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COLLABORATIVE LOGISTICS NETWORKS

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Abstract

The logistics and transportation sectors play a vital role in modern economies, representing countries competitiveness enhancement opportunities and, in the meantime, imposing significant social and environmental challenges. In 2015, logistics and transportation costs accounted to 7.85% and 9-10% of United States and European Union GDPs, respectively. In the same year, these industries contributed for the 5.5% to global GHG emissions. These results derive as from new market trends and requirements emergence (e.g., urbanization, e-commerce, etc.) as from logistics and transportation systems "complex" nature (e.g., multiple actors with different goals, uncertainty, etc.).

To face the mentioned issues, reorganisations of current logistics and transportation systems have still to be studied, planned, tested and evaluated. In recent years, the "City Logistics" and the "Physical Internet" theoretical frameworks, focusing on urban and inter-urban environments respectively, have been gaining momentum between researchers and practitioners. Nevertheless, real implementations of such paradigms are still far to be deployed: indeed, innovative collaborative logistics business and organisational models as well as technological enablers supporting a successful execution of logistics and transport activities are still missing.

With these premises, the general goal of this work is to contribute to the understanding of collaborative logistics, focusing on emerging business and organizational models such as the Physical Internet. To this aim, the present research addresses three major aspects. First, the problem is tackled from a conceptual point of view:

indeed, since the current collaborative logistics types classification (i.e., the "classic" vertical, horizontal and diagonal ones) is missing a concept to emphasise the emergence of "innovative" models characterized by a simultaneous application of multiple classical approaches, a new collaborative logistics type called "interconnected" is coined.

Second, in order to fill the scientific literature gap represented by the absence of a harmonised methodology to analyse collaborative logistics management implications, a taxonomy for scientific contributions classification and future research areas identification is proposed.

Finally, starting from the results of the theoretical analysis, a practical application is derived. In particular, the ICT and decision technologies innovation gaps is addressed by presenting a general procedure for cloud-based collaborative logistics platforms design, deployment and preliminary performance evaluation.

Keywords: *Collaborative Logistics, Physical Internet, Taxonomy, Cloud-based Collaborative Logistics Platforms, Decision Support System (DSS).*

Riassunto espositivo

I settori della logistica e dei trasporti svolgono un ruolo fondamentale nelle economie moderne, rappresentando da un lato un'opportunità di accrescere la competitività dei Paesi e dall'altro imponendo delle sfide significative sotto il profilo ambientale e sociale. Nel 2015, i costi della logistica e dei trasporti hanno rappresentato il 7,85% e il 9-10% del PIL, rispettivamente, degli Stati Uniti e dell'Unione Europea. Nello stesso anno, i summenzionati settori hanno contribuito all'emissione del 5,5% di gas ad effetto serra su scala globale. Tali risultati derivano da un lato dall'emergere di nuove tendenze sui mercati, quali ad esempio l'urbanizzazione, la diffusione dell'e-commerce e dall'altro dalla natura intrinseca dei settori logistici e di trasporto, tipicamente definiti "sistemi complessi" a causa della presenza di molteplici attori con obiettivi diversi, la presenza di incertezza della domanda, ecc.

Al fine di affrontare le problematiche sopraelencate, si ritiene necessario studiare, pianificare, gestire, simulare le prestazioni di possibili riorganizzazioni degli attuali network logistici e di trasporto. Negli ultimi anni, le teorie denominate "City Logistics" e "Physical Internet", rispettivamente applicabili alla distribuzione urbana delle merci e ad attività logistiche extra-urbane, hanno continuato ad attirare l'interesse di ricercatori e operatori di mercato. Ciononostante, la realizzazione concreta di tali paradigmi è ostacolata dalla mancata individuazione di modelli organizzativi innovativi, di modelli di business di tipo collaborativo nonché di tecnologie a supporto di una proficua esecuzione delle attività logistiche e di trasporto.

Con queste premesse, l'obiettivo generale di questo lavoro è quello di contribuire alla comprensione del tema collaborazione in logistica con particolare attenzione ai modelli organizzativi e di business emergenti nell'ambito del Physical Internet. Con questo obiettivo, la presente Tesi affronta il problema sia dal punto di vista concettuale che pratico. In primo luogo, dal momento che l'usuale classificazione delle tipologie di logistica collaborativa in verticale, orizzontale e diagonale non incorpora i modelli emergenti che prevedono un'applicazione simultanea di più approcci classici, è stata introdotta una nuova tipologia denominata "interconnessa".

In secondo luogo, poiché allo stato attuale la letteratura scientifica manca di una metodologia armonizzata per l'analisi delle implicazioni gestionali dei modelli di collaborazione in logistica, si propone una tassonomia utile all'analisi dello stato dell'arte e all'identificazione delle future aree di ricerca.

Infine, a partire dai risultati dell'analisi teorica si propone un'applicazione pratica. In particolare, allo scopo di colmare l'attuale mancanza di tecnologie ICT abilitanti l'implementazione del Physical Internet, si introduce una procedura generale volta alla progettazione di piattaforme logistiche collaborative basate su cloud.

Parole chiave: *Collaborazione in Logistica, Physical Internet, Tassonomia, Piattaforme Cloud per la Collaborazione in Logistica, Sistemi di Supporto alle Decisioni (DSS).*

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Chapter 1

Introduction

Goods production and services provision are key sectors of modern economies. Service providers and producers operate in supply chain environments, networks characterised by "material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user", with the aim to satisfy customers demand [Vitasek, 2013]. Supply chains complexity may vary greatly from industry to industry and from firm to firm [Cutting-Decelle et al., 2007]. Typically, supply chains encompass different processes such as procurement, production, distribution, transportation and warehousing. The mentioned processes are linked by information, physical and financial flows representing all together the value chain.

In this context, logistics is in charge of "planning, implementing, controlling the efficient operation of the value chain to profitably fulfil customer requirements and expectations". In other words, *logistics aims to provide the right item in the right quantity at the right time at the right place for the right price in the right condition to the right customer* [Bubner et al., 2014]. Freight transportation is a relevant logistics domain, responding to shippers requirements in terms of freight movements from origin to destination. Even if freight transportation presents proper issues and challenges about planning, management and control of operations, there is a methodological convergence in planning transportation and logistics systems (e.g., network design, service design, routing, etc.).

The logistics and transportation sectors play a vital role in modern economies, affecting countries competitiveness enhancement opportunities and, in the meantime, imposing significant social and environmental challenges. In 2015, logistics and transportation costs accounted to 7.85% and 9-10% of United States and European Union GDPs, respectively (cf. www.logisticsmgmt.com) and [The European Union, 2016]. In the same year, these industries contributed for the 5.5% to global GHG emissions [Lohani et al., 2016]. Such inefficiencies are mostly caused by:

- *New market trends*: in recent years worlds population has been growing, overcoming the threshold of 7.4 billions in 2016. In 2015, the 54% of the worlds population was living in urban environments, reaching the value of 78% in the most developed countries [Habitat, 2016]. Globalisation has been expanding worldwide, imposing relevant economic and social issues (e.g., delocalised production, increased competition, etc.). The technological progress has been enabling real-time interconnection among suppliers and customers every time, everywhere, for a huge variety of consumable products and services;
- *Emerging requirements*: logistics actors aim to increase profitability through high quality and at the same time offer low-price products and services in a global and volatile economy [Crainic, 2015]. Moreover, they are forced to contribute in reducing environmental and social issues;
- *Logistics and transportation systems "complex" nature*: the planning, management and operation of such systems require the application of different knowledge domains, the presence of multiple stakeholders with distinct objectives, etc.

To face the mentioned issues, good analyses, policies, operating structures, strategies, business and organisational models and plans concerning individual firms, their partners and the whole logistics and transportation networks have to be adopted. The Operations Research can contribute by providing planning and management methods and tools for systems and operations with the general objective to optimise profitability, operations efficiency, service quality for each component of the system and globally realising more flexible, resilient and agile supply chains.

From a logistics management perspective, researchers and practitioners have recently started to design potential reorganisations exploiting a "smooth transition from the current independent supply chains, where transport and logistics resources cannot be shared or accessed by different freight carriers and shippers, to *open logistics networks* where resources are compatible, accessible and easily interconnected" [ALICE, 2014]. Two theoretical frameworks have been gaining momentum so far, the "City Logistics" and the "Physical Internet", focusing on urban and inter-urban environments respectively. These emerging paradigms are founded on common principles. First, the logistics resource utilisation maximisation by matching shipment demand with the available transport and logistics services (i.e., *horizontal collaborative logistics* models exploiting freight flows consolidation). Secondly, "the provision of door-to-door services based on the synchronization and dynamic update of logistics and transport plans, across modes and actors" (i.e. *vertical collaborative logistics models* exploiting logistics and transportation tasks coordination) [ALICE, 2014]. Finally, the separation of commercial transactions generating transportation demand and the actual transportation and logistics activities.

However, real implementations of such paradigms are still far to be deployed due to both theoretical and practical motivations: in particular, innovative collaborative logistics business and organisational models as well as technological enablers supporting a successful execution of logistics and transport activities are still missing.

With these premises, the general goal of this work is to contribute to the understanding of collaborative logistics, focusing on emerging business and organizational models such as the Physical Internet. To this aim, the present research addresses three major aspects. First, the problem is tackled from a conceptual point of view: indeed, since the current collaborative logistics types classification (i.e., the "classic" vertical, horizontal and diagonal ones) is missing a concept to emphasise the emergence of "innovative" models characterized by a simultaneous application of multiple classical approaches, a new collaborative logistics type called "interconnected" is coined.

Second, in order to fill the scientific literature gap represented by the absence of a harmonised methodology to analyse collaborative logistics management implications, a taxonomy for scientific contributions classification and future research areas identification is proposed.

Finally, starting from the results of the theoretical analysis, a practical application is derived. In particular, the ICT and decision technologies innovation gaps is addressed by presenting a general procedure for cloud-based collaborative logistics platforms design, deployment and preliminary performance evaluation.

To this aim, the Thesis is organised as follows:

- Chapter 2 introduces the research domain reporting logistics and transportation systems fundamental concepts, also evidencing current major trends, requirements and inefficiencies. Then, collaborative logistics is presented as a promising research field for business and organisational models and technological enablers innovation. Finally, an overview of the most recent theoretical conceptualisations, the "City Logistics" and the "Physical Internet", is proposed;

- Chapter 3 proposes a collaborative logistics taxonomy as a harmonisation tool to perform state of the art and research gaps analysis. The classification canvas is validated through a scientific literature review concerning "classic" collaborative logistics models;

- Chapter 4 reports the collaborative logistics taxonomy application to the City

Logistics and Physical Internet emerging paradigms, illustrating a state of the art analysis and, for the latter, a research agenda;

- Chapter 5 deals with a concrete applied research activity concerning innovative ICT and decision support tools enabling a Physical Internet roll out. In particular, the case of a cooperative Decision Support System (DSS) for the Trieste intermodal transportation network is presented;

- Finally, Conclusions summarize the main results and highlight where further research is still needed.

Chapter 2

Problem Statement and Research Objectives

In this Chapter, a brief presentation of logistics and transportation systems is proposed. First, several key concepts and definitions are synthetically reported, in order to create the basic knowledge for the research field understanding. Secondly, the concept of *collaborative logistics* is introduced as a promising logistics management domain. Since the 1980s, business models exploiting such concept have continued to arouse interest becoming more and more sophisticated, so as to be considered nowadays as key pillars of emerging logistics paradigms. In conclusion, the Chapter presents the major dissertation scientific contribution areas.

2.1 Supply Chain Networks and Logistics Systems

Modern economies aims to fulfil customers demand through goods production and services provision. Nowadays, the achievement of such a goal is up to supply chains, complex networks of entities and organisations linked each other by business relationships concerning finalised to better manage the following flows:

- *Physical* as parts and components, finished products, etc.;

- *Information* as orders, schedules, demand forecasts, etc.;
- *Financial* as investments, payments, etc.;

typically referred to the following processes:

- *Procurement:* activities consisting in planning, managing and operating strategic supplies (i.e., resources, parts and components, services fundamental for production processes) and usual supplies (i.e. products and services required for the general entity functioning) acquisition;
- *Production:* activities consisting in planning, managing and operating transformation activities encompassing raw materials extraction, parts and components manufacturing, intermediate product and deliverable goods assembly. Typically, these tasks are performed within plants and production facilities characterised by specific processing costs and capacity constraints in terms of type and mix of parts, components, finished products realisable;
- *Transportation:* activities consisting in planning, managing and operating the movement of vehicles, people, deliverable or intermediate goods from an origin to a destination;
- *Distribution:* activities consisting in planning, managing and operating handling, storage and maybe assembly activities, packing and delivery to final customers. Normally, the mentioned activities are performed in facilities or depots characterised by specific processing costs, handling and storage capacity constraints.

Through a SC, the complex of material, information and financial flows moved by various transportation modes and services, from producers of raw materials, through transformation, fabrication, and assembly facilities, passing through (and waiting at) warehouses, depots, and distribution points, to be delivered to the final users represent the *value chain*. In this context, *logistics* represent the process of planning, implementing, controlling the efficient operation of the value chain to profitably fulfill customer requirements and expectations [Vitasek, 2013]. More in detail, logistics must ensure “having the right item in the right quantity at the right time at the right place for the right price in the right condition to the right customer” [Bubner et al., 2014].

2.1.1 Logistics Actors

Logistics processes involve a multitude of actors, public and private organisations, private citizens, etc. playing various roles and having different individual goals. The paper of [Crainic and Montreuil, 2015] propose a classification of 4 categories: logistics service legislators, logistics service users, logistics service enablers and, finally, the logistics service providers.

2.1.1.1 Logistics Service Legislators

Typically public entities having the role to determine policies and regulations fixing the boundaries within which logistics activities can be performed (e.g., free trade agreements, labour laws, technological standards, etc.):

- Governmental Entities (e.g., international, national, regional, local);
- Public Agencies in charge of collecting taxes and tributes on behalf of governmental entities (e.g., Customs);
- Public Authorities in charge of proposing rules and policies related to specific logistics sectors and processes (e.g., Port Authorities, Transport Regulation Authorities, etc.).

2.1.1.2 Logistics Service Users

Companies or individuals requiring logistics services to fulfil a shipment. Typically, two macro-categories can be distinguished: who starts the shipment (i.e., shippers) and who requires and receives it (i.e., consignees). Refining the classification, the following logistics users are generally identified:

- Suppliers: people, companies or organizations that sells or supplies raw materials, intermediate products, services and goods to a buyer (i.e., generally a manufacturer). To evidence the commercial distance between a supplier and a buyer, a tier ranging from 1 to n in dependence of the number of production layers required to provide the required supplies to a buyer is associated;
- Manufacturers: companies or organizations that generates goods or services for sale using labour, machines, tools, chemical and biological processing or formulation;
- Distributors: companies that buy product lines, warehouse them and resell them directly to the final customer or to another distributor positioned in the next step in the supply chain (wholesaler to retailer to final customer). Two types of distributors:
  - Wholesalers: sale goods or merchandise to retailers or to industrial, commercial, institutional or other professional business users or to other wholesalers. They perform a Business-to-Business activity (i.e., B2B). Wholesalers act like brokers or agents in buying merchandise for someone or reselling merchandise to someone. Frequently wholesalers physically assemble, sort and grade goods in large lots, break bulk, repack and redistribute in smaller lots. Normally wholesalers facilities are positioned close to the market to serve (regional/intercity areas). Wholesalers have high inventory levels.

- Retailers: people or companies that sell consumer goods and/or services to customers through multiple channels of distribution to earn a profit. They perform a Business-to-Consumer activity (i.e., B2C). Generally, it is possible to distinguish between two main categories:
  - Retail outlets: marketplaces, high street stores, malls, supermarkets, discount stores, consumer cooperative;
  - Retail chains: retail outlets that share a brand and central management, and usually have standardized business methods and practices.

- Final Customers: public or private entities, private citizens that buy products or services in front of a cash payment. In supply chains, final customers are manufacturing units, institutions, offices, stores/shops and, finally, private citizens.

2.1.1.3 Logistics Service Providers

Specialized companies offering logistics services to satisfy the logistics users needs. In general, the mentioned business involves various stakeholders categories:

- First-Party logistics providers (1PLs): single service provider in a specific geographic area specialized in certain goods or shipping methods (e.g. port operators; depot operators). They generally provide transportation and warehousing contracting [Hiesse, 2009];

- Second-Party logistics providers (2PLs): entities providing specialized logistics services in a larger (national) geographical area in respect to 1PLs. 2PLs supply proper and external logistics resources like trucks, forklifts, warehouses (e.g. couriers; express or parcel services). Typically, 2PLs support logistics service users in transportation and warehousing outsourcing [Hiesse, 2009], proposing standardised services to customers;

- Third-Party logistics providers (3PLs): firms offering a wide service portfolio (e.g., physical distribution activities, management of commercial, industrial and information-related operations), typically integrated or bundled [Fulconis et al., 2011]. In respect to 2PLs, 3PLs have extended competencies about customs procedures and international trades. They operate with long-term contracts offering customised services to their customers, generally executed with proper logistics resources (i.e., asset-based model);

- Freight Forwarders (as 3PLs): companies that organize shipments for individuals or corporations to get goods from the manufacturer or producer to a market, customer or final point of distribution. Traditionally, the freight forwarder has been the link between the owner of the goods and the carrier by providing forwarding or clearing services. The forwarder acted as the agent for the owner of the cargo or the carrier, assuming a role of enabler of logistics services (generally national level of activities). With the advent of multimodal transportation, freight forwarders have changed their role in Multimodal Transport Operators (MTOs), organisations that take the freight in a specific place of origin (e.g., port, airport, train station, etc.) and transport it until the destination by using different transportation modes;

- Fourth-Party logistics providers (4PLs): independent non asset-based integrator with accumulated expertise and wide business relationships. They assemble proper resources, capabilities and technology with the ones of other entities such as 3PLs to design and sell tailored logistical solutions to customers ([Fulconis et al., 2011];

- Fifth-Party logistics providers (5PLs): organisations providing supply chain management consultancy and services to customers, typically aggregating 3PLs or other logistics actors demand in order to reduce negotiation costs with carriers (e.g., shipping lines) and to optimise assets utilisation rates;

- Freight Carriers: specialized companies in charge to physically move the goods from a point of origin (e.g. plant, warehouse, terminal) to a point of destination (e.g. plant, warehouse, terminal, customer). A distinction among freight carriers can be based on three criteria: the fleet ownership, the distance covered and the type of service supplied. In particular, a first distinction concerns the fleet property, in other words if shippers own and operate their fleet (i.e., proprietary fleet) or they outsource transportation tasks to specialized carriers (i.e., for-hire carriers). Second, freight carriers can perform intercity routes (i.e., long-haul distances, few points visited, one or more days of trip) or urban routes, (i.e., short distances, pickup and delivery routes serving several customers, within a day). Finally, freight carriers can supply customized transportation services or consolidation transportation services. In the former case, the vehicle/convoy is dedicated to the demand of one customer (the shipper) and performs a door-to-door service between the shipper and the customer. In the latter case, the loads of several customers are grouped, consolidated into the same shipment and move together on the same vehicle/convoy.

  Freight carriers are active in all transportation sectors (i.e., road, sea and inland waterways, railway and air). Starting by the road transportation sector, freight carriers can be listed as follows:

  - Full Truckload motor carriers (FTLs): for-hire trucking companies that supply customized transportation services. In general, this type of actors move the freight of a single customer in entire trailers, containers, swap bodies. The freight is loaded in the shipper's plant, warehouse or in a hub terminal (e.g., port) and dropped in the destination indicated by the shipper (e.g., another hub terminal, customer's warehouse, etc.). FTLs motor carriers cover international, national, regional routes;
  - Less than Truckload motor carriers (LTLs): for-hire companies that supply consolidation transportation services. LTLs mix freight from several

customers in each trailer or container (shipments that individually are not sufficient to meet the minimum truckload quantity). LTLs perform intercity routes picking the freight from several shipper's plant, warehouse or from hub terminals and drop in the destination indicated by the shipper (e.g. a logistics platform, a city distribution centre, a customer's warehouse);

- Last Mile Delivery Companies (LMDCs): generally, for-hire trucking companies that supply consolidation transportation services. LMDCs pickup freight of several customers in a logistic platform/city distribution centre/warehouse, transport it through urban environments and deliver it in the destination indicated by the shipper (e.g. a retailer store, offices, final customers). In some cases, big distributors like Walmart own their proper last mile delivery fleet.

Considering the sea and inland waterways transportation sectors, shipping lines supply transportation services by aggregating and consolidating freight in trailers or containers in a port of origin and delivering it in a port of destination. Shipping lines offer regular transportation services on long-haul routes via sea or rivers.

In the railway sector, freight carriers are generally private companies providing consolidation transportation services by loading entire trucks, trailers, containers or bulks in a factory or multimodal terminal of origin and move them by rail to a factory or multimodal terminal of destination. Railway freight carriers operate long-haul distances at international and national levels.

In the airline sector, freight carriers are generally private companies providing consolidation transportation services by loading freight in pallets or specific boxes in an airport of origin and move them by plane to an airport of destination. Airline freight carriers operate long-haul distances at international and national levels.

- Logistics Infrastructure Managers: organisations responsible for the management of different logistics infrastructure types devoted to store, cross-dock, etc. various product or transportation units categories. They can be characterized by several criteria:
  - Goals: if the logistics infrastructures are owned by private organization/s, generally the goal is to ensure the private owner profitability while if they are owned by public entities the goal mostly concerns the optimisation of trade flows in a specific area, the enhancement of local companies competitiveness and the avoidance of freight transportation negative externalities;
  - Equipment: they usually have loading docks, cranes and forklifts for moving different goods and transportation units types;
  - Provided services: order processing/order fulfilment, inventory, handling, packaging, consolidation of loads, cross-docking, etc.;
  - Geographical position: different areas dedicated to different layers of inventory.

  As a consequence, it is possible to distinguish among the following logistics infrastructures types:

  - Regional Distribution Centres (RDCs): warehouses with high storage capacity finalised to serve a wide geographical area, generally positioned far from the final market;
  - City Distribution Centres (CDCs): warehouses with limited storage capacity, serving a minor geographical area and located close to final market;

  - Logistics Platforms: logistics infrastructures located close to urban areas and dedicated to store low inventory levels in a context of intermodal transportation networks;

- Logistics Terminal Operators: public or private organisations responsible for the management of logistics infrastructures equipped to provide handling, parking, transshipment, etc. services for general cargo or intermodal transportation units. Depending as on the number of transportation modes served as the type of freight considered, three major logistics terminals typologies are identified:

  - Unimodal: logistics infrastructures dedicated to a specific transportation mode;
  - Multimodal: logistics infrastructures dedicated to at least two transportation modes;
  - Intermodal: logistics infrastructures specialised in interchange/transshipment operations of intermodal transportation units (e.g., containers, semi trailers, swap bodies) performed between different transport modes.

2.1.1.4 Logistics Service Enablers

Specialised entities playing the role of intermediaries among the other logistics actors categories. It is possible to distinguish among:

- Freight Forwarders (role of agent): companies organising shipments for individuals or corporations, taking possession of the items being shipped. Traditionally, the freight forwarder has been the link between the owner of the goods and the carrier by providing forwarding or clearing services [Saeed, 2013]. In recent years, the evolution of international trades has changed the freight forwarders role letting them become 3PLs supplying a wider range of services;

- Freight Brokers: companies representing the link between individuals or other companies that need shipping services and an authorized motor carrier. Freight brokers support shippers in finding reliable carriers and assist these last in maximising vehicles load factors; they differ to freight forwarders because they never take possession of the freight being shipped;

- Customs Brokers: professionals expert in freight clearing operations, typically preparing the required documents, paying import/export duties and connecting with other logistics actors on their customers behalf.

2.1.2 ICT and Decision Technologies in Logistics and Transportation Systems

The technological development experienced in the last 50 years has led enormous changes in logistics management practices, both in internal organisations processes and external interfirm relationships. This evolution has impacted the business in two major ways. First, the technological widespread has enabled functions and processes reengeneering, thus making supply chains more efficient. Second, new business and organisational models have emerged with the aim to exploit a transition towards high value-added services.

Nowadays, almost all logistics activities generate data whether they refer to internal entities management processes or to interorganizational relationships. Data have to be converted into information in order to support decision-making at strategic, tactical and operational levels. To this aim, data manipulation techniques are typically applied to information, thus converting them into knowledge [Asadi, 2011].

In general, the digitalisation of logistics processes is mostly based on:

- *Information and Communication Technologies (ICT):* set of methods and technologies devoted to realize the transmission, reception and processing of information. An ICT subset is represented by the Information Technologies (IT) which consist in the application of computers to store, retrieve, transmit and manipulate data, often in the context of a business or other enterprise (i.e., from data to information);

- *Decision Technologies (DT):* computer-based systems which helps decision makers to solve complex problems.

In order to meet user requirements always more complex, currently various ICT and DT types are adopted by logistics actors. Sometimes these tools are devoted to process a specific information life cycle step while, in other cases, to a wider processing spectrum (i.e., information hubs). Table 2.1 overviews the main ICT and DT used by private actors in logistics and transportation systems.

Table 2.1: ICT and DT used by private logistics actors.

Data Collection	
Automatic Data Capturing Systems	• Bar-codes and readers • Optical Character Recognition (OCR) • Radio Frequency Identification (RFiD) • Electronic Product Codes (EPC) • Other smart tags
Positioning Systems	Global Positioning System (GPS)
Data Communication	
Communication Networks	• Radio frequency • Satellite • Cellular • Local Area Networks (LAN) • Wide Area Networks (WAN) • Electronic Data Interchange (EDI) • Web Services
E-business	• Intranet portals (B2E) • Extranet portals (B2B) • Internet portals (B2C, C2B, C2C)
Data Storage	
Databases	Excel or more sophisticated tools
Data Retrieval	
Database Management Systems	MySQL, Oracle, etc.
Data Manipulation	
Data Mining	• Big Data and novel data analysis methods • Artificial Intelligence methods (AI)
Decision Making	
Optimisation techniques	Exact Methods, Heuristics, Metaheuristics
Simulation techniques	Continuous Time, Discrete Events
Information Hubs	
Information Systems (IS)	• Enterprise Resource Planning (ERP) • Customer Relationship Management Systems (CRMS) • Warehouse Management Systems (WMS) • Transportation Management Systems (TMS) • Supply Chain Management Systems (SCMS)
Decision Support Systems	Umbrella term to describe any computerized system that supports decision making in an organization [Turban et al., 2011]

In order to introduce digitalisation in Small and Medium Enterprises (SMEs), typically less structured in organizational and financial terms, over the past decade the *cloud computing* has emerged. This solution is economically more affordable because the IT tools are physically possessed and supplied by a technology provider.

Moreover, as already mentioned in Section 2.1.1, various types of public/private (e.g., dry-ports) and public actors (e.g., Customs) operate in logistics and transportation system mostly through the monitoring and control, the operations execution, the business transactions facilitation. The performance of those activities is generally supported by the use of the following Information Hubs:

- National Logistics Platforms (e.g., UIRNet);
- Port Community Systems (PCS) (e.g., Sinfomar in Trieste);
- Customs IT systems (e.g., AIDA/CARGO in Italy);
- ...

In the last 30 years, the public sector has committed in the enhancement of logistics and transportation systems efficiency by introducing the so called *Intelligent Transportation Systems (ITS)*. The Directive 2010/40/EU defines ITS as "systems in which ICT is applied in the field of road transport, including infrastructure, vehicle, users and traffic management and mobility management, as well as interfaces with other modes of transport" [PARLIAMENT and UNION, 2010]. These are advanced applications that, even if they are not equipped with own intelligence, aim to provide innovative services related to different modes of transport and traffic management by enabling information visibility to users, making the use of safer and coordinated transportation systems.

In recent years, a new generation of ITS is becoming widespread in the road transportation sector: the *Cooperative ITS (C-ITS)*. The mission is to enable all the transportation system parts to share information useful to improve users decision making process by introducing automation in transportation systems. C-ITS are currently under test, typically within public-supported experimental initiatives and projects (e.g., the European Union TEN-T and CEF research, innovation and deployment programmes). More in detail, C-ITS encompass the following technologies:

- Vehicle-to-Infrastructure (V2I) communication protocols exploiting dedicated short range communications, such as wireless networks;
- Vehicle-to-Vehicle (V2V) communication protocols exploiting medium-long range cellular communication.

2.1.3 Logistics and Transportation Systems Challenges

Transportation and logistics systems are caracterised by the following peculiarities [Clemente, 2016]:

- Heterogeneous and geographically distributed elements;
- Different and competing stakeholders objectives;
- Logistics management cross-disciplinary areas of expertise;
- Data heterogeneity;
- Uncertainty;
- Human behaviour.

For the mentioned reasons, logistics and transportation systems are considered typical examples of *complex systems*, i.e., systems “comprised of a (usually large) number of (usually strongly) interacting elements, processes, or agents, the understanding of which requires the development, or the use of, new scientific tools, nonlinear models, out-of equilibrium descriptions and computer simulation” [Schweitzer, 1998].

Stakeholders decision making processes have to deal with the intrinsic complexity of these economic sectors in order to enhance the performance of as their individual organisations as the whole supply chain networks. Moreover, planning and management practices have to consider the on-going megatrends reported in Table 2.2.

Table 2.2: Megatrends in logistics and transportation systems.

Megatrends	
Globalisation	• Increased competition • Price erosion • Increased geographical market coverage • Passing from a manufacturing-based society to a service-based society
Urbanisation	Demand located in urban environments
Explosion of B2C e-commerce	Increased frequency of deliveries
Technology widespread	• Big Data/Open Data • Cloud logistics • Internet of Things • Robotics and automation
Environmental concerns	• Reduce global and local air pollution • Reduce noise in urban areas • Reduce congestion • Reduce competition between passenger and freight transport • Reduce tons/km driven
Shortened product life cycles	Reduced time to market
Change in customers behaviours	• Reduced customer loyalty • Large fluctuations in demand • Demand for higher and constant service levels • Bullwhip Effect
Societal issues	• Public-private partnerships to develop freight transportation policies • Regulations on working hours for truck drivers

To face the aforementioned issues, new business needs are emerging, particularly in terms of systems resilience, interconnection, sustainability and flexibility. The work of [Crainic, 2015] presents potential implications from planning and management perspectives:

- More comprehensive planning and increased automation;

- More integrated and forward-looking planning;
- Rapid reaction and adjustments of plans and schedules;
- Rapid and efficient recovery;
- More sophisticated analysis and decision support models, methods and tools.

In conclusion, research and innovation contributions are needed to develop new organizational and business models exploiting innovative planning and operations management processes, thus facing logistics and transportation systems major challenges. In this context, *collaborative logistics models* are gaining momentum in the scientific community.

2.2 Collaborative Logistics

Collaborative logistics models emerged during the 1980s as a new Supply Chain Management (SCM) application field that "encompasses the planning and management of all activities involved in sourcing and procurement, conversion and all logistics management activities. Moreover, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies" (https://cscmp.org). SCM researches mostly focus on two areas [Kannan and Tan, 2005]:

- *Logistics management*: coordination of the logistics operations in the value chain;
- *Supply base*: rationalization and integration of suppliers into production activities (i.e., product design, product development, manufacturing processes).

In compliance with SCM principles, logistics actors started to optimise their individual supply chain networks with the aim to create added value for customers.

Over time, the possible business strategies concerning the planning and execution of logistics activities have became [Cruijssen et al., 2007a]:

- Keep the execution in-house;
- Outsourcing;
- Seek partnerships with sister companies to exploit synergies.

Since internal reorganization processes have been almost completed so far, the efforts have been centred on a better management of external relationships.

In this context, the present work is placed. In deepening the collaborative logistics theme, it is first necessary to distinguish between the terms *"cooperative logistics"* and *"collaborative logistics"* often used as synonims in the scientific literature [Leitner et al., 2011]. In terms of interfirm relationship "magnitude" and "closeness", the former requires a lower level of closeness because does not implies a willingness to participate actively in planning and information sharing activities [Golicic et al., 2003]. Moreover, collaborative logistics entails superior levels of risks, knowledge, and profits [Mentzer et al., 2000]. [Vachon and Klassen, 2008] evidence that the higher value is represented by the possibility of "inter-organizational learning" .

Companies, firms decide to collaborate when they are expecting to generate a relational rent that is a supernormal profit jointly generated in an exchange relationship that cannot be generated by either firm in isolation and can only be created through the joint idiosyncratic contributions of the specific alliance partners [Dyer and Singh, 1998]. A synthetic list of potential benefits is illustrated in Table 2.4.

Collaborative logistics implementations typically follows a sequence of steps, hereafter reported in Figure 2.1.

Table 2.3: Collaborative logistics definitions.

Authors, Year	Definition
[CSMP, 2013]	Joint work and communication among people and systems - including business partners, suppliers, and customers - to achieve a common business goal.
[Audy et al., 2012]	Logistics Collaboration occurs when two or more autonomous and self-interested business units form a coalition and exchange or share resources (including information) with the goal of making decisions or undertaking activities that will generate benefits that they cannot (or only partially) generate individually.
[Cao and Zhang, 2011]	A partnership process where two or more autonomous firms work closely to plan and execute supply chain operations toward common goals and mutual benefits.
[Simatupang and Sridharan, 2008]	Collaboration describes the cooperation among independent, but related firms to share resources and capabilities to meet their customers most extraordinary or dynamically changing needs.

Table 2.4: Collaborative logistics expected benefits.

Macroarea	Type of benefit
Business synergies	• Business knowledge and decision making enhancements • Risk management • Capacity enhancements • Business strategies coordination • Increased scale of operations at clients • Bullwhip effect negative impacts reduction
Service quality enhancement	• Reliability improvements • Economies of scope
Innovation	• R&D investments increase • Shorter product life cycles • ICT and DT innovation • Agile and responsive services
Market position	• Price wars prevention • Barriers to enter the market

2.2.1 Collaborative Logistics Types

Collaborative logistics models have evolved over time in order to meet logistics and transportation stakeholders requirements. Historically, mono-dimensional models

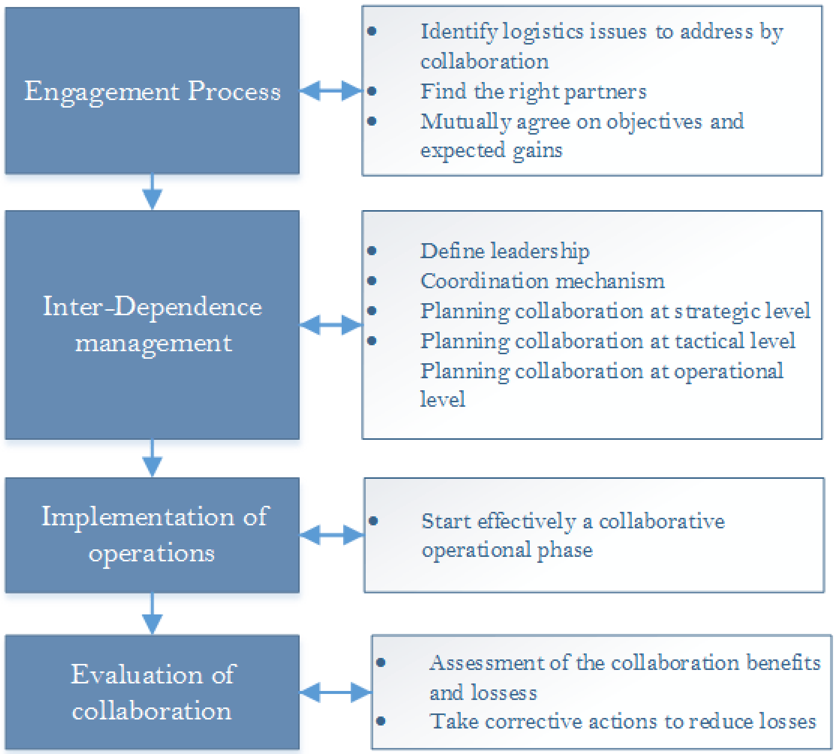

Figure 2.1: Collaborative logistics life cycle. Source: [Audy et al., 2012].

have emerged, mostly between actors operating or in different layers of a same supply chain network (i.e., vertical collaboration type) or in the same layer but in different supply chain networks (i.e., horizontal collaboration type). However, in recent years the increasing pressure on logistics and transportation systems has brought logistics actors to develop bi-dimensional collaboration strategies aiming at enhancing supply chains flexibility. These approaches belongs to the *diagonal collaboration type*.

In perspective, the emergence of new logistics paradigms (i.e., the Physical Internet and the City Logistics) might require innovative collaborative logistics models, characterized by a simultaneous and interactive application of both mono-dimensional and bi-dimensional strategies. In order to emphasise the raise of this new collaborative logistics application fields, in this manuscript a new collaborative logistics type is coined: the *interconnected collaboration type*.

Table 2.5 overviews the four collaborative logistics types, reporting per each of them a reference definition.

Table 2.5: Collaborative logistics types.

Type	Authors, Year	Definitions
Vertical	[Xu, 2013]	Vertical collaboration occurs when different organizations such as suppliers, manufactures, LSPs and retailers share their responsibilities, resources, and performance information to better serve relatively similar end customers.
Horizontal	[Gonzalez-Feliu et al., 2013]	The collaboration between a group of stakeholders of different supply chains acting at the same levels and having analogous needs.
Diagonal	[Okdinawati et al., 2015]	Diagonal collaboration aims to gain more flexibility by combining and sharing capabilities both vertically and horizontally.
Interconnected	[Rusich et al., 2016]	Interconnected collaboration aims to reduce social, economic and environmental impacts of current logistics systems by combining various simpler collaborative logistics types at various levels and in various modes simultaneously, thus creating interconnected logistics networks.

2.2.1.1 Vertical Collaborative Logistics Models

Vertical collaborative models emerged in the 1980s as a consequence of the SCM spread [Kannan and Tan, 2005]. Table 2.6 reports an overview of the most recent vertical collaboration definitions.

The aforementioned definitions evidence the following major peculiarities:

- *Different echelons within a supply chain:* vertical collaboration occurs between two (i.e., bilateral) or more (i.e., multilateral) business units operating at different layers of a same supply chain (e.g., shipper-LSP, LSP-distributor, etc.);

- *Collaboration objective:* [Audy et al., 2012] report that business actors are finalized to reduce the bullwhip effect through an enhanced synchronization

Table 2.6: Vertical collaboration definitions.

Authors, Year	Definitions
[Okdinawati et al., 2015]	Vertical Collaboration concerns two or more organizations, such as a receiver, a shipper, and a carrier, which share their responsibilities, resources and data information to serve relatively similar end customers.
[Gonzalez-Feliu et al., 2013]	A common process management in a supply chain by sharing complementary knowledge and resources in order to efficiently use synergies for planning, deployment, operation follow-up and control.
[Xu, 2013]	Vertical collaboration occurs when different organizations such as suppliers, manufactures, LSPs and retailers share their responsibilities, resources and performance information to better serve relatively similar end customers.
[Zhang et al., 2008]	Vertical collaboration is defined as collaboration between parties that succeed each other in a particular generation process and therefore have different activities.
[The European Commission, 2001]	Agreement or concerted practice between 2 or more enterprises, each operating, for the purposes of the agreement or concerted practice, at a different level of the production or distribution chain, and which relate to the conditions under which the parties may purchase, sell or resell certain goods or services.

between supply and demand. [Mason and Lalwani, 2006] identify the achievement of a better balance between logistics costs and customer service levels as a common goal of suppliers and customers relationships. [Carbone and Stone, 2005] describe several European cases of LSPs and shippers partnerships aiming to expand the market coverage;

- *Collaboration scope:* synchronise supply chain processes.

The scientific literature mostly reports collaborative relationships among logistics service users (i.e., suppliers, manufacturers, retailers) while marginally presents examples of collaborative relationship among logistics service users and the other logistics actors categories.

2.2.1.2 Horizontal Collaborative Logistics Models

The scientific literature reports about several definitions of horizontal collaboration in logistics and transportation systems. A brief list is reported in Table 2.7.

Table 2.7: Horizontal collaboration definitions.

Authors, Year	Definition
[Okdinawati et al., 2015]	Horizontal Collaboration concerns two or more unrelated or competing organizations that cooperate by sharing their private information or resources.
[Gonzalez-Feliu et al., 2013]	The collaboration between a group of stakeholders of different supply chains acting at the same levels and having analogous needs.
[Bahinipati et al., 2009]	A business agreement between two or more companies at the same level in the supply chain or network in order to allow greater ease of work and cooperation towards achieving a common objective.
[Zhang et al., 2008]	Horizontal collaboration is characterized by cooperation between (potential) competitors or parties at the same level in the market.
[Cruijssen et al., 2007b]	Exploiting a win-win situation among companies that are active at the same level of the supply chain in order to increase performance.
[The European Commission, 2001]	A cooperation is of a “horizontal nature” if an agreement or concerted practice is entered into between companies operating at the same level(s) in the market.

