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# The role of service procurement mechanisms in collaborative freight transport networks: design and investigation using simulation and gamification approaches

Mariam Lafkihi

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**THÈSE DE DOCTORAT**  
**DE L'UNIVERSITÉ PSL**

Préparée à MINES ParisTech

**The Role of Service Procurement Mechanisms in Collaborative Freight Transport Networks: design and investigation using simulation and gamification approaches**

Ouverture des réseaux de transport logistique : conception et investigation des modèles d'interconnexion, potentiels et applicabilité

Soutenue par

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Le 19 juin 2020

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**Sciences de la Décision, des Organisations, de la Société et de l'Échange**

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## ABSTRACT

The importance of freight transport is amplified today by the rapid boom in E-commerce, and in particular new online-to-offline business strategies. To boost competitiveness, e-tailers and logistics service providers have devoted adequate efforts to managing express fulfillment services, e.g., same-day delivery (one or two-hour delivery), and various distribution and delivery channels. This has resulted in massive, high-frequency shipments with short lead times and fluctuating volumes. Moreover, freight transport organizations have undergone rapid changes. New markets and new technologies have emerged that will probably require innovative solutions as efficiency is still low. There is thus a strong motivation, involving economic, social, and environmental objectives, to develop more sustainable and efficient freight transport systems.

In this vein, horizontal collaboration has been largely studied, and its effectiveness and efficiency in freight transport have been proven in the recent literature (Pan et al., 2019). In particular, Collaborative Transport Networks are a horizontal collaboration solution attracting increasing attention (Berger and Bierwirth, 2010). Given the important role of freight transport in logistics and the multiple, compounding challenges faced by actors, an innovative, effective, and sustainable management of transport services procurement is needful for the emerging new collaborative transport networks. Moreover, new collaborative incentive mechanisms and rules are required to manage interactions between all the independent stakeholders in such networks.

This dissertation intends to explore collaborative mechanisms that manage the interactions between actors and guide the self-interested decisions of individuals toward an optimal global solution in such a way that these individuals are motivated to choose the optimal and rational solutions.

First, Chapter 2 presents a review based on the related literature and real-world practices providing insights into the organization and procurement mechanisms in current freight transport markets. Some evolving and disrupting trends are observed. These observations and gaps have motivated new research questions in the field.

Chapter 3 investigates the development and design of novel collaborative mechanisms for freight transport service procurement that are appropriate for the emerging CTN. The aim of the proposed collaborative mechanism is to increase the efficiency, effectiveness, and

sustainability of the network without decreasing the individual profit of the independent stakeholders. In order to test and evaluate the performance of the collaborative mechanisms, two approaches were used to gather theoretical and practical insights.

In chapter 4, a multi-agent simulation approach is presented to evaluate the theoretical performance of the collaborative mechanisms, and in chapter 5, the Serious Game approach is presented to analyze the practicability and usage barriers of the innovative collaborative mechanisms in the real-world.

This dissertation provides a picture of existing mechanisms for freight transport service procurement, challenges components of existing research, and provides ground for further research.

## RÉSUMÉ

La logistique est une dimension croissante et déterminante du management et de la compétitivité des entreprises qui entraîne avec-elle une part importante de la performance de l'économie et de l'emploi en Europe. Sans le développement de la logistique, toutes les innovations des deux derniers siècles n'auraient pas été possibles. Nous sommes certes arrivés à un niveau de performance extrême, avec notamment des livraisons en moins de 2 heures, mais cela a un coût : 25 % des trajets des transporteurs se font à vide et le taux moyen de remplissage des poids lourds ne dépasse pas les 65% dans les pays développés. Le transport de marchandises est actuellement piégé par un système peu utilisé et peu respectueux de l'environnement. Ce dilemme peut être résumé par : comment continuer à satisfaire les exigences toujours plus pointues tout en maîtrisant les coûts et en respectant des normes environnementales et sociales plus exigeantes ? Au-delà d'une transition énergétique nécessaire mais insuffisante, des solutions émergent, notamment la mutualisation et l'interconnexion des transports de marchandises à grande échelle.

La mutualisation en transport et logistique est un accord de partenariat qui consiste à la mise en commun volontariste de moyens physiques, d'informations et de compétences dans le but d'obtenir à long terme des gains économiques, écologiques et financiers. Le cadre de cette coopération peut revêtir des formes juridiques et organisationnelles variables en fonction de la nature des parties, des moyens et des produits ou services (Chai et al., 2013).

Depuis quelques années, les grands distributeurs ont compris rapidement l'intérêt de partager des capacités de transport ou de stockage en recourant notamment à des prestataires de services logistiques communs. Ce partage est une source d'avantage concurrentiel dans la mesure où il permet à la grande distribution, alimentaire ou spécialisée, de bénéficier d'économies d'échelle, et d'optimiser l'usage de ressources logistiques rares.

Les démarches de mutualisation connaissent toutefois aujourd'hui une réelle accélération. Des solutions de mutualisation logistique et de transport multimodal voient le jour dans plusieurs régions où les industriels travaillent ensemble en collaboration avec les clients et les transporteurs. Sur cette base, l'objectif de cette thèse est de proposer des mécanismes de collaboration, sur la base de la théorie des « Mechanism Design », permettant la gestion des relations entre les différents acteurs d'un réseau de transport collaboratif, d'évaluer leur

potentiel économique et écologique et d'étudier leur applicabilité dans un réseau de transport collaboratif.

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## **CHAPTER 1: General introduction and dissertation plan**

### **1.1. Research context**

Mark is a logistics manager in a distribution center for a retailer in France. With his team, he must supervise millions of packaged products every day. From inventory control, warehousing, and material handling to order processing and transport, Mark is aware that he must perform at a high level in order to be economically efficient and fight the intense competition.

To manage pallets and packaging, Mark traditionally had his own personal specialized logistics network comprised of logistics platforms linked by logistics services to suppliers and points of consumption. Given the size of the shops, it was impossible for Mark to serve all of the shops directly from the suppliers. So, he centralized the hypermarket's stock in warehouses between the plants and the customers where products were grouped before being redistributed. He entrusted his goods to asset-based carriers for delivery in exchange of an agreed-upon payment for the service or created a private carrier that transported the goods to the hypermarkets. By doing this, Mark was certain that the transport service was available when needed at a known cost. The operating cost could, however, be potentially very high as the carrier only works for the hypermarket and may be idle when demand for transport is low. Mark did his best to make good choices to control costs and still meet the delivery expectations of his customers.

Today, with the growth of technological innovations and the development of e-commerce, the nature of the transactions is changing. Mark's distribution center is no longer delivering to a limited number of sites consuming large volumes, but is making frequent deliveries of very small shipments from a multitude of sites and potentially to everyone – at their home, their place of work, or somewhere near them. Mark noticed that a dedicated and centralized network assigned to the distribution of his own consumer packaged goods was no longer an efficient solution. He then decided to share his logistics network with the network of another hypermarket serving the same customers for the sake of transport synergy. In addition, he outsourced part of his transport needs to non-asset-based 3PLs or 4PLs, which are logistics providers that focus on systems as their major assets (Sheffi, 1990) and do not invest in warehouses or trucks but subcontract that part of the business to asset-based providers (Regan and Song, 2001).

Peer-to-peer collaboration between firms is growing and taking on more importance with the trend in outsourcing. Collaborating firms collectively and mutually define and revise logistics and transport constraints (lane, lead time, delivery time windows, volumes, etc.) to increase logistics performance and reduce costs (Ergun