed inventory strategy exploiting interconnected logistics services in the Physical Internet". International Journal of Production Research, 55(9): 2685-2702.* ***Thesis (1)*** *1. Yang, Y. (2016). Towards more efficient and resilient supply chain management through interconnection of logistics networks. Ph.D., MINES ParisTech. (co-supervised)*

[*] *Works or projects in progress*
[#] *Full conference papers with peer-review not extended for journal article or book chapter*
[§] *Doctoral theses, of which each may be concerned with multiple issues*