The mentioned definitions evidence the following major peculiarities:

- *Same echelon in the supply chain:* horizontal collaboration occurs between two (i.e., bilateral) or more (i.e., multilateral) business units operating at the same industry layer (e.g., production, logistics service provision, etc.) in the supply chain;
- *Different types of horizontal relationships:* as reported by [Bengtsson and Kock, 1999], four types of horizontal relationships can be identified. Firstly, *cohexistence* relationships occurs when no inter-firm economic exchanges are

planned and companies goals are fixed independently. Secondly, *cooperation* relationships arise in case of organisations pursuing common goals through logistics processes joint planning and execution. Thirdly, *competition* relationships consist in "action-reaction patterns with companies using the same suppliers or targeting the same customers" in the supply chain [Cruijssen et al., 2007b]. Finally, logistics actors can set up *coopetition* relationships in which they cooperate in certain supply chain activities (i.e., tipically non-core processes) even if they compete in strategic resources and final markets. Common objectives are fixed for cooperative areas. A 3PL can play the role of neutral mediator avoiding conflicts between competing partners and ensuring at the same time an efficient cooperation [Hiesse, 2009];

- *A common objective:* many authors have described horizontal collaboration potential benefits, evidencing cost reduction as the main driver [Pomponi et al., 2013]. Further opportunities consist in strengthened market position; improved productivity and service quality; enhanced innovation and supply chain responsivness; increased social relevance [Schmoltzi and Marcus Wallenburg, 2011];

- *Shared logistics resources:* involved organisations share material (e.g., vehicles, platforms, etc.), human (e.g., drivers, logistics managers, etc.) and immaterial (e.g. software tools, information, etc.) logistics resources to improve the logistics network performance as a whole [Chan and Zhang, 2011] and [Xu, 2013]. The common use of logistics resources represent a key element of *logistics pooling strategies*, horizontal collaborative practices characterized by organisations co-designing a logistics network to overcome vertical collaborations schemes constraints and inefficiences [Moutaoukil et al., 2012]. Typically, an optimised use of resources is proposed [Pan et al., 2014]. Examples of pooling strategies in warehousing and transportation are explicitly reported in sections 3.3.3.3 and 3.3.3.4.

[Pomponi et al., 2013] propose a horizontal collaborative logistics implementation scheme evidencing a transition from a joint planning at operational level, fixing objectives and shared assets for a short-term horizon, to tactical and strategic shared decision-making processes concerning medium and long-term time horizons. The presented evolution cannot be reached in case of lacking commitment and trust among the involved organisations (i.e., typically if competing actors are involved).

2.2.1.3 Diagonal Collaborative Logistics Models

In recent years, the increasing pressure on logistics and transportation systems has brought logistics actors to develop bi-dimensional collaboration strategies aiming at enhancing supply chains flexibility. These emerging approaches belongs to the *diagonal collaboration* type, whose recent definitions are shown in Table 2.8.

Table 2.8: Diagonal collaboration definitions.

Authors, Year	Definition
[Okdinawati et al., 2015]	Lateral collaboration aims to gain more flexibility by combining and sharing capabilities both vertically and horizontally.
[Xu, 2013]	Lateral collaboration aims to gain more flexibility by combining and sharing capabilities in both vertical and horizontal collaboration.
[Chan and Prakash, 2012]	Lateral collaboration combines the benefits and sharing capabilities of both vertical and horizontal integration.
[Mason and Lalwani, 2006]	Lateral collaboration combines horizontal and vertical forms of collaboration.
[Simatupang and Sridharan, 2002]	Lateral collaboration aims to gain more flexibility by combining and sharing capabilities in both vertical and horizontal manners.

The reported definitions evidence two lateral collaboration peculiarities:

- *Collaboration objective:* logistics actors require to enhance supply chains flexibility in order to promptly react at demand variations in terms of quality, quantity, time to delivery, geographical region of delivery, etc.;

- *Collaboration scope:* the enhancement of logistics and transportation systems flexibility requires the combination of supply chain management approaches finalised to synchronise supply chains (i.e., vertical collaborations) and to optimise the logistics resources use (i.e., horizontal collaborations).

Such a wider collaboration scope does not seem properly emphasized by the taxonomy "lateral collaboration", typically used in the scientific literature, because it mostly reflects the horizontal dimension. The taxonomy *"diagonal collaboration"* appears more appropriate to represent the field of bi-dimensional collaborative paradigms emerging in logistics and transportation systems. The "diagonal" nomenclature explanation is depicted in Figure 2.2.

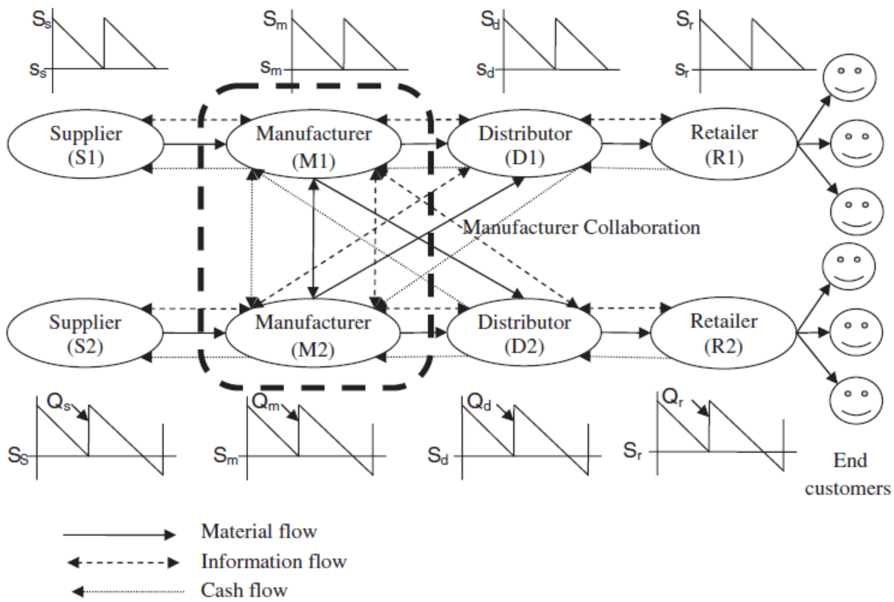

Figure 2.2: Example of diagonal collaboration between a LSP and a manufacturer. Source: [Chan and Prakash, 2012].

2.2.1.4 Interconnected Collaborative Logistics Models

The growing importance of emerging logistics paradigms impose to look beyond the types described in the previous Sections. A reorganisation of current logistics systems exploiting the principles of openness, reliability, synchronisation, sustainability and efficiency requires the proposal of new business and organisational models enabling a simultaneous combination of various collaborative logistics types. Classic models are expected to evolve into more sophisticated and complex ones in terms of collaborative dimension (e.g., joint planning, resource sharing, etc.).

That being stated, in this Section a new type is coined: the *interconnected collaborative logistics*. As already reported in Table 2.5, "interconnected collaboration aims to reduce social, economic and environmental impacts of current logistics systems by combining various simpler collaborative logistics types at various levels and in various modes simultaneously, thus creating interconnected logistics networks".

2.2.2 Collaborative Logistics Forms

Collaborative logistics can take place not only at several supply chain layers, as reported in the previous Section, but also with different levels of interaction. The topic has been already object of various scientific contributions, resulting in various collaboration forms classifications. The publications of [Crainic and Laporte, 1997] and [Baglin, 2009] are taken as a reference by the research community. The former focuses on interfirm relationships in freight transportation while the latter is specific for collaborative logistics. Both studies converge on the following taxonomy:

1. *Transactional collaboration:* the involved entities coordinate and standardise administrative practices and exchange techniques requiring information and communication systems;

2. *Informational collaboration:* the involved entities commit to mutually share information aiming at enhancing individual planning processes. Typically, the information exchange concerns sales forecasts, stock levels and delivery dates. The shareable information types are restricted for competition and confidentiality motivations;

3. *Decisional collaboration:* the involved entities coordinate various planning and management decisions belonging to various planning stages:

    - Operational planning: joint decision making or shared individual plans related to daily operations (i.e., short-term planning);
    - Tactical planning: joint decision making or shared individual plans related to middle-term planning finalised to establish a relation of trust between the collaborators. Tactical decision concerns, for example, sales forecasts, shipping operational decisions, stock and production management and quality control;
    - Strategic planning: joint decision making or shared individual plans related to long-term planning concerning strategic decisions such as network design, facility location, finance and production planning.

The work of [Gonzalez-Feliu and Morana, 2011] refers to the previous publications, specifying that in logistics and transportation the involved entities can share tangible (e.g., vehicles, infrastructures, etc.) and intangible (e.g., orders, plans, etc.) resources. In this framework, shared planning (i.e., joint planning) means that different entities contribute in the strategic and/or tactical decision making while at operational level each actor make its individual decisions. The following sharing approaches can be implemented:

- Non-collaborative sharing: each entity manage independently the shared resources;
- Collaborative sharing with hierarchical decision making: joint management of shared resources but decisions result from a hierarchic process (e.g., leader-follower model);
- Collaborative sharing with non-hierarchical decision making: joint management of shared resources and common effort in joint planning.

The work of [Frayret et al., 2003], although converging with the aforementioned reference works of [Crainic and Laporte, 1997] and [Baglin, 2009], propose a more analytic classification taking into consideration the information exchange and the commitment intensity. Figure 2.3 illustrate a schematic representation of this approach.

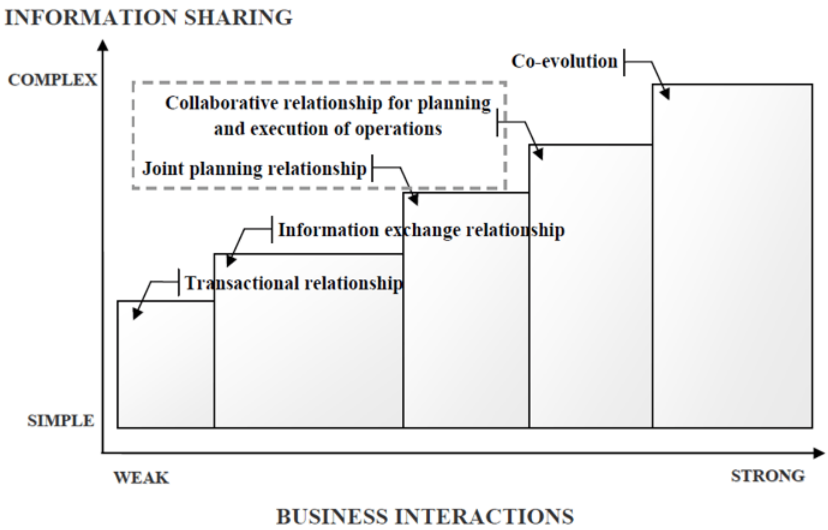

Figure 2.3: Collaborative logistics forms. Source: [Frayret et al., 2003].

The most relevant difference in respect to previous contributions consists in the decisional collaboration form split into two subsets, one related to the only joint planning process and the other concerning also the joint execution of mutual plans. A second difference refers to the strategic decision level, classified as a stand alone form of collaboration called co-evolution.

That being stated, the present work takes as a reference the collaborative logistics forms taxonomy proposed by [Crainic and Laporte, 1997] and [Baglin, 2009], although with the appropriate adjustments. First of all, in the rest of treatment the transactional collaboration form is not considered mostly because there are few basic common goals, no decisions taken in common, etc. Moreover, being understood the *informational collaboration form as entry level*, the subsequent levels concerning the so called "decisional collaboration" are presented as follows:

1. *Coordinated Planning*: the involved entities commit to jointly plan a common operational vision, referred to a single or more business tasks. Consequently, each actor harmonise its individual plans in respect to the common vision;

2. *Integrated Planning*: the involved entities commit to integrate the respective individual planning processes, thus acting as a unique organisation. So far, this form of collaboration has almost no real applications, except in the case of merges and acquisitions. Two distinguished approaches are currently under study:

   - Integrated Centralised Planning: the involved entities joint planning process is performed via a unique decision-center (e.g., a joint venture, an IT platform, etc.). The planning objective consists in the optimal solution identification for the whole collaboration community. Classic multi-agent decision-making approach, which presents the following limitations:
     - Operational: strong willingness to collaborate (e.g., in data harmonization, shared plans, time lines, resources, etc.);
     - Methodological: the planning model might require an high computational time to compute the optimal solution, as well as unavailable resources;
   - Integrated Distributed Planning: emerging approaches aiming to avoid the aforementioned limitations. A distributed integrated planning process has the advantage of removing decision-making autonomy to operators even if the disadvantage consists in the result, which is limited to a suboptimal solution. A typical case are the agent systems, invented in computer science and then introduced in logistics as a consequence of the ICT and DT applications widespread in the field. Distributed agent systems theory is currently applied to model CL and PI systems behaviours, thus representing a promising research area.

Both coordinated and integrated planning forms of collaboration may concern strategic, tactical and operational decision levels.

2.3 Moving Towards Innovative Paradigms

Logistics and transportation systems are affected by mostly three types of inefficiencies [Montreuil, 2012]:

- Economical: worldwide logistics costs grow faster than world trade;
- Environmental: growing negative contribution while nations goals aims for heavy reductions;
- Social: lack of fast, reliable and affordable accessibility and mobility of physical objects for the vast majority of the worlds population. Moreover, too often precarious logistic work conditions.

The unsustainability of current logistics and transportation processes has induced researchers and practitioners to commit in inefficiencies reduction. With this aim, in recent years several visions have emerged, among which two innovative theoretical frameworks are gaining momentum: the City Logistics (CL) and the Physical Internet (PI).

2.3.1 The City Logistics

The City Logistics paradigm aims to decrease the presence of freight vehicles in urban areas and their unpleasant consequences, without penalizing the city activities and development [Crainic et al., 2009]. The vision exploits two major concepts:

- Integrated urban freight planning based on optimised multi-customer (i.e., shippers or carriers) loads consolidation within the same delivery vehicle;

- Coordination of the resulting freight transportation activities within the city.

From a methodological perspective, this research field is well known even if appropriate business models are still under study. Proof of this are the various organisational models proposed by different cities through experimental projects and initiatives. From a planning perspective, two network design configurations have been proposed so far:

- Single-tier: typical network configuration for small and medium cities characterised by the presence of a unique shared logistics facility, a City Distribution Center, for inbound urban deliveries consolidation;
- Two-tier: metropolitan areas network configuration based on two levels of loads consolidation, respectively performed in a City Distribution Center located far from the city center and satellites positioned close to the final market.

In recent years, research contributions have pointed out new emerging scopes, such as green vehicles fleets adoption and public-transport infrastructure integration.

2.3.2 The Physical Internet

The Physical Internet (PI) nomenclature was proposed for the first time by The Economist in 2006. Since that time, the paradigm has continued to arouse the interest of Governments, logistics actors and researchers committed to propose a reorganisation of current logistics and transportation systems. Indeed, the PI mission is "to improve the economic, environmental and societal efficiency and sustainability of the way physical objects are moved, stored, realized, supplied and used all across the world" [Montreuil, 2011], [Montreuil, 2012].

The PI envisages the realisation of an "open global logistics system leveraging interconnected supply networks through a standard set of modular containers, collaborative protocols and interfaces for increased efficiency and sustainability" [Ballot et al., 2015]. The general idea is to take inspiration by the Digital Internet concept in telecommunications and adapt it to logistics and transportation networks in order to consider properly the differences between data packets and physical objects (i.e., freight cannot move by itself). Similarly to the Digital Internet, freight movements are independent of the actual operations of the transportation, terminal handling, storage infrastructure, other services and proceed in an openly consolidated way through a series of carrier services and relay facilities.

The PI vision is based on three key components, fundamental elements to create the interconnection between the logistics services of transportation, storage, etc.

- π *-containers*: role of protecting shipments, representing a private space, providing a standardised interface (i.e., communication and physical) with the logistics system. Key component of the PI network interoperability (i.e., intermodal transportation-based Logistics Web). An example of π -container is reported in Figure 2.4;

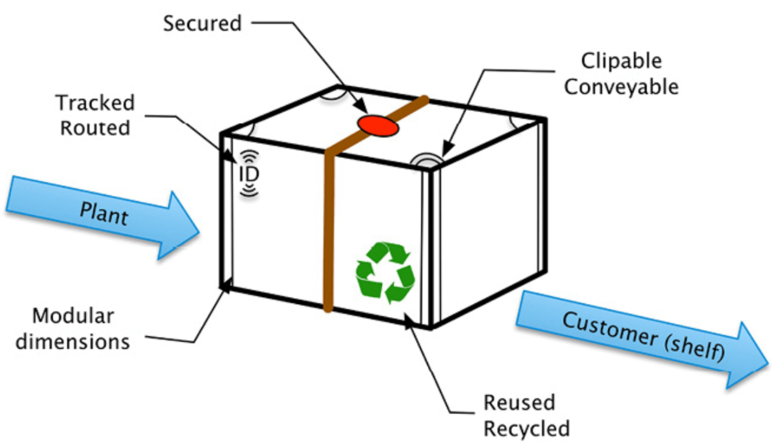

Figure 2.4: Sketch of a π -container. Source: [Ballot et al., 2015].

- π *-protocols*: role of defining the right operation to be performed and under which conditions. In order to operate services in an interconnected network, each stakeholder has to observe a set of professional rules. In such a way, services can be structured in layers according to standardised protocols. As Digital Internet based services have been structured into seven layers according to the Open System Interconnection (OSI) reference model, PI services are structured following the Open Logistics Interconnection (OLI) reference model, hereafter illustrated in Figure 2.4;

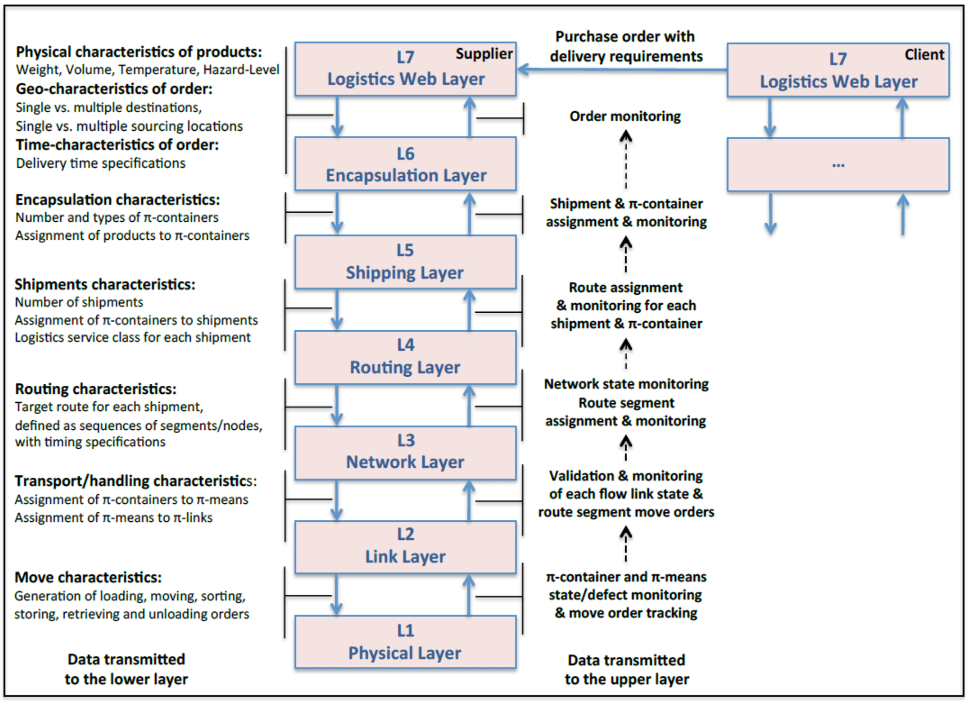

Figure 2.5: Sketch of the OLI reference model. Source: [Montreuil et al., 2012].

- π *-hubs*: role to limit storage in transshipment facilities by routing directly each shipment of appropriate sizes to customers. Figure 2.6 illustrate the design of a rail-road π -hub.

The PI will result in a Logistics Web composed by 5 layers/modules:

- *Open global Production web:* shared production networks minimising physical moves and storages by digitally transmitting knowledge and materialising products as locally as possible through the open realization web. Production

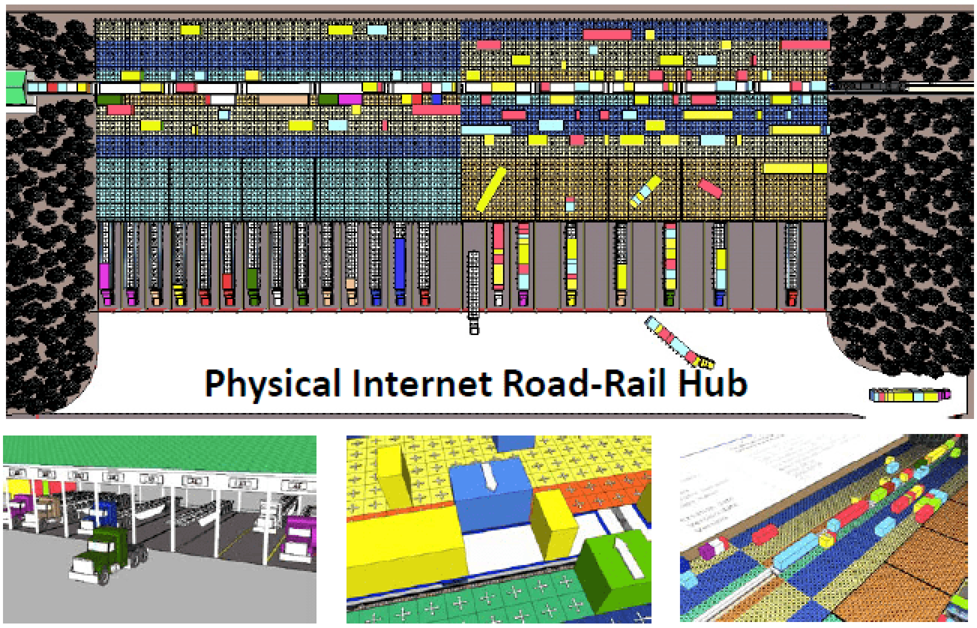

Figure 2.6: Sketch of a road-rail π -hub. Source: [Montreuil, 2012].

webs exploit extensively knowledge-based dematerialization of products and their materialisation in physical objects at the point of use [Montreuil, 2012];

- *Open global Distribution web:* most companies design, run and optimize independently their private distribution networks, investing in DCs or engaging in long-term leases and contracts. with a Distribution web, each company could deploy its products through a open web of multiple DCs [Montreuil, 2012];

- *Open global Mobility web:* redesign transportation service networks from point-to-point or hub-and-spoke transport to distributed multimodal transport. In a Mobility web, a modular container might follow multi-segment routes from origin to destination [Montreuil, 2012];

- *Open global Supply web:* networks of interrelated supply networks, each embedding interlaced supply chains, involving multiple organizations (e.g., suppliers and subcontractors) with collaborative or competitive relationships. Supply Webs are characterised by the following peculiarities:

- Their nodes are openly accessible to most actors, be they producers, distributors, logistics providers, retailers, or users;
- The service capacity of their nodes is available for contract on demand, on a per-use basis, be it for processing, storage or moving activities;
- Dynamic and interlaced virtual private networks are created by actors for realizing and deploying the products, services and solutions in anticipation of and response to stochastic demand from clients [Montreuil, 2011].

• *Open global Service web:* open networks of interrelated service networks, each embedding multiple users and service providers [Montreuil, 2011].

At this point in time, several studies have simulated PI networks behaviours generally evidencing a positive influence on logistics and transportation performances. For example, [Montreuil, 2011] simulate the potential benefits of a PI network design in the French retailing industry.

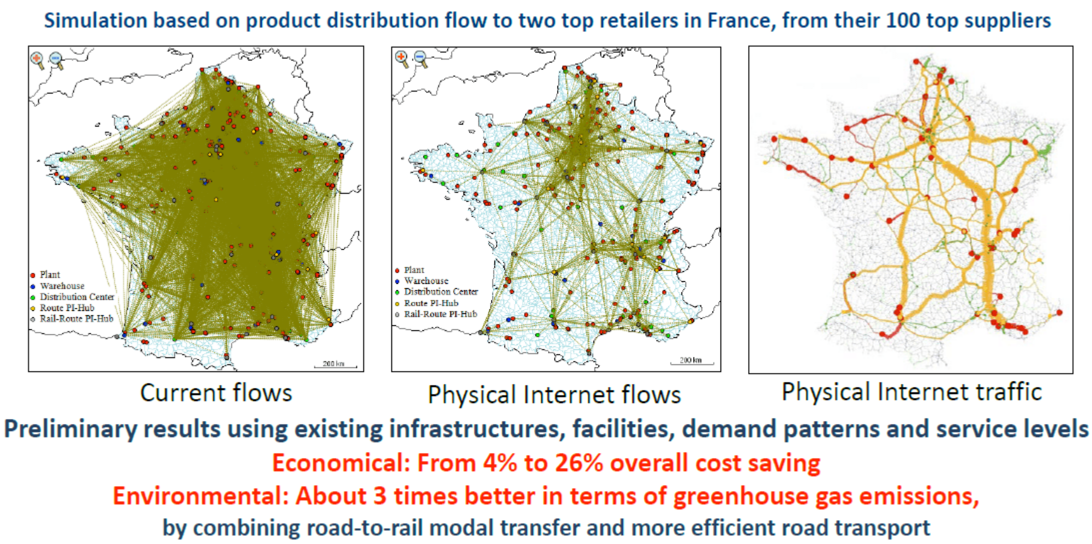

Figure 2.7: Preliminary simulation results concerning a Physical Internet-based consumer goods industry in France. Source: [Montreuil, 2012].

The authors assume that the two major companies in the sector, Carrefour and Auchan, decide to collaborate at the level of information sharing, thus putting orders together and let them to be delivered by a sample of one hundred top suppliers. It is assumed to have a PI network already in place, thus implying that a set of carriers operate in a collaborative manner to optimise freight movements in terms of costs, load factor and time to delivery. The preliminary simulation results are reported in Figure 2.7 [Montreuil, 2012].

2.4 Research Objectives

Given what has been previously illustrated in the present Chapter, this work *aims to contribute to the understanding of collaborative logistics, with a particular focus on emerging business and organizational models, such as the Physical Internet.* In particular, the problem is dealt from both theoretical and practical points of view, targeting three major research gaps.

1. *Theoretical open issues*

   (a) Collaborative logistics classification framework: the current collaborative logistics types classification (i.e., the "classic" vertical, horizontal and diagonal ones) is missing a concept to emphasise the emergence of "innovative" models characterized by a simultaneous application of multiple classical approaches;

   (b) Harmonised methodology for collaborative logistics models analysis: the scientific literature is missing a structured approach to analyse collaborative logistics management implications, both regarding scientific literature review and future research areas identification;

2. *Practical open issues*

    (a) ICT and Decision Technologies innovation: design and development of new tools supporting decision makers in planning and managing logistics and transportation processes in interconnected collaborative networks.

Chapter 3

A Collaborative Logistics Taxonomy

This chapter presents a taxonomy for a better understanding of the existing and emerging collaborative logistics business and organisational models. The tool supports logistics researchers and practitioners aiming at identifying current research gaps and future areas from a logistics management perspective. The Section 3.1 is devoted to present the taxonomy methodology, while Sections 3.2, 3.3 and 3.4 illustrate a taxonomy application to classify the scientific literature concerning classic collaborative logistics models (i.e., vertical, horizontal and diagonal types). Section 3.5 remarks the most relevant outputs.

3.1 Taxonomy Methodology

A collaborative logistics state of the art analysis represents the first step in the business and organisational models innovation process. Such a general understanding enables researchers and practitioners to identify the current gaps and barriers, thus addressing the research towards emerging research areas. To do so, the existing collaborative logistics models have to be analysed from a logistics management perspective (i.e., the part of the supply chain management that plans, implements and controls the efficient, effective forward and reverse flow and storage goods, services and related information between the point of origin and the point of consumption in order to meet customers requirements).

In this section, a taxonomy for collaborative logistics models is proposed as a tool to tighten and harmonise classic and innovative models descriptions. The hierarchy characterising the classification tool concept is sketched in Figure 3.1.

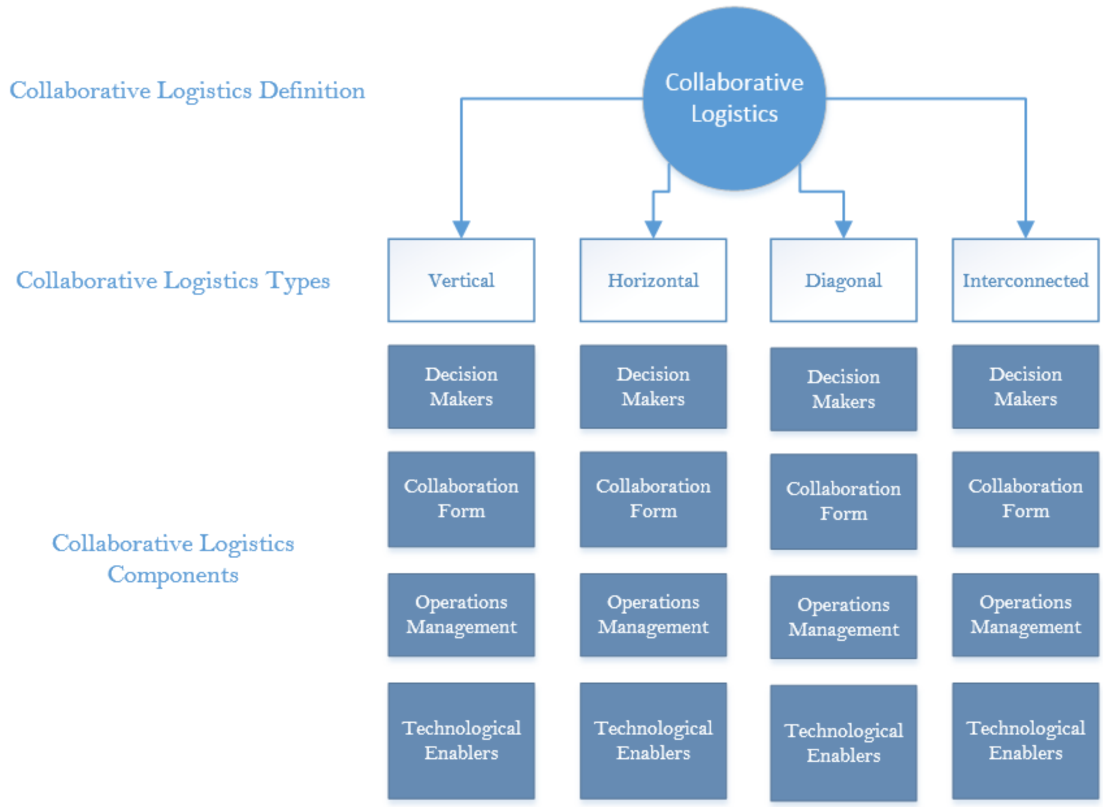

Figure 3.1: A taxonomy for collaborative logistics.

The first step consists in reporting the collaborative logistics definition in order to clearly identify the field of study. A first analysis refinement is represented by the identification of the collaborative logistics type, which based on Section 2.2.1 can be vertical, horizontal, diagonal and interconnected. Consequently, both classic collaborative logistics models and emerging logistics paradigms fit in one of the four categories. At this point, the taxonomy identifies two most relevant areas of information to be collected (i.e., second analysis refinement):

- *The business model*: descriptions concerning the key components of a market strategy. With reference to collaborative logistics, they are represented by the *decision makers*, the *collaboration form* and the *operations management*;
- *Implementation requirements*: descriptions concerning the key components to deploy and run the business model. For collaborative logistics, they are ICT and DT.

Figure 3.2 sketches the key components of a collaborative logistics model, as identified by the proposed taxonomy.

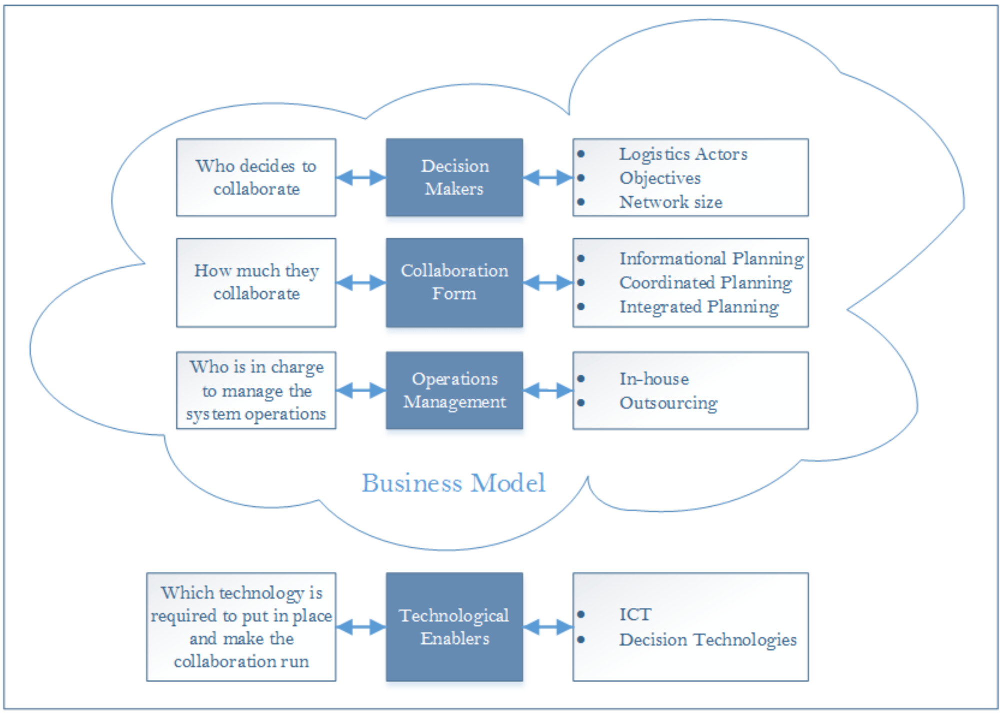

Figure 3.2: Key components of collaborative logistics models.

3.1.1 Decision Makers

Knowledge about which and how many public or private entities commit to establish supply chain management strategies belonging to the collaborative logistics domain. The decision makers can be identified only at the end of the first step of the collaborative logistics life cycle, the engagement process. At this stage, each supply chain actor presents the proper logistics issues to be addressed through a business collaboration and its expected benefits. By evaluating several aspects such as compatibility of goals, organizational culture and willingness to collaborate, it is possible to find the right partner with whom mutually agree on the collaboration objectives and the expected gains. The decision makers belong to the four macro-categories of logistics actors reported in Section 2.1: logistics services users, logistics services providers, logistics services enablers, logistics services legislators.

Moreover, it is relevant to report how many layers of the supply chain are involved in the collaboration. The relationship can assume a two-tier structure, as in the case of synergies between a manufacturer and a supplier, or an n-tier structure, involving suppliers and customers operating at different levels in supply chain networks. Finally, the decision makers criteria requires to describe the common goals pursued through logistics collaboration.

3.1.2 Form of Collaboration

During the inter-dependence management step of the collaborative logistics life cycle, the decision makers set up the strategy tendering to create a common added value. Typically two processes are investigated:

- *Joint decision making*: collaborative synergies at planning level. As illustrated in Section 2.2.1, three levels of intensity can be established: informational planning, coordinated planning and integrated planning. In the last two cases, the joint planning process can occur at strategic, tactical and operational level;

- *Shared logistics resources*: descriptions about the level of participating organisations commitment in terms of shared material (i.e., capacity, facilities, etc.), immaterial (i.e., knowledge, information, etc.) and human resources to design and operate shared networks and services.

3.1.3 Operations Management

During the execution stage of the collaborative logistics life cycle, the plans are translated in day-by-day business operations. As reported by [Gonzalez-Feliu and Morana, 2010] "in transportation and logistics sharing, operational decisions are in general individually made". In other words, each partner is in charge to manage the operations of competence, in compliance with the formal or informal agreements established during the engagement stage. In some collaborative logistics approaches, the execution of one or more tasks should be outsourced to a third entity, external of the coalition. In this context, the present classification criteria reports, first, the distinction between partners-managed or outsourced operations management and, secondly, contains the description of tasks performed by each participating actor.

3.1.4 Technological Enablers

Before making the business model run, the partners have to identify the technological requirements enabling the implementation and, consequently, the execution stage. Depending on the agreed collaborative form, different levels of technological readiness should be required: the adequacy of the in-house ICT and decision technologies have to be identified in order to support the execution of the planned information sharing and decision-making procedures. Potential technological gaps have to be filled through appropriate investments in technology. If new infrastructures have to be deployed and managed, the partners should adapt or integrate their internal ERP systems with new ICT tools like devices, sensors, software and communication protocols enabling the provision of new functionalities or logistics services. Per each collaborative logistics approach, the technological enablers classification proposed in Section 2.1.3 is taken as a reference. Consequently, two macro categories of technological enablers are identified: ICT and decision technologies. The former enable data collection, storage, retrieval, analysis, processing, manipulation to obtain useful information; the latter exploit data mining, optimization and simulation techniques to support the decision-making process.

3.1.5 Taxonomy Application Fields

In order to validate the usefulness of the presented tool in reviewing the collaborative logistics domain, a scientific literature classification is presented. More in detail, the following Sections overview the classic collaborative logistics models belonging to the vertical, horizontal and diagonal collaboration types. The literature review continues in Chapter 4 where the collaborative logistics requirements of the emerging logistics paradigms are illustrated, mostly focusing on the Physical Internet.

Overall, a sample of 181 scientific publications has been considered during scientific literature review process. Figures 3.3 and 3.4 illustrate, respectively, the publications categories and the collaborative logistics types considered. The researches selection process has been performed in two steps:

1. *General keywords search*: the words *logistics collaboration*, *logistics cooperation*, *logistics coopetition*, *vertical logistics collaboration*, *horizontal logistics collaboration*, *transportation collaboration*, *supply chain management*, *supply chain partnerships*, *supply chain integration*, *supply chain synchronization*, *logistics outsourcing*, etc. have been searched in Google Scholar, Scopus, Sciencedirect, IEEE and Emeraldinsight on-line research platforms;

2. *Specific collaborative logistics model search*: the specific nomenclatures of the most reported logistics collaboration approaches have been used in the same electronic platforms such as *JIT*, *Quick Response*, *ECR*, *Collaborative Trans-*

portation Management, *Shared Logistics Infrastructures*, *Joint Route Planning*, *City Logistics*, etc.

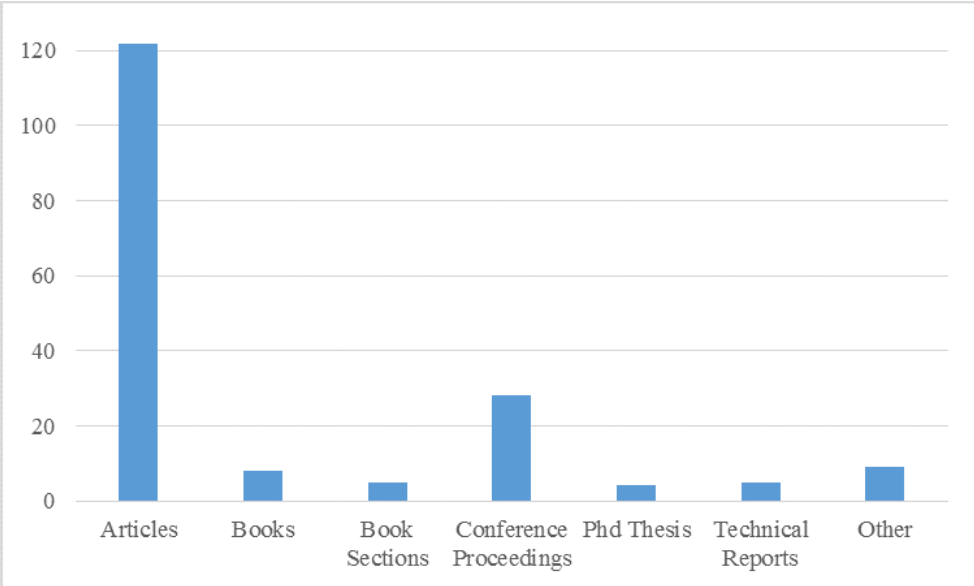

Figure 3.3: Scientific publications sample overview.

As reported in Figure 3.4, the scientific publications sample composition evidences that researchers have mostly focused on vertical types rather than the others. Only few works about diagonal collaborative logistics have been proposed so far, a trend even more marked for the emerging logistics paradigms.

In the following sections, the classic collaborative logistics models scientific literature classification is reported. The taxonomy proposed in Section 3.1 is applied to review the vertical, horizontal and diagonal collaborative logistics domains.

3.2 Vertical Collaborative Logistics

As already mentioned in Section 2.2.1, vertical logistics collaboration occurs when different organisations such as suppliers, manufacturers, LSPs and retailers share

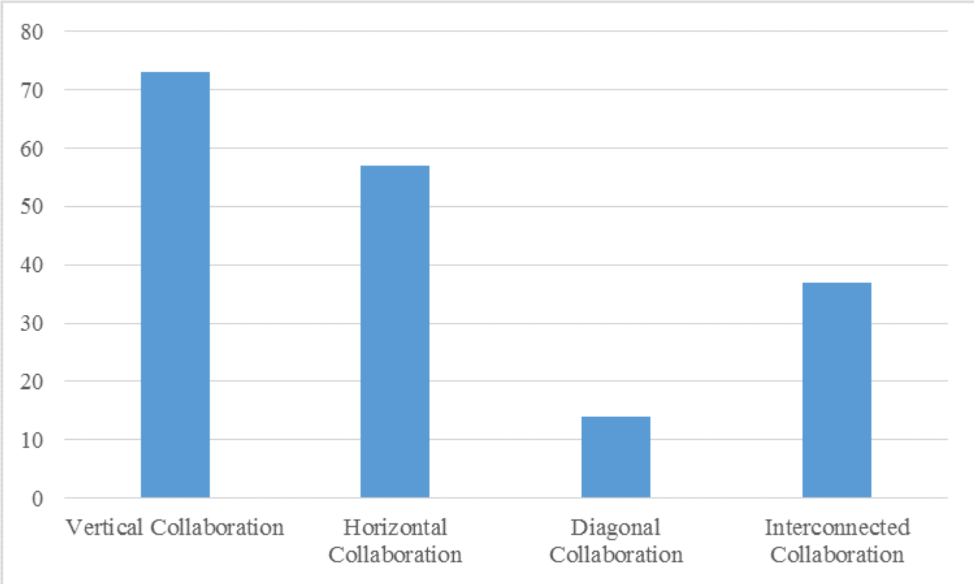

Figure 3.4: Scientific publications sample overview per collaborative logistics type.

their responsibilities, resources and performance information to better serve relatively similar end customers [Okdinawati et al., 2015]. Since first business and organisational models emerged at the end of the 1950s, this research area is currently deeply studied. Hereafter, the collaborative logistics taxonomy is applied to the major examples of vertical collaborative relationships involving several supply chain networks layers (i.e., processes).

3.2.1 Procurement and Production

Upstream in supply chains, manufacturers started to implement sourcing strategies aiming to improve products quality, reduce procurement costs, increase productivity levels and sales to customers. The establishment of a *strategic supplier relationship* has been representing a way of managing the sourcing process together with key suppliers finalized "to create fast, flexible, reliable and cost effective supply chain" [Leeman, 2010]. Once suppliers are selected based on pre-defined quality-focused criteria, the partners create a service level agreement in which suppliers become in charge to deliver on time core materials and components to manufacturers, to put in place systems for a continuous quality and performance improvement, to invest in B2B IT systems enabling processes and systems integration. On the other hand, manufacturers provide on time, correct and complete purchase orders, guarantees an annual product order volume and "set up merchandise planning and IT systems integration with the supplier" [Leeman, 2010]. The integration of the respective ERP systems through B2B networks is a critical factor of success, generally performed in three steps. First, the partners identifies the processes to be integrated (e.g., product development). Secondly, the B2B network is built with the aim to electronically manage order and delivery processes. EDI-based applications are nowadays the most common but new initiatives integrate processes directly via web-EDI using XML standards. The B2B network results in a supplier portal, a web page in which each supplier logs on, identifies itself and uses the authorized functions. Thirdly, the partners establish performance evaluation methods (e.g., suppliers plants inspections) in order to improve constantly the quality of the collaboration. The most famous strategic supplier relationship approach reported in the scientific literature is the *Just In Time (JIT)*, a strategy emerged in the Japanese automotive industry during the 1960s to face globalization challenges in a country characterized by a scarcity of raw materials. [Canel et al., 2000] defines the JIT as "an operating concept designed to eliminate waste avoiding everything other than the minimum amount of equipment, materials, parts, space and worktime". The manufacturing process was reviewed with the result that the relationship with suppliers emerged as one of the main areas of waste. Nowadays, the JIT is applied in both production of goods and service sectors, mainly in manufacturing and sourcing processes, and is widespread in all dveloped countries [Singh and Garg, 2011].

3.2.1.1 Just In Time (JIT)

Hereafter, the collaborative logistics taxonomy is applied to review the scientific literature on JIT purchasing strategies.

Decision Makers In manufacturing systems, logistics service users collaborate in the purchasing process "to eliminate waiting times so that inventory investments can be minimized, production lead times can be shortened, demand changes can be quickly addressed, and quality problems can be uncovered, and solved" [Canel et al., 2000]. The JIT philosophy induce manufacturers to establish partnerships with key suppliers finalized to pass from the traditional competitive buyer-supplier relationships characterized by "buyers carrying large inventories to compensate long lead-times and poor quality of incoming parts", to new collaborative buyer-supplier relationships, characterized by frequent and reliable deliveries of high quality parts performed in small shipment sizes [Singh and Garg, 2011]. The adoption of a JIT purchasing process enables the productive logic evolution from a *push system* (i.e., materials are pushed into production independently by a previous movement in exit) to a *pull one* (i.e., material movements based on demand) [Koufteros, 1999]. [Kannan and Tan, 2005] report that the adoption of a JIT purchasing and manufacturing processes generate benefits in terms of excess inventories reduction or elimination and a more efficient use of resources. [Yasin et al., 2003] make a literature review and remark that JIT tends to eliminate material waste, to reduce purchasing costs and lead-times, to increase productivity. [Alcaraz et al., 2014] lists the work of 35 authors and makes a ranking of the most cited JIT benefits, resulting in productivity increase and total production reduction. A soft JIT strategy implementation can involve only direct suppliers (i.e., single-tier network) while extensive implementations can involve suppliers operating in multiple layers upstream the manufacturing stage (n-tier network).

Collaboration Form The scientific literature concerning JIT reports heterogeneous examples of purchasing relationships even if two main approaches are identified. [Sako, 1992] compares buyer-supplier relationships implemented in Japan and Britain, differentiating between “short term arms length contractual relationships” and “long term obligational contractual relations”. The former are typically British applications characterized by firms independency in decision making process and reduced information sharing among partners; the latter are proper of the Japanese manufacturing system and are characterized by participating organizations linked by “high trust cooperativeness to trade over long run”. [Gélinas et al., 1996] differentiate between “concurrency relationship strategies”, short-term relationships with a multiplicity of suppliers that share a certain purchasing volume, and “partnership strategies”, characterized by long-term agreements with few key “intelligence suppliers” establishing a win-win cooperation. A discrete number of studies focus the attention of strategic JIT purchasing relationships, in which suppliers are considered as “outside partners”, extensions of the manufacturers corporate organizations [Gunasekaran, 1999], [Yasin et al., 2003], [Gélinas et al., 1996], [De Toni and Nassimbeni, 2000], [Dong et al., 2001]. These configurations of JIT purchasing relationships start with the key supplier selection process in which buyers generally rank and identify the potential partners based on their geographical location closeness to the production plant, their financial stability, their product and delivery qualities [Dong et al., 2001]. Once identified the right partners, different types of agreements can be signed to define the operations management procedure (i.e., Kanban, blanket orders). The participating organization develop a relationship based on mutual trust, communication and teamwork. A coordinated planning collaborative form with hierarchical decision-making is established in which the manufacturer assume the leading role with the aim to create and manage a network of competent suppliers. At strategic level, coordinated decisions concern shared investments, product co-design, manufacturer’s processes development and contractual incentives. At tactical level, coordinated decisions concern the production rate, the corresponding workforce and inventory levels per each production cycle. The involved organizations agree on common quality standards and the related evaluation procedures. At operational level, the scheduled production and delivery plans are adapted to satisfy the manufacturer's requirements of materials and components. Information sharing is a fundamental element in the JIT purchasing. In order to synchronize production and delivery processes, partners share production schedules and demand forecast. When a product co-design or process development relationship is established, the manufacturer shares information concerning product and processes engineering with the supplier [De Toni and Nassimbeni, 2000].

Operations Management JIT production requires that the purchasing process is able to deliver small-sized lots of the right materials and/or components to the right workstation, with the right price and in the right time [Benton and Shin, 1998]. In order to achieve this goal, the partners sign contractual agreements defining the operations management procedures. The Japanese Kanban agreements aim to synchronize production and delivery activities on a daily basis. The partners agree to maintain only the required short-term manufacturing inventory and to replenish it based on a signal sent to suppliers in correspondence of the materials and components movements from inventory to production workstations. The operations synchronization is based on a signal sent by the manufacturer to suppliers when they have to deliver a new shipment. Thus, based on the evidenced manufacturer requirements suppliers produce the small-sized lots of items [De Toni and Nassimbeni, 2000]. If order blankets agreements are signed, the buyer issues a blanket purchase order and the supplier agrees to ship materials at different times throughout a set period (e.g., once a month, every quarter, etc.) at predetermined prices. Independently of the type of agreement signed between buyers and suppliers, transportation tasks are outsourced to a contract freight carrier based on agreements defining dates and times in accordance with the manufacturers schedule.

Technological Enablers The scientific literature reports about several information technologies enabling the deployment of JIT production networks while no particular decision technologies are evidenced. The major functionalities to be implemented are intra-firm materials and components depletion traceability, inter-firm information sharing and electronic found transfer among partners. Hereafter, a summary of the information technologies required to deploy the mentioned operational functionalities:

- Automatic Identification and Data Capture technologies: JIT production deployments generally requires to collect data regarding inventoried materials and components. For this purpose, items identification is enabled by bar codes whose passage from a workstation to the next one is detected by laser scanners or optical readers generating an advice for supplier replenishment. In Kanban systems, kanban cards to signal depletion of materials or components are used. The technological progress has enabled the development of electronic kanban systems (e-kanban). These new systems are based on bar codes, mainly used in movements between companies, or RFID-bar codes for inter-firm movements, used to identify containers. After the usage, the bar code or the RFID-bar code is removed from the container;

- Communication Networks and Data Exchange technologies: EDI usage is widespread to link partners operations. In Kanban and advanced e-kanban systems, EDI based on EANCOM standards or web-EDI using XML standards enable buyer-supplier communication [Leeman, 2010].

- Electonic Found Transfer technologies: electonic founds transfer systems (EFT) enable automatic payments between the buyer and the supplier [Gunasekaran, 1999];

- Information Hubs: in recent years, e-kanban systems have started to be integrated in information hubs, such as ERP systems, dedicated to manufacturing companies. As reported by [Kouri et al., 2008], the main ERP system vendors have started to integrate Kanban modules in ERP systems. Nowadays, BMW, Toyota, Ford in the automotive sector as Bombardier Aerospace manage their operations through e-kanban systems;

- Decision Technologies: the publications survey has not evidenced the use of JIT dedicated decision technologies extra the decision support functionalities already included in the information hubs (e.g., production scheduling, etc.).

3.2.2 Freight Transportation, Warehousing, Distribution

In accordance with the research of [Soosay and Hyland, 2015], the scientific literature looks downstream in the supply chain at buyer-supplier collaborations. In this type of business relationships, buyers are interested to establish long-term partnerships with few key suppliers in order to reduce costs, improve efficiency and increase customer service [Giunipero et al., 2001]. The partners sign a service level agreement in which the supplier become in charge to deliver on time core materials, components, products to buyers, to put in place systems for a continuous quality and performance improvement, to invest in B2B IT systems enabling processes integration. On the other hand, buyers provide on time, correct and complete purchase orders, guarantees an annual product order volume and “set up merchandise planning and IT systems integration with the supplier” [Leeman, 2010]. The partners establish common performance evaluation methods (e.g., KPIs) in order to constantly improve the collaboration quality. During the 1990s, supply chain reengineering concepts emerged in the US grocery and apparel industries under the name of, respectively, Efficient Customer Response (ECR) and Quick Response deliveries (QR). The objective was to identify the most efficient method to produce and distribute products and services. The existing processes were questioned, variations were assumed as in the firm organisation as in the supply chain network bringing to the development of a new system. ECR and QR have reengineered the supply chain through inter-firm electronic data communication based on emerging technologies like EDI, allowing an automated flow of information from the point of sale to different layers of suppliers. As reported by [Drake and Marley, 2010], ECR and QR systems were industry-specific both using real-time sales data to pull inventory through the distribution network.

3.2.2.1 Efficient Customer Response (ECR)

Hereafter, the collaborative logistics taxonomy is applied to classify the scientific literature on Efficient Customer Response (i.e., ECR) models.

Decision Makers Originated in the US grocery industry of the early 1990s [Finne and Sivonen, 2008], the ECR concept was developed by the major supermarket chains to face market share reductions derived by the widespread of alternative store formats [Kurnia et al., 2002]. The ECR Europe Executive Board defined the ECR as "the realisation of a simple, fast and consumer driven system, in which all links of the logistic chain work together, in order to satisfy consumer needs with the lowest possible cost". Through ECR, suppliers and retailers reengineered the supply chain with the aim to identify and cut non-value-added activities, thus to obtain operating costs and inventory levels reductions and to enhance the grocery industry competitiveness through a greater value offered to customers. The supply chain collaborative network could be single-tier, involving a manufacturer and a retailer (i.e., department store), or n-tier, involving logistics actors operating in different layers of the supply chain (i.e., key suppliers, manufacturer, department store, independent retailers). [Leeman, 2010] reports that in single-tier networks, manufacturers aim to reach space control enabling reduced time-to-market while department stores aim to be faster with less transaction costs.

Collaboration Form The scientific literature defines the ECR as a supply chain management strategy finalized to "optimise the synchronization of supply and demand" [Leeman, 2010]. Three strategic macro-areas of interventions are identified: *demand management*, *supply management* and *IT enablers*. Improvements in demand management are finalized to enhance product availability at stores shelfs by optimizing freight flow planning, assortments optimization, promotions optimization, product introductions optimization and infrastructure establishment [De Toni and Zamolo, 2005]. Enhancements in terms of suppliers integration, operations reliability, synchronized production, continuous replenishment, cross docking and automated store ordering are pursued aiming at reducing transaction costs. Finally, IT enablers are required to make the partners faster and efficient. The decision-makers establish a coordinated planning collaborative relationship at operational level without hierarchical decision-making process. The participating business organizations develop long-term partnerships based on mutual trust and commitment in which they jointly re-design the distribution channel by taking decisions concerning the three macro-areas of intervention mentioned in the previous lines. As reported by [Holweg et al., 2005], joint teams of specialists, trade marketing teams or key account managers should be involved in the re-design of category management processes. Investments in IT systems are required to enable one-to-one electronic standardized inter-firm communication. By sharing sales information, suppliers production plans and deliveries schedules, the department store is enabled to make decisions concerning the space allocation at stores.

Operations Management Two main operational programs support the implementation of the fourth strategic initiatives: the *Category Management (CM)* and the *Continuous Replenishment Program (CRP)*. The CM consists in a business collaboration between the retailer and the manufacturer finalized to jointly manage product categories as strategic business units within each store. On the other hand, the CRP is a practice incentivizing business partnerships in the distribution sector finalised to ensure the provision of the right product to the right place at the right time in the right quantity [Kurnia et al., 2002], [Europe, 2004].Figure 3.5 reports a schematic representation of the ECR theoretical framework.

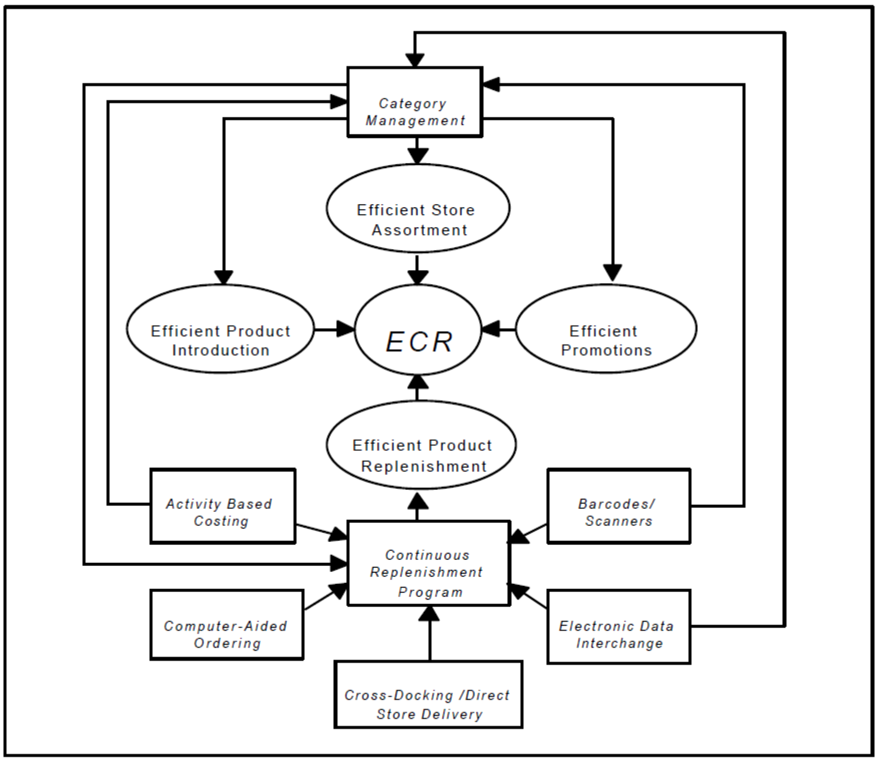

Figure 3.5: ECR theoretical framework. Source: [Kurnia et al., 2002].

The manufacturer provides order recommendation and order limits information to the retailer which uses them to optimise sales productivity, stock turn and markdown percentage. The department store collects and elaborates the point-of-sale data in order to forecast demand per product category and, consequently, to generate a purchase order [Caputo and Mininno, 1996]. The purchase order, the inventory levels and sales productivity data are electronically forwarded to the manufacturer which in turn relays them to its suppliers. The required products are delivered at manufacturer's warehouse, where they are picked and packed in cartoons based on the store of destination and labelled with a unique standard code (i.e., in Europe EAN 128 bar codes). Consequently, the manufacturer delivers a dispatch advice to the regional distribution centres of the department store. Generally, transportation tasks are outsourced to a freight carrier in charge to perform frequent shipments directed to the regional distribution centre for cross-docking operations to the individual stores. Finally, the manufacturer transmits an electronic invoice to the department store.

Technological Enablers The scientific literature reports about several information technologies enabling ECR deployment strategies while no particular decision technologies are evidenced. The following technological enablers are required to enhance the efficiency of distribution networks:

- Automatic Identification and Data Capture technologies: Electronic Point-Of-Sale (EPOS) systems based on laser scanners and bar codes support a fast sales data collection, the inventory level data update and contribute to collect shareable information for trading partners [Kurnia et al., 2002]. Bar codes systems are currently under replacement by Electronic Product Codes (EPC). The adoption of innovative technologies like RFID would enable to optimise supply chains speed, flexibility, visibility and costs;

- Communication Networks and Data Exchange technologies: EDI or web trade portals enable information sharing among partners in a worldwide standardised format. With the spread of Internet, the XML language is surfacing EDI in interfirm communication nonetheless EDI currently remains the most used one. The spread of electronic data exchanges among logistics actors, collaboration opportunities may emerge in cross-docking processes and new added-value service provision [Leeman, 2010];

- Electronic Found Transfer technologies: EFT systems enable an automatic computer-based transfer of money between the partners bank accounts and without the direct intervention of bank staff;

- Information Hubs: the partners involved in the collaboration generally adopt ERP systems to manage the intra-firm processes. The scientific literature reports about several modules that can be integrated in ERP systems in order to support specific ECR functionalities. Computer Aided Ordering (CAO) or Electronic Order Systems (EOS) enable automatic orders generation for replenishment when a minimum pre-determined inventory threshold is overtaken while Activity-Based Costing (ABC) software are used for accounting purposes finalized to assess ECR benefits and to identify improvements opportunities [Christopher, 2011], [Lyu et al., 2010], [Kurnia et al., 2002];

- Decision Technologies: the publications survey has not evidenced the use of ECR dedicated decision technologies extra the decision support functionalities already included in the information hubs.

3.2.2.2 Quick Response (QR)

Hereafter, the collaborative logistics taxonomy is applied to classify the scientific literature on Quick Response deliveries models (QR). A graphical representation of the QR paradigm is shown in Figure 3.6.

Decision Makers QR strategies emerged in the United States at the end of 1980s with the aim to increase competitiveness of American retail industry against growing imports. Suppliers of fibres, apparel manufacturers and retailers operating in the textile sector were requiring more flexibility in manufacturing and distribution processes in order to reduce lead times and to quick respond to customers demand [Finne and Sivonen, 2008], [Emberson and Storey, 2006], [Drake and Marley, 2010]. To this aim, the QR concept proposed to enhance the supply chain responsiveness by capturing demand "as close to the final customer as possible" [Christopher, 2011]. By on-line electronic communication of sales data from retailers to vendors, the latter could quickly supply the freight needed to recover a jointly predetermined level of inventory [Fiorito et al., 1995]. The vendors (i.e., suppliers) expected benefits consist in a better capacity of planning production and schedule replenishments,

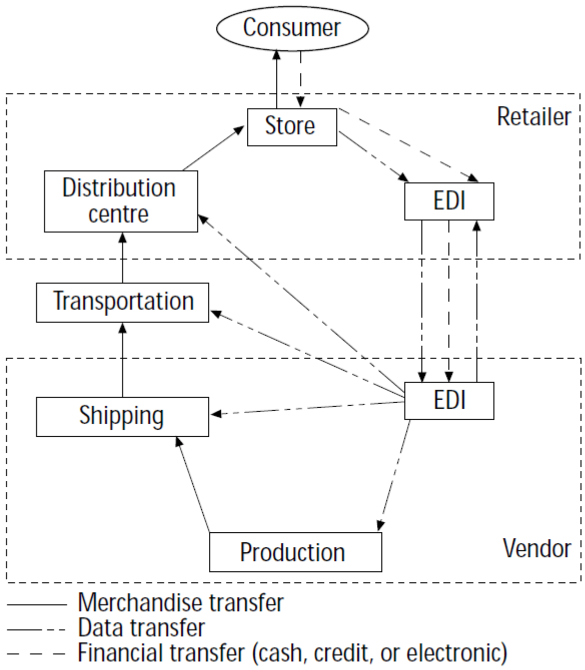

Figure 3.6: QR theoretical framework. Source: [Fiorito et al., 1995].

while retailers aimed to reduce lead times, stock outs and inventory levels.

Collaboration Form A QR strategy starts with an agreement among the retailer and its suppliers concerning a sales data sharing to be hold as confidentials. The partners also agree on the information to be shared, on the IT infrastructure required to transmit information, on the timing of both the information and the inventory flow as well as trading terms and conditions. A priori of the implementation, a coordinated planning without hierarchical decision-making process establishes the merchandise levels to be stocked in each store of the retail firm, the delivery frequency, the transportation means used to ship the merchandise to the retailer distribution centre [Fiorito et al., 1995]. The parties jointly develop expected sales forecasts indicating the minimum inventory level per retail store and including variations due to seasonal, promotional or other demand changes. During the QR functioning phase, the partners synchronize the respective operations by exchanging sales data. In more sophisticated configurations, the partners also share invoices, order status reports and advanced shipping notices typically via EDI [Palmer and Markus, 2000].

Operations Management The retailer collects product sales data (i.e., size, colour, brand, etc.) through EPOS systems and gathers customers feedbacks data at point-of-sales. Data are transmitted to the manufacturer via EDI. The retailer compares the sales data with the inventory model, identifying the main products sold [Lyu et al., 2010]. When a pre-agreed minimum level of inventory is overtaken, the retailer emits a purchase order concerning the items required to restore the required inventory models level. The manufacturer receives the order and plans production based on daily demand and delivery schedule [Zinn and Charnes, 2005]. A flexible production process is required, based on a pull logic of economies of scope (i.e., small products quantities of a wider range, frequent deliveries) against a traditional push logic of economies of scale (i.e., large stocks, low products changeover, occasional deliveries) [Christopher, 2011]. At manufacturer warehouse, the merchandise is packed and shipped to the regional distribution centres of the department store. Generally, transportation tasks are outsourced to a freight carrier in charge to perform frequent shipments directed to the regional distribution centre for cross-docking operations or to individual stores. Finally, the manufacturer transmits an electronic invoice to the department store.

Technological Enablers The scientific literature reports about several information technologies enabling QR deployment strategies while no particular decision technologies are evidenced. The QR strategy implementation requires partners investments in technologies enabling internal operations management and external information communication:

- Automatic Identification and Data Capture technologies: retailing stores have to be equipped with electronic point-of-sale (EPOS) systems with laser scanners able to read Universal Product Code (UPC) automatically updating the inventory [Drake and Marley, 2010]. RFID technologies enable material handling and order picking costs reductions in distribution centres thanks to an increased data storage, long distance scanner procedures and multiple objects identification in respect to traditional bar codes [Cheng and Choi, 2010];

- Communication Networks and Data Exchange technologies: EDI standardized electronical communication protocols enable the interfirm information exchange finalised to adapt operations [Christopher, 2011], [Lyu et al., 2010]. With the spread of Internet, XML is technologically surfacing EDI technologies in interfirm data exchange processes;

- Electronic Found Transfer technologies: EFT systems enable an automatic computer-based transfer of money between the partners bank accounts and without the direct intervention of bank staff;

- Information Hubs: all the partners have to adopt ERP systems to improve the management of the company's business processes. This enterprise information hubs have to be integrated with sophisticated web-based Electronic Order Systems (EOS) enabling real-time orders tracking and inventory visibility among the IT systems linked in the QR network;

- Decision Technologies: the publications survey has not evidenced the use of QR dedicated decision technologies extra the decision support functionalities already included in the information hubs.

The widespread of the ECR and QR supply chain reengineering strategies implied the re-design of a huge variety of production and distribution process with a particular attention to collaborative replenishment models, such as *Vendor-Managed Inventory (VMI)* and *Continuous Replenishment Planning (CRP).*

3.2.2.3 Vendor-Managed Inventory (VMI)

In the following lines, the collaborative logistics taxonomy is applied to classify the scientific literature on Vendor-Managed Inventory models (VMI).

Decision Makers VMI approaches emerged during the 1980s as a replenishment strategy in which the vendor (i.e., manufacturer) is authorized to manage the inventory at buyer (i.e., retailer) distribution centre. The manufacturer no longer receives orders from the retailer but makes ordering decision on the customer behalf based on the variation of stock levels in the buyer's distribution centre in respect to a pre-agreed inventory level [Pramatari et al., 2005]. Through VMI, the collaboration partners aim both to reduce inventory levels and stock outs downstream in the supply chain and to increase customer satisfaction levels [Yao et al., 2007]. The collaborative network may assume a single-tier structure, involving a vendor and a retailer, or an n-tier structure, involving multiple vendors in the management of the inventory at retailer distribution centre.

Collaboration Form Vendors and buyers establish a coordinated planning at operational level relationships based on mutual trust and common goals. As reported by [Lyu et al., 2010], the vendor is selected based on its capacity to manage replenishment activities, to handle demand forecast and to control inventory levels. The collaboration starts with a joint agreement on the inventory plan, containing the indication of the delivery dates and of the levels of stocks in the distribution centres. The partners jointly decide also the performance evaluation framework [Roy et al., 2006]. During the operations, the manufacturer is in charge to maintain the inventory plan by proposing orders (i.e., product mix, quantity, date of delivery) based on the monitored inventory levels and the available point of sales data [Yao and Dresner, 2008]. The inventory levels coordination is enabled by an exchange of inventory reports (i.e., shipments data to the stores, distribution centre inventory levels, orders in transit, product shortages), demand forecasts and orders data.

Operations Management The retailer transmits product availability data (i.e., inventory levels) and product short-term demand forecasts to the manufacturer via EDI. The manufacturer uses the mentioned data to decide "timing of resupply and quantity to be supplied" at retailers distribution centre [Arora et al., 2010]. The retailer is in charge to ensure a continuous flow of information to enable the manufacturer to make reliable provisions. The manufacturer creates a planned replenishment order. At the planned time to delivery, the manufacturer dispatches an electronic advice to the retailer in order to enable the freight drop off at the distribution centre. The deliveries are characterized by short replenishment times, high frequency and punctuality [De Toni and Zamolo, 2005]. In general, transportation tasks are outsourced to a LSP (i.e., freight carrier or 3PL provider) which physically moves the freight from the production plant to the retailer's distribution centre. The consignment agreement defines the rules for invoicing and payment procedures. The partners may decide that the manufacturer sends the invoice only when the products are sold by the retailer. In this case, the retailer sends a sales report to the manufacturer, triggering the invoicing process. The alternative is represented by the case in which the retailer receives the invoice together with the products shipment. [Hiesse, 2009] reports that in cases of n-tier networks, a 3PL or a 4PL provider should be involved in the partnership. In the former case, the 3PL acts as a vendor consultant coordinating orders proposals and sales forecasts with the aim to optimize the transportation means load factors. In the latter case, the 4PL coordinates both as the vendor as the retailer by proposing possible orders and managing the organization of the validated shipments.

Technological Enablers The scientific literature reports about several information technologies enabling VMI deployment strategies. Several IT applications can be integrated in enterprise IT systems such as ERP with the aim to set up an efficient collaborative logistics relationships. Most of the mentioned applications target a specialized process (e.g., warehouse management, etc.) relatively to which the entire data life cycle, from data collection to decision-making, is managed. In the following lines, a summary of the major information and decision technologies enabling VMI collaboration deployments is reported:

- Communication Networks and Data Exchange technologies: several studies indicates EDI and lately web-EDI as enabling technologies for interfirm communication between partners [Caputo and Mininno, 1996], [De Toni and Zamolo, 2005], [Yao and Dresner, 2008], [Pramatari et al., 2005];
- Information Hubs: a VMI collaboration is enabled by intrafirm specialized IT applications. [De Toni and Zamolo, 2005] report that the following technological modules may be integrated in partners ERP systems:
  - Computer-Assisted Ordering (CAO): to support the vendor in suggested order preparation;
  - Automated Receivable-Payment Systems: to manage vendor-buyer electronic payments;
  - Electronic Forecasting Systems: to share information concerning sales forecasts for multiple product lines. Simulation techniques can be a core part of this type of IT application;
  - Warehouse Management Systems (WMS): to manage day-to-day operations within warehouses. Simulation and optimisation techniques can be a core part of this type of IT application;
  - Transportation Management Systems (TMS): to plan, execute and follow-up deliveries. Simulation and optimisation techniques can be a core part of this type of IT application;
- Decision Technologies: the publications survey has not evidenced the use of

VMI dedicated decision technologies extra the decision support functionalities already included in the information hubs.

3.2.2.4 Continuous Replenishment Planning (CRP)

In the following lines, the collaborative logistics taxonomy is applied to classify the Continuous Replenishment Planning (CRP) scientific literature.

Decision Makers CRP is part of the ECR initiative developed in the US grocery industry in the early 1990s. The CRP strategy implies that producers regularly send full loads to the retailer distribution centre even if the product mix of each shipment is decided a short-term before the delivery [Caputo and Mininno, 1996]. The retailer shares information related to inventory levels at distribution centres with one or more vendors which use these data to implement a continuous replenishment process maintaining a pre-agreed inventory level [Yao and Dresner, 2008]. The partnership can assume a two-tier structure, involving a manufacturer and a retailer, or an n-tier structure, involving multiple vendors in the management of the inventory at retailer distribution centre. With CRP, the retailer aims to avoid stock outs and minimize inventory levels at distribution centre [Lee et al., 2010]. Instead, the vendor objective consist in enhancing production and distribution processes flexibility.

Collaboration Form A CRP strategy implementation requires a coordinated planning collaborative relationship at operational level among partners. More in detail, the collaboration starts with a joint agreement on delivery dates, stocks management policy at retailer distribution centre (i.e., inventory plan) and on a performance evaluation framework. During the operations, the retailer daily exchanges information related to demand forecasts or provisional orders based on sales data and distribution centre inventory levels data [Caputo and Mininno, 1996]. As reported by [Danese, 2011], the difference with the VMI consists in the fact that the manufacturer can collect EPOS data at retailer point of sales in order to “predict customers sales" and plan replenishments. The manufacturer transfers order proposals and invoice information to its customer [De Toni and Zamolo, 2005]. The retailer finally transmits the order confirmation.

Operations Management The retailer collects sales data at stores and outgoing distribution centre information which are used to forecast demand and to suggest an order to the manufacturer. These information are shared with the manufacturer which arranges order replenishment requirements based on the received product sales data and in conformity with the prearranged inventory levels at retailer distribution centre. An order proposal is sent to the retailer which confirms or not the order. A definitive order is sent to the manufacturer, enabling the provision of the replenishment activities. Transportation tasks may be outsourced to a LSP (i.e., freight carrier, 3PL) [Caputo and Mininno, 1996], [Yao and Dresner, 2008].

Technological Enablers Same as VMI.

During the 1990s, supply chain collaborations emerged also in the field of demand forecasting and planning. Collaborative forecasting strategies aimed to increase forecasts accuracy and reduce the bullwhip effect through closer relationships among suppliers and retailers. Based on information sharing, the partners jointly developed sales forecasting and ordering forecasting [Småros, 2007]. On the other hand, collaborative planning strategies occurred when supply chain actors decided to commit in establishing relationships based on information sharing and finalized to enhance the organizations ability to "schedule production plans, manufacture products and deliver them" [Lyu et al., 2010]. In 1998, the Voluntary Interindustry Commerce Standards (VICS) integrated the collaborative replenishment, forecasting and planning strategies in a unique collaborative concept, the Collaborative Planning, Forecasting and Replenishment (CPFR). The original concept was readjusted in 2004.

3.2.2.5 Collaborative Planning, Forecasting and Replenishment (CPFR)

In the following lines, the collaborative logistics taxonomy is applied to classify the Collaborative Planning, Forecasting and Replenishment models (CPFR) scientific literature.

Decision Makers The CPFR is a partnership-based strategy considered as the "second generation of ECR" [Seifert, 2003], [Ramanathan and Gunasekaran, 2014]. The initiative was introduced in the US retailing industry during the mid-90s as a pilot project between Wal-Mart and Warner-Lambert, a multimantional retailing company and a pharmaceutical one. The CPFR aimed "to enhance the supply chain visibility by improving order forecasts and fulfilment through continuous communications among multiple supply chain partners" [Min and Yu, 2008]. CPFR consisted in a sequential approach evidencing relevant tasks to be undertaken to implement supply chain collaboration. CPFR extended the operational benefits deriving by CRP and VMI replenishment strategies by enhancing coordination and information sharing [Cassivi, 2006]. The collaborative network may assume a single tier structure, involving a manufacturer and a retailer, or an n-tier structure, involving suppliers operating at different layers in the supply chain and retailers. More in detail, the expected benefits consisted in a capital investments reduction in warehouses and production plants, a decrease of inventory levels by minimizing safety stocks, a maximization of order fills, an increase in sales revenues by avoiding stores out-of-stocks, a reduction in customer response time [Europe and GmbH, 2002], [Min and Yu, 2008].

Collaboration Form In 1998 and consequently in 2004, the VICS identified four main stages to be followed developing a supply chain collaboration. The first stage is represented by *strategy and planning*. In this phase, the partners jointly plan strategic collaboration aspects such as the mission, the objectives, the resources shared in the collaboration, the information needs and jointly develop a business plan harmonized with the respective partners corporate strategies. [Danese, 2007] reports that the joint business plan encompasses decisions on order minimums and multiples, lead times, reorder frequency and promotions for those stock-keeping units (SKUs) upon which they will collaborate. The partners also develop event and promotion plans related to the planning horizon. *Demand and supply management* represents the second stage. The partners jointly make tactical decisions developing sales forecasts and order forecasts. The third stage concerns the *execution*, a step characterized by operational decisions related to order generation and fulfilment. Finally, the *analysis* stage is required to assess the collaboration performance and to plan adjustments for a continuous improvement. [Leeman, 2010] underlines that the implementation of a CPFR collaboration required top-management commitment to drive the change to a collaborative organization: "customers teams from the manufacturer's side and category teams at the retailer's side work together to manage the merchandise forecasting, planning and delivery process". The planning and forecasting activities require an intensive information exchange not only at the logistics level but also in sales management, marketing and finance planning.

The CPFR theoretical framework is sketched in Figure 3.7. Thanks to its modular structure, not necessarily all the stages have to be implemented. As evidence of this, the scientific literature reports about several CPFR forms [Seifert, 2003], [Danese, 2006], [Danese, 2007], [Danese, 2011], [Panahifar et al., 2015]. As an example, the study of [Danese, 2007] identifies two dimensions characterizing the CPFR collaboration, the number of units involved and the depth of the collaboration. The author presents several contingency factors (e.g., CPFR goals, characteristics of products and markets, peculiarities of the supply networks physical structure, etc.) which influence the selection of the collaborative form. The author analyses seven case studies and concludes that three CPFR forms emerged. The collaborative dimension is proper of informational collaborations (i.e., sharing

Figure 3.7: CPFR theoretical framework. Source: [VICS, 2004].

of order forecasts plans, etc.) when partners objective consists in achieving cost reductions. The remaining two types of collaborative forms belong to a unique category, the coordinated planning relationships, nonetheless with different levels depth levels. A limited coordinated planning occurs when partners "exchange data as well but in addition they synchronize their plans and manage the exceptions" with the aim to enhance supply chain flexibility. Finally, a full coordinated planning occurs when the following conditions are present: the partners "sell and market the same products, demand elasticity in case of price variation is high, and spatial complexity among CPFR partners is low". Only in this context, the partners are encouraged to "jointly develop business plans, manage sales and order forecasts".

Operations Management Based on Electronic Point of Sales (EPOS) data and promotion planning, the participating organizations create sales forecasts and cooperate to identify and solve problems related to possible exceptions (i.e., scarce forecasts accuracy, wrong executions, etc.) which are excluded by the joint forecasting process and are managed separately. Then, order forecasts are developed based on the combination of sales forecasts, joint business plans and partners inventory strategies, with the aim to minimize safety stocks levels. Newly, the partners collaborate to identify and solve orders exceptions with the goal to create new adjusted order forecasts. Finally, the partners establish the replenishment plan by transforming the order forecast into a committed order, generating the real order [Danese, 2006]. At this point, the participating organizations joint activities leave the place to individual task execution. The manufacturer produce the ordered products and organizes the shipment process. On the other hand, completes the buying process and provides support in the organization of the distribution logistics process. The coordination of trading activities and transportation tasks is performed by converting order forecasts in shipment forecasts through Collaborative Transportation Management (CTM) complementary strategies [Panahifar et al., 2015]. The logistic service provider is in charge to replenish the retailer's distribution centre or its point-of-sales.

Technological Enablers The scientific literature reports about different information and decision technologies requirements for CPFR strategies deployments, based on the collaborative form selected [Sparks and Wagner, 2003]. A major distinguishing element is the intensity usage level of internet-based systems. Generally, low-tech partnerships (i.e., not intensive internet-based systems) are developed through face-to-face one-to-one meetings in the planning stage while forecasting and replenishment processes are enabled by the following information and decision technologies [Danese, 2006]:

- Communication Networks and Data Exchange technologies: fax messages are disposed to share sales data daily, electronic data exchanges (i.e., e-mails, intranet or extranet, EDI) enable the transmission of spreadsheet of sales, ordering and promotional data;

- Decision Support applications: Advanced Planning and Scheduling supports scenario and what-if analysis in the planning stage while Distribution Planning Model (DPM) software allow the extraction and transmission of distribution centres data on stocks and outgoings. The reported tools are typically integrated in individual partners ERP systems.

[Seifert, 2003] reports about CPFR intensive internet-based collaborations in which a many-to-many communication among supply chain actors occurs in order to enhance information visibility of "forecasts, promotional activities, inventory plans, EPOS data, transportation requirements and changes to previously agreed-to plans". The following rows summarize the technological enablers requirements in case of intensive internet-based collaborations:

- Communication Networks and Data Exchange technologies: in recent years, RFID technology linked with new barcoding systems (i.e., Electronic Product Code, EPC) are even more adopted in the retailing industry to enable a wide spectrum of supply chain applications "from upstream warehouse and distribution management down to retail-outlet operations" as well as for the "products traceability" in the whole supply chain [Bardaki et al., 2007]. [Sari, 2010] states that business actors operating in retailing systems are interested to discover potential applications of RFID technology in the establishment of VMI and CPFR supply chain collaborations;

- Information Hubs: a CPFR collaboration is enabled by intrafirm specialized IT applications. [Seifert, 2003] reports that ERP systems have to be integrated with event management and analysis solutions supporting exceptions monitoring and management;

- Decision Technologies: the publications survey has not evidenced the use of

CPFR dedicated decision technologies in addition to the the decision support functionalities already included in the information hubs.

By concluding, as reported by [Ramanathan and Gunasekaran, 2014] a full CPFR approach implementation requires an intensive information exchange among supply chain partners, enabled by "computer networking, information technology and other internet-based technologies".

The widespread of the mentioned SCM strategies has affected the freight transportation sector, requiring the development of collaborative relationships. [Kayikci and Zsifkovits, 2012] define transportation collaboration as "innovative holistic approaches with socio-technical systems encompassing platform-based, automated, adaptive technologies supporting business processes and proactive human collaboration". Closer vertical relationships are established among three different logistics actors. Transportation users (i.e., shippers and receivers) define the transportation demand by managing shipments and arranging consolidation flows. Transportation providers (i.e., freight carriers and 3PLs providers) are in charge to plan and execute customers requests through different transportation modes. Finally, technology providers (i.e., platform providers) coordinate the collaborative network enabling information sharing among the participating organizations. In general, transportation collaborations are finalized at the elimination of transport inefficiencies (i.e., empty trips, low load factor, etc.) through the achievement of the optimal balance between costs and service levels. In the scientific literature, several levels of transportation collaboration are reported. [Crainic and Laporte, 1997] identify three levels of freight transportation collaboration. The lowest level is represented by a transactional collaboration characterized by business units independency and is limited to communication coordination. The intermediate level occurs when an informational collaboration is established: the participating organizations continue to make decisions individually but are supported by an increased information visibility (e.g., delivery dates). A decisional collaboration represents the closest relationship level, characterized by a joint decision making-process ranging from the operational level (e.g., cross-docking) to the strategical one (i.e., transportation modes selection). [Lambert et al., 1999] classify four levels of transportation collaboration. The lowest one is represented by an arm's length relationship in which the participating organizations coordinate their operations through a limited number of occasional exchanges. The second collaborative stage occurs when a limited collaboration is established, characterized by a short-term planning horizon and use of resources. An integrated collaboration represents the third level in which the partners jointly develop plans and coordination mechanisms with a mid-term horizon. By concluding, the highest level consists in a strategic partnership in which through a long-term engagement each company considers the other/s as an extension of itself.

[Fugate et al., 2009] collect data with qualitative motor carriers focus groups and semi-structured interviews identifying two main shipper-carrier relationships: strategic and operational collaborations. The authors report that a strategic collaboration occurs when shippers and receivers try to face uncertainty in their supply resources by establishing closer relationships with carriers characterized by top management commitment, trust, common long-term objectives and incentive alignment mechanisms. On the other hand, an operational collaboration is encompassed in strategic partnership finalized to plan and manage the day-by-day activities. The partners align visions and goals, display internal resources with the aim to achieve business advantages at operational level. Figure 3.8 illustrates a general shipper-carrier collaboration scheme at operational level.

In 2004, the VICS stated the key role of transportation in collaborative replenishment strategies through the conceptualization of a series of processes complementary to the CPFR, defined under the umbrella term of Collaborative Transportation Management (CTM) [Panahifar et al., 2015].

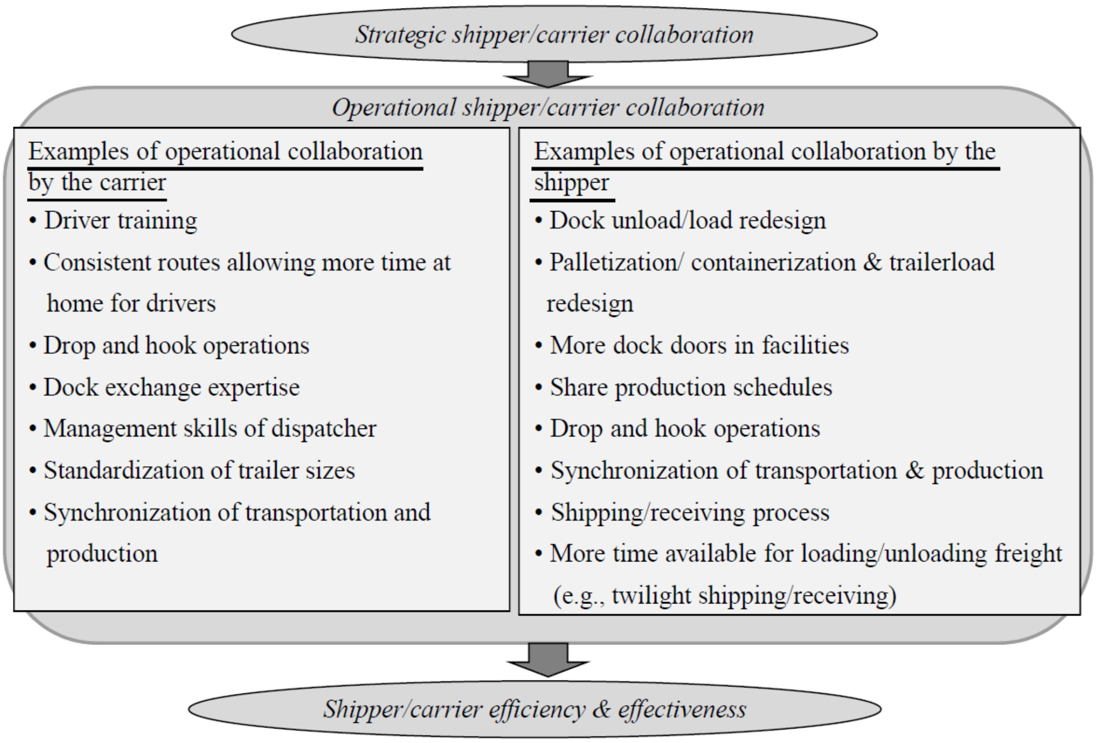

Figure 3.8: Shipper-carrier operational collaborations. Source: [Fugate et al., 2009].

3.2.2.6 Collaborative Transportation Management (CTM)

The collaborative logistics taxonomy is applied to classify the Collaborative Transportation Management (CTM) scientific literature.

Decision Makers The CTM is "an holistic process that brings together supply chain trading partners and service providers to drive inefficiencies out of the transport planning and execution process". Shippers-receivers partnerships finalized to implement CPFR strategies are extended to one or more transportation providers such as freight carriers or 3PLs with the aim to ensure efficient and effective shipment delivery in even more just-in-time operational contexts. If a 3PL provider is involved, it should act as a coordinator of multiple carriers (i.e., n-tier CTM configuration). Although the CTM was developed as a complementary CPFR process, the concept is also applicable as a stand-alone strategy without links to CPFR. Trading partners require uncertainty reduction and enhanced information visibility to reduce handling and inventory costs while transportation providers major goal is the enhancement of shipment forecasting and planning processes [Chan and Zhang, 2011], [Esper and Williams, 2003]. [Wen, 2012] provides a factorial analysis evidencing that in CTM implementations freight carriers develop highly integrated relationships with the aim to achieve competitive advantages in terms of cost-leadership and customer-service capability. A CTM theoretical framework representation is sketched in Figure 3.9.

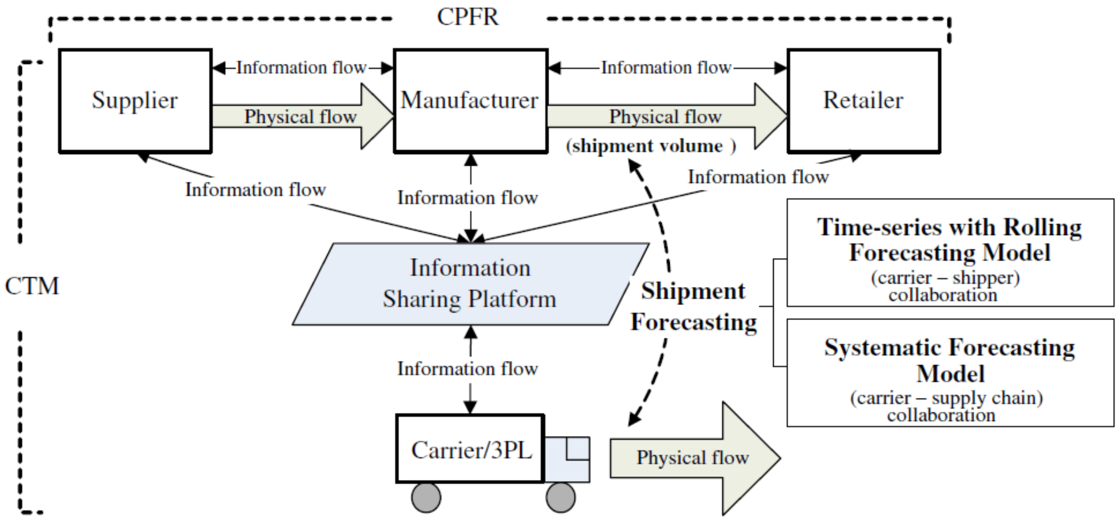

Figure 3.9: CTM theoretical framework. Source: [Wen, 2012].

Collaboration Form The CTM is a coordinated planning form of collaboration based on information sharing among the shipper, the receiver and the carrier (or 3PL). At strategic level, the participating organizations formalize joint decisions related to the collaboration common goals, scope (i.e., process steps involved, information exchanged, communication procedures), time horizon, network model, service levels and prices in front-end agreements. The joint planning process takes into consideration a long-term horizon. At tactical level, the partners jointly plan their inter-firm information exchange in order to share forecasted order volumes. As reported by [Wen, 2011] these information consist in "supplier and manufacturer shipment data, manufacturer product data and retailer order/sale data". These information are converted by the carrier(s)/3PL provider in shipment forecasts with the aim to schedule future equipment and resources demand (i.e., capacity planning and scheduling). [Okdinawati et al., 2015] report that partners push their effort in shipment forecasting modelling finalized to improve vehicle capacity utilization and carrier assignment modelling aiming to select appropriate carriers per each collaborative business process. At operational level, trading partners and transportation providers define picking and delivery schedules and reserve resources for their accomplishment on a daily base horizon. Routing models are developed in order to minimize transportation costs, travel distances and times. The partners agree on shipment documentation formats, exceptions protocols, accounting processes. Moreover, they ensure that the needed data to evaluate the individual organizations performance are regularly exchanged. During operations, electronic order tenders, shipping documentation, payments and performance evaluation data (i.e., shipment characteristics, shipment tendering results, in-transit shipment status, scheduled pickup and delivery times, claims information, freight payment data) [VICS, 2004].

Operations Management During CTM operations, each partner manages the production, transportation and distribution tasks of competence. The trading organisation, in charge to manage the relationship with the freight carrier/3PL, consolidate partners orders into shipments, based on a pre-agreed load creation policy. An electronic load tender is transmitted to the freight carrier/3PL requiring the shipment execution. The transportation provider evaluates if the resources available are sufficient to fulfil the shipment, activating an exemption protocol in case of a negative feedback. If the feedback is positive, the order tender is accepted. Consequently, pickups and deliveries are scheduled and resources are reserved. When the shipper has prepared the transportation units, freight documentation is shared with all partners in a pre-agreed format. Finally, the transportation provider executes the shipment [VICS, 2004].

Technological Enablers The scientific literature reports the following information and decision technologies enabling CTM deployment strategies:

- Automatic Identification and Data Capture technologies: RFID smart tags attached to transportation units (i.e., pallets, containers, etc.) are used to monitor in real-time the physical movements of freight along the supply chain [Mason and Lalwani, 2006];
- Positioning Systems: vehicles mat be equipped with on-boards computers connected to a GPS receiver communication modules, on-board keypad, navigation module and screen;
- Communication Networks and Data Exchange technologies: the partners communication, traditionally performed via fax or phone, is enhanced by electronic standardized communication formats (i.e., EDI) or internet technologies. Consequently, the order tenders transmission and reception and the shipment status information forwarding processes can be performed several times during a day without risks of errors [Esper and Williams, 2003];
- Information Hubs: a CTM collaboration is enabled by intrafirm specialized Transportation Management Systems (TMS). These IT application can be as stand-alone as integrated in companies ERP information hubs;
- TMS (stand-alone): to plan, execute and follow-up deliveries. As reported by [Okdinawati et al., 2015], several operations research (i.e., exact methods, heuristics, methaeuristics) and simulation techniques can be exploited in such tools.

In recent years, the scientific literature concerning logistics collaboration has started to emphasize *new emerging scopes* in buyer-supplier relationships, new requirements to be satisfied through synergic partnerships. [Soosay and Hyland, 2015] report a literature review evidencing three most relevant areas.

- Technology-enabled supply chains: to investigate logistics actors efforts in implementing technologies to enhance the supply chain performance;
- Collaborative humanitarian supply chains: to cope with logistics issues in case of natural disasters and emergencies;
- Collaborative environmental relationships: to develop more sustainable supply chains, mostly in terms of air pollution, congestion, etc.

3.2.2.7 Collaboration for Sustainable Supply Chains (CSSC)

In the following lines, the collaborative logistics taxonomy is applied to classify the scientific literature related to emerging environmental collaborative approaches.

Decision Makers [Albino et al., 2012] define environmental collaboration as "any formal or informal collaboration between two or more organizations which is aimed at developing common solutions to environmental problems". Any combination of commercial organizations (i.e., suppliers and customers), governmental organizations, non-governmental organizations (i.e., NGOs) and research institutions (e.g., universities) moved by the supply chain sustainability objective. The scientific literature mainly focuses on manufacturers relationships with key suppliers or customers finalized to jointly plan, develop and evaluate environmental projects and solutions [Vachon, 2007], [Green Jr et al., 2012]. In general, manufacturers collaborative practices with upstream suppliers aim to enhance procurement and production processes sustainability in terms as of fast and reliable deliveries as of flexibility in event management (i.e., process-based collaboration). On the other hand, manufacturers collaborative practices with downstream customers are focused on products quality in terms of conformance to environmental specifications and durability (i.e., product-based collaboration) [Vachon and Klassen, 2008]. [Theißen et al., 2014] underlines companies learning effects in developing and implementing carbon footprint mitigation strategies derived from collaborations with most experienced partners.

Moreover, companies supporting less-skilled partners might improve their public social reputation. The scientific literature reports that not only business relationships enable environmental performances enhancements, indeed positive results can be achieved also through collaborative relationships between business actors and NGOs or governmental organizations [Albino et al., 2012].

Collaboration Form [Vachon and Klassen, 2008] define environmental collaboration as "the interaction between organizations in the supply chain pertaining to joint environmental planning and shared environmental know-how and knowledge". The partners establish a coordinated planning collaborative relationship in which the jointly make decisions which may range from strategic to operational level. More in detail, at strategic level the partners identify common environmental goals (e.g., overall emission levels and corresponding costs) [Ramanathan and Gunasekaran, 2014], [Benjaafar et al., 2013]; establish the financial resources to invest in cooperative environmental solutions development, testing and implementation [Vachon, 2007]; identify expertise, knowledge, capabilities, resources to be shared in order to enchance the supply chain sustainability [Albino et al., 2012]. An applicative example can be represented by joint product development and design [Stefan Schaltegger et al., 2014]. At tactical level, forecasting processes and environmental data collection models development (i.e., life cycle assessment models, LCA) are jointly performed. At operational level, the involved organizations have to mutually plan daily interfirm interactions, such as sharing information related to sales quantities and green policies, enabling a real-time environmental management at different supply chain layers [Nakano and Hirao, 2011].

Operations Management The scientific literature concerning logistics environmental collaborative approaches reports about scarce and not harmonized operations management processes. In supplier-customer relationships, each organizations operate in order to meet the common environmental goals by modifying procedures, products etc. On a daily basis, the partners exchange information (e.g., product features) and use the IT applications supporting sustainable logistics implementations. In case of collaborations between LSPs and their customers, the latter might outsource the environemtal impacts estimation process related to their operations to LSPs able to provide specialized web-portals, IT tools, services [Colicchia et al., 2013].

Technological Enablers A scientific literature overview evidences that only few authors have currently reported examples of information and decision technologies enabling environmental collaboration in logistics. More in detail:

- Information Hubs: participating firms ERP systems have to support buyer-supplier information sharing. In particular, buyers green requirements have to be known by suppliers and, on the contrary, suppliers have to emphasise the efforts put in place to satisfy environmental buyers needs [Green Jr et al., 2012]. [Cholette and Venkat, 2009] and [Colicchia et al., 2013] illustrate LSPs collaborations with customers implemented through web-portals able to compute energy and CO_2 emissions. More in detail, in the reported business cases the LSP manages an environmental assessment tool able to estimate the energy consumption and CO_2 emissions related to customers freight movements (e.g., DHL Eco TransIT World service).
- Decision Technologies: specific IT applications can be integrated with ERP systems with the aim to support decision-making in specific logistics processes. [Colicchia et al., 2013] report about planning and routing software finalized to minimize travel distances in shippers-LSPs collaborations.

3.3 Horizontal Collaborative Logistics

[Gonzalez-Feliu et al., 2013] defines the horizontal collaboration as "the collaboration between a group of stakeholders of different supply chains acting at the same levels and having analogous needs". Such research area is still in an early stage if compared with the vertical collaborations one [Krajewska et al., 2008], [Verdonck et al., 2013]. More in detail, [Pomponi et al., 2013] evidence a lack of "comprehensive scheme which supports the design and implementation of effective horizontal collaborations" while [Soosay and Hyland, 2015] state that existing scientific contributions mainly focus on transportation/distribution management practices. In the following Sections, the collaborative logistics taxonomy is applied to classify the horizontal collaboration research area. Three major research domains are considered:

- Subsection 3.3.1: Horizontal collaborative relationships in policy-making and regulation processes;
- Subsection 3.3.2: Horizontal collaborative relationships in procurement and production;
- Subsection 3.3.3: Horizontal collaborative relationships in transportation, warehousing and distribution;

3.3.1 Policy-Making and Regulation

Modern economies are characterized by globalised supply chains requiring harmonised regulatory and policy frameworks to be efficient from an economic, social and environmental perspective. At the current state of the art, further interventions are still needed in the logistics and transportation field. For example, [Muñuzuri et al., 2012] analyse city logistics initiatives in Spain, evidencing the carriers need to have a common national and international regulatory framework to enable simplified and law respectful urban freight carriage operations. To cope with these problem types, logistics legislators have started to collaborate in order to find appropriate solutions targeting market needs. Two major examples are reported in the scientific literature:

- The creation of Emission Trading Systems (ETSs) to harmonise caps and trade legislation for greenhouse gas emissions;
- The development and adoption of standardised e-customs procedures and solutions.

3.3.1.1 Emission Trading Systems (ETS)

In the present Section, the collaborative logistics taxonomy is applied to review the *logistics legislators* horizontal collaborative approaches concerning standardised carbon footprint policies and regulations.

Decision Makers As a consequence of the Kyoto Protocol agreement, policy-makers started to plan carbon footprint abatement strategies and legislators began to provide regulatory frameworks supporting successfull plans implementations. In this context, Emission Trading Systems (ETSs) emerged as an opportunity for international and national governments to reach the declared CO_2 emission targets. ETSs support cost-effective mitigation actions without significative public intervention finalized to ensure harmonised and stable carbon prices. Nowadays, ETSs exist in Australia, Canada, Europe, Japan, New Zeland and United States. In general, ETSs concern energy-intensive industries such as power sectors, transportation fuels, heating distribution and the aviation sector. As reported by [Ellerman and Buchner, 2007], a global harmonisation is still missing (current implementations mostly cover a regional area). In recent years, few bilateral initiatives have expanded the geographical coverage. The Québec and California national governments, both members of the Western Climate Initiative (WCI), have started to coordinate their carbon markets regulations in order to achieve the WCI 15% carbon emission reduction target [De Jong, 2015]. A second example is represented by the European Commission and the Swiss national government negotiation started in 2010 with the objective to plan EU ETS and Swiss ETS harmonisations for period 2013-2020.

Collaboration Form National and international governments coordinate their plans in order to introduce potential changes enabling ETS regulatory frameworks harmonisation. Based on shared emission caps information and exchanged periodical reports concerning CO_2 emissions monitoring results, legislators and policy-makers jointly design coordination mechanisms. In the Québec-California case, a Consultation Committee has been established to monitor the effective coordination of emission caps. Moreover, periodically consultations to "ensure ongoing harmonisation of regulations" are performed.

Operations Management Each national government set a cap on the amount of authorised pollutant emissions, in coordination with international agreements. The fixed cap is allocated to business organisations as emission allowances exchangable in the ETS [Chaabane et al., 2012].

Technological Enablers In the following lines, a summary of the major information and decision technologies enabling standardised carbon footprint policies and regulations is reported:

- Data Storage Technologies: ETSs require national carbon emissions registers, generally web-based databases;
- Communication Networks and Data Exchange technologies: in order to link ETSs, the stored data have to be shared with collaborating national and/or international governments via internet-based communication [Chaabane et al., 2012];

- Decision Technologies: the publications survey has not evidenced the requirement of specific decision technologies enabling the ETSs deployment.

3.3.1.2 Standardised Customs Procedures (SCP)

In the present Section, the collaborative logistics taxonomy is applied to review the *logistics legislators* collaborative approaches concerning standardised e-customs procedures and solutions.

Decision Makers International import and export processes impact regional (e.g., European Union) and national Global Domestic Products (GDPs). In order to strengthen the economic growth, policy-makers cooperate to introduce trade facilitators enabling competitive advantages. A promising intervention area is represented by customs procedures standardisation. The related scientific literature reports about several multilateral agreements among logistics legilators and policy-makers. For example, the study of [Raus et al., 2009] descibe the case of European Commission (EC) and Member States Governments joint initiatives to enhance Government-to-Government (G2G) communication and data exchange. The EC provides implementation guidelines whose adoption is in charge of each Member State. Moreover, [Phuaphanthong et al., 2009] reports the case of several Asian national governments committed to jointly design an interagency collaborative single window platform for international trade flows management.

Collaboration Form Governments of different countries share respective experiences and knowledge in customs matters. Once common issues are identified, policy-makers coordinate their efforts in planning new procedures facilitating international trades and, at the same time, ensuring physical and digital shipments security.

Operations Management The adoption of a single window platform simplifies logistics operators administrative declarations in import-export processes by switching from a paper-based document provision to an internet-based one. Thus, logistics operators are enabled to electronically submit all the shipment data required by Customs Agencies in advance or when the shipment physically reaches the border. Once data are collected, all public stakeholders operating a same shipment start to process their proper procedures [Phuaphanthong et al., 2009].

Technological Enablers In recent years, the customs procedures standardisation problem has been faced by developing single window collaborative platforms, information hubs exploiting internet-technologies for data communication and storing data in centralised databases. The publications survey has not evidenced the requirement of specific decision technologies.

3.3.2 Procurement and Production

Upstream in supply chains, logistics actors involved in procurement and production processes are moving towards horizontal synergies with the general aim of cost reduction. Typically, coopetition relationships are established. In this field, several authors report examples of collaborative purchasing practices under the name of *collaborative purchasing*, *group purchasing* and *purchasing consortia*.

3.3.2.1 Purchasing Groups (PGs) and Purchasing Consortia (PC)

In the present Section, the collaborative logistics taxonomy is applied to review collaborative purchasing or group purchasing practices.

Decision Makers The terms “collaborative purchasing” or “group purchasing” are both used to describe supply chain management approaches implemented by competing industrial operators (e.g., producers, manufacturers, suppliers) deciding to collaborate in the procurement process. The objective is the assumption of a stronger negotiation position towards a common supplier, minimizing procurement costs through economies of scale. Potential risks are purchasing process increased complexity and reduced flexibility. The collaborative network may assume a two-tier structure in case of bilateral agreements between two industrial operators while a n-tier structure emerge in case of multilateral agreements involving more than two business units.

Collaboration Form In horizontal collaborative purchasing relationships, a coordinated planning process is established among buyers having the common goal to minimize procurement costs. The involved organisations jointly decide how to achieve the collaborative mission. As reported by [Huber et al., 2004], multiple approaches can be pursued. A first example is represented by the establishment of an Electronic Purchasing Consortia (EPC), a voluntary formal or informal agreement, to build an efficient ICT-based communication infrastructure enabling demand aggregation. A second more formal and structured option occurs when buyers decide to reduce purchasing costs through e-marketplaces, B2B platforms acting as a lead source of procurement providing materials, components, products information and specifications. This approach is typical of automobile, chemicals, retailing industries and implies the sharing of buyers R&D and operating costs [Granot and Sošić, 2005]. Another option is represented by the case in which the collaborative purchasing group decides to outsource non-core procurements to a common 3PL provider [Shi et al., 2016]. Information sharing is a key factor of success in the implementation of a group purchasing strategy, since it supports individual partners demand aggregation.

Operations Management During the operational phase, each buyer electronically execute the proper purchasing tasks on the B2B platform or e-marketplace. In this way, the matching between demand and supply is easier, faster and introduces more competition among suppliers. If an e-marketplace is adopted, the platform is generally managed by an independent company in charge to process the transactions between suppliers and buyers. If procurement tasks are outsourced to a 3PL, the logistics service provider negotiate procurement demand and supply respectively with buyers and suppliers, with the aim to aggregate demand on their behalf.

Technological Enablers Horizontal collaborative relationships in procurement and production processes require communication networks and data exchange technologies, such as information hubs and trade portals, to be implemented. More in detail, the coordination of procurement flows between suppliers and customers can be achieved by developing an internet platform based on XML (e.g., B2B platform) or through the creation of a virtual network enabling a consortium of companies to collaborate (e.g., e-marketplaces) [Muffatto and Payaro, 2004]. The publications survey has not evidenced the requirement of specific decision technologies.

3.3.3 Freight Transportation, Warehousing, Distribution

As already reported in Section 3.3, the majority of publications concerning horizontal collaborative relationships in logistics and transportation systems focuses on transportation and distribution management practices. Several authors have tried to sum up the existing approaches in few macro-categories. [Pérez-Bernabeu et al., 2015] consider "loads consolidation centres, purchasing groups and joint route planning" as horizontal collaboration peculiarities in freight transportation. [Verdonck et al., 2013] classify freight carriers horizontal collaborative strategies based on order sharing and capacity sharing. [Morana and Gonzalez-Feliu, 2009] state that organisations operating at the same supply chain layer generally adopt strategies belonging to three main areas of intervention: transportation planning through shared information, infrastructure sharing and vehicle sharing by loads consolidation. This dissertation resumes the latter taxonomy and analyse three major horizontal collaborative approaches:

- *Transportation planning through shared information:* group of horizontal collaborative relationships based on orders information sharing in transportation services procurement and planning phases aiming at optimising routes, scheduling and resources allocation. This macro-category encompasses two major collaborative forms: the cases of the *joint procurement of transportation services* and the *joint route planning*, respectively discussed in Sections 3.3.3.1 and 3.3.3.2;

- *Infrastructure sharing:* group of horizontal collaborative relationships based on physical space sharing (i.e., within a same warehouse or distribution centre) and information sharing aiming at achieving multiple objectives. In particular, the major goals are the sharing of investments risks related to capital intensive assets, the provision of loads consolidation services and the reduction of logistics activities negative externalities. This macro-category encompasses several examples of the *"collaborative warehouse"* concept illustrated in Section 3.3.3.3;

- *Vehicle sharing by loads consolidation:* group of horizontal collaborative relationships based on capacity sharing aiming at increasing transportation means utilisation rates. This domain encompasses the major approaches belonging to the *freight transportation pooling* domain, research field presented in Section 3.3.3.4.

3.3.3.1 Joint Procurement of Transportation Services (JPTS)

The joint procurement of transportation services represents a typical example of horizontal collaboration exploiting information sharing for a better transportation planning. The related scientific literature is analysed and organised following the collaborative logistics taxonomy proposed in Section 3.1.

Decision Makers In the truckload shipping industry, shippers negotiate prices for truckload freight movements with carriers. Because customers needs have to be satisfied in a timely manner, frequent shipments of small product quantities can be unbalanced in terms of origin-destination locations. Thus, carriers unable to fill vehicles capacity are constrained to face asset repositioning costs and have to maintain higher prices for their services [Nadarajah, 2008]. In this context, both truckload transportation services buyers and providers are interested to increase profitability. In the procurement process, shippers can establish a collaborative relationship finalized to negotiate better truckload transportation rates with a common carrier, usually achievable in case of larger shipments volumes and reduced empty trips [Agarwal et al., 2009]. Generally, multilateral approaches (i.e., n-tier network structure) are preferred since they ensure higher shipments volumes, bundled lanes and tours opportunities.

Collaboration Form The participating shippers establish an informational collaboration relationship based on shipping orders information sharing (e.g., pick up and delivery dates, freight type and weight, etc.) [Lozano et al., 2013].

Operations Management Shippers merge their transportation needs and ask to a common carrier to execute the entire shipments volume. In general, electronic platforms are used to know other's truckload transportation service procurement orders, thus exploiting two business opportunities:

- Buying group: the electronic platform provides bulletin services in which shippers search for similar partners and form a buying group;
- Private community: shippers operate within a private community in which shipments are aggregated based on e-marketplaces recommendations.

In order to better exploit collaboration synergies, shippers may nominate a leading organisation responsible for demand harmonisation and rates negotiation with carriers [Zhang et al., 2008]. Once the aggregated transportation demand is communicated to the carrier, appropriate routing and scheduling software are used to bundle lanes, finding tours, etc., thus optimising vehicles utilisation rates and reducing asset repositioning operations.

Technological Enablers Joint procurement of transportation services strategies require communication networks and data exchange technologies to be implemented. The EDI technology can be adopted to share individual truckload transportation needs among shippers and to forward the aggregated demand information to the logistics actor in charge to execute the shipments [Hingley et al., 2011]. Otherwise, e-marketplaces may be adopted to match truckload transportation demand and capacity [Ergun et al., 2007], [Zhang et al., 2008]. Once the aggregated demand has been communicated to the carrier, appropriate decision support tools such as routing and scheduling softwares are used to optimize the overall asset utilization (i.e., truck capacity). Heuristics are generally used to solve the unique multi-depot pickup and delivery requests with time windows (PDPTW) over the entire customer set problem [Krajewska et al., 2008]. In case of 3PL providers involvement to orchestrate the shippers collaboration, a web-based information exchange can be implemented [Taherian, 2013].

3.3.3.2 Joint Route Planning (JRP)

The joint route planning is a strategy exploiting horizontal collaboration by information sharing for a better transportation planning. The related scientific literature is analysed and organised following the collaborative logistics taxonomy proposed in Section 3.1.

Decision Makers In full truckload and less than truckload transportation industries, freight carriers or shippers typically share transportation orders data to simultaneously plan optimised route schemes. By pooling shipment requirements, a joint transportation planning phase is performed with the aim to exploit economies of scale in terms of distribution costs reduction (e.g., less travel distance, empty trips, required vehicles, etc.) [Verdonck et al., 2013]. As reported by [Cruijssen et al., 2007a], the JRP benfits can be measured as the difference between the distribution cost "in the original situation where all entities perform their orders individually and the cost of the system where all orders are collected and route schemes are set up simultaneously". JRP strategies are typically implemented as bilateral horizontal collaboration forms [Soysal et al., 2016], even if the scientific literature reports also examples of multilateral relationships [Frisk et al., 2010].

Collaboration Form JRP initiatives require transportation orders data sharing among two or more shippers or carriers. These intangible resources are pooled, thus becoming a unique data input for mutual route planning. The joint decision-making process can be isolated or centralised, expoliting two collaborative forms [Vornhusen et al., 2014]:

- *Coordinated planning:* case of isolated JRP. Each organisation uses proper routing softwares to schedule pick up and delivery operations (i.e., trips, assign drivers and vehicles, etc.). Further optimisations are possible: the collaboration members exchange informations about unsufficiently profitable trips in order to coordinate individual routing plans (e.g., find bundles, tours, etc.). Thus, the JRP brings to a partial transportation optimisation. As reported by [Verdonck et al., 2013], transportation companies typically exploit synergies through profit margins auction-based mechanisms;
- *Integrated planning:* case of centralised JRP. Each organisation pool all its transportation orders, thus a routes global optimisation is performed. The joint transportation planning process requires a unique decision-maker in charge to optimally assign routes among collaborating shippers or carriers (e.g., the collaboration members establish a joint venture or outsource transportation

planning to a common LSP) [Cruijssen and Salomon, 2004].

Operations Management The operations management process differs depending on the logistics actors performing a JRP strategy. More in detail, in a shippers JRP each organisation share a part or all its transportation requirements which are pooled in order to coordinate pickup and delivery operations planning. Typical examples are the cases of coordinated multi-picks in which producers or distributors agree on a prearranged sequence of pickups and coordinated multi-drops in which they prearrange a sequence of deliveries. The transportation service provision can be performed by a third party such as a freight carrier or a LSP. If the JRP is performed within a transportation companies collaboration, each carrier puts part or all its customers orders into a pool. Consequently, appropriate Vehicle Routing Problem (VRP) techniques are used "to allocate a set of requests to each carrier" and to identify potential routing optimisations (e.g., tours, bundles, etc.), thus maximising the collaboration members profits [Dai and Chen, 2012]. Thus, each individual carrier executes the assigned routes with its proper transportation means. If a coordinator is established, this organisation is in charge to collect collaboration members transportation orders, to plan and execute freight physical movements and, finally, to allocate benefits and costs among the involved business actors.

Technological Enablers A JRP strategy implementation is based on the following information and decision technologies:

- Communication Networks and Data Exchange technologies: the joint operational decision-making process requires that transportation orders data are exchanged in advance among the collaboration members. The information sharing process is typically performed via EDI one-to-one data exchange technologies or via XML data transfer among companies DBMS (i.e., one-to-many information sharing) [Buijs and Wortmann, 2014];

- Information Hubs and Software Packages: pooled transportation orders are processed by information hubs such as TMS, DSS or specialized routing and scheduling software packages exploiting operations research (OR) applications in transportation planning. Typically, appropriate Vehicle Routing Problem (VRP) algorithms are used to support collaboration members in planning shared routes. In this field, several research contributions focus on "demonstration of gains through simulation" approaches and "actual case studies" [Defryn et al., 2016]. Various OR solution methods can be applied:
  - Exact Methods: [Frisk et al., 2010] propose a DSS based on linear programming models to support a coalition of southern Swedish forestry companies in transportation planning coordination and costs allocation. [Vornhusen et al., 2014] presents a "what if" analysis concerning the case of two carriers exchanging transportation requests and planning routes together with or without transshipment. The problem is formulated as a multi-depot pickup and delivery problem with transfer time windows (PDPTW) and it is solved through a mixed-integer programming algorithm (MIP).
  - Heuristics: [Alshamrani et al., 2007] propose an heuristic procedure to simultaneously plan pickups strategies and routes in the blood distribution reverse logistics sector;
  - Metaheuristics: [Defryn et al., 2016] propose a methaeuristic approach to solve a selective VRP characterized by customers orders sharing within a coalition of transportation companies finalised to plan a unique delivery to customers by using multiple vehicles.

3.3.3.3 Logistics Infrastructure Sharing (LIS)

The scientific literature evidences that logistics infrastructure sharing approaches commonly do not require collaboration among platform users (e.g., shippers, receivers, carriers). They share physical space within a facility provided by a LSP who is in charge to manage the platform. Each operator uses the platform resources (i.e., workforce, equipments, IT systems, etc.) following its own purposes. Typical examples are the case of multiple producers renting space slots within a same warehouse or the case of multimodal transportation services in which the freight of multiple shippers or receivers can be temporarily stored by a LSP waiting to change transportation mode [Gonzalez-Feliu and Morana, 2010]. Nonetheless, several authors indicate strategies assuming the horizontal logistics collaboration peculiarities. In general, all of them represent different applications of the *collaborative warehouse* concept [GCI, 2008]. Hereafter, the collaborative logistics taxonomy proposed in Section 3.1 is applied to classify the LIS scientific literature.

Decision Makers A collaborative warehouse is a logistics platform in which two or more operators share a physical space and the related information to improve the overall supply chain performance. The concept has applications in several industries and in both production and distribution networks. [Higginson and Bookbinder, 2005] report the case of multiple suppliers of materials, parts and components sharing a common warehouse (i.e., a *multi-supplier warehouse*) with the aim to provide the required materials to a common customer. This type of facilities are typical of the automotive industry, where shared storage facilities located close to production plants are used to break large suppliers shipments into smaller ones based on production material requirements. [Bartolacci et al., 2012] mention the case of *manufacturers consolidation centres*, shared warehouses used by small and medium manufacturers not having sufficient individual production volumes to be shipped at a common distribution centre. The mentioned approach lets “manufacturers consolidate warehousing and transportation from production to a retailer transfer point” [GCI, 2008]. A business case study is reported by [Xu, 2013] that report the example of two tyre brands which have decided to build a shared warehouse to optimise their distribution process through a common transport operator. In distribution networks, decision-makers can be shippers or carriers. Shippers can be multiple producers shipping freight at a shared distribution centre/cross-dock where goods are sorted, consolidated and assigned to common delivery routes. A similar approach is currently adopted in the Dutch flower distribution sector [Bahrami, 2013]. [Graham, 2011] illustrates the case of Bridgestone and Continental jointly managing outbound deliveries in France through a shared regional distribution centre located close to Orléans. The two companies have built a common area between two parallel distribution centres, a space managed by a 3PL in charge to organise joint outbound deliveries. [Caputo and Mininno, 1996] report the case of *multi-distributor centres* used in the Italian grocery industry by distributors not having enough delivery volumes to justify the opening of an individual regional distribution centre. In the city logistics sector, CDCs are typically shared by local freight carriers in order to perform transshipment operations finalised to consolidate order sets intended for distribution in urban areas [Danielis et al., 2007]. Typically, these horizontal collaboration forms are forced by Public Authorities aiming to reduce freight transportation negative externalities in urban environments [Franklin and Spinler, 2011].

Figure 3.10 provides a supply chain example in which upstream manufacturers collaborate by sharing a common storage facility while dowstream distributors operate inter-urban deliveries using a common regional distribution centre and urban deliveries in a common city hub (i.e., transshipment facility). This configuration lets loads consolidation through freight transportation pooling among stakeholders requiring to move freight along a common transport chain (i.e., tipically starting at a shared logistics platform and reaching common customers delivery points). Thus, the collaborative warehouse concepts are tipically integrated in freight transportation pooling strategies. Major retailing companies such as Tesco, Carrefour, Walmart are moving in this direction by proposing experimental projects finalized to improve their corporate social responsibility [Bălan et al., 2010].

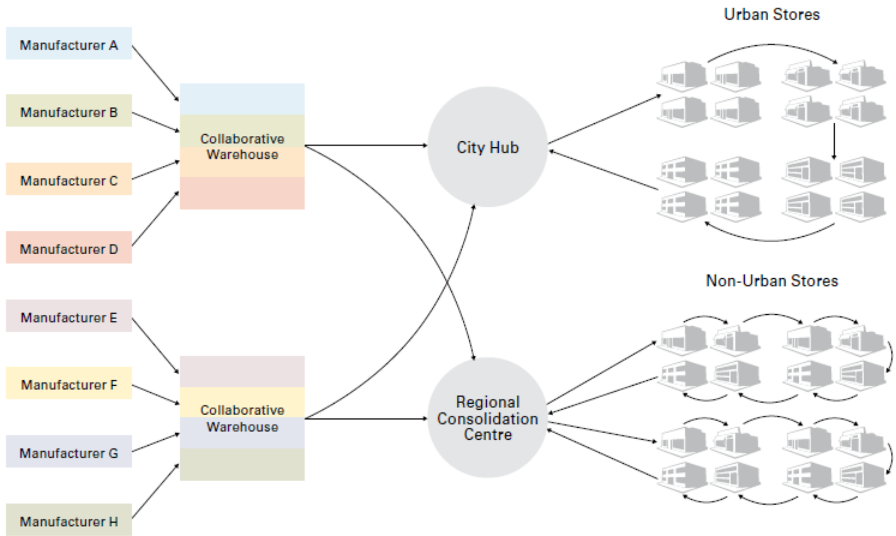

Figure 3.10: Example of logistics infrastructure sharing in production and distribution processes. Source: [GCI, 2008].

Collaboration Form In order to begin an horizontal collaboration exploiting the collaborative warehouse concept, decision makers have to jointly re-design their individual business networks by identifying a common node, a shared logistics infrastructure. At this stage, a coordinated planning process at strategic level is required, focused on the following aspects:

- Facility location: decisions concerning the location of the shared facility. At which supply chain layer freight flows have to meet? Which facility geographical position (e.g., close to a production plant, to the final market, etc.)? Are there located existing infrastructures or a new facility has to be built? Thus, decisions about real estate shared investments have to be made;

- Space allocation: facility physical space sharing agreements [GCI, 2008];

- Facility resources sharing: workforce, equipments and IT systems required to operate the common logistics platform can be fully shared, thus authorising all collaboration members to use them (and pay for them), or partially shared as in the case of "warehouse within a warehouse" approaches. More in detail, this occurs in coopetitive relationships in which a competing organisation decides to manage its independent resources, thus sharing only partially the facility ones and paying only the facility general expenses [Franklin and Spinler, 2011];

- Facility management: agreement on the warehouse management strategy. Collaboration members may decide to outsource warehouse management and consolidated shipments arrangement processes to a jointly selected LSP or, only in rare cases in which high mutual trust and committment are shown, they can manage the facility by their own [Hiesse, 2009].

The warehouse management strategy influences the collaborative dimension concerning tactical and operational decisions. More in detail, two options can be followed:

- Informational collaboration: cases in which the shared logistics infrastructure is managed by a LSP. A centralised decision making process at tactical and operational level is performed, requiring collaboration members to share their own delivery and pick up scheduling and inventory information with the LSP;

- Coordinated planning: cases in which the shared facility is managed directly by the collaboration members through, for example a joint venture. A joint decision-making process at tactical level is required to agree on common inventory management procedures, generally storing freight per customer type in order to enable easier consolidated transportation arrangements, and pickup and delivery time windows scheduling. At operational level, transportation consolidation synergies are exploited based on inventory orders information sharing about real-time freight and orders availability.

Operations Management Typically, a LSP (e.g., 3PL, 4PL) takes the role of facility manager. By exchanging information about pickup and delivery scheduling and inventory levels with each individual collaboration member, the LSP act as operations coordinator by arranging vehicle inbound and outbound movements and ensuring appropriate inventory stock levels [Xu, 2013]. Collaboration members continue to manage individually their deliveries and pickup operations.

Technological Enablers A typical warehouse management process requires barcodes and readers to detect inbound and outbound freight movements within a logistics infrastructure. The collected data are stored and processed by specific information hubs, software packages such as WMS, MRP and ERP enabling tracking, planning and analysis functionalities. The decision making process is typically supported by optimisation tools, such as Adavnced Planning and Scheduling tools. Since the mentioned information and decision technologies have been developed to support single-firm processes, currently they are not fully supporting enhancements in terms of "flexibility, agility, responsiveness and consolidation of warehousing" [Reaidy et al., 2015]. With these premises, technological enablers requirements concern:

- Communication Networks and Data Exchange technologies: RFID or wireless sensor networks, typically in combination with WMS, enable real-time inventory stocks levels data collection and communication among various facility departments and among collaboration members [Lim et al., 2013]. Moreover, such devices can be embedded on trucks, forklifts, freight, personnel with the aim to monitor in real-time the overall warehousing and transportation resources;

- Information Hubs: unlike typical warehouse management tools, Distribution Resource Planning (DRP) systems have been develped to provide inventory replenishment planning among multiple supply chain actors. This characteristic makes them interesting solutions to deploy collaborative warehouse strategies. More in detail, DRP software packages enable inventory policy information collection among collaboration members and support the decision making process by computing optimised warehouse replenishment schedulings [Higginson and Bookbinder, 2005].

- Decision technologies: several top-down optimisation techniques can be adopted to support decision making in collaborative warehouse issues. Some examples from the literature:
  - Facility location in multi-echelon systems problem: [Crainic et al., 2012] propose a top-down framework for integrated urban freight management based on a location-allocation formulation;
  - Inbound and outbound freight docking scheduling: priority-rule based heuristic to optimise truck docking scheduling sequence with a temporary distribution buffer in a distribution center [Yu and Egbelu, 2008].

In recent years, several authors started to report emerging bottom-up "intelligent" warehouse management applications based on WMS and IoT infrastructure integration [Yang, 2012].

3.3.3.4 Freight Transportation Pooling (FTP)

The scientific literature concerning logistics pooling strategies reports multiple examples of shippers or LSPs horizontal relationships aiming at optimising logistics and transportation resources utilisation [Moutaoukil et al., 2012]. In freight transportation, pooling strategies occur when two or more logistics actors mutually share the transportation capacity of a same transportation means aiming at enhancing load factors. All the involved organisations participate in the decision-making process concerning transportation planning and execution [Gonzalez-Feliu, 2011]. In this section, the collaborative logistics taxonomy proposed in Section 3.1 is applied to classify the scientific literature concerning freight transportation pooling strategy applications in sea cargo shipping, air cargo and less than truckload business sectors.

Decision Makers In freight transportation, pooling strategies are typically implemented among shippers or among LSPs with the aim to increase profitability through an optimised use of available resources (i.e., vehicles' capacity utilisation). The LTL shipping sector is a typical freight transportation pooling strategies application field. Indeed, since usually individual shipment volumes are insufficient to organise a dedicated transportation service and, at the same time, frequent deliveries to customers have to be performed, a pooling strategy allows to exploit economies of scale thus sharing transportation rates related to a common trip chain [Mesa-Arango and Ukkusuri, 2015]. Moreover, the achievement of better service leves (e.g., more frequent deliveries) and the reduction of supply chains environmental impacts drive shippers to implement pooling strategies [Bălan et al., 2010]. Typically, bilateral collaborations are established.

LSPs (i.e., freight carriers) implementations occur in business environments characterized by "regular scheduled service routes" operated by high capacity assets: in this context, risks related to high fixed costs and capital investments are substantial. Freight carriers operate in a competitive marketplace in which customers orders are sensible information that cannot be directly shared with competitors [Verdonck et al., 2013]. Typical examples are the ocean liner cargo shipping, the air cargo and the cargo railway business sectors. In these contexts, individual carriers are pushed towards cooperative approaches based on pooling routes and/or fleets with the aim of maximising vehicles utilisation rates. By sharing transportation means capacity, carriers maximise the overall profit by distributing fixed costs (e.g., infrastructure setup and capital investments) and variable ones (i.e., transportation services provision costs), thus exploiting economies of scale resulting from larger shipped volumes. At the same time, by harmonising service levels and tariffs LSPs assume a stronger market position [Agarwal et al., 2009] and [Cruijssen et al., 2007b]. Typically, LSPs freight transportation pooling strategies link multiple actors in a network, as in the cases of *conferences* in the ocean liner cargo shipping and of *strategic alliances* in the air cargo business sectors. For example, the Asia-West Coast South America Freight Conference (AWCSA) counts 17 members, among which competing ocean carriers as CMA CGM, Evergreen, Maersk Line, MSC, etc. In the air cargo industry, the biggest strategic alliance, "SkyTeam Cargo", aggregates 12 relevant players, thus ensuring a wider coverage of the Chinese, European and North American markets.

Collaboration Form Freight transportation pooling strategies can be classified as "coordinated planning" forms of collaboration: the members co-design a transportation network exploiting vehicle capacity sharing mechanisms to increase their overall profitability. The word "co-design" means that a joint decision making phase is performed by harmonising the stakeholders individual service network design plans at tactical and operational levels. Sector by sector, the coordination mechanism varies. In the LTL shipping sector, shippers establish horizontal collaboration relationships exploiting operational synergies based on vehicles shared capacity (i.e., full trucks, trailers, semitrailers, etc.). The involved organisations exchange information about both delivery/backhauling routes to be performed and shipment volumes. If common itineraries emerge, individual transportation plans can be coordinated at tactical level in order to optimise the vehicles utilisation rates along a shared route. To this aim, typically a shared logistics platform is identified with the aim to converge and consolidate individual shipments within a same transportation means [Hiesse, 2009]. The joint decision making process brings to a multi-echelon with cross-docking transportation network design [Gonzalez-Feliu, 2012]. The invoice related to the pooled transportation path is shared among collaborating shippers. Alternatively, the collaboration members can share backhauling transportation capacity by adopting a common ICT platform enabling easier backloading opportunities identification and fleets activities coordination. Thus, a joint decision making process is performed at tactical level to cope with empty balancing problems by minimising the number of necessary vehicles and transportation costs [Juan et al., 2014]. By eliminating empty journey legs, Nestlé and United Biscuits (i.e., competing companies in the biscuit/confectionery market) saved around 280,000 vehicle-km per year. Similarly, Kelloggs and Kimberly-Clark (i.e., firms with compatible products and complementary transport demands) jointly save around 430,000 vehicle-km per year thanks to a backhauling transportation operations co-ordination [Waters and Rinsler, 2014].

In the liner cargo shipping sector, conferences are strategic alliances of multiple shipping lines typically established to harmonise tariffs and service levels through mutual agreements. Some conferences are based on pooling mechanisms: agreements concerning the co-design of a service network in which routes allocation and vessels utilisation rates are globally optimised. Moreover, revenue management techniques can be adopted to share the overall conference income among members. A sequence of joint decisions at tactical and operational levels have to be made by the conference members [Agarwal and Ergun, 2010]:

- Service network design and operated routes selection;
- Vessels allocation to serve the chosen network;
- Vessels capacity assignment among conference members;
- Identification of compatible cargo and transportation paths.

Individual shipping schedules (e.g., port of origin and destination, arrival and departure times, etc.) are shared to support the coordinated planning process. Individual fleets are pooled and assigned to the chosen routes. Consequently, shipping lines acquire fractions of vessels capacity from partners, based on their individual customers demand to be satisfied [Verdonck et al., 2013].

In the cargo airline sector, cargo carriers alliances typically reflect the structure of passenger carriers alliances. For example, Sky Team airline alliance and Sky Team Cargo Alliance have the same members. This happens because cargo airline transportation is commonly combined with the passenger business. In this context, alliance members coordinate their plans at strategic and tactical levels. Joint strategic decisions generally concern future alliance developments, such as to introduce another partner or to expand the alliance market coverage. At tactical level, the partners coordinate their respective service network design plans in order to increase individual profits by optimising the use of resources. With this perspective, several sharing initiatives are implemented. For example, alliance members can optimise airport facilities utilisation by sharing warehouses, as done by Air-France/KLM Cargo, Alitalia Cargo and Delta Cargo at the Amsterdam airport. Other examples of coordination at tactical level are the co-location practices within a same terminal and airport services sharing approaches (e.g., check-in desks, joint handling contracts, etc.) [Ankersmit et al., 2014]. Finally, alliance members can optimise vehicles utilisation rates by pooling freight within a shared aircraft. In this context, alliance members jointly decide how much space to assign to each member and how to distribute revenues [Agarwal et al., 2009]. *Code share agreements* are typically arranged in order to make the collaboration operative.

Operations Management In maritime shipping and the airline cargo sectors, liner shipping companies and airlines operate the allocated service routes and reserve to collaboration members the assigned vehicle capacity [Agarwal and Ergun, 2010]. In the less than truckload shipping sector, the freight flows consolidation process is usually executed by a 3PL.

Technological Enablers Proprietary information systems such as ERP are commonly used as data sources for companies transportation planning. In SMEs, this process is still often performed manually while bigger logistics actors typically use specific software packages. Routes and vehicle fleets optimisation modules represent key TMS functionalities to enable shippers transportation tactical and operational planning and LSPs transportation execution. Moreover, sector-specific tools, such as Flight Schedule Management Services in the cargo airline industry, support carriers in designing optimised liner service networks. The mentioned tools represent baseline technological requirements to deploy a freight transportation pooling strategy: each shipper or LSP starts planning transportation at tactical and operational level with the aim to increase its profit by allocating routes and vehicles in an optimal manner. These systems support B2B one-to-one information and documents exchange (e.g., routes, schedules, etc.) via *communication networks and data exchange technologies* such as extranet, web (i.e., emails), fax and EDI thus identifying common trips and freight transportation pooling arrangements [Buhalis, 2004].

When the pooling collaboration involves multiple logistics players, *freight exchange platforms* are typically used "to match available vehicle space with available freight" in order to maximise resources utilisation rates and minimise empty legs [Miksa, 2013]. In general, these tools are web-based IT information hubs enabling data standardisation, routes comparison and shipments consolidation. The mentioned functionalities are supported by various sector-specific e-platforms such as CargoX for air cargo, Teleroute for road transportation, etc. Typically, these e-platforms require the following *decision technologies*:

- Optimisation techniques useful to answer "how-to" questions (i.e., to support collaboration members in optimising the overall transportation network performance through shipments consolidation, pooled routes planning and vehicle capacity sharing);
- Simulation techniques to support decision makers by performing "what-if" analyses.

Sometimes, one of the collaboration members is in charge to develop the shared IT platform. For example, Lufthansa has developed a Global Distribution System (i.e., Amadeus) enabling information sharing and logistics coordination among several Star Alliance members. In other cases, external entities provide technical guidelines, support and tools to collaboration members. This is the case of air cargo industry, where the IATA and SITA ventures exploit common platforms based on single window technical architecture and e-Freight paperless services.

3.4 Diagonal Collaborative Logistics

In the last decade, logistics stakeholders have started to develop and implement collaborative logistics models combining simultaneously horizontal and vertical collaboration strategies with the aim to enhance supply chains flexibility. So far, the major application field is represented by holistic Collaborative Transportation Management (CTM) strategies while very few studies report about intermodal transportation propositions [Kayikci and Zsifkovits, 2012], [Groothedde et al., 2005] and inventory management practices in manufacturing supply chains [Chan and Prakash, 2012].

3.4.1 Freight Transportation

In the early 2000s, the American organisation VICS has formalised the CTM theoretical framework in order to address the continuous pressures exerted on transportation systems. The CTM general concept and its existing vertical applications have been already presented in Section 3.2.2.6. In recent years, several researchers have started to report about CTM business cases implementing a diagonal collaboration among the involved logistics actors. Hereafter, the collaborative logistics taxonomy proposed in Section 3.1 is applied to classify the scientific literature on diagonal collaborative models in freight transportation.

Decision Makers The scientific literature classification about CTM vertical collaboration forms is proposed in Section 3.2.2.6. The same decision makers are involved in planning and deploying diagonal CTM schemes: buyers and sellers already deploying a CPFR collaboration strategy (i.e., vertical collaboration form) decide to establish closer relationships with multiple freight carriers, eventually substituted by a 3PL/4PL provider, in order to "create superior value adding solutions to SCs" [Okdinawati et al., 2015]. Various n-tier diagonal collaboration settings are possible, as illustrated by the business cases reported by [Mason and Lalwani, 2006]:

- Retailing industry: several major retailing companies jointly decide to coordinate their transportation flows by establishing a coordinator (e.g., a 4PL) in charge to organise shipments involving multiple transport operators;
- Manufacturing industry: case of a three manufacturers collaboration exploiting information sharing among a network of LSPs with the aim to provide a better freight tracking service for shippers and customers;
- Short-haul transportation sector: case of a transportation hauliers consortia collaborating with local suppliers to establish a pallet network.

Collaboration Form The deployment of diagonal CTM strategies typically requires a coordinated planning process in which the involved stakeholders jointly decide how to re-design the supply chain network in order to better synchronise distribution activities and to optimise transportation assets use. The scientific papers majority focuses on strategic and operational decision-making levels, even if a detailed joint decision-making process analysis is missing [Okdinawati et al., 2015]. At strategic level, the diagonal collaboration planning involves the logistics network design [Ozener, 2008], for example by introducing cross-docking facilities to consolidate freight in shared vehicle fleets serving the same customers, and to select committed partners [Gonzalez-Feliu et al., 2013] and [VICS, 2004]. Few contributions discuss tactical planning of diagonal CTM strategies. At the operational level, the collaboration members identify the technological requirements and the operations management models, such as routing models, to deploy a CTM strategy [Mason and Lalwani, 2006] and [Ozener, 2008].

About information sharing CTM requirements, see the homologous paragraph in Section 3.2.2.6. Moreover, the sharing of material logistics resources is needed such as vehicle fleets, vehicle capacity and logistics infrastructures (e.g., facilities, logistics platforms, etc.).

Operations Management For a general understanding, see the homologous paragraph in Section 3.2.2.6. About diagonal CTM operations management, various approaches are possible depending on the collaboration setting. Considering that the holistic management of logistics tasks among several entities is challenging, usually a coordinator such as a 4PL provider is in charge of operations management. This figure acts as a driver of change pushing the involved stakeholders towards more collaborative business relationships. Moreover, it ensures the right execution of collaboration members' logistics and transportation tasks exploiting network synergies related to a better asset utilisation, increased service levels and a wider market coverage [Mason and Lalwani, 2006]. For example, this occurs when a 4PL act as a catalyst of buyer-seller transportation orders and coordinates loads exchange among a community of freight carriers with the aim to optimise vehicle fleets utilisation [Ozener, 2008].

Technological Enablers See the homologous paragraph in Section 3.2.2.6.

3.5 Concluding Remarks

In this Chapter, a taxonomy for collaborative logistics is proposed with the general aim to review the field and to identify current gaps and future research areas from a logistics management perspective. The proposed taxonomy harmonises current and emerging business and organisational models descriptions by summarising them in four key components: decision makers, collaboration form, operations management and technological enablers. The tool has been applied to perform a state of the art analysis of classic collaborative logistics models (i.e., vertical, horizontal, diagonal types). The most relevant results are reported per collaborative logistics type in Tables 3.1, 3.2, 3.3.

Table 3.1: Vertical collaborative logistics state of the art analysis.

General	
Research field status	Most studied research area
Most studied applications	• in procurement and production processes: Just In Time • in transportation, warehousing and distribution: Efficient Customer Response, Quick Response, Collaborative Replenishment Process, Vendor-Managed Inventory, Collaborative Planning Forecasting and Replenishment, Collaborative Transportation Management
Collaboration dimension	Mono-dimensional
Decision makers	
Type of logistics actors	Logistics Service Users and Providers
Type of collaborative network	Evolving from single-tier to n-tier networks
General objectives	To create fast, flexible, reliable and cost-effective supply chains: • Increased productivity • Overall supply chain costs reduction • Reduced time to market • Increased customer service levels • Increased product quality • Optimised inventory stocks • Bullwhip effect reduction
Collaboration forms	
Type of collaboration form	Depending on the setting: • Starting level: arms' length relationships • Intermediate level: informational planning • High level: coordinated planning at operational decision level
Commitment	• Shared responsibilities • Shared complementary knowledge • Shared logistics resources (e.g., investments, data and information, work-force, IT systems, etc.)
Type of information shared	• Production schedules • Demand forecasts • Real-time sales data • Stocks and inventory levels reports

Technological enablers	
ICT	• Automatic Identification and Data Capture technologies: Electronic Point of Sales systems based on laser scanners and bar codes, RFID, Electronic Product Codes • Communication Networks and Data Exchange technologies: EDI, web-EDI, internet, XML standard • Electronic Forecasting Systems • Electronic Found Transfer Systems • Information Hubs: Enterprise Resource Planning, Electronic Ordering Systems, Warehouse Management Systems, Transportation Management Systems
Decision technologies	Simulation and optimisation techniques included in the following software packages: • Warehouse Management Systems • Transportation Management Systems • Advanced Planning and Scheduling systems • Distribution Planning Models
Supported functionalities	• Operations synchronisation • Continuous replenishment • Cross docking • Automated store ordering • Inter-firm material, components, products tracing • Inter-firm information sharing • Electronic Founds Transfer
Operations management	
Collaboration members	• Inventory Management • Category management • Continuous replenishment
Outsourcing	Transportation tasks are typically outsourced to a LSP (i.e., freight carrier, 3PL, etc.)
Future research areas	
New emerging scopes	• Technology enabled supply chains • Collaborative humanitarian supply chains • Collaboration for sustainable supply chains
New application fields	Reverse logistics

Table 3.2: Horizontal collaborative logistics state of the art analysis.

General	
Research field status	• Research area still in early stage if compared with the vertical logistics collaboration domain • The scientific existing contributions mostly focus on transportation/distribution management practices
Most studied application fields	In policy-making and regulation processes: • Emission Trading Systems • Standardised customs procedures In procurement and production processes: • Purchasing groups and consortia In transportation, warehousing and distribution: • Transportation planning through shared information: Joint Procurement of transportation services, Joint route planning • Infrastructure sharing: Logistics infrastructure sharing • Vehicle sharing by loads consolidation: Freight transportation pooling
Collaboration dimension	Mono-dimensional: logistics actors operating at the same supply chain echelon
Horizontal relationship types	• Coexistence • Cooperation/collaboration • Competition • Coopetition
Decision makers	
Type of logistics actors	• Logistics service legislators • Logistics service providers • Logistics service users
Type of collaborative network	Depending on the business sector, range from bi-lateral (most widespread) to multi-lateral
General objectives	• Overall supply chains costs reduction • Strengthen market position • Improved productivity through an efficient assets utilisation • Enhanced customer service levels • Enhanced innovation and supply chain responsiveness • Increased social relevance
Collaboration forms	
Type of collaboration form	Depending on the business industry and on the setting: • Mostly coordinated planning approaches • Informational planning approaches are implemented in joint procurement of transportation services and logistics infrastructure sharing • Integrated/centralised planning of transportation routes

Commitment	• Shared material logistics resources: vehicles, logistics infrastructures • Shared human resources • Shared immaterial logistics resources: knowledge, experiences, data and information • Harmonised policies, regulations, service levels
Type of information shared	• Material and components procurement orders • Transportation orders • Shipping orders • Pickup and delivery schedules • Routes
Technological enablers	
ICT	• Automatic Identification and Data Capture technologies: RFID, wireless sensor networks • Communication Networks and Data Exchange technologies: EDI, web-EDI, internet, XML standard, B2B internet platforms, e-marketplaces, trade portals • Information Hubs: single window platforms, Transportation Management Systems, Warehouse Management Systems, Material Resource Planning, Enterprise Resource Planning, Distribution Resource Planning
Decision technologies	Operations research (OR) techniques included in the following software packages: • Warehouse Management Systems • Transportation Management Systems • Advanced Planning and Scheduling systems Two types of OR approaches: • Optimisation techniques: exact methods, heuristics, metaheuristics • Simulation techniques: game theory Typically VRP algorithms are used
Supported functionalities	• E-customs • Emission trading • Routing • Scheduling • Inter-firm information sharing • What-if analysis • Loads consolidation • Tracking and tracing • Performance evaluation

Operations management	
Collaboration members	• Demand aggregation • Multi-picks and multi-drops coordination • Route selection • Logistics resources allocation to the chosen network • Logistics resources assignment • Identification of compatible paths and freight
Outsourcing	• 3PL as e-marketplaces manager • 3PL/4PL as demand aggregation coordinator • 3PL as stakeholders collaboration managers • 3PL as shared logistics facility manager
Future research areas	
Decision makers	• Scarce literature on logistics services legislators horizontal collaboration forms • The LSPs horizontal collaboration forms are described from a game theory and market analysis points of view. The organisational and business models perspective have still to be investigated
Collaboration form	An harmonised description of the horizontal collaboration forms has to be provided (i.e., goal of this chapter)
Technological enablers	DSS applications finalised to manage in an holistic way the horizontal collaboration network
New application fields	Reverse logistics

Table 3.3: Diagonal collaborative logistics state of the art analysis.

General	
Research field status	Emerging research area
Most studied applications	In procurement and production: • Inventory management In transportation, warehousing and distribution: • Collaborative Transportation Management full integrated approaches • Intermodal transportation
Collaboration Dimension	Bi-dimensional: combined vertical-horizontal collaborative logistics domains
Decision makers	
Type of logistics actors	• Logistics service providers • Logistics service users
Type of collaborative network	Multi-lateral collaboration

General objectives	To enhance supply chains: • Flexibility: create superior value adding new solutions to supply chains • Efficiency: increase productivity by optimising the use of resources • Sustainability: reduce air pollution, noise and congestion
Collaboration forms	
Type of collaboration form	Coordinated planning process at strategic and operational decision levels in diagonal Collaborative Transportation Management approaches
Commitment	Various combinations of the elements reported in the same section in Table 3.1 and Table 3.2
Type of information shared	Various combinations of the elements reported in the same section in Table 3.1 and Table 3.2
Technological enablers	
ICT	Various combinations of the elements reported in the same section in Table 3.1 and Table 3.2
Decision technologies	Various combinations of the elements reported in the same section in Table 3.1 and Table 3.2
Supported functionalities	Logistics and transportation tasks coordination
Operations management	
Collaboration members	Various combinations of the elements reported in the same section in Table 3.1 and Table 3.2
Outsourcing	4PL as a driver of changes: • Push stakeholders towards more collaborative approaches • Ensure the right execution of stakeholders transportation tasks • Exploit network synergies
Future research areas	
Collaboration forms	• Missing decision-making integration process contributions • Research on the topic of coordinated planning at tactical decision-making level in diagonal Collaborative Transportation Management approaches is still missing
Technological enablers	Missing research on advanced ICT and decision tools to plan, manage, monitor, control and evaluate such integrated systems
New application fields	Intermodal transportation

The results of this Chapter are based on publication [Rusich et al., 2016].

Chapter 4

Collaborative Requirements in Emerging Logistics Paradigms

In recent years, the research community has started to propose innovative logistics paradigms aiming at reorganising current logistics and transportation systems leading to a societal, economic and environmental inefficiencies reduction. In this context, the *City Logistics* and the *Physical Internet* are the major concepts gaining momentum. Such theoretical frameworks are based on common core principles even if they have different application fields: the City Logistics refers to *urban areas* while the Physical Internet takes into consideration logistics and transportation systems *on a global scale*. The implementation of both frameworks require the development of collaborative business and organisational models (still not available) to be implemented.

In this chapter, the collaborative logistics taxonomy proposed in Section 3.1 is applied to classify the emerging logistics paradigms scientific literature. Sections 4.1 and 4.2 propose, respectively, a state of the art analysis of City Logistics and Physical Internet. This work is preparatory to the research gaps identification to be bridged in the near future. To this aim, Section 4.3 propose a Physical Internet collaborative logistics requirements research agenda.

4.1 Towards Interconnected Collaborative Logistics

The City Logistics (CL) and the Physical Internet (PI) visions propose, respectively for urban and interurban environments, a smooth "transition from the current independent supply chains, where transport and logistics resources cannot be shared or accessed by different freight carriers and shippers, to *open logistics networks* where resources are compatible, accessible and easily *interconnected*" [ALICE, 2014]. The general understanding is to promote the sharing of individual logistics actors networks in order to realize a *Logistics Web* characterised by the following peculiarities [Bektas et al., 2015]:

- *Logistics resource utilisation maximisation:* efficient matching between shipment demand with the available transport and logistics services (i.e., horizontal collaborative logistics models exploiting freight flows consolidation based on intermodal transportation);
- *Provision of door-to-door services:* synchronization and dynamic update of logistics and transport plans, across modes and actors (i.e. vertical collaborative logistics models exploiting logistics and transportation tasks coordination) [ALICE, 2014];
- *Separation of commercial transactions generating transportation demand and the actual transportation and logistics activities.*

From a logistics management perspective, such a transition requires the development of innovative and complex collaborative business and organisational models combining simultaneously and interactively classic vertical, horizontal and diagonal relationships. In a near future, each entity might represent a node with multiple linkages within an interconnected logistics web. To emphasise the emergence of such new collaborative logistics models the *interconnected collaborative logistics type* has been coined. Currently, the available researches assume that somehow the business models required to operate smoothly and seamlessly CL or PI systems have already been found. In reality, if recent scientific works on CL have almost identified simple business models, for PI researchers are not so close. Therefore, further studies are required.

4.2 The City Logistics Literature Review

Hereafter, the collaborative logistics taxonomy proposed in Section 3.1 is applied to review the CL scientific literature with the aim to present the current state of the art and to illustrate collaborative logistics future research areas.

Decision Makers In the last decades, the number of freight vehicles circulating in modern cities has grown as a consequence of several business trends:

- e-Commerce: end customers requirement of increased deliveries volumes;
- Urbanisation: people is moving from countryside to urban environments;
- Production and Distribution practices: low inventories and timely deliveries.

The high presence of commercial vehicles in urban road networks generate congestion and environmental nuisances, such as air pollution and noise. The CL paradigm has been coined with the general aim to reduce freight transportation impacts in urban environments without affecting economic activities. More specifically, the objectives are:

- Reduction of the dimension and number of commercial vehicles operating within the urban context;
- Reduction of the number of empty vehicle-kilometres;

- Improvement of freight movements efficiency.

The CL vision concerns the planning and deployment of an *integrated logistics system* in which all the participating stakeholders might be part of a community committed in planning and operating a more sustainable urban freight delivery network (i.e., n-tier structure). All the actors should be linked in such a way, tipically exploiting public-private and innovative partnerships [Crainic et al., 2009]. A brief summary of potential CL stakeholders is reported in the work of [Benjelloun et al., 2010]:

- Governments: international (e.g., European Commission), national and regional policy makers encourage the development of innovative business models and promote technological standards (e.g., cellular communication in ITS);
- Municipalities: active neutral partners (e.g., regulators, initiators, etc.) in all the existing implementation;
- Shippers and Consignees: always involved in CL initiatives at planning level;
- LSPs: freight carriers and warehousing operators are always part of the operations management process;
- End Customers: citizens in B2C supply chains while stores, offices, hospitals etc. in B2B supply chains are typically involved in CL projects performance evaluation and business models validation.

Traditionally, CL initiatives have been launched by Public Authorities; recently, emerging city challenges and customers demand variations have led groups of private companies to get involved in the CL market. As a consequence, the most recent scientific publications look at the City Logistics from a private side (e.g., express couriers, last mile service providers, 3PLs, shop owners, etc,).

Collaboration Form From a theoretical point of view, the CL vision proposes a smooth transition towards collaborative logistics networks exploiting *integrated planning* at strategic, tactical and operational decision levels and *operations coordination* [Nuzzolo and Comi, 2014]. The current studies typically assume that carriers are willing to collaborate together, thus sharing facilities and vehicle fleets as a business model is already in place. In a such hypothesis, strategic planning in CL should concern the urban delivery *network design*, the *cost-benefit analysis* of setting up and operating the system (i.e., potential costs and benefits) and the *revenue management.* A CL network design should include:

- *Supply modelling:* modelling the transportation infrastructure and services;
- *Demand modelling:* identify logistics actors' transportation demand in terms of origin-destination markets, type of product flows, mode choices;
- *Assignment modelling:* multi commodity flows assignment to the designed transportation network (i.e., matching demand and supply).

The process should result in the identification of the network layout: so far, two major configurations have been proposed. *Single-tier* CL networks are typically developed in small and medium cities: the freight reaches the urban area within full-loaded vehicles which deliver it at a CDC, shared facilities in which loads consolidation takes place and distribution activities are coordinated. Smaller urban vehicles are used to deliver the freight directly from the CDC to the final customers. On the other hand, *two-tier* CL networks have been proposed in order to better address large cities freight transportation requirements. In such systems, the freight loaded on larger trucks arrives in an peripheral urban area, where a CDC is located. There the freight is sorted and consolidated into smaller fully-loaded urban freight vehicles which performs the route from the CDC to satellites, cross-docking facilities positioned close to the city center. In these facilities, loads are transferred to city freighters, even smaller vehicles in charge to deliver the goods to the final customers [Bektas et al., 2015].

Tactical planning in CL should focus on the *service network design*. CL networks are conceived as consolidation-based transportation systems in which "departure times, routes and loads of vehicles, the routing demand and, when appropriate, the utilisation of second-tier consolidation facilities and the distribution network among them" [Crainic et al., 2009]. In such a way, the goals of a better assets utilisation rate and of an efficient operations management might be achieved. Tactical planning in CL has a short planning horizon due to day-by-day demand visibility.

Operational planning in CL might be related to *schedule the work of drivers and logistics facilities personnel*. Moreover, the real-time control of the system might imply *dynamic vehicles and terminal schedules adaptations*.

From an operations coordination point of view, various CL organisational and business models have been proposed in the last 40 years, exploiting differentiated functionalities and scopes. An overview of the first CL initiatives is presented in Table 4.1.

Table 4.1: City Logistics first initiatives overview.

City/Country	Years	Business Model	Functionality
Germany and Switzerland	1992-1995	Private companies with low government support	Loads consolidation based on a CDC and voluntary carriers collaboration
Netherlands	Mid '90s - On-going	Local Authorities active role	Permits reducing vehicle loads and number within the city area to force carriers collaboration in loads consolidation; policies promoting EVs
Monaco	Mid '90s - On-going	Urban Distribution as a Public Service	Unique urban operator (public moved to private) for freght delivery between the CDC and the final customers
Japan	Since 1999	Local Authorities active role	ITS deployment and stakeholders voluntary collaboration stimulation
France	Since 2000s	Urban Distribution as a Public Service	Public-private partnerships for express courier deliveries

As reported by [Benjelloun et al., 2010], the logistics collaboration requirements have evolved with time. Before the 1990s the public sector was the main protagonist of CL projects, typically investing in infrastructures (i.e., CDC) and regulating the urban distribution sector (i.e., no logistics collaboration). Since the 1990s, collective cooperative logistics-based initiatives have been conducted at experimental level in Western Europe and Japan: carriers were pushed to cooperate in vehicle fleets and customers demand management by local Public Authorities **??**. Since the 2000s, the CDC and carriers horizontal collaboration concepts were affirmed and integrated with a broader range of functionalities and scopes [Benjelloun and Crainic, 2008]:

- Public-private partnership models;
- Shippers and consignees voluntarily collaboration in loads and and transportation destinations pooling;
- Modal Shift;
- Freight corridors in North America;
- Advanced ICT and decision technologies application in the field of urban delivery management (i.e., ITS);
- Underground systems to reduce congestion on the urban road network [Kikuta et al., 2012];
- Green vehicles fleets (most recent conceptualizations);
- Cargo hitching: urban freight transportation integration with the public transportation infrastructure (most recent conceptualizations).

An overview of the most recent projects is presented in Table 4.2.

Table 4.2: City Logistics most recent initiatives overview.

City/Country	Years	Business Model	Functionality
Franch Cities	Since 2000s	Private Initiative	2-tier CL network structure in which EVs deliver freight to final customers (Chronopost International project)
Amsterdam	Since 2000s	Private Initiative	Combination of tram and truck modes in a 2-tier CL network structure plus EVs deliver freight to final customers (CityCargo project)
Spain	2000s	Local Authorities active role	Policies and regulations plus cooperation with carriers associations [Muñuzuri et al., 2012]
Japan	Since 2010s	Systemic Initiative	Urban delivery system based on a combined network of trucks and subway
London	Since 2010s	Systemic Initiative	Micro-CDC plus electric vans and trycicles use for last mile deliveries

By concluding, full integrated CL implementations have started recently and are not so widespread. At the current state of the art, the various CL real piloting, experimental and implementation experiences have confirmed that the CL paradigm deployment requires a simultaneous and interactive combination of various collaboration forms (i.e., interconnected collaboration). Recent CL systemic implementations have started only in the last years and currently are limited to few cities.

Operations Management Various operations management models and approaches exist as a consequence of the various business and organisational models that have been proposed so far.

Technological Enablers The deployment of sustainable urban freight delivery systems requires technology applications related to ICT, decision technologies and vehicles (i.e., hybrid or electric vehicles). Since vehicle technology is out of the manuscript scope, this section only illustrates the CL technological enablers belonging to the first two categories.

ICT are fundamental enablers of efficiency enhancements in urban freight delivery systems. These technologies perform data collection and information sharing between demand and supply side information systems, thus supporting CL operations both from a planning perspective (e.g., delivery routes and schedules) and from an operations management one (i.e., vehicles operations monitoring) [The European Union, 2015].

- Communication Networks and Data Exchange technologies:
  - EDI and internet networks for one-to-one or one-to-many data and information exchange in web-sites or e-marketplaces and moreover, for stakeholders participation in the collaborative decision process;

  - Satellite and wireless communication networks to enable real-time access to information from "anywhere";

- ITS to enable the following CL systems functionalities as "number-plate recognition, controlled access to Limited Traffic Zones (LTZ), tracking/tracing to better optimize routing operations of cooperating carriers". The following items are typically included:

  - Advanced Traffic Management Systems (ATMS) in combination of Advanced Traveller Information Systems (ATIS) to provide better information on traffic-conditions and support drivers in decision-making;
  - E-payment systems for tolls and congestion charges;
  - Automatic Vehicle Identification (AVI) systems to detect vehicle license plates entering into ZTL areas;
  - Advanced Fleet Management Systems (AFMS) able to interact with city ATMS/ATIS in order to have an expanded dataset of inputs to be used in combination of optimization techniques and algorithms in order to plan efficiently the fleet allocation and to control in real-time vehicles' operations;

- Sensing technologies enabling V2I bi-directional communication functionalities (e.g., automatic number plate recognition).

From a decision technologies perspective, CL systems require *DSSs* embedding operations research, simulation, statistics and econometrics methodologies enabling the design, analysis, planning, management, and control of such systems [Benjelloun et al., 2010].

4.3 The Physical Internet Literature Review

Since the first publication on the Economist in 2006, the PI paradigm has continued to attract the attention of governments, researchers and industries even if, at this point in time, it *still represents a theoretical framework with very few real-implementations*. So far, the research field knowledge has mostly concerned the following general aspects:

- PI concept descriptions [Ballot et al., 2015], [Montreuil, 2012], etc.;
- PI key components design (e.g., π -protocols, π -hubs, π -containers, etc.) [Sallez et al., 2016], etc.;
- PI networks impact and performance assessment [Venkatadri et al., 2016], [Fazili, 2016], etc.;
- Logistics management models proposition related to several application fields:
  - Inventory Management [Pan et al., 2013], [Pan et al., 2015], [Yang et al., 2015];
  - Routing in rail-road π -hubs [Pach et al., 2014];
  - Revenue Management [Qiao et al., 2016];
  - Emerging scopes [?];
- Etc.

Few studies have focused on PI business models proposition [Cimon, 2014], [Oktaei et al., 2014], even less on collaborative logistics business models. To contribute to the field, a collaborative logistics requirements state of the art analysis is proposed in order to identify research gaps, thus structuring a roadmap for future studies. The collaborative logistics taxonomy proposed in section 3.1 is applied to classify the PI scientific literature.

Decision Makers The PI paradigm was coined in order face the major critical issues related to the way goods are produced and shipped around the world. In particular:

- Economical issues: worldwide logistics costs grow faster than world trade;
- Environmental issues: growing negative contribution while nations goals aim for heavy reductions (e.g. CO_2 emissions, energy consumption, congestion, etc.);
- Societal issues: too often precarious logistic work conditions, etc.

To contibute in solving such problems, the PI vision figures the transition towards an *"open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols"* [Montreuil, 2012]. The concept is inspired by what happened in the telecommunications sector with the Digital Internet: the interconnection of IT networks. However, adaptations are needed since in logistics physical goods cannot move by themselves as data packets in telecommunications. To face the challenge, the PI concept proposes to stimulate the transition from current individual supply chains towards a *Logistics Web*, an open global network of shared logistics networks currently operated by various logistics actors:

- *Production networks*: shared assembly and production plants, warehouses belonging to multiple producers and manufacturers;
- *Transportation networks*: shared unimodal, multimodal, intermodal hubs and transits belonging to on-demand carriers (e.g., FTL motor carriers, express couriers, etc.), regular scheduled services operators (e.g., LTL motor carriers, rail and air carriers, etc.), terminal managers;
- *Distribution networks*: shared regional distribution centres, depots, outlets, etc. belonging to multiple wholesalers, retailers, LSPs.

In addition, a PI roll-out requires the commitment of other relevant players. Logistics legislators should try to harmonise worldwide trade legislations, customs regulations and to develop policies pushing business environments towards collaborative logistics. Moreover, technology providers might be in charge to define common standards enabling interconnection among networks, such as optimal π -containers sizes, sketch and deploy π -protocols, design π -hubs etc. Therefore, the *whole global logistics community* might be committed in the Logistics Web realization. Concretely, the following logistics actors have already started real initiatives:

- *Logistics service legislators*: international and national governments by:
  - Funding: public economical support devoted to research and experimental projects aiming at forecasting PI benefits and overcoming existing barriers (e.g., European Commission research and innovation programmes, such as FP *7th* and Horizon 2020, include several calls for proposals related to the PI);
  - Regulation: so far only indirect international agreements (e.g., COP21 Conference on Climate Changes held in Paris in December 2015 about the CO_2 emission targets);
- *Logistics service providers and users*: shippers, LSPs and final customers of various types (e.g., private citizens, stores and shops, offices, major distribution chains). So far, the relevant contributions have come from major private companies interested to study *industrial PI applications*. They support the PI roll-out by:
  - Validating current issues;
  - Participating in research projects finalised to simulate the logistics performance in a PI scenario (e.g., the retailers Carrefour and Casino in France);

  - Participating in experimental projects aiming at "performing trials and removing obstacles" [Ballot et al., 2015];

- *Research Centres and Academia*: support public authorities and private organisations in identifying the existing logistics systems major issues and in proposing research and innovation contributions (e.g., planning, organisational and business models, technologies etc.). The research consortium *"The Physical Internet Initiative"* plays at the moment a leading role in supporting a PI realization. The consortium organises thematic scientific conferences to stimulate the research community in submitting publications related to new enhancements in the field.

By concluding, the decision makers identification represent a key step to design and develop PI collaborative logistics models. Depending on the decisional level under analysis, the decision makers might be a subset of all the various stakeholders categories playing an active role on logistics and transportation systems. Moreover, it should be noted that a same logistics actor may assume various decision roles at the same time, as in the case of major distribution chains (i.e., shippers and consignees simultaneously).

Collaboration Form In contrast to classic collaborative logistics strategies, appropriate business models for the PI and CL have still to be defined (CL almost there). Thus, the way to realise interconnected logistics networks is still undefined. As a consequence, the proposed collaboration form analysis can only be performed assuming potential scenarios based on the more realistic hypothesis.

The scientific literature has already converged on the assumption concenring that PI networks deployment requires the *harmonisation (even better the integration) of stakeholders plans* and *operations coordination.* Differently respect to the CL research domain where some authors have assumed a business model in place in order to propose a planning framework for such networks [Crainic et al., 2009], similar contributions are scarce for PI. The work of [Sohrabi and Montreuil, 2014] is the most significant contribution in terms of planning PI networks. More in detail, the paper aims to support the realisation of an Open Distribution Web enabling "any business to dynamically deploy its products across geo-markets, in numerous open distribution centres owned and operated by other businesses". From a planning perspective, various decision making levels are sketched. At the strategic one, the partnering companies are supposed to design their shared distribution network or building new distribution centres jointly or sharing existing logistics facilities. At tactical (i.e., service network design) and operational (i.e., resource deployment) ones, the partners would be interested to consolidate freight flows in order to reduce transportation costs through economies of scale. To this aim, the choice is supposed to be between the transportation and delivery tasks outsourcing to a LSP or the management of such processes through collaborative logistics models. The output consists in a distribution web, an interconnection of various distribution networks, easily adaptable according to dynamic market conditions.

A second assumption concerns how to put in place a planning harmonisation mechanism (or even better integration) and operations coordination. Currently, the research community converges in excluding a scenario characterized by the presence of a unique agency in charge of the global Logistics Web realisation and management. Such hypothesis seems to be not desirable in terms of marketplace competition reduction, moreover it appears difficult to implement considering the existing global differences in terms of economies, legislations, policies, business practices etc. As a consequence, the required innovative business models should fall in the *collaborative logistics domain*.

A third assumption concerns the requirement to move from centralised collaborative decision-making approaches, typical of classical collaborative logistics models, to *decentralised/distributed* ones [Ballot et al., 2015]. Therefore, each logistics actor should simultaneously play an active role in the PI web design and management (i.e., multi-agent systems). How to concretely put in place a such open system? The answer is still not known, some hypothesis are illustrated in Section 4.4. The more realistic scenario seems to be the one characterised by a smooth transition towards the realisation of a global Logistics Web. Probably, the move will first start at regional level and lately will assume a global dimension: logistics actors of a certain region will decide to collaborate by establishing a *regional coordinator*, potentially a 4PL or a 5PL, in charge to harmonise individual plans and synchronise operations. Moreover, the regional coordinator will act as the regional community interface with the other networks.

A fourth assumption regards the requirement to *share individual logistics networks* with the other members of the logistics community, thus creating a network of interconnected networks (i.e., a Web). In such a way, the whole logistics system performance is expected to improve. Such hypothesis has been confirmed by various researches. For example, [Furtado and Frayret, 2014] propose a simulation between a traditional and a PI transportation systems resulting in a better financial, operational, social and environmental performance of the whole transportation operations in the PI case. In terms of production, the Realisation Web would result by the mutualisation of investments in new manufacturing and assembly facilities, shared existing production plants and assembly facilities, shared production plans, shared workforce, shared IT facility, shared materials and components procurement orders, etc. Moreover, a Mobility Web would result by the simultaneous sharing of vehicle fleets, vehicles capacity, transportation orders, schedules and routes, terminals, e-marketplaces, etc. The work of [Furtado and Frayret, 2014] highlights the potential benefits related to resource sharing in transportation.

From theory to practice, Table 4.3 overviews the research, applied research and innovation projects evidencing public and private joint efforts towards a PI roll-out. Note that PI collaborative logistics business models theme has recently started to raise in importance.

Table 4.3: Physical Internet initiatives to establish and validate the issues overview. Source: [Ballot et al., 2015].

Project	Country	Logistics Actors	Objective
PREDIT	France	Public Authorities and Research Centres	Holistic simulation to assess the PI impacts on the French distribution of fast-moving consumer goods industry
CELDi	USA	Research Consortium and Private Partners	Current logistics systems issues validation within the US context
	Canada	CIRRELT Research Centre	Simulation to estimate the potential for energy, economic, environmental and social gains of a Mobility Web in the province of Québec
	Canada	CIRRELT Research Centre	To estimate the potential energy, environmental and financial gains for a manufacturer exploiting an open distribution network

Table 4.4: Physical Internet initiatives to perform trials and remove obstacles overview. Source: [Ballot et al., 2015].

Project	Country	Logistics Actors	Objective
CELDi	USA	Research Consortium and Private Partners	Optimization of the number of containers required in the consumer packaged goods industry based on the diversity of the products and containers
CELDi and CIRRELT	USA and Canada	Research Centres and Private Partners	PI-hubs design with 3D modelling
OpenFret	France	Research Centres, Academia with Government Support	3D modelling methodology development for road/rail hubs
PI-Nuts	France and Canada	Research Centres and Academia	Study of hybrid control architectures to control physical internet cross docking systems
OTC-KAYPAL MR	France	Academia and Private Partners	Demonstrate the benefits of combining RFID, EPCIS technologies and innovative business models in the retailing industry

Table 4.5: Physical Internet initiatives to perform trials and remove obstacles overview. Source: [Ballot et al., 2015].

Project	Country	Logistics Actors	Objective
CRC Services	France	Research Consortium and Private Partners	Collaborative Routing Centre specifications definition
ATROPINE	Austria	Research Centres, Private Partners with Government support	Design a PI model region with an open logistics system following standardized protocols
MODULUSHCA	European Union	Research Centres, Academia and Private Partners	Demonstrate (i.e., technical solution testing) the benefits of a small set of modular containers introduction in the consumer packaged goods industry
iCargo	European Union	Research Centres, Academia, Private Partners with Government Support	Development of an open ICT ecosystem to publish logistic services and compose door-to-door chains based on multiple LSPs collaboration
CO3	European Union	Research Centres, Academia, Private Partners with Government Support	Address horizontal collaboration issues like business models, legal and operational tools

Operations Management Since a PI business model has not been developed yet, consequently specific operations management models are still under study. At this point in time, several scenarios may be sketched. In the foreseeable future, individual operations management practices might continue to be implemented. Over time, an increasing level of operations coordination among the logistics community might be achieved, in compliance with the business and organisational model type adopted.

A full PI roll-out will require a significant change in current operations management practices. In particular, mechanisms to coordinate resource deployment along the shared networks and to dynamically react to network conditions should be implemented. Nowadays, it is assumed that new operations management models should satisfy two major requirements:

- *Transition from static to dynamic operations management models*: individual operational plans should be adaptable in real-time based on monitored network conditions;

- *Distributed resource deployment*: in order to build flexible and resilient PI networks, logistics resources have to be distributed in various nodes. In such a way, multiple logistics hubs would be able to satisfy customers demand by delivering freight to a common customer or by producing freight as much close as possible to the final market.

So far, scientific contributions have mostly focused on the following application fields:

- *Production management*

- *Inventory management*

- *Transportation management*

Hereafter, each application field is discussed in detail. About production, new models might exploit the following features:

- *Production plans harmonisation*: the collaborating producers should have to daily adapt their harmonised production plans in order to fill the capacity of each shared production and assembly facility;
- *Products assembly close to final markets*: in order to reduce transportation and distribution costs, modular production schemes have to be developed in order to exploit "the dynamic deployment of (containerized) production modules in open facilities across territories for enhanced flexibility and adaptability" [Marcotte and Montreuil, 2017].

A second operations management models innovation area concerns the storage process, in particular the inventory management. Current models are typically centralised storage approaches dedicated to specific customers demand. They are based on hierarchical inventory strategies where the source is assigned in advance for each shipment order. As a consequence, current distribution systems are not flexible to react at demand fluctuations. In order to avoid such inefficiency, PI networks should exploit *decentralised storage models* implying the adoption of innovative inventory management models characterised by the following peculiarities:

- *Multi-sourcing option*: every order might be satisfied by more than one sourcing point according to the real-time status of the potential sources and the selection criteria [Pan et al., 2013]. For example, the choice of the closest hub to end users would let "shortening response times and increasing service levels" [Hambleton and Mannix, 2014];
- *Inventory repositioning between hubs*: the goods owner might transfer them from one hub to another based on real-time storage levels and customers demand forecasts;

- *Dynamic changing of inventory locations according to the variation of demands from the market* [Pan et al., 2015].

Finally, the transportation management models innovation is supposed to affect two relevant areas: the *transportation services assignment to demand* and the *routing*. Several researchers contribute in the understanding of the former application area. More in detail, the best transportation service per each container route has to be identified in a context where containerized goods are supposed to be shipped from one hub to the another until the final destination. Therefore the matching between offers and demands should become more dynamic, thus requiring efficient allocation mechanisms. So far, the most efficient mechanism to allocate containers bundles to transportation services is a combinatorial auction mechanism based on mechanism design theory, as illustrated by [Othmane et al., 2014]. The system might work in such a way: "shippers post their freights to the PI interface; a π -auctioneer runs a unique combinatorial auction to procure transportation services of all shippers freights; and carriers compete to win these services by bidding prices".

About routing, currently shipment trips are entirely defined by the chosen network or operator. In such a way, in case of network difficulties it is complex to guarantee a contanier seamless and continous movement through an alternative route. To overcome such inefficiency, a more *distributed and shared architecture* offers alternatives and therefore presents greater robustness and resilience [Ballot et al., 2015]. Moreover, the general understanding converge in assuming that containers should have to automatically move along PI networks, based on their real-time status. To this aim, the Logistics Web should have to be equipped with dynamic routing tools supporting decision makers by updating regularly routes status, thus enabling a route reschedule in case of difficulties (still under study).

Technological Enablers So far, logistics systems have been designed as indipendent and individual networks. As a consequence, logistics information systems have been developed following the same approach (i.e., centralised systems). Nowadays, major companies are sufficiently powerful to adopt their proprietary systems, typically closed and ad hoc solutions with a very low level of openess to other information systems. In addition, the communication among them is often difficult due to the multiplicity of communication standards adopted by the various actors. Moreover, SMEs are not able to buy and use such expensive and complex systems, thus operating their businesses in a less efficient way. A smooth evolution from a such technological panorama is required to deploy a global logistics system based on the interconnection of a set of networks [Ballot et al., 2015]. The ALICE Consortium identifies as a first technological innovation milestone the *interoperability between networks and IT applications for logistics* [ALICE, 2014]. In other words, enhanced good management practices will have to be developed based on new IT architecture exploiting the concept of interoperability among existing proprietary systems. [Rajsiri et al., 2010] define interoperability as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged". Thus, a first step is represented by the implementation of information sharing functionalities among ERP, TMS, freight exchange platforms and so on. In perspective, probably the interconnection process might push towards the integration of such systems [Sallez et al., 2015].

The proposal of innovative IT architectures, compliant with the PI principles, represent an emerging research domain. Because PI business models are currently missing, consequently also the related IT architectures and technological enablers are still under study. Nonetheless, several researchers have contributed to the field putting in evidence the following general peculiarities of a PI IT architecture:

- *Decentralised IT architecture*: each object within the network (π -containers as core objects) acts as a Web Server equipped with data capture technologies (i.e., sensors) able to answer to requests and to interact with other objects (i.e., Internet of Things paradigm) [Whitmore et al., 2015]. Each object is marked with a unique identification code to whom an Ipv6 internet address is assigned, thus ensuring a secure information transmission through the Digital Internet. The information is interpreted, published in order to support stakeholders dynamic decision making process. The information availability should enable several types of application in cloud environments, enabling each entity to monitor and dynamically manage assets, goods and environments in real-time [Ballot et al., 2015]. In such a way, the logistics systems reliability might be increased. A decentralised information systems deployment requires the following ICT elements, many of which are already available on the market [Koubâa and Andersson, 2009]:

- Automatic Identification and Data Capturing Technologies: data collection sensors useful for π -containers traceability, electronic identification and internal/external conditions monitoring. Π -containers have been already designed and tested, typically equipped with different technologies such as:
  * RFID: currently the most suitable data acquisition means for smart π -containers;
  * EPCglobal: event information capturing technologies;
  * EPICS: generic technologies of the Internet of Things.

  Note that these technologies currently remain proprietary systems at high cost, which still limits their application to high value cargo;
- Positioning Systems: GPS;
- Communication Networks and Data Exchange technologies: Internet, cellular, satellite, wireless, radio frequency communication networks to enable real-time access to information from "anywhere";
- *ITS and C-ITS:* the former support a more efficient management of certain transportation operations (e.g., traffic management, operations

monitoring, etc.) while the latter enables vehicles to communicate and cooperate with their immediate environment (e.g., G5 V2I short-range communication);

– Cloud Computing: logistics application run on shared pool of configurable computing resources easily accessible on-demand, enabling users collaboration at reduced computing costs [Darvish et al., 2014];

In addition, the deployment of a such decentralised IT architecture requires and embedded intelligence to autonomously make decisions, such as routing a containers from origin to destination based on real-time networks conditions. Thus, advanced decision technologies might be required mostly exploiting collected data interpretation and dynamic decision making support features. So far, advanced data analytics softwares to improve the planning and operations management processes have still to be developed. In particular, *big data* applications to PI logistics environments would represent significative enablers to extract knowledge from huge data volumes within an IoT architecture. Nowadays, the topic is studied by researchers and pratictioners even if specific scientific contributions are still scarce [Zhong et al., 2014]. If the development of such decision support tools is still in infancy, so far authors mostly report about the development of *simulations technologies* applied to PI networks performance and impact assessment processes, PI networks design and what if analysis [Hakimi et al., 2012]. In recent years, *optimisation technologies* have started to be combined to simulation models, both in research and applied research projects [Fazili, 2016].

- *Open but secure IT architecture*: key PI component. The locally collected information have to be transmitted to various stakeholders through the Digital Internet. These information are useful inputs for the provision of logistics services in cloud environments. All the mentioned processes have to be protected by cyber security systems and protocols (e.g., access rights, etc.), assuring that external entities would not have unauthorised access to collaborative members sensitive data. Otherwise logistics actors would still remain reluctant to share sensitive data with others. At this point in time, appropriate data management models are still under study. Some hypotesis have already been sketched. For example, [Thompson, 2013] propose to adopt a registration mechanism based on "both capabilities in terms of value/business services and data policies of an actor" ;

- *Service Oriented Architecture (SOA)*: suitable solution to meet interoperability requirements among two or more logistics actors. With SOA, IT systems integration is based on interface softwares, called "services", easily reconfigurable and reusable in new collaborations. Nowadays, the design and adoption of methods, tools and platforms exploiting SOA seems to be one of the major strategies to introduce collaboration among business organisations. The scientific literature reports about various initiatives proposing *collaborative logistics platforms* based on SOA. Typically, researchers contributions are dedicated to provide support framework for collaborative situation by deploying agile Mediation Information Systems (MIS) among partners [Rajsiri et al., 2010]. For example, [Touzi et al., 2009] propose a "Collaborative Information System (CIS)", a special pool playing the role of a mediator among four different partners information systems with the aim to orchestrate synchronisation between different collaborative tasks of partners.

In addition to the IT architecture innovation, a PI roll-out requires also the re-engineering of π -containers, π -protocols and π -hubs. The former are currently under a prototype testing and evaluation phase while the latter have already been designed by adapting the OSI model of Digital Internet to the logistics field, thus proposing the Open Logistics Interconnection (OLI) [Montreuil, 2011]. Moreover, the scientific literature reports about 22 types of unimodal and multimodal π -hubs, even if the majority of publications focus on the bimodal rail/road facility design and performance assessment [Chargui et al., 2016].

4.4 Physical Internet Research Agenda

In Section 4.3 several research gaps emerged, thus pointing out further studies and contributions requirements. Note that research agendas on supply chain collaboration, coordination and ICT enablers have been recently proposed by the consortium "Alliance for Logistics Innovation through Collaboration in Europe (ALICE)". Hereafter, a summary of the major results is reported. The Working Group number 4, dedicated to "coordination and collaboration among stakeholders in global supply networks", has stressed out the following research and innovation challenges [ALICE, 2014]:

- *Collaborative supply chain network design*:
  - Strategic collaborative network design: requirement of coordinated network design exploiting multi-criteria and multi-stakeholder approaches;
  - Tactical planning in collaborative supply chain networks: requirement of coordinated logistics services provision enabled by new tools exploiting logistics resources utilization maximisation;
  - Operational planning in collaborative supply chain networks: requirement of new tools enabling both automated and timely synchronization and event management across multiple stakeholders and systems;
  - Risk management: requirement of both safety, security and resiliency standards for collaborative supply chains;
  - Business models: requirement of innovative business and organisational models to ensure economically sustainable provision of logistic services in open and collaborative supply networks.

- *Integration of manufacturing and logistics*:
  - Introduction of new manufacturing technologies;
  - Development of shared production/manufacturing resources models;
  - Development of logistics models for agile, modular and distributed production/manufacturing.
- *Collaboration and coordination drivers and enablers*:
  - Change management approaches;
  - Best practices diffusion;
  - Legislative actions;
  - Etc.

Moreover, the Working Group number 3, dedicated to "information systems for interconnected logistics" has pointed out the following technological gaps related to future PI networks deployments [ALICE, 2014]:

- Rapid and agile technical interconnection of supply networks;
- ICT systems, information interfaces and business models simplification;
- Device interconnections simplification and standardisation;
- Open cloud based collaboration platforms development enabling the dynamic and cost-effective management of complex systems;
- Secure and reliable data management approaches development;
- Standards and data collection systems for commercial and social reporting;
- The adoption, integration and use of smart infrastructures, ITSs, IoT devices and other intelligent edge-based technologies adoption in real logistics environments.

In addition, a roadmap to overcome the existing barriers for a PI networks implementation is presented in the work of [Ballot et al., 2015]. The major outputs are briefly listed:

- Research on PI systems components;
- Identification of current logistics systems conditions enabling a smooth transition towards more shared and interconnected PI networks;
- Conduction of sector-specific researches identifying real business constraints for a PI roll-out;
- Identification of sharing mechanisms for freight and logistics.

All the reported contributions illustrate generic fields of research and innovation which deserve to be deepened. In the present Section, the collaborative logistics requirements gaps emerged in the PI scientific literature classification process proposed in Section 4.3 are reported and briefly discussed. In order to follow the logical thread of topics covered in this manuscript, the following discussion mostly focus on logistics planning and management insights from an operations research perspective. For the sake of dissertation simplicity, the PI field of study is restricted to three networks: the realization (i.e., producers), distribution (i.e., warehouse managers) and mobility (i.e., carriers and terminal managers) ones. The contents are presented following the structure of the collaborative logistics taxonomy proposed in Section 3.1, thus figuring out research requirements per each component of innovative collaborative logistics models (i.e., decision makers, collaboration form, operations management and technological enablers).

Decision Makers

- *Who is going to push the transition from current logistics systems towards a PI open global network is still an open question*: logistics legislators are expected to guide the process by promoting regulations and policies in favour of a PI roll-out. However, how they will act is not known so far. Several scenarios seem to be assumed:

  – Strict regulation imposing collaboration to logistics actors: a collaborative logistics business model is imposed by public authorities to various stakeholders which, consequently, are obliged to implement it in order to operate on the market. For example, regional and local governments might impose the freight village as a reference model for future reorganisations;
  – Public incentives/subsidies to encourage collaborative logistics initiatives: logistics actors operating in collaboration with other entities might be supported with founding, permissions, licenses or other support instruments. In such a way, these operators are both stimulated to collaborate and privileged over competitors because of their reputation.

- *LSPs role definition*: since the collaborative environment complexity is expected to increase, 4PL or 5PL are expected to play a central role. They probably will ensure several system functionalities such as the neutrality of the benefit allocation mechanisms in a local open network of shared networks. Speaking about a global open system, multiple 4PL or 5PL might collaborate in order to ensure door-to-door logistics services to final customers all around the world.

Collaboration Form Section 4.3 has evidenced a PI business models lack in the literature which have to be addressed by future researches. Potential scenarios in terms of collaborative logistics approaches are proposed in the followings:

- *Joint decision-making in PI networks: harmonised or integrated planning process*? So far, it seems reasonable to think about a progressive evolution from harmonised to integrated plans, thus inducing also a logistics network performance enhancement over time. In the next years, probably producers would exchange their production orders with carriers in order to schedule pickup operations (i.e., realisation and mobility webs harmonised planning). In the mean time, carriers would share their schedules with distributors in order to book storage spaces in logistics facilities for delivery operations (i.e., mobility and distribution webs harmonised planning). In such a context, the logistics performance optimisation might be improved even if, from an operations research point of view, an integrated planning process would more easily lead to find the best optimal solution. For this reason, in the future a transition towards integrated planning models might occur, probably enabled by innovative ICT platforms development enabling joint decision making processes.

- *Planning and operations coordination in PI networks*: differently in respect to CL, the scientific literature on PI is lacking of contributions concerning the full logistics web planning. So far, the work of [Sohrabi and Montreuil, 2014] has significantly contributed to the field by proposing an open distribution web planning framework. Hereafter, the mentioned work is extended to a wider application area represented by three networks: realisation, mobility and distribution.

  At strategic level, planning a such interconnected network might concern the following aspects:

  - *Network design*: identify an optimal logistics system configuration compliant with the PI vision of a smooth transition from networks characterised by specific services to a network of open and shared networks. Three major process steps:

    * Supply modelling: modelling the network of shared infrastructures (e.g., production plants, warehouses, terminals, etc.) and the net-

work of shared logistics services;

    * Demand modelling: identify customers shipment requirements in terms of origin-destination nodes, type of product flows, mode choices, etc.;
    * Assignment modelling: multi-commodity flows assignment to the designed logistics web (i.e., matching customers demand with available logistics services).

  – *Cost-benefit analysis*: to identify the optimal system configuration and to forecast its potential evolutions;
  – *Revenue management*: to identify an optimal income sharing mechanisms for the jointly provided logistics services.

At tactical level, planning might concern the *service network design*. Since the PI vision exploits a consolidation-based transportation systems in which the shipment moves among a combination of logistics services provided by different actors. Each actor might maintain its service network design and would harmonise it with the other ones. The output of a such process might be a *hierarchy of preferred paths*: a sort of operations guideline whose content might be a ranking of preferred paths for each pair of origin-destination nodes in the PI network. In such a way, the shared networks resilience would be ensured by offering alternative suboptimal routes to be pursued in case of problems along the shared networks. The approach is similar to the Digital Internet hierarchy of routes. How to realise it in concrete is under study. For example, the PI scientific literature does not take into account how carriers would provide shared transportation services. More in detail, how on-demand and regular scheduled services operated by various carriers types might be synchronised to provide a shared transportation service? Is the ideal mobility web a full on-demand transportation system in order to ensure high flexibility and reduce synchronisation issues? It could be assumed that shared transportation services might result as a combination of synchronised shuttle services operated by trucks in regional areas. In such a way, a mobility web realisation might imply a transition from door-to-door or hub-and-spoke transport to distributed multimodal transport (Figure 4.1).

Figure 4.1: Simulation of a trailer transport journey Québec City (Canada) to Los Angeles (USA).

At operational level, planning PI networks might concern the *resource deployment*, the drivers and logistics facilities personnel work scheduling. For example, in a mobility web this would concern vehicles and drivers assignment to certain shared networks nodes, based on demand forecasts and customers orders sharing among shippers and consignees. Moreover, the real-time system control implies a *dynamic vehicles routing and terminal schedules adaptations* based on the network conditions. In particular, a transportation service will follow the operational routing guidelines set at tactical planning level per each origin-destination set, thus selecting the proposed hierarchy of paths based on the real-time network conditions (e.g., an accident in the first ranked route).

- *Collaboration forms in PI networks*: since a joint planning process is assumed to be an important element of future collaborative logistics models, the identification of appropriate collaboration forms is on-going. Currently, no studies contribute on this topic. Hereafter, several scenarios for interconnected realisation, mobility and distribution webs are sketched.

- *Informational planning*: producers might share production plans on an yearly basis in order to optimise the production capacity utilisation within shared plants. Production schedules are also shared with carriers, in order to let them assign optimally their fleets based on the shipment demand. In order to optimise the vehicles capacity utilisation, transportation orders information are exchanged among carriers with the aim to pool freight. Finally, transportation schedules are forwarded to distributors in order to let them organise handling, sorting, consolidation and storage processes. The information sharing occurs through an ICT collaborative ecosystem in which information are made visible to all the interested stakeholders;
- *Coordinated planning*: scenario in which the collaborating partners jointly decide to commit on certain or all their activities. Producers, carriers and distributors might exchange sensible information via a LSP in charge to coordinate operations in a certain local or regional area. In such a way, the coordinator might harmonise production, transportation and distribution processes of the reference area. Moreover, the LSP might become an interface with other regional shared networks, thus enabling the provision of interregional logistics services.

Operations Management The scientific literature classification process has evidenced several lacking research contributions, listed in the following lines:

- *Operational processes have still to be invented*: since the PI is a decentralised system operated by independent entities, mechanisms to coordinate activities are required. How producers, carriers and distributors would be able to optimise their respective operations providing, at the same time, a standardised service? How resource deployment would adapt to real-time network conditions? Currently, in order to answer to all these kind of questions, researchers are working on the development of the so called π -protocols. They have been sketched taking the Digital Internet OSI model as a reference even if real implementations are not available yet;

- *PI potential impacts on the bullwhip effect*: probably the decentralised structure of the logistics web might lead to significant bullwhip effect reductions. The network of networks performance might be studied comparing various simulation results exploiting different inventory management policies, eventually also "combining the existing ones for hubs and retailers" [Pan et al., 2015];

- *Transportation management policies to be identified*: so far, the majority of researchers have considered the auction mechanism as potential transportation services assignment policies in PI networks. This hypothesis still requires further insights: for example, the currently used auction mechanisms might enhanced by adding other decisional variables, such as the carriers reputation [Othmane et al., 2014], or by considering different assignment policies.

Technological Enablers The scientific literature classification process has evidenced several lacking research contributions, concerning first the PI key components (i.e., π -containers, π -hubs, π -protocols) and, secondly, ICT and decision technologies enablers. About the former, further scientific contributions are needed in the following areas:

- *Technological enablers for PI business models*: the current PI business models absence implies a lack of knowledge in terms of ICT and decision technologies required to deploy them. Further research is needed to identify the appropriate PI business models, thus consequently bringing to further studies concerning appropriate IT architectures, hardware, software etc.;

- π *-containers engineering*: so far modular containers have been sketched (e.g., optimal number, dimensions, equipment, etc.) and they are currently under a test phase. However, these advancements typically concern the mass distribution sector and thus consumable goods. What about other types of goods? Would modular containers assume the role of unique intermodal transportation units, thus being used to transport all types of goods (e.g., liquids, corn seeds, hazmat, machineries, etc.)? If we look at current logistics and transportation systems, each goods category is stored, transported and handled in specific solutions based on the physical, chemical, etc. features. Therefore, the modular containers adoption might be extended to other product categories. Moreover, per each of them, studies are needed to understand technical requirements in terms of π -containers engineering;

- π *-hubs cost-benefit analysis*: in the PI, π -hubs receive the freight and route it towards the next hub in order to reach the final shipment destination. Several functionalities might be exploited, such as sorting and consolidation, cross-docking, stocks inventory, etc. In order to configure a such system, probably high investments in new or converted/adapted facilities might be required, thus leading to financial and economic issues. For example, the realisation of the so called PI rail-road hubs, how much might it cost? Who would face such investments? How long does it take to reach the investment break-even point?

- π *-protocols implementation and test*: so far scientific contributions have proposed a set of protocols, called the OLI model, taking inspiration by the OSI model used in the Digital Internet. Nowadays, ICT and decision technologies enabling the implementation of the OLI model in real logistics environments are still under study. In a second step, tests in real environments for validation would be required.

While, for ICT and decision technologies:

- *SOA for logistics IT networks engineering*: nowadays, several researches and European projects have faced the challenge related on how to build a SOA enabling the provision of digital logistics services to various types of actors. Typically, these studies and initiatives have considered a restrict number of system users, thus focusing on certain aspects of the logistics processes. Therefore, in order to increase the existing knowledge, future research and innovation activities might focus on new logistics services provision, based on the system users needs. To this aim, the range of covered business, logistics processes etc. would have to be extended to a wider range of user stories, user requirements and specifications;

- *Decision technologies innovation*: if the required ICT enabling IoT-based logistics networks are mostly already available on the market, the same cannot be said for decision technologies. More in detail, the most relevant research and innovation fields concern:

  - Support and planning systems for PI networks design, service network design and execution;
  - Data analytics systems able to extract valuable business information from historical data, thus leading to a logistics networks performance enhancement;
  - Big data systems able to manage huge unstructured data volumes with low processing times

By concluding, a PI roll-out would required high levels of automation (e.g., handling operations) and dematerialisation (e.g., paperless procedures).

4.5 Concluding Remarks

In recent years, the scientific community has evidenced two most promising logistics paradigms targeting respectively urban environments, the CL, and global supply chain networks, the PI. These theoretical frameworks promote the transition from current individual logistics networks to interconnected logistics systems sharing individual networks with the aim to reduce current economic, social and environmental inefficiencies.

In this context, the present Chapter, firstly, contributes to the field by reporting a scientific literature classification of CL and PI collaborative logistics requirements. The second part of the Chapter specifically focuses on the PI paradigm with the aim to emphasize current research and innovation gaps. Hereafter, Table 4.6 summarises the major results related to the CL while Table 4.7 overviews the major insights concerning the PI.

Table 4.6: The City Logistics collaborative logistics requirements.

General	
Research field status	Emerging research area
Most studied applications	Urban delivery processes
Collaboration dimension	Depending on the business model, it should vary from no collaboration to interconnected collaborative logistics domain
Decision makers	
Type of logistics actors	• Logistics service legislators: Public Authorities, municipalities, etc. • Logistics service providers: carriers, terminal managers, etc. • Logistics service users: shippers, consignees, end customers, etc. Trend: moving from public to public-private or private initiatives
Type of collaborative network	1-tier network (CDC) or two-tier networks (CDC and satellites)
General objectives	• Reduction of the dimension and number of commercial vehicles operating within the urban context • Reduction of the number of empty vehicle-kilometres • Improvement of freight movements efficiency

Collaboration forms	
Type of collaboration form	• Integrated planning process in the CL theoretical framework • Real CL implementations range from informational to coordinated planning
Commitment	• Shared vehicle fleets • Transportation orders pooling • Shared logistics facilities (e.g., CDCs)
Type of information shared	• Transportation orders • Delivery schedules • Inventory stocks data • Traffic data
Operations management	
Collaboration members	Operations coordination depending on the implemented organisational and business model
Outsourcing	Monaco business model (urban deliveries as a public service - task outsourced to a public operator and consequently moved to a private one)
Technological enablers	
ICT	Communication networks and data exchange technologies: • EDI, internet networks, e-marketplaces • Satellite and wireless networks Intelligent Transportation Systems (ITS): • Advanced Traffic Management Systems • Advanced Traveller Information Systems • Automatic Vehicle Identification systems • Advanced Fleet Management Systems • E-payment systems Sensing technologies: V2I bi-directional communication
Decision technologies	DSSs embedding OR, simulation, statistics, econometrics methodologies to design, plan, manage and control CL systems
Supported functionalities	• Freight flows consolidation within the same delivery vehicles • Logistics and transportation tasks coordination • Separation of commercial transaction generating transportation demand and the actual transportation and logistics activities
Future research areas	
Collaboration forms	• In depth analysis of the CL collaboration requirements • Decision-making integration/coordination process related contributions
Technological enablers	Missing research on advanced ICT and decision tools to plan, manage, monitor, control and evaluate such integrated systems
Other logistics processes	Missing contributions about outbound logistics flows
Emerging scopes	• Green vehicle fleets for urban freight delivery • Integration of passenger transportation infrastructure and urban freight delivery
New Emerging Paradigms	Interconnected PI and CL theoretical frameworks

Table 4.7: The Physical Internet collaborative logistics requirements.

General	
Research field status	Emerging research area
Most studied applications	• PI concept description • PI key components (i.e., π -containers, π -protocols, π -hubs) design • PI networks impact and performance assessment • Logistics management models proposition Very few studies on PI business models proposition
Collaboration dimension	Depending on the business model, a logistics actor might simultaneously implement various collaboration types: • Mono-dimensional • Bi-dimensional • Multi-dimensional
Decision makers	
Type of logistics actors	• Logistics service legislators: international and national governments, etc. • Logistics service providers: carriers, terminal managers, etc. • Logistics service users: shippers, consignees, B2B and B2C end customers • Research centres and academia
Type of collaborative network	Open global network of shared individual supply chain networks
General objectives	Reduction of current logistics and transportation systems economic, societal and environmental inefficiencies
Collaboration forms	
Type of collaboration form	Because business models are not already defined, various assumptions maybe sketched: • Requirement of stakeholders plans harmonisation and operations coordination • Requirement of innovative business models belonging to the collaborative logistics domain • Transition from centralised collaborative decision-making approaches to decentralised/distributed ones • Start at regional level and over time move towards a global logistics web So far, concrete collaborative logistics initiatives have assumed the form of projects aiming at: • Establishing and validating the issues • Performing trials and remove obstacles
Commitment	Shared individual supply chain networks
Type of information shared	• Shipment orders • Production and transportation schedules • Real-time network conditions • Real-time π -containers data • Real-time inventory stocks data • Etc.

Operations management	
Collaboration members	Because business models are not already defined, various general assumptions maybe sketched: • Individual operations management should continue in the near future • Over time, transition from static to dynamic models • Over time, transition from centralised to distributed resource deployment Innovation requirements in production management: • Production plans harmonisation • Product assembly close to final markets Innovation requirements in inventory management: • Multisourcing • Inventory repositioning among hubs • Dynamic change of inventory locations according to demand variations Innovation requirements in transportation management: • Transportation services assignment to demand • Collaborative dynamic routing
Outsourcing	Because business models are not already defined, various general assumptions maybe sketched: • 4PLs/5PLs might assume the role of regional coordinators in charge to harmonise plans and to ensure operations execution • 4PLs/5PLs might assume the role of regional interfaces with the other regional networks of shared networks
Technological enablers	
PI IT architectures	Because business models are not already defined, various assumptions maybe sketched: • General requirement: interoperability between networks and IT applications in logistics • Near future, implementation of information sharing features among proprietary systems • Over time, shared IT architectures Main peculiarities: • Decentralised IT architectures • Open but secure IT architectures • Service Oriented Architectures (SOA)
ICT	Communication networks and data exchange technologies: • EDI, internet networks, e-marketplaces • Cellular, satellite, wireless, radio networks Advanced identification and data capture technologies: RFID, EPCglobal, EPICS, etc. Intelligent Transportation Systems (ITS) and Cooperative ITS (C-ITS) Sensing technologies: V2I bi-directional communication Cloud computing Positioning systems: GPS, etc.

Decision technologies	• DSSs embedding OR, simulation, statistics, econometrics methodologies to design, plan, manage and control CL systems • Data analytics software • Big data applications
Supported functionalities	• Freight flows consolidation within the same delivery vehicles • Logistics and transportation tasks coordination • Separation of commercial transaction generating transportation demand and the actual transportation and logistics activities
Future research areas	
Decision makers	• Who is going to push the transition from current logistics systems towards a PI open global network is still an open question • The hypothesis of 4PLs/5PLs as regional coordinators has to be validated by the business environments
Collaboration forms	• Studies concerning the joint decision making process in PI networks: harmonisation or integration • PI planning and operations coordination frameworks design • Collaboration forms identification
Operations management	• Operational processes have still to be invented • Studies concerning the PI potential effect on the bullwhip effect • Transportation management policies to be identified
Technological enablers	Missing research and innovation on advanced ICT and decision tools to plan, manage, monitor, control and evaluate such interconnected systems • π -containers engineering • π -hubs cost-benefit analysis • π -protocols implementation and test • SOA for logistics IT networks engineering • Automation in logistics processes • Dematerialisation in logistics processes
New Emerging Paradigms	Interconnected PI and CL theoretical frameworks

Chapter 5

Cloud-based Collaborative Logistics Platforms for the Trieste Intermodal Transportation Network

This Chapter presents the ICT and decision technologies research and innovation activities conducted within the 7th Framework Program EU project CO-GISTICS. The CO-GISTICS vision aims to enhance the continental logistics systems performance through the deployment of 5 C-ITS services in 7 pilot sites: one of them is represented by the Trieste intermodal network. The project is currently on-going and so far has led to develop an open cloud based platform, a Decision Support System (DSS), enabling information sharing and joint decision making among the local stakeholders. Such initiative is propedeutics to the realisation of a second H2020 EU project called AEOLIX aiming at establishing a pan-European collaborative ecosystem for information sharing among continental logistics actors. Both the initiatives represent concrete contributions aiming at fulfilling attempts to support a transition towards interconnected logistics networks.

5.1 The European Freight Transportation Sector

The transportation sector has relevant impacts on economic and social aspects of the European society. In 2014, transportation contributed for about 5.1% of the total EU-28 gross value added (GVA) and employed 5.1% of the total workforce. Congestion costs represented the 1% of the European gross domestic product (GDP). On the other hand, transport activities were responsible of the 33.3% of EU energy consumption. Moreover, the sector impacted for about the 27.12% on total greehouse gases emissions, thus representing the second biggest source after energy [The European Commission, 2015]. Freight transportation activities have amounted to 3,524 billion ton-kilometres, of which the 49% was performed by road transport [The European Union, 2016]. These trends are in contrast with the European 2020 strategy key objectives, defined in a reduction of the 20% of EU greenhouse gas emissions from 1990 levels and in a 20% improvement in the continetal energy efficiency [The European Commission, 2011].

In order to target these goals, road freight transport must be optimized, acting on fleet management, transport planning and introducing technology in daily operations. About the latter, one of the most promising solutions is represented by the development and deployment of Cooperative Intelligent Transport Services (C-ITS). A cooperative service is based on the interchange of information between the vehicles and the infrastructure (V2I and I2V) and between vehicles (V2V), aiming at using this information for improving the performance of the transport of both passengers and freight.

In recent years, the European Commission has financed both several research and innovation and implementation projects concerning C-ITS applied to freight transport. In this Chapter, the 7$^{\text{th}}$ Framework Programme EU project "COoperative loGISTICS for sustainable mobility of goods (CO-GISTICS)" is briefly illustrated. Such initiative currently represent a concrete implementation action supporting a smooth transition towards interconnected logistics networks at continental level [ALICE, 2014].

5.2 The FP7 th EU Project CO-GISTICS

The 7th Framework Programme EU project "COoperative loGISTICS for sustainable mobility of goods (CO-GISTICS)" is the first initiative fully dedicated to deploy cooperative intelligent transport systems (C-ITS) for logistics. The vision is to integrate and deploy cloud services enhancing supply chains efficiency through the convergence of machine-to-machine (M2M) and cooperative technologies, as shown in Figure 5.1.

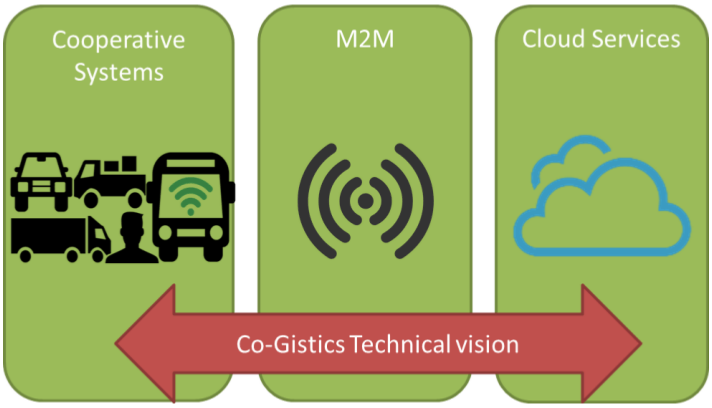

Figure 5.1: Cooperative logistics in CO-GISTICS.

The CO-GISTICS services are presented in Figure 5.2. A synthetic description per each services is also reported, thus providing information about the general and specific service objectives, the key users and the cities where services are deployed. In particular, seven European logistics hubs have been selected to install and operate the CO-GISTICS services: Arad (Romania), Bordeaux (France), Bilbao (Spain), Frankfurt (Germany), Thessaloniki (Greece), Trieste (Italy) and Vigo (Spain).

- *Intelligent truck parking and delivery areas management (ITP)*: the general aim is to optimise traffic activities along vehicles journeys by reducing stops.

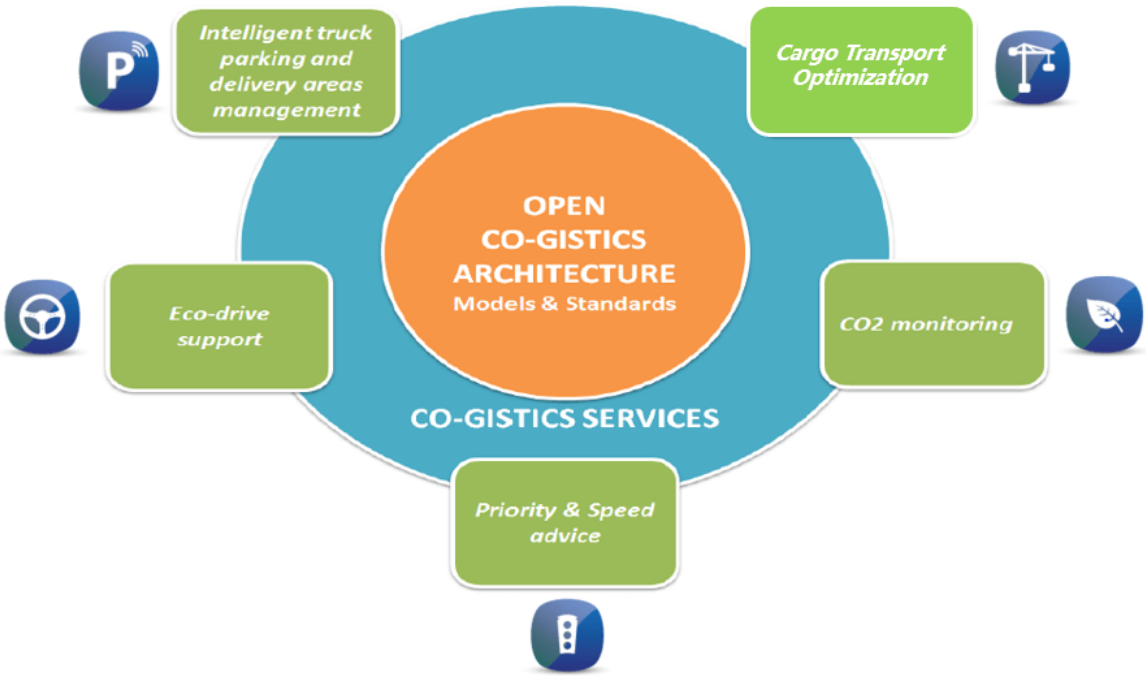

Figure 5.2: CO-GISTICS services.

More in specific, the service supports truck parking operations by providing real-time information on parking spots availability. The key users are truck drivers, fleet operators, terminal operators operating in the Arad, Bilbao, Frankfurt and Vigo pilot sites;

- *Cargo transport optimisation (CTO)*: the general aim is to optimise and increase cargo transport operations efficiency. In specific, the service supports planning and synchronisation between different logistics operations. Moreover, it provides real-time information on delivery operations. The key users are truck drivers, fleet operators, service providers, local authorities operating in the pilot sites of Bordeaux, Thessaloniki and Trieste;

- *Priority and speed advice (PSA)*: the general aim is to use C-ITS at intersections, thus enabling an on-board vehicle speed alert finalised to reduce the number of stops and accelerations. Specific objectives are:

  - Fuel consumption, emissions and heavy vehicles presence in urban areas reduction;
  - Drivers support with speed information;
  - Drivers support with time to green/time to red traffic lights information;
  - Trucks stops and accelerations reduction;
  - Cargo transport efficiency enhancement;

  Key users are truck drivers, fleet operators, infrastructure operators, public authorities operating in the Arad, Bordeaux, Thessaloniki, Trieste and Vigo pilot sites.

- *CO_2 footprint estimation and monitoring (CFEM)*: the general vision is to use GPS data or CANBUS related data to measure the fuel consumption. The specific objective consists in the development and application of standardised approaches to estimate and measure CO_2 emissions related to freight transportation activities. Key users are truck drivers and fleet operators operating in the Arad, Bilbao, Frankfurt Thessaloniki, Trieste and Vigo pilot sites.
- *Eco-Drive Support (EDS)*: the general aim is to reduce fuel consumption and CO_2 emissions through the adoption of low carbon mobility applications for mobile devices. Key users are truck drivers and fleet operators operating in the pilot sites of Arad, Bilbao, Frankfurt Thessaloniki, Trieste and Vigo.

The CO-GISTICS consortium is composed by 33 heterogeneous entities (i.e., local authorities, logistics and freight organisations, large private companies and SMEs). The project started in January 2014 and is ending in June 2017.

5.2.1 The Trieste Pilot Site

Trieste is a cosmopolitan city, the capital of the autonomous region Friuli-Venezia Giulia. The city is part of the TEN-T Mediterranean Corridor linking the Iberian

Peninsula with the Hungarian-Ukrainian border with the aim to establish closer transport connections between Western and Eastern Europe. The Trieste Port is a free port, considered as an international hub for overland and sea trade with the dynamic market of Central and Eastern Europe. The port area of about 2.3 million sq.m of which about 1.8 million sq.m of free zones. This particular status gives competitive advantages in the international trade context, mainly related to customs duty exemptions in the different phases of load/unload, storage, freight processing.

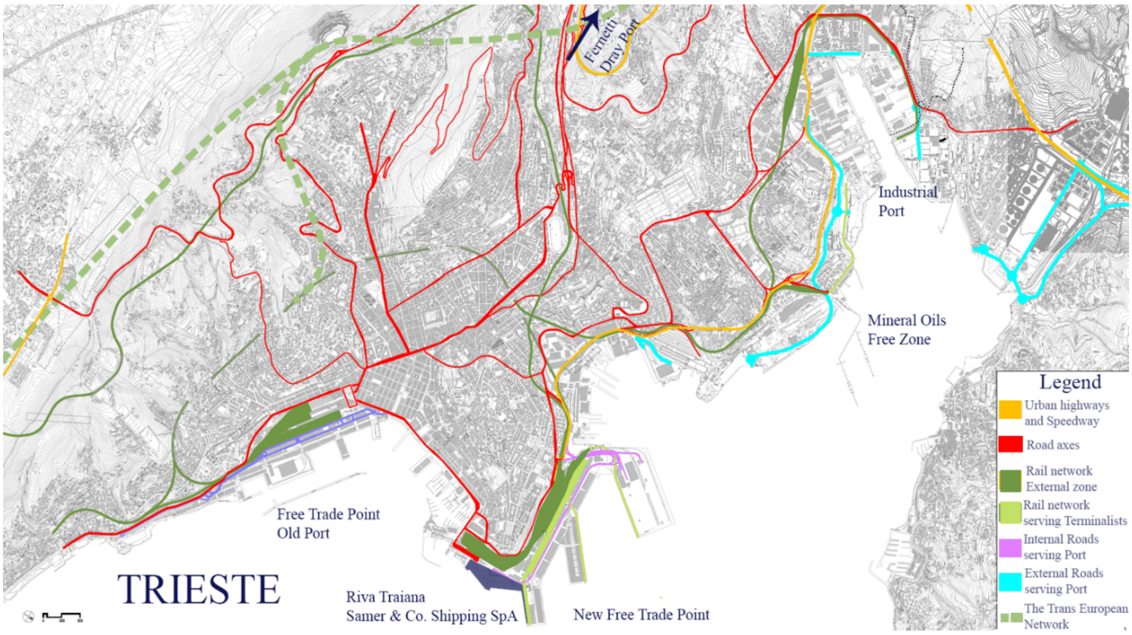

Figure 5.3: The Trieste Port area.

As Figure 5.3 shows, the Trieste port is located in an urban environment, without sufficient possibility of development in the neighbouring areas. This situation, added to the increase of trade traffics, has led to the realization of the Interporto di Trieste inland terminal 18 kilometres outside the urban context. This logistics infrastructure consists of 30.000 m^2 of warehousing and 130.000 m^2 of open space for parking/customs bond/storage yards and is directly connected to the railway station of Villa Opicina, authorized for inter-container traffic; the motorway to Venice (route to Italy - Switzerland - France - Spain); Tarvisio (route to Austria - Germany) and Ljubljana (route to Slovenia - Central Southern Europe). Figure 5.4 shows illustrates the Interporto di Trieste inland terminal area.

Figure 5.4: Interporto di Trieste inland terminal area.

Finally, the Trieste pilot site area encompasses the A4 Torino-Trieste motorway network up to the city of Portogruaro, on the east side, while up to the city of Tarvisio on the north side. Figure 5.5 overviews the Trieste pilot site area.

In CO-GISTICS, the Trieste pilot site implements all the proposed cooperative services in order to support the daily operations of the inland terminal managing organisation, the Interporto di Trieste S.p.A., the RO-RO terminal operator Samer&Co. Shipping Ltd. and, finally, the local fleet operator Autamarocchi S.p.A. The implementation of the CO-GISTICS services is based on the following *user stories and requirements*:

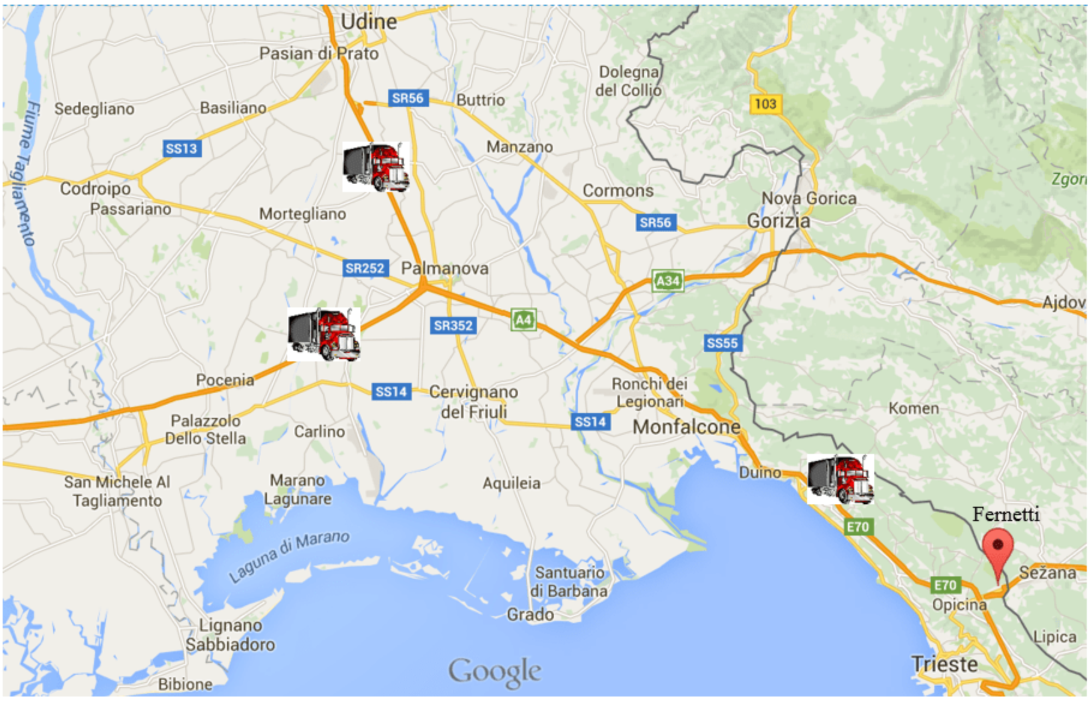

Figure 5.5: The Trieste pilot site area.

5.2.1.1 The Trieste intelligent truck parking service

The Interporto di Trieste inland terminal manager has recently installed a new access control system, which has introduced automatic truck license plate detections at entrance/exit gates. The current payment procedure is still manual, imposing queues at payment cashes. To avoid a such drawback, a new electronic payment system is integrated with the new access control system. The idea is to consider CO-GISTICS as an opportunity to implement and test new ICT solutions used in the field of electronic parking payment. In particular, the parking management platform myCicero, supplied by the technology provider Pluservice S.r.l. is considered.

5.2.1.2 The Trieste cargo transport optimisation service

The local RO-RO terminal operator, the Samer&Co. Shipping Ltd., coordinates the trade flows between continental Europe and the Turkey passing through the

Trieste port area. Nowadays, the company has to mandatory direct trucks through Interporto di Trieste inland terminal before accepting them in the Trieste port. This calling policy often generates queues at port gates, congestion in the urban highway and loss of terminal efficiency. The operator requires to manage differently the aforementioned vehicle flows directed to the Trieste port. A general understanding between the terminal operator and the local Port Authority suggests to establish a cooperation with the motorway manager Autovie Venete S.p.A. in order to detect truck license plates along the motorway. This is expected to support data collection related to vehicles identification and position in advance in respect to their arrival. These information, matched with the data concerning congestion at port gates, congestion in the RO-RO terminal, ship status and weather conditions should be used to identify a priori the optimal route to follow (i.e., through the inland terminal or directly to the Trieste port). The new procedure is supposed to reduce congestion at port gates, thus optimizing the intermodal transportation activities related to road and sea transportation modes.

5.2.1.3 The Trieste speed advice service

Local fleet operators involved in the trade traffics between the continental Europe and the Turkey are interested to test new ICT and decision support solutions able to reduce the impact of fuel usage on the transportation costs (whole trip). Currently, the speed profiles static and dynamic (real-time) management represents a promising solution they desire to test in experimental initiatives.

5.2.1.4 The Trieste eco-drive and CO_2 estimation and monitoring services

In a fragmented market, Italian road fleet operators are pushed as to reduce operational costs as to supply added-value services to their customers. In such a context, the Autamarocchi S.p.A. is interested to test and adopt new ICT and decision technologies enabling a fuel consumption and air pollutants emissions reduction.

5.2.2 A DSS Approach

To cope with the aforementioned user stories and requirements, Decision Makers (DMs) need the capability and flexibility to incorporate, as fast as possible, technological advances enabling information sharing and joint decision-making processes. The efficacy of the decisions depends on the quality of the available information, the number of options, and the appropriateness of the modeling effort available at the time of the decision. Although personal qualifications remain valuable, the increasing complexity of modern business environment imposes the use of advanced decision technologies. The possibility to bring together the personal experience and the huge amount of available data is offered by Decision Support Systems (DSSs). A DSS can be defined as an interactive computer based system, which helps DMs to utilize data and models to solve unstructured problems. In a general way, [Turban et al., 2011] considers a DSS as an umbrella term to describe any computerized system that supports decision making needs. A DSS is based on management science, operational research, control theory and behavioural science with the means of computer, simulation and information technology [Xie and Rui, 2010]. DSSs are widely used in different environments such as healthcare applications, where they are employed for medical diagnosis [Van Calster et al., 2008], or for health calculators on topics such as stress, nutrition, and fitness [Power, 2000]. The DSSs are also key enablers of logistics decision-making at strategical, tactical and operational levels [Vasilakos et al., 2012].

In recent years, several studies focus on DSS applications in intermodal transportation systems (i.e., people or freight transportation from an origin to a destination by sequence of at least two transportation modes). The fundamental idea is to consolidate loads for efficient long-haul transportation in the same loading unit or vehicle [Bektas and Crainic, 2007]. Intermodal logistics actors require decision-making support tools able to increase the coordination of intermodal operations [Caris et al., 2013]. A state of the art analysis evidences DSS developments for both static [Macharis et al., 2011], [Kengpol et al., 2012], [Shen et al., 2009] and dynamic environments [Dullaert et al., 2009], [Boschian et al., 2011].

Nenetheless the scientific literature proposes a lot of DSSs in the logistics field, the vast majority of them refers to a standalone company and decisions concern the task of only one actor. In particular, [Dotoli et al.,] proposes a model to optimize the freight trains composition, maximizing the company profit, while respecting physical and economic constraints. In this case there is only one company and any shared information. Moreover, in [Wang, 2009] the authors propose an XML solution aiming to transfer and exchanged data between the DSS, the ERP and the users: all these systems belong to the same company. In [Turki and Mounir, 2014] the authors prose a web-based DSS as hybrid system that is driven by acommunication base, a database and a knowledge base: it focuses only on a single operation of the reverse logistics process. In addition, in [Costanzo and Faro, 2012] a DSS able to access and use different information sources is presented, but the decisions involve only a single user.

The literature review points out a lack of contributions about the specifications of DSS for intermodal logistic systems related to different actors and users committed to pursue common and shared objectives. To fill this research gap, a cloud based cooperative DSS aiming at integrating logistics management and decision support for intermodal transportation systems is specified. More precisely, the proposed DSS is devoted to manage logistics networks in order to synchronise different transportation means by using modern ICT tools and taking into account environmental objectives. The novelties of the DSS are twofold:

- The cooperative approach among different stakeholders enables to share decisions, information and both historical and real-time data provided by sensors and ICT tools;

- The DSS cloud and web-service based architecture is easy to manage and update, able to provide flexibility in information exchange operations among the cooperative partners.

The two aspects are linked since the DSS architecture enables cooperation among the stakeholders that share information and data. Indeed, the proposed DSS approach is based on the individual users stories and requirements, common objectives moreover it takes into account the global logistics system performance. In this context, the DSS acts as an independent entity that collects information and suggests advices to the logistics operators, in order to improve the global performances, thus improving the specific objectives of the involved logistics agents. Sharing stakeholders information allows introducing coordination in tactical and operational planning of intermodal logistics tasks and represents the basis for the cooperative intermodal network performance evaluation.

The adopted cloud-based architecture simplifies DSS interoperability with existing ICT infrastructures already deployed by the involved organisations, reducing business risk and maintenance costs [Zhang et al., 2010]. The choice of cloud-based solutions for DSSs is widely discussed in the related literature [Demirkan and Delen, 2013] and in particular for logistics systems [Matkovic et al.,]. Furthermore, web service interfaces are used for platform independent data exchange, simplifying the integration with legacy systems [Wang et al., 2004]. However, also in all of these contributions the DSS decisions involve only a single DM [Miah and Ahamed, 2011], [Moulik et al., 2015].

The architecture and the structure of the proposed DSS are specified in order to realize the modules supporting DMs in three *decisional fields*, corresponding to the CO-GISTICS *cargo transport optimisation, intelligent truck parking and* CO_2 *estimation and monitoring services.*

Moreover, the four main phases that have to be followed in order to specify and realize the logistics decision modules and a general methodology for the user requirements collection and evaluation framework design are presented. The proposed management strategies for the cargo transport optimisation and the intelligent truck parking decision fields are described by the Unified Modelling Language (UML) [Miles and Hamilton, 2006] and are assessed by evaluating the system performances measures on the basis of discrete event simulation.

5.2.2.1 The DSS Structure and decision fields

This section introduces the structure of the cloud-based cooperative DSS for intermodal transportation system management. Figure 5.6 reports the functional scheme and the interaction of the DSS that receives data from the real system, elaborates them and suggests decisions to the DMs about the considered decision fields. In particular, the DSS works by exploiting the historical and real-time information from different sources: infrastructures, market places, emergency centres and operation control centres.

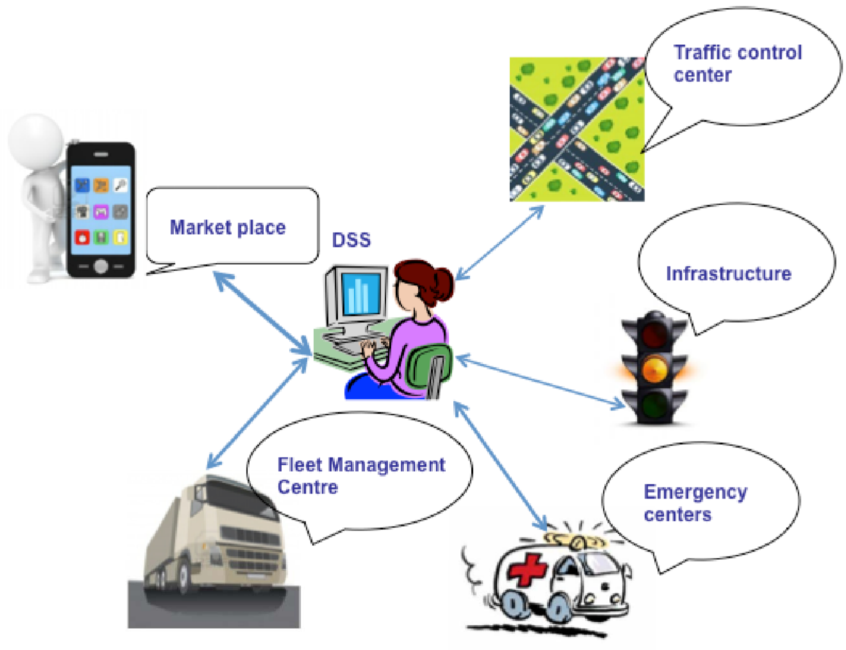

Figure 5.6: The DSS functional scheme.

A typical intermodal transportation system is characterized by the use of different transportation modes carrying goods in the same loading unit or vehicle. It involves three main logistics activities:

- *Transport* that consists on the journey legs between intermodal nodes;
- *Parking* that represents a waiting action before the loading/unloading operations;
- *Loading/unloading* that are activities for changing transportation modes.

In an intermodal transportation system different heterogeneous actors interact, for instance highway managers, carriers, parking and terminal operators. Figure 5.7 sketches the main activities of an intermodal transportation between road and sea and highlights the involved main stakeholder for each phase.

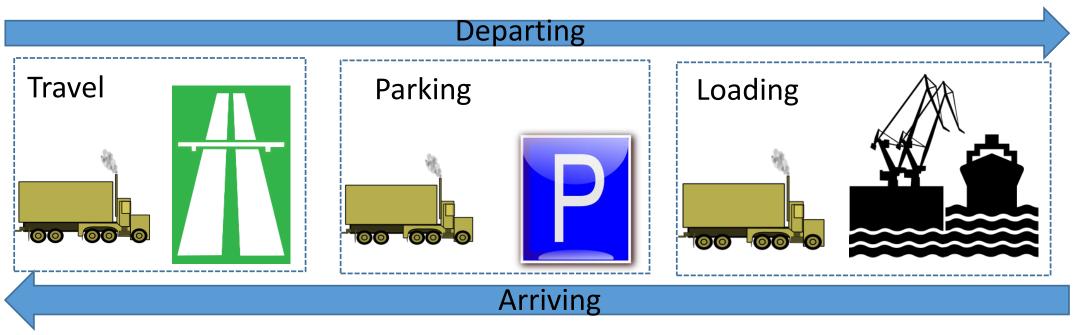

Figure 5.7: Main activities of an intermodal transportation system.

In particular, the transport activity involves drivers, carriers, shippers and motorway infrastructure managers; the parking involves drivers, carriers and parking operators; finally the loading/unloading involves drivers, parking and terminal operators. The DSS allows all the involved actors to share information and decisions: each stakeholder decides and guides the behaviour of the other actors. For instance, if the terminal operator cannot board a booked truck, it can redirect the truck to another long term parking area even if carrier and terminal operator are different companies. Moreover, the truck position is available to the terminal operator so that it can estimate if the truck will be in time for boarding. In case of delay, the terminal operator can automatically move the truck on the next ship before the arrival of the truck. All these decisions are allowed thanks to a deep cooperation of the involved actors: they do not only share information but each actor can affect the decisions of other actors. On the other hand, the DSSs presented in the related literature typically support decisions of only one company on the basis of different information sources.

The architecture and structure of the DSS are specified in order to realize the modules supporting DMs in an intermodal transportation system including port, inland terminals and roads. In this context, three main decision fields are considered:

- *Cargo transport optimization*: the planning and synchronization of different transportation modes involve carriers, drivers, terminal and vessel operators that have the common objectives of bringing the trucks to the port in time to be embarked. The DSS acquires real-time traffic information and truck location from the infrastructure operators and evaluates the possibility that the truck is in time to embark, according to the vessel time table. On this basis, the DSS provides suggestions to drivers and terminal operators about the embarking procedures;

- *Intelligent Truck Parking (ITP)*: on the basis of the estimated truck arrival, embarking times, vessel position in the maritime terminal, the DSS provides suggestions to drivers and parking operators about the optimal parking resource allocation. This allows parking operators, carriers and drivers to achieve an efficient use of available spaces and reduce the embarking operation times

- *CO_2 Footprint Monitoring (CO2M)*: the CO_2 output of the vehicles are measured and an estimation of CO_2 emissions of specific cargo operations are provided. Thanks to these data and the traffic and weather condition information provided by the infrastructure operators, the DSS provides suggestions to truck drivers in order to adopt a more energy efficient driving style and therefore reducing fuel consumption and CO_2 emissions. As a consequence of such decisions, the costs of the transport operations are reduced with also a social objective of pollution reduction.

These decision fields are selected on the basis of the actual needs of the logistics key stakeholders setting up strategies to manage intermodal logistics activities.

5.2.2.2 The DSS Architecture

The DSS implements a set of integrated modules to support decisions in the enlightened intermodal transportation decision fields. Thanks to a common interface, a sharing information cloud allows implementing a cooperation among the actors accessing to the DSS cloud. Moreover, through a plug and play approach it is easy to add new actors and modules. Figure 5.8 schetches the high level architecture of the DSS and its connections with the real system by means of smart devices and sensors.

The DSS architecture is based on cloud computing and web service infrastructures, where resources are available online and operate by following the Software as a Service (SaaS) model [Armbrust et al., 2010]. SaaS advantages for the users are that both installation and maintenance of the software are not required. Moreover, the SaaS provider takes care of the performance, availability, and security of the software. The DSS architecture is depicted in Figure 5.9 users and administrators are connected to the portal dashboard that provides an interface for the DSS

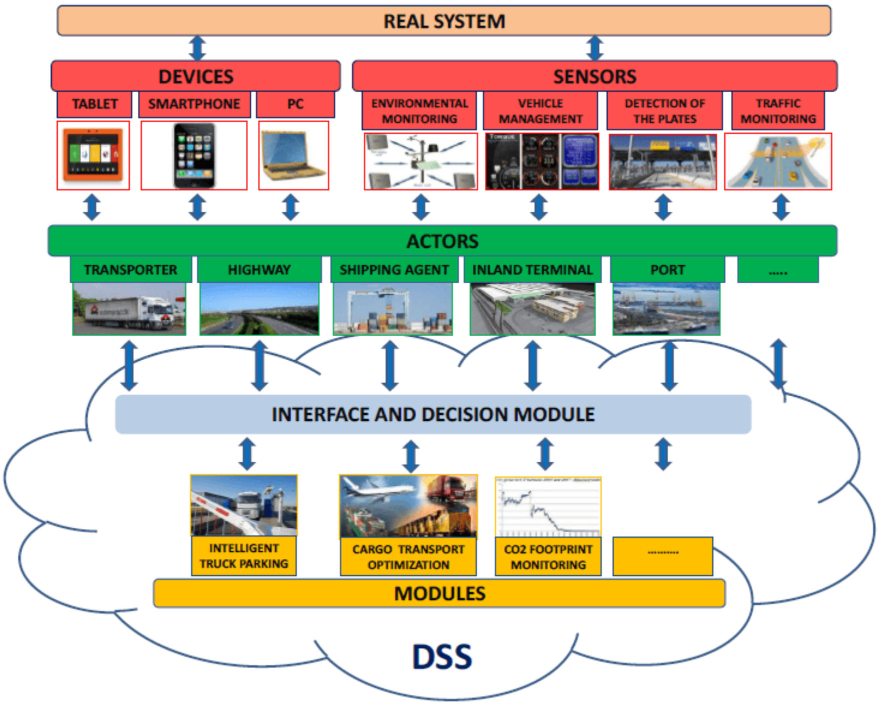

Figure 5.8: Cooperative logistic DSS architecture.

engine. The implementation of the decision modules employs heterogeneous hardware and software resources providing multi- platform access of the implemented functionalities.

More specifically, the core of the DSS is the service engine, that includes four main layers: *data layer, model layer, decision layer and interface layers* [Turban et al., 2011]. The data layer collects two kinds of data: the first one represents the historical and structural data, the second one collects the real-time data. The historical data represents structural data describing the system such us size, capacity, number of roads and statistical data about accidents and unpredictable events. Moreover, these data can be collected from external databases owend by carriers, highway managers, shipping agents, inland terminal managers and port authorities. The real-time data come from devices and sensors that monitor environments, vehicles, traffic and weather conditions. All the data are stored on the cloud and may

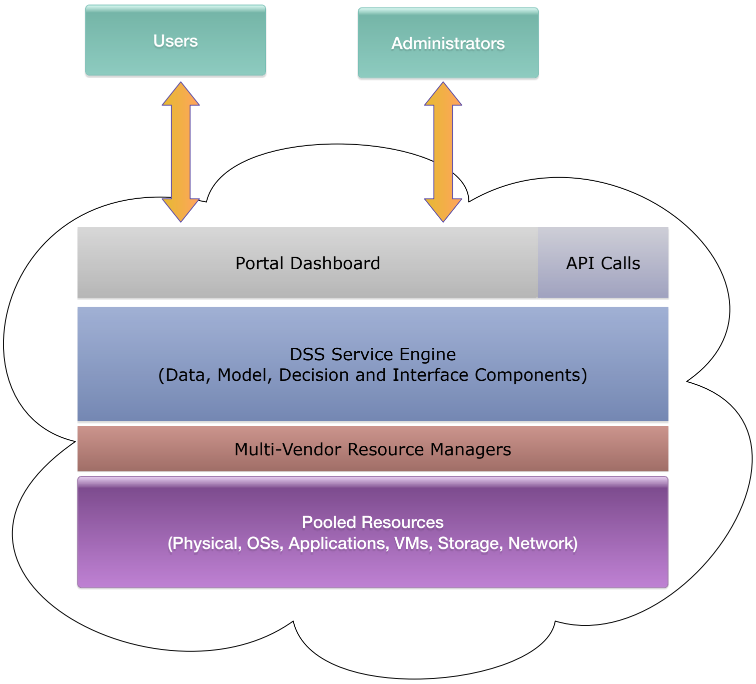

Figure 5.9: DSS cloud architecture.

have specific privacy and security restrictions. The model layer mainly includes the model of the system dynamics that can be formalized by mathematical models or description languages such as UML [Miles and Hamilton, 2006]. This layer describes the operations in various levels and the type of functions used according to the operation to be supported. The decision layer is in charge to suggest and support the DM during the decision process. It can merge information coming from the data and the model layers in order to propose solutions to the DM through the interface layer. The interface layer is responsible of the communication and interaction of the DSS with the DMs and the real system. In particular, it provides the outputs of the DSS and ensures that the DM is able to take advance of the system capabilities.

5.2.3 Requirements and KPIs

This section presents a general methodology to develop a DSS enabling cooperative logistics and to evaluate its performance in terms of stakeholders common goals achievement. The approach consists of two main steps: the *user requirement collection* and the *evaluation framework design*.

5.2.3.1 The User Requirements Collection

The user requirement collection consists in a consultation process aiming at identifying stakeholders expectations about system functionalities to be deployed. The literature review analysis points out that resulting information should belong to the following domains:

- *Technological:* systems integration and information sharing [Vieira et al., 2015];
- *Operational:* decision-making to implement new business processes [Fanti et al., 2015a], [Fanti et al., 2015b];
- *Environmental Sustainability:* reduce logistics sector negative environmental externalities [van Rooijen and Quak, 2014];
- *Usability:* technological user acceptance of real-time data collection and feedback procedures [Hoorn, 2014];
- *Safety and Security:* information flows, physical flows and payment flows risk management expectations [Chang et al., 2014];
- *Legal and Policy:* compliance to existing legal and policy frameworks [Marlow and Nair, 2008].

User requirements are transformed in system requirements, i.e., detailed formal descriptions of system functionalities that are relevant to design the DSS technical architecture [dos Santos Soares et al., 2011]. Furthermore, user requirements indicate expectations in terms of common logistic systems performance objectives to be pursued through cooperation. These hypothesis have to be periodically verified by system designers through performance evaluation processes with the aim to support DMs in planning further DSS updates, further deployments or possible corrective actions.

5.2.3.2 The Performance Evaluation Framework

An appropriate evaluation framework is necessary to assess cooperation goals achievement. The DSS performances should be evaluated in different business conditions (i.e., ex-ante and ex-post deployment) or business areas (i.e., business units, pilot sites, etc.) through Field Operational Tests (FOTs), largescale testing programmes aiming to assess the efficiency, quality, robustness and acceptance of ICT solutions [Barnard et al., 2015]. As a first step, a FOT preparation requires system evaluators to perform a cooperative logistics stakeholders consultation process finalized to define the following relevant aspects:

1. *Cooperative functionalities*: selection of the DSS functionalities enabling logistics cooperation to be tested in the FOT (e.g. information sharing, decision support, etc.);

2. *Research hypothesis*: description of the evaluator performance expectations ex-ante the FOT;

3. *Use cases*: analytical system operations description.

In a second step, system evaluators have to provide a state of the art analysis concerning performance assessment procedures of DSS-based cooperative logistics. In particular, they should review both the scientific literature and the practitioner experiences concerning DSS applications in cooperative logistics networks. The output is represented by a matrix reporting a first draft selection of the following elements:

- *Evaluation criteria*: descriptions concerning performance macro areas supposed to be affected by ICT cooperative deployments in logistic networks;

- *Key Performance Indicators (KPIs)*: core procedure aiming at identifying per each evaluation criteria the appropriate set of quantitative or qualitative indicators to assess the performance of the tested system. KPIs are derived from one or several measurements and expressed as percentages, indices, rates or other values, which are monitored at regular or irregular time intervals and can be compared to one or more criteria [FESTA, 2011]. The selection procedure requires an internal consultation process that should involve system evaluators, users and, eventually, other stakeholders. In case of quantitative KPIs, appropriate formulas are defined;

- *Measurements*: description of the data required to estimate the selected KPIs. Several measurement types can be considered: direct and indirect measures, events and self-reported measurements.

The specification of the sensors requested for the measurements collection and KPIs computation are specified in the FOT data acquisition process [Salanova Grau et al., 2016]. Table 5.1 reports a general evaluation criteria and KPIs matrix selected to evaluate ICT-based cooperative logistic networks. Four performance macro-areas are identified:

- *Network Efficiency*: ICT solution impacts assessment on logistic network efficiency. Quantitative KPIs estimate variations of travel times, logistic resources and infrastructures utilization rates. Road Side Units (RSUs) and On Board Units (OBUs) represent the sensors used to gather the measurements required to compute the selected KPIs;

- *Safety and Security*: ICT solution impacts assessment on logistic network safety and security. Quantitative KPIs evaluate the variations between the situation ex-ante and ex-post the ICT solution deployment;

- *Environmental Sustainability*: ICT solution impacts assessment on logistic network energy consumption and CO_2 emissions. Quantitative KPIs evaluate the variations between the situation ex-ante and ex-post the ICT solution deployment;

- *Economic Sustainability*: ICT solution impacts assessment on stakeholders profits. Quantitative KPIs estimate variations in costs and revenues ex-ante and ex-post the ICT solution deployment.

5.2.3.3 Logistics Decision Modules Specification

In this subsection we describe the four main phases that have to be followed in order to specify and realize logistics decision modules of a DSS for intermodal transportation systems.

1. *System description*: during this step the system behaviour is described and analysed. This analysis includes a detailed observation of the real systems and a set of interviews and questionnaires to obtain qualitative and quantitative descriptions. In addition, the UML diagrams can be used to represent and resume the system behaviour;

2. *KPI identification*: during this phase a set of KPIs suitable to identify the main characteristics of the systems is selected. This step is executed by the DM that takes into account the KPIs of Table 5.1 on the basis of the needs and the data available in the considered system;

3. *Decisions identification*: this is the core of the decision process. In particular, the DM specifies the decisions that will be supported by the service. Moreover, a set of policies is identified to choose the best strategy to be applied in order to optimize the selected KPI. As a results, a set of parameters is selected as decision variables;

4. *What if analysis*: during this phase a set of different scenarios is created by choosing different values of the decision variables. Then for each scenario, the

Table 5.1: General evaluation criteria and KPIs for cooperative logistics services.

Evaluation Criteria	**KPIs**	**Description**
Network efficiency	Average journey time of a route	Mean route duration of a freight transportation mean
	Average lead time	Mean duration of a freight transportation mean loading operations in a certain terminal
	Average lateness of freight transportation operations	Mean difference between the freight transport operation scheduling and the time (i.e. real or estimated) in which the task is performed
	Average length of queues at logistics hubs gates	Mean number of transportation units waiting to be operated in a certain terminal per unit of time
	Average load factor	Mean capacity utilization rate of a freight transportation mean in a certain route
	Average handling unit utilization	Mean time in which a handling unit is in use per unit of time
	Percentage change in parking areas utilization	Variations in the number of occupied parking spots in respect to the total capacity of a parking area per unit of time

Safety and security	Percentage change in accidents along a route	Variations in the number of reported accidents along a route per unit of time
Environmental sustainability	Average energy consumption	Mean energy units consumed by a freight transportation mean to perform a certain route
	Average CO_2 emissions	Mean carbon footprint of logistic operations per unit of time
Economical sustainability	Percentage change in maintenance costs	Variations of the amount of money spent to maintain freight vehicles, infrastructures and ICT systems by a logistics operator per unit of time
	Percentage change in sales volume	Variations of logistics operator incomes per unit of time
	Average throughput	Mean number of units operated in a certain terminal per unit of time

KPIs are estimated by simulations or mathematical models. Moreover, the results are compared and proposed to the DM in order to support him during the decision process.

In the following section the DSS to realize the modules supporting DMs in the aforementioned decision fields. Since the DSS design is strictly related to the considered real system, it is described by considering the case study of the intermodal logistic flow involved in the port of Trieste (Italy), the Interporto di Trieste inland terminal and the routes connecting the two sites.

5.2.4 The Cargo Transport Optimisation Service

This section focuses on the cargo transport optimisation of the Trieste intermodal transportation case study and specifies the four phases to realize the DSS decision module.

5.2.4.1 Description of the Flow of Trucks

The first phase of the cargo transport optimisation specification is the description of the flow of truck and goods in the considered case study by the UML activity diagram shown in Figure 5.10. The main cooperating actors are the following: customers, truck drivers, fleet managers, inland terminal operators, RO-RO terminal operators and the Customs Agency.

The freight flow starts when the goods are ready to be delivered to customers. When the shipment leaves the customers plant, it communicates to RO-RO terminal staff the identity of the truck and the carried goods. An important decision is taken by truck drivers approaching the Trieste highway exit tollbooth: go directly to the RO-RO terminal or to the inland terminal. If they go straight to the port, they can do Customs operations, check the load and wait for boarding. If they choose to stop at the inland terminal, the flow is quite different. The inland terminal has two separated areas: the parking area 1 is dedicated to trucks that have already

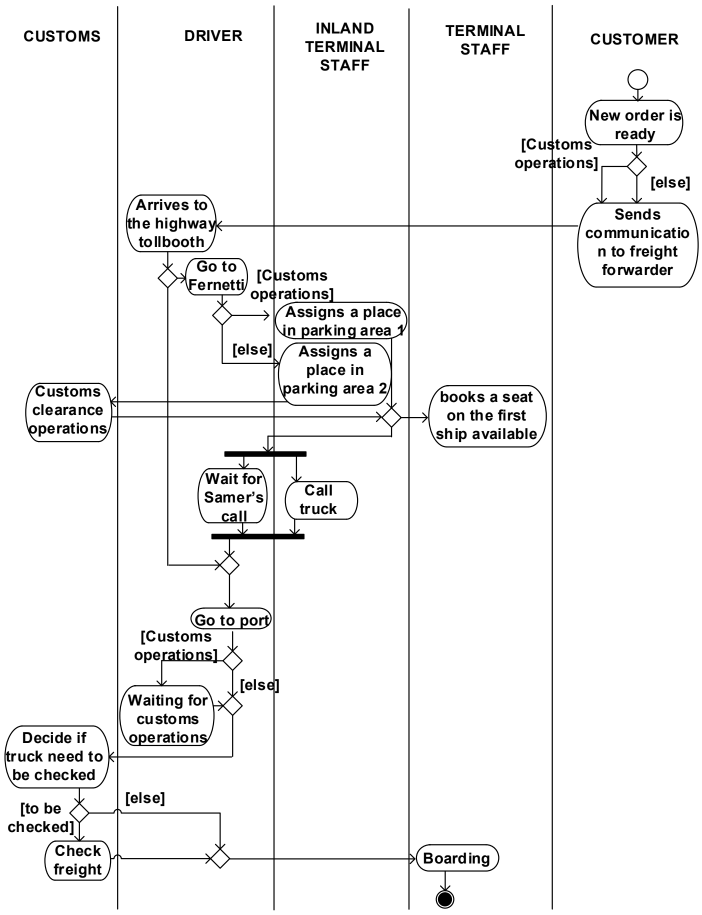

Figure 5.10: The activity diagram of the truck flow procedure.

cleared the transported goods, the parking area 2 is dedicated to trucks that have to do the custom clearance operations. When the customs operations are ended, the driver waits for the call to go to the port. Indeed, when the ship arrives in the port and it is ready to be loaded, the truck driver receives a communication through a monitor located in the inland terminal. The driver receives from the terminal staff the transport document, pays the ticket for the time spent in the terminal and goes to the port. At the entrance of the port the Customs staff decides if it is necessary or not to inspect the semi trailer which, finally, has to be loaded on the ship.

Analysing the process it is possible to note two main drawbacks of the logistic flow:

- The driver cannot perform booking and customs operations by web;
- The decision of the driver to go to the port or to the inland terminal is not based of the system state.

These detected drawbacks of the flow can be overcome by ICT applications and new decision policies.

5.2.4.2 KPIs and Decision Policies

According to the requirements of the DMs and the system description, the selected KPIs for the cargo transport optimisation are the following:

- *Average throughput of trucks* i.e., the number of trucks served per time unit;
- *Average lead time of trucks* (in hours), i.e., the time elapsed between the truck arrival at the highway tollbooth and the departure of the truck on the ship;
- *Average lead time of ships* (in hours), i.e., the time elapsed between the arrival of the ship to the berth and the departure of ship;
- *Average lateness of ships* (in hours), i.e., the difference between the scheduled departure time of a ship and the real departure time.

In order to speed up and improve the synchronization of the cargo transport optimisation decisions, we introduce two new actors: the DSS and the highway management society. Hence, a set of decisions is proposed by the DSS on the basis of new ICT applications:

- The on-line operations, i.e., the booking and payment of the parking areas and the ship can be performed on line;
- The paperless customs operations, i.e., the drivers can send by email the documentations of the freight before the departure;

- The truck arrival communication, i.e., the highway manager detects and communicates to the DSS the trucks position by reading the truck plates at the tollbooth;
- The truck routing procedure, i.e., on the basis of the information about the traffic, the ship, the congestion of the port, the DSS suggests the suitable truck destination (the inland terminal or the port);
- The gate assignment to the trucks, i.e., the DSS assigns the gate to the truck that arrives to the port. Moreover, a new gate to enter the port is introduced *a fast lane* that can be used by the trucks that employ the ICT system and have performed the booking and paperless Customs operations.

The DSS can synchronize the truck arrivals at the port with the unloading of the booked ship. Hence, the following three main decisions are supported by the DSS cargo transport optimisation module:

- *Routing selection*: when a truck arrives at the Trieste tollbooth, the DSS suggest to the terminal staff if the truck can go to the port or to the inland terminal;
- *Assigning the port gate*: when the DSS routes a truck towards the port of Trieste, it has to assign the gate to enter on the basis of the congestion. We consider 3 lanes: lane 1, lane 2 and the new introduced fast lane;
- *Calling policy*: from the inland terminal: when the trucks are directed to the inland terminal, the DSS suggests the best moment to call the trucks for reaching the port and boarding.

In order to describe in detail the main activities managed by the DSS in the cargo transport optimisation (*routing selection* and *calling policies*), we use the UML activity diagrams.

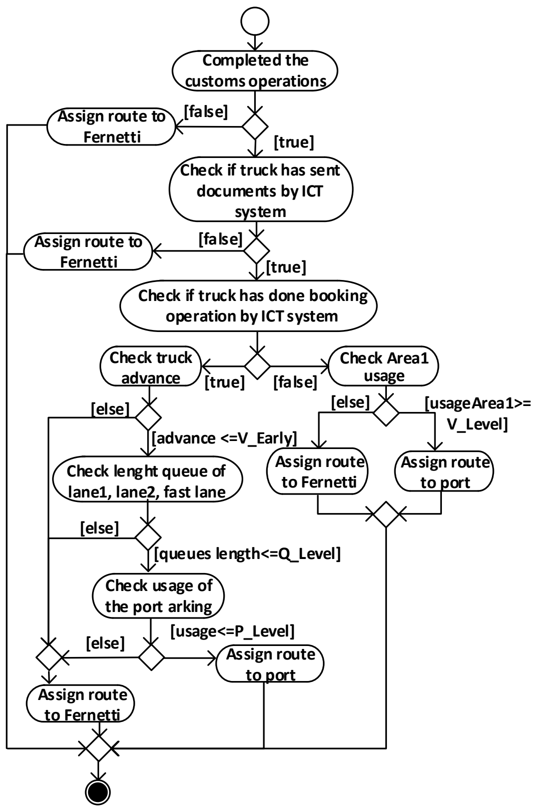

Figure 5.11: The activity diagram of the routing procedure.

Figure 5.11 shows the activity diagram describing the DSS routing selection that is composed by the following steps:

1. *Checking if the truck completed the customs operations*: the DSS checks if the truck completed the customs operations before leaving. In this case the truck is routed to Area 2 of the inland terminal;

2. *Checking if the truck sent documents by the ICT system*: if the truck did not send the documents then it is routed to the inland terminal;

3. *Checking if the truck performed booking operations by ICT system*: if not the truck should go directly to the inland terminal in order to book a ship;

4. *Checking the Parking Area 1*: if a truck did not book a ship before leaving,

the DSS checks the utilization of Area 1. If the occupation of the area exceeds a threshold (denoted by V_Level), then the truck is directed to the port, otherwise it is directed to the inland terminal;

5. *Checking the ship departure time*: the DSS checks the departure schedule of the booked ship. If the truck arrives before a threshold time denoted by V_Early, then it goes to the inland terminal, in order to avoid to overcrowd of the port area;

6. *Checking the queue length of the port gates*: the DSS verifies the length of the queues at the port gates. If the sum of the queue lengths exceeds the established threshold (denoted by Q Level) then the truck is rerouted to the inland terminal;

7. *Check the port parking area*: if the port parking area is available then the truck can go to the port, else the truck is routed to the inland terminal.

The UML activity diagram of Fig. 5.12 shows the details of the calling procedure:

- the DSS checks if the ship assigned to the current truck is performing the unloading operations, in this case the procedure continues;
- the DSS checks the number of trucks n to be unloaded: if $n <$V_Calling, then the DSS calls the trucks to be boarding from the inland terminal.

5.2.4.3 What If Analysis

The cargo transport optimisation can support the DM in the selection of the best values for the identified decision variables: V_Level, V_Early and V_Calling. The described truck flow are modelled in a discrete event system framework whose dynamics depends on the interaction of discrete events, such as demands, departures and arrivals of carriers at facilities, acquisitions and releases of resources by vehicles,

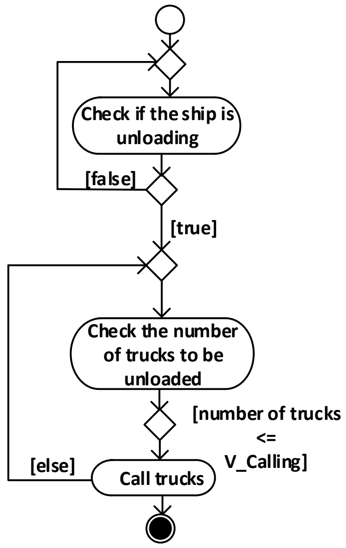

Figure 5.12: The activity diagram of the calling policy procedure.

blockages of operations. In order to estimate the effects of the decision variables, in this section a simulation campaign evaluates the impact on the system KPIs of the variables V_Early, V_Level and V_Calling. To this aim, the selected performance indicators are evaluated by simulating the system in 10 scenarios that consider different values of the parameters V_Early, V_Level and V_Calling as specified in Table 5.2.

Moreover, two additional scenarios are analysed in order to assess the application of the ICT strategies by modifying scenario SC1 as follows:

- In scenario SC1.1 the truck drivers complete the paperless customs operations but do not send the documents by email;
- In scenario SC1.2 the trucks do not complete the paperless customs operations, i.e., this is the actual truck flow case.

The system model is simulated in the ARENA environment, that is a discrete

Table 5.2: Scenario description.

Scenarios	**V_Early**	**V_Level**	**V_Calling**
SC1	18	0.8	0.99
SC2	18	0.8	0.01
SC3	18	0.8	0.5
SC4	18	0.8	0.75
SC5	18	0.99	0.99
SC6	18	0.6	0.99
SC7	10	0.99	0.99
SC8	6	0.99	0.99
SC9	10	0.6	0.99
SC10	6	0.6	0.99

event software [Kelton et al., 1998] particularly suited for dealing with largescale and modular systems. The UML activity diagrams are used to generate the ARENA simulation model [Boschian et al., 2013].

The inter arrival time of trucks are randomly generated according to an exponential distribution of mean 5 minutes producing about 100,000 trucks per year, according to the actual flow values. Moreover, we consider two incoming ships per day at a scheduled arrival time: 9 a.m. and 4 p.m. In addition, the processing times (in minutes) of the activities have a triangular distribution, specified in Table 5.3. In particular, the second column reports the modal values of the processing time distributions, the third and fourth columns show the maximum and minimum values of the range in which the firing delay varies, denoted, respectively, by D_δ and d_δ. Note that the triangular distribution is commonly used in cases in which the exact form of the distribution is not known, but the estimates of the minimum, maximum, and most likely values are available.

Table 5.3: Activity process times.

Process time	δ	D_δ	d_δ
New order from the customer	180	205	150
Sending communication to terminal staff	5	6	4
Travel time from the tollbooth to the terminal	30	36	24
Checks at the inland terminal entrance	6	10	5
Stock in Area 1	5	6	4
Stock in Area 2	5	6	4
Customs clearance procedures	30	60	15
Consign documentation	10	12	8
Booking ship	3	3.6	2.4
Give documentation to the driver	5	6	4
Pay ticket	30	42	15
Transport freight to the port	30	120	24
Check documents	30	42	15
Insert data into the system	180	205	150
Inspect freight	120	145	90
Load freight on ship	144	240	120

The performance indicators are evaluated by a long simulation run of 365 days with an initial transient period of 10 days. In particular, the performance indicators estimations are deduced by 50 independent replications with a 95% confidence interval. Besides, the percentage value is evaluated as 2.2% of the confidence interval on the throughput evaluation to assess the accuracy of the indices estimation. The average CPU time for a simulation run is about 3 minutes on a PC with a 1.83 GHz processor and 8GB RAM: the presented modelling and simulation approach can be applied to large and complex systems.

In order to validate the simulation and determine how closely the simulation model represents the real system, here the procedure proposed in [Law and Kelton, 1982] is applied by the well-known single mean test. In particular, the model assumptions and data are reviewed by experts that provided the Average Real Values (ARV) of the throughput of trucks and of the lead time of trucks. The values of ARV, the Simulated Values (SC) of the corresponding KPI and the width of the confidence intervals (denoted by ρ) are shown in Table 5.4: it holds $SV - \rho \leq ARV \leq SV + \rho$. Applying the single mean test, the results prove that the simulation closely represents the current system.

Table 5.4: Simulation validation.

Performance Index	**Simulated value** SV	**Real value** ARV	**Confidence interval width** ρ
Throughput of trucks	101502	100000	1900
Lead Time of trucks	25.5	26	0.53

The bar diagrams shown in Fig. 5.13, 5.14, 5.15 and 5.16 compare the values of the KPIs in the different scenarios.

The results highlight the following trends:

- if the value of V_Calling decreases, then the trucks are called later. In such a case the KPIs worsen, i.e., the throughput decreases and the minimum value is obtained in scenarios SC2; the lead times and the lateness increase;
- if the value of V_Early decreases (i.e., the trucks leaves the inland terminal

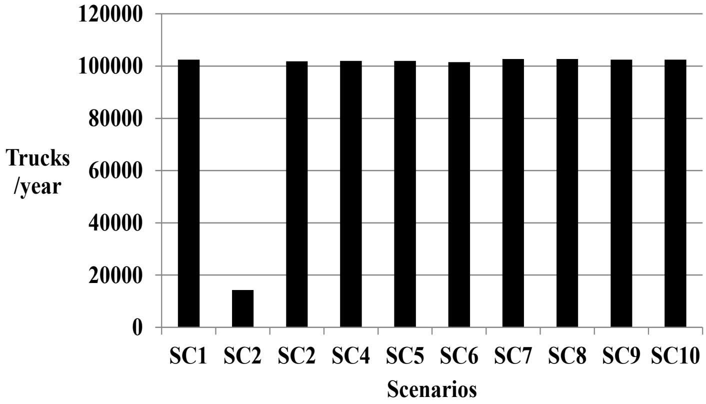

Figure 5.13: Average throughput of trucks.

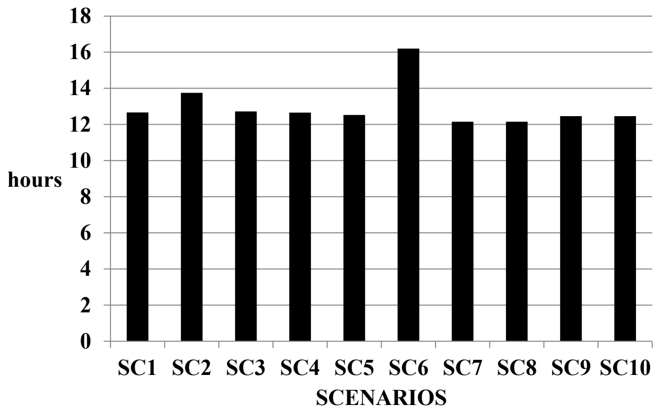

Figure 5.14: Average lead time of trucks.

later), then the performance improves. In such a case, the throughput is about constant, the average lead times and the average lateness of the ship departures decrease;

- if the value of V_Level decreases (i.e., a larger number of trucks is directed to the inland terminal), all the KPIs exhibit a limited improvement.

Summing up, the results show that the best scenarios are SC7 and SC8.

Finally, Figure 5.17 compares the maximum lead time of the trucks for the scenarios SC1, SC1.1 and SC1.2. The greatest improvement of the lead time is

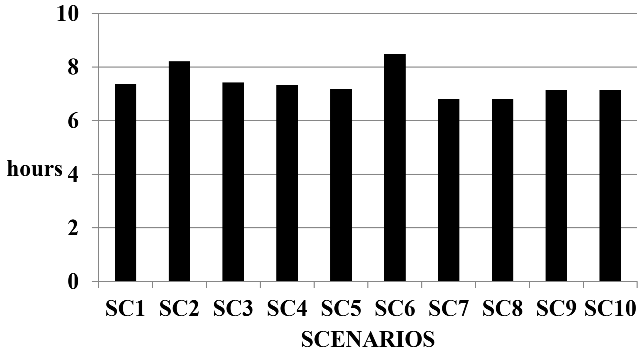

Figure 5.15: Average lead time of ships.

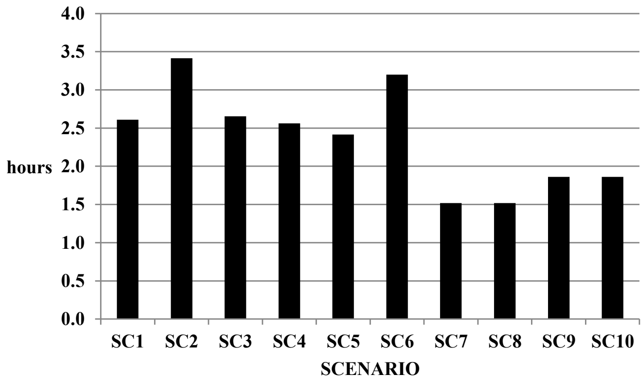

Figure 5.16: Average lateness of ships.

obtained for trucks adopting the new ICT based procedure SC1: the maximum lead time of trucks decreases by about 15 hours with respect to SC1.2. Moreover, in the case SC1.1 a limited application of the ICT policy is performed and an improvement is obtained with respect to SC1.2: the maximum lead time of the trucks decreases of about 13 hours with respect to SC1.2.

5.2.5 The Intelligent Truck Parking Service

The intelligent truck parking is a key issue to improve the performance of the cargo truck management inside the dry-port and the port areas. Considering the Trieste case study, the RO-RO terminal can allocate about 450 truck units in nine parking

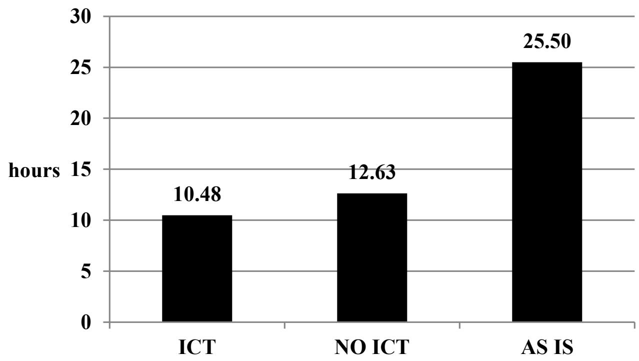

Figure 5.17: Maximum lead time of trucks.

areas, three ships arrive per day and each ship can transport 255 trucks. Due to the parking area size, the terminal can not allocate all the trucks before the boarding.

Figure 5.18 shows the terminal areas including two berths and nine truck parking areas. Each area is characterized by capacity, distance from the berths and distance from the entrance point: Table 5.5 shows the average time (in minutes) necessary to reach the berths starting from the entrance point of the parking area. The terminal has a number of trailers that are used to board the tows and are shared between the berths and the parking areas.

In order to analyse the system performances, the following KPIs are selected for the intelligent truck parking service:

- *the average boarding time* expressed in minutes, i.e., the time needed to load all the assigned tows on the boat;
- t*he average boarding time for a single tow* on the assigned boat. it is expressed in minutes;
- *the percentage utilization of the parking area.*

Two different policies are compared:

- Policy 1 (P1) the trucks are parked as close as possible to the entrance point;

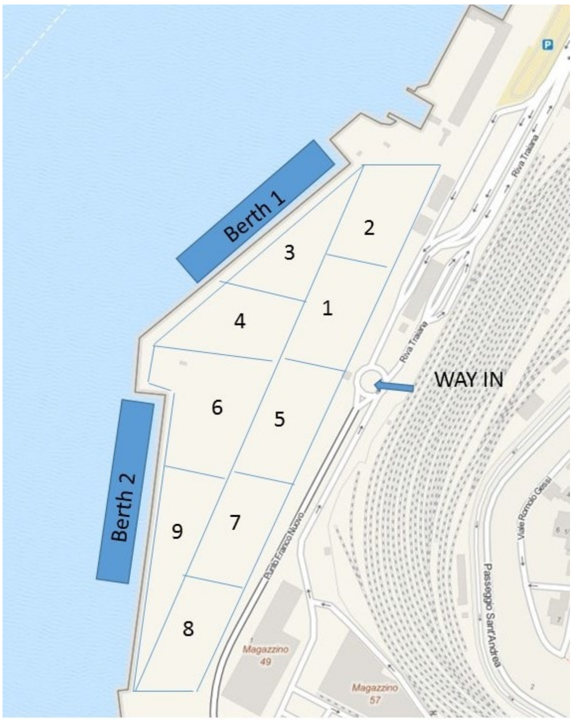

Figure 5.18: The Samer terminal in the Trieste Port area.

- Policy 2 (P2) the trucks are parked as close as possible to the berth scheduled for the ship they are waiting for.

The *what if* analysis is carried out by simulating the system in six scenarios specified in Table 5.6 and characterised by a different number of semi trailers and the application of two parking policies.

The performance indicators are evaluated by a long simulation run of 375 days with an initial transient period of 10 days. In particular, the estimates of the performance indexes are deduced by 50 independent replications with a 95% confidence interval. Besides, the percentage value is evaluated as 3.2% of the confidence interval on the average boarding time evaluation to assess the accuracy of the indexes estimation.

Fig. 5.19 depicts the average loading time for each ship: the results show the impact of policy P2 on the system. In particular, it shows that using 15 semi

Table 5.5: Process time activities.

Area ID	**Berth 1**	**Berth 2**
1	15	25
2	10	20
3	20	20
4	15	15
5	25	15
6	5	15
7	20	10
8	10	10
9	15	5

Table 5.6: Scenario analysis based on a varying number of semi trailers and parking policies application.

Scenario	**Number of semi trailers**	**Policy**
S1	15	P1
S2	15	P2
S3	20	P1
S4	20	P2
S5	25	P1
S6	25	P2

trailers, if P1 is implemented then the system is not able to manage all the tows in an acceptable way. On the contrary, if policy P2 is adopted, then the system obtains good results. Increasing the number of the semi trailers, P1 shows an improvement, but P2 works better.

Fig. 5.20 shows the average loading time spent by a single tow. The results show that P2 reduces dramatically the loading time; on the other hands as we expected, the number of semi trailers does not affect the loading time of a single tow. Fig. 5.21 describes the utilization of the RO-RO terminal parking area: all the scenarios show a good utilization value.

Concluding, the policy P2 leads to better system performances: Fig. 5.20 shows that it is possible to obtain good results reducing the number of semi trailers. On the other hands, if the number increases, then the difference between the performances of the two policies decreases.

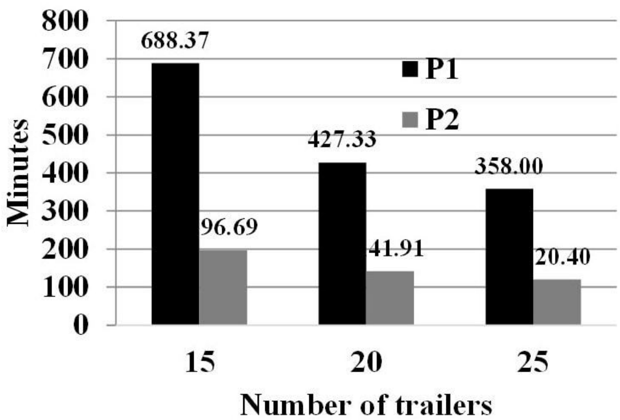

Figure 5.19: The average boarding time in minutes.

5.2.6 The CO_2 Estimation and Monitoring Service

Climate change is the consequence of the following greenhouse gas emissions in the atmosphere: carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O) and ozone (O_3). Legislators adopted several regulations to constraint road freight carriers

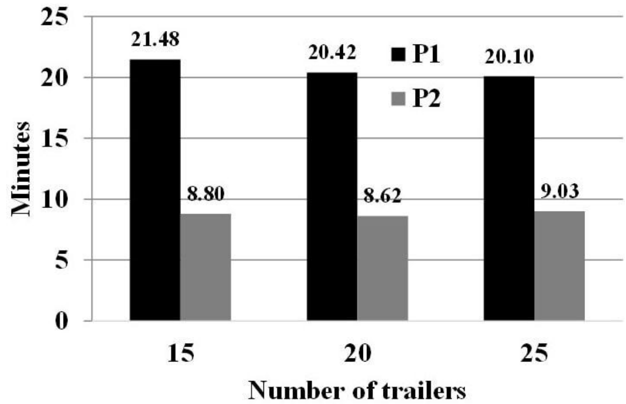

Figure 5.20: The average boarding time in minutes for a single tow.

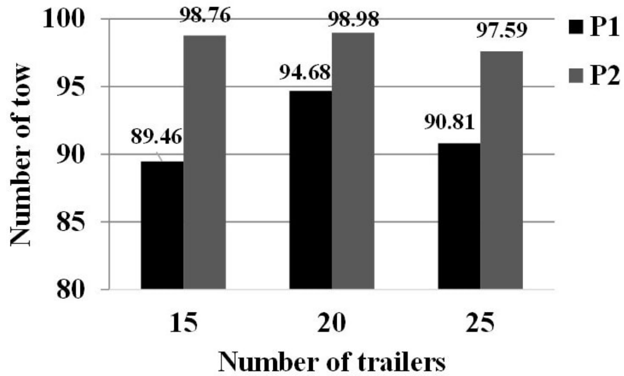

Figure 5.21: The parking area percentage of utilization.

and reduce the climate change impacts of their cargo operations. An example is the Regulation of the European Union (EU) N. 510/2011 imposing an emission cap of 147 gCO_2/km for commercial vans [Eurostat, 2015]. Consequently, road freight carriers started to require CO_2 monitoring and estimation services that aim at cutting their emissions under the EU fixed caps. In this context, ITSs represent the major enabler for green mobility of goods consisting in ICT applications in transportation systems. The study in [Suthaputchakun et al., 2012] identifies in cruise control, platooning and traffic signal management the main approaches under development. In particular, the OBUs are able to combine data gathered by injector sensors and GPS data in order to assess the real fuel consumption of a truck in the downstream phase, named Tank-To-Wheel (TTW). Other ICT tools, such as the EcoTransIT web portal (http://www.ecotransit.org), estimate the TTW energy consumption taking into account the following list of parameters:

- Vehicle data: vehicle typology (e.g., 7.5 ton truck, RO-RO ship, etc.), size and weight, energy (e.g., diesel, electricity, etc.), payload capacity, motor concept and transmission;
- Cargo specification: typology (e.g., pallets, containers, etc.), weight of freight;
- Capacity utilization: load factor, empty trips;
- Driving Conditions: number of stops, speed profiles, acceleration profiles, etc.;
- Route: typology (e.g., urban roads, motorways, etc.), conditions (e.g., traffic, weather etc.), distance.

The upstream energy use, named Well-To-Tank (WTT), is estimated by multiplying the resulting TTW energy use for the energy related upstream energy consumption. The unity of measure used to express energy consumption in freight transportation is the tonne-kilometre (tkm), representing the energy used to move one tonne of freight over a distance of one kilometre. In order to compute the total energy use, named Well-To-Wheel (WTW), the sum of the WTT energy use (EU_{WTT}) and (EU_{TTW}) has to be multiplied by the total mass of freight transported M and the total distance travelled D [UK Department for Environment and (Defra), 2013] as follows:

$$EU_{WTW} = (EU_{WTT} + EU_{TTW}) \cdot M \cdot D. \tag{5.1}$$

The WTT, TTW and WTW energy uses represent the basis for the freight transportation emission estimations. Consequently, conversion factors evidencing the carbon content per energy unity of fuel (i.e., gasoline, diesel, etc.) are applied to the EU_{WTW}. Table 5.7 reports the list of CO_2 conversion factors identified in [CEN, 2012]. Therefore, the total CO_2 emissions (CO_{2WTW}) is estimated in kg as follows:

Table 5.7: CO_2 conversion factors per fuel type.

Fuel type	**conversion factor**	**Unit of measure**
Diesel	2.639	kg/liter
Gasoline	2.304	kg/liter
Biofuel	0.000	kg/liter
Compressed Natural Gas (CNG)	2.728	real number
Liquefied Petroleum Gas (LPG)	0.000	kg/liter
Electric	0.541	kg/kWh

$$CO_{2WTW} = EU_{WTW} \cdot CO_2 \cdot K, \tag{5.2}$$

where K is a conversion factor. The CO_2, CH_4, N_2O global warming potential in terms of CO_2 equivalences (CO_{2eq} in grams) is determined by the following formula [CEN, 2012]:

$$CO_{2eq} = CO_2 + 25 \cdot CH_4 + 298 \cdot N_2O. \tag{5.3}$$

The CO_2 monitoring and estimation services are deployed in the Trieste logistics case study. The Port Authority requires introducing a methodology for the environmental impact assessments of the cargo operations of the port of Trieste. In order to satisfy the requirements, a functionality of the presented DSS is dedicated to the provision of post-trip CO_2 estimations based on the trucks data. The environmental assessment requires information sharing between the systems of the interested road freight carriers and the DSS data component. In particular, post-trip data concerning the fleet energy use are shared with the DSS by web-services.

The DSS model layer uses the mentioned data to compute the EU_{WTW} and CO_{2WTW} according to equ. (2). In addition, the DSS model layer aggregates the CO_{2WTW} estimated for freight carrier in a common global index, representing the macro impact in terms of CO_{2equ} emissions of the freight transportation flows performed in the Trieste logistics network in a specific reference period (i.e., day, week, month). The DSS decision layer supports fleet managers by detecting overshooting of the EU CO_2 emissions. The DSS interface component consists in a web page in which the information are reported.

5.3 The H2020 EU Project AEOLIX

The deployment of pan-European solutions applied to logistics and transportation businesses currently represent a requirement for public and private stakeholders interested to increase the performance of the existing networks and simultaneously to reduce environmental and social negative externalities. Therefore, new ICT platforms have to be developed, mostly to face two major challenges:

- Lack of connectivity among IT solutions: nowadays information systems are developed to manage a specific business, being quite often close solutions. Moreover, SMEs do not often use sophisticated information systems and specific software due to their expensive costs. In this context, the connectivity among logistics stakeholders is lacking, thus representing a barrier for collaborative logistics models;

- IT solutions fragmentation: differences in user requirements, data models, system specification and business models have led to a proliferation of information systems, information channels, solutions, etc.

To overcome the mentioned technological barriers, a consortium of 34 heterogeneous entities (i.e., public authorities, fleet and infrastructure operators, shippers, etc.) has committed in the H2020 EU project “Architecture for European Logistics Information Exchange (AEOLIX)” (http://ertico.com) for a three years period (September 2016-August 2019). More in specific, the initiative aims to develop a cloud-based collaborative logistics ecosystem for configuring and managing (logistics-related) information pipelines thus creating visibility across the supply chain and enabling more sustainable and efficient transport of goods across Europe. The AEOLIX vision consists in a two step process:

- AEOLIX IT architecture development: a user stories and requirements collection process will lead to design and develop a cloud-based collaborative ecosystem;
- AEOLIX IT architecture test: the developed solution will be tested in real business environments through a continuous execution process (i.e., *living lab* format).

In AEOLIX, 11 Living Labs (LLs) will be deployed in various European cities and logistics networks. The city of Trieste will host one of them, entitled “Intermodal e-Customs”.

5.3.1 The Trieste Living Lab

The Trieste LL vision consists in adapting the AEOLIX IT architecture based on local intermodal transport operators requirements which aim to optimise customs procedures and to enhance the local network performance. Figure 5.22 illustrate the use cases considered in the AEOLIX collaborative ecosystem testing:

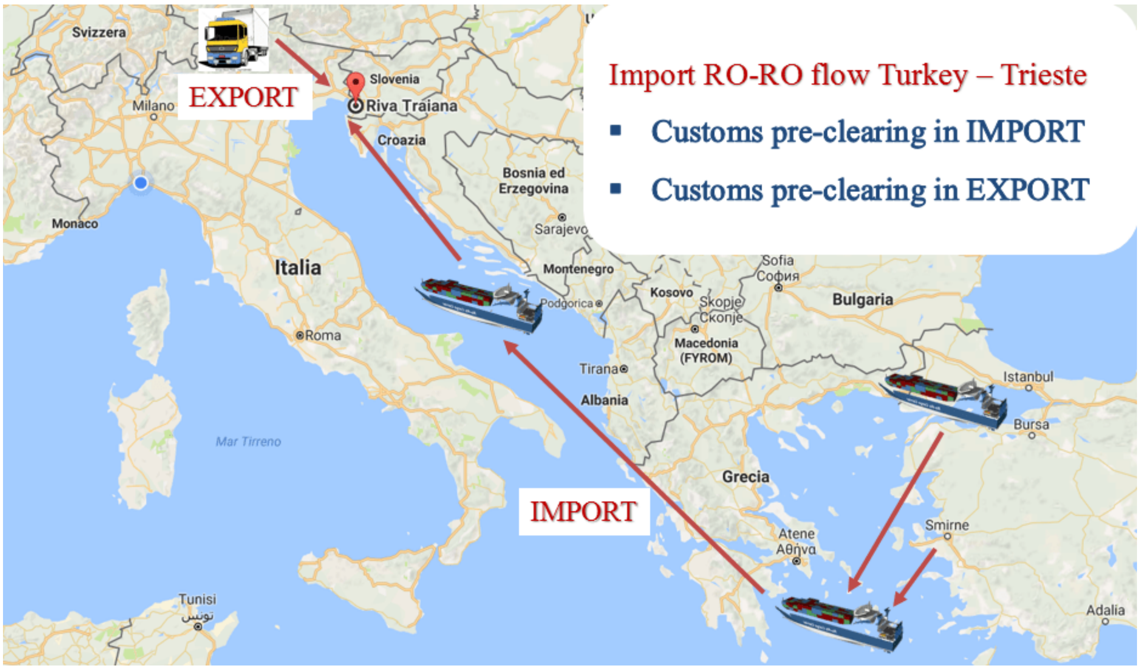

Figure 5.22: The Trieste living lab use cases.

- *Export trade flows between Continental Europe and Turkey*: improving the COGISTICS cargo transport optimisation service. Trucks reaching the Trieste port along the motorway will be able to perform customs and administrative procedures associated with the Trieste free port status along their route. The objective is to reduce queues at port gates and to enhance the operations synchronisation between two transportation modes: trucks and vessels;

- *Import trade flows between Turkey and Continental Europe*: currently the customs procedures related to RO-RO vessels reaching the Trieste port from Turkey can be finalised only when the ship is docked. This exclude the possibility to unload the carried intermodal transportation units and immediately pick them up for delivery by truck or train. In order to speed up the process, customs procedures might be performed in advance, along the ship route. Thus, the AEOLIX platform will support the implementation of secure, paperless procedures enabling to digitally submit the required documentation before the ship arrives at the Trieste port.

Through the AEOLIX collaborative ecosystems, the customs data will be visible to all the European interested actors. The Trieste living lab is realised thanks to the commitment of the following stakeholders:

- Interuniversitary Consortium Of Operations Research (ICOOR - leader);
- Università degli Studi di Trieste (Third Party of ICOOR);
- Polytechnic of Bari (Third Party of ICOOR);
- Interporto di Trieste S.p.A.;
- Samer & Co. Shipping S.p.A.

5.4 Concluding Remarks

This Chapter presents the architecture of a cloud-based DSS that integrates cooperative logistics management and decision support for intermodal transportation systems. In particular, the specified DSS focuses on the new paradigm of cooperative logistics: different stakeholders share information, historical and real-time data and decisions by pursuing shared objectives. Using modern ICT tools, the DSS can provide suitable applications for planning, coordinating and synchronizing logistics activities as well as effectively reducing fuel consumption and CO_2 emissions. In order to describe the main modules of the DSS, the cargo transport optimisation, the intelligent truck parking and the CO_2 footprint estimation and monitoring services are introduced. Moreover, the advantages of the proposed DSS application are assessed by a simulation study that allows achieving two objectives:

- Determining the values of the thresholds necessary to implement the decision modules;

- Comparing the performance measures in a set of scenarios.

Future research will specify in details other DSS decision modules that can provide decisions to stakeholders in different intermodal transportation systems, for instance involving trains or planes. Moreover, the decision making process could include real-time information about weather forecasts and emergency issues and could involve other actors such as the Customs.

Finally, as regards the customs procedures enhancement, the new H2020 European founded project AEOLIX will exploit the results of CO-GISTICS and will address new Trieste intermodal transportation network challenges. In particular, the cargo transport optimisation service deployed in CO-GISTICS will be integrated with further functionalities concerning the pre-clearing paperless procedures in export. Moreover, also the import trades will be considered by enabling pre-clearing paperless procedures for RO-RO traffics.

The results of this Chapter are based on publication [Fanti et al., 2017] and [Salanova Grau et al., 2016].

Chapter 6

Conclusions

In this dissertation, the collaborative logistics research domain is discussed with the general aim to contribute to the understanding of classic models and, especially, of emerging business and organisational paradigms such as the Physical Internet.
In particular, the problem is dealt from both theoretical and practical points of view, targeting three major research gaps.

1. *Theoretical open issues*

    (a) Collaborative logistics classification framework: the current collaborative logistics types classification (i.e., the “classic” vertical, horizontal and diagonal ones) is missing a concept to emphasise the emergence of “innovative” models characterized by a simultaneous application of multiple classical approaches;

    (b) Harmonised methodology for collaborative logistics models analysis: the scientific literature is missing a structured approach to analyse collaborative logistics management implications, both regarding scientific literature review and future research areas identification;

2. *Practical open issues*

    (a) ICT and Decision Technologies innovation: design and development of new tools supporting decision makers in planning and managing logistics and transportation processes in interconnected collaborative networks.

In addressing the aforementioned research gaps, this work has led to the following major results.

1. *Theoretical contributions*

    (a) A new collaborative logistics type has been coined with the aim of expressing the peculiarities of innovative business and organisational logistics models i.e., openness, reliability, synchronisation, sustainability and efficiency. Such type has been denominated "interconnected" and a proper definition has been introduced;

    (b) A collaborative logistics taxonomy has been designed as a tool to tighten and harmonise classic and innovative models descriptions. In particular the developed tool has a two-level structure. At the first layer, the considered business model is analysed, evidencing its key components: the decision makers, the form of collaboration and, finally, the operations management. Then, in order to highlight the technological enablers necessary for the deployment of such business model, the related ICT and decision technology tools are sketched at the second layer of the taxonomy;

2. *Practical contributions*

    (a) A cloud-based collaborative platforms supporting decision makers in planning and managing logistics and transportation processes in interconnected collaborative networks has been developed. In particular, the case of a Decision Support System (DSS) for the Trieste intermodal transportation network has been presented. The advantages of the proposed DSS application are enlightened by specifying three main decision modules: the cargo transport optimisation, the intelligent truck parking and the CO_2 footprint estimation and monitoring. Moreover, the applicability of the proposed DSS is described by specifying a DSS for the case study of the logistics network of the Trieste Port (Italy), including the port, the inland terminal, and the highway connecting them. Some simulation campaigns both to set the decision modules and to evaluate the DSS application benefits.

In conclusion, this Thesis contributed to study the collaborative logistics requirements leading up to a transition from current individual logistics and transportation networks to shared and interconnected Physical Internet-based logistics Webs.

Future research will address:

- *Theoretical contributions*: the taxonomy proposed in Chapter 3 and 4 has enhanced the need of addressing further gaps in both the classic and innovative collaborative logistics models .
- *Practical contributions*: further DSS decision modules have to be specified that can provide decisions to stakeholders in different intermodal transportation systems. Moreover, the decision-making process could include real-time information about weather forecasts and emergency issues and could involve other actors such as the Customs.

Finally, the H2020 European Project AEOLIX will exploit and enrich the concepts presented in this work with the aim of developing a cloud-based collaborative logistics ecosystem to configure and manage (logistics-related) information pipelines thus creating visibility among the supply chain and enabling more sustainable and efficient transportation of goods across Europe.

Chapter 7

List of Acronyms

The following table describes the meaning of the acronyms and abbreviations used throughout the thesis.

Abbreviation	Meaning
ABC	Activity Based Costing
AEOLIX	Architecture for EurOpean Logistics Information eXchange
AFMS	Advanced Fleet Management System
AI	Artificial Intelligence
AIDC	Automatic Identification and Data Capture technology
ALICE	Alliance for Logistics Innovation through Collaboration in Europe
API	Application Programming Interface
APS	Advanced Planning and Scheduling
ARV	Average Real Value
ATIS	Advanced Traveller Information System
ATMS	Advanced Traffic Management System
AVI	Advanced Vehicle Identification
AWCSA	Asia West Coast South America freight conference
B2B	Business-to-Business

Abbreviation	Meaning
B2C	Business-to-Consumer
B2E	Business-to-Enterprise
CAO	Computer Aided Ordering
CDC	City Distribution Center
CEF	Connecting European Facility EU Programme
CELDi	Center for Excellence in Logistics and Distribution
CFEM	CO_2 Footprint Estimation and Monitoring
CH_4	Methane
CIS	Collaborative Information System
C-ITS	Cooperative Intelligent Transportation System
CL	City Logistics
CM	Category Management
CNG	Compressed Natural Gas
CO-GISTICS	COoperative loGISTICS for sustainable mobility of goods
CO_2	Carbon dioxide
CPFR	Collaborative Planning Forecasting and Replenishment
CPU	Computer Processing Unit
CRMS	Customer Relationship Management System
CSSC	Collaboration for Sustainable Supply Chain
CTM	Collaborative Transportation Management
CTO	Cargo Transport Optimisation
C2B	Consumer-to-Business
C2C	Consumer-to-Consumer
DBMS	Database Management System
DC	Distribution Center
DI	Digital Internet
DPM	Distribution Planning Model
DSS	Decision Support System

Abbreviation	Meaning
DT	Decision Technology
EC	European Commission
ECR	Efficient Customer Response
EDI	Electronic Data Interchange
EDIFACT	Electronic Data Interchange For Administration, Commerce and Transport
EDS	Eco-Drive Support
EFT	Electronic Found Transfer
EOS	Electronic Order System
EPC	Electronic Product Code
EPICS	Experimental Physics and Industrial Control System
EPOS	Electronic Point Of Sale system
ERP	Electronic Resource Planning
ETS	Emission Trading System
EU	European Union
EV	Electric Vehicle
FESTA	Field opErational teSt supporT Action
FOT	Field Operational Test
FTL	Full Truckload motor carrier
FTP	Freight Transportation Pooling
GDP	Gross Domestic Product
GDS	Global Distribution System
GPS	Global Positioning System
GVA	Gross Value Added
G2G	Government-to-Government
IATA	International Air Transport Association
ICT	Information and Communication Technology
IoT	Internet of Things

Abbreviation	**Meaning**
ISO	International Organisation for Standardisation
IT	Information Technology
ITP	Intelligent Truck Parking
ITS	Intelligent Transportation System
JIT	Just In Time
JPTS	Joint Procurement of Transportation Services
JRP	Joint Route Planning
KPI	Key Performance Indicator
LAN	Local Area Network
LCA	Life Cycle Assessment
LDC	Local Distribution Center
LIS	Logistics Infrastructure Sharing
LL	Living Lab
LMDC	Last Mile Delivery Company
LPG	Liquefied Petroleoum Gas
LSP	Logistics Service Provider
LTL	Less Then Truckload motor carrier
LTZ	Limited Traffic Zone
MIP	Mixed Integer Programming
MIS	Mediation Information System
MODULUSCHA	MODUlar Logistics Units in Shared Co-modAl networks
MRP	Material Requirement Planning
MTO	Multimodal Transport Operator
M2M	Machine-to-Machine
NGO	Non Governmental Organisation
$\mathbf{N_2O}$	Nitrogen Oxides
OBU	On Board Unit
OCR	Optical Character Recognition

Abbreviation	Meaning
OLI	Open Logistics Interconnection
OR	Operations Research
OSI	Open System Interconnection
OTC	Open Tracing Container
$\mathbf{O_3}$	Ozone
PC	Purchasing Consortium
PCS	Port Community System
PDPTW	Pick-up and Delivery request with Time Windows
PG	Purchasing Group
PI	Physical Internet
PI-Nuts	Physical InterNet crossdocking hUb conTrol System
PSA	Priority and Speed Advice
QR	Quick Response
RAM	Random Access Memory
RDC	Regional Distribution Center
RAM	Random Access Memory
RFID	Radio Frequency Identification
RO-RO	Roll-on/Roll-off
RSU	Road Side Unit
SaaS	Software as a Service
SC	Supply Chain
SCM	Supply Chain Management
SCMS	Supply Chain Management System
SCP	Standardised Customs Procedures
SKU	Stock Keeping Unit
SITA	Socit Internationale de Tlcommunications Aronautiques
SME	Small and Medium Enterprise
SOA	Software Oriented Architecture

Abbreviation	Meaning
SV	Simulated Values
SW	Single Window
TEN-T	Trans-European Transportation Network
tkm	tonne-kilometre
TMS	Transportation Management System
TTW	Tank-to-Wheel
UML	Unified Modeling Language
UPC	Universal Product Code
US	United States
VICS	Voluntary Interindustry Commerce Standards
VMI	Vendor-Managed Inventory
VRP	Vehicle Routing Problem
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WAN	Wireless Area Network
WCI	Western Climate Initiative
WMS	Warehouse Management System
WS	Web Service
WTT	Well-to-Tank
WTW	Well-to-Wheel
XML	eXtensible Markup Language
1PL	First Party Logistics Service Provider
2PL	Second Party Logistics Service Provider
3PL	Third Party Logistics Service Provider
4PL	Fourth Party Logistics Service Provider
5PL	Fifth Party Logistics Service Provider

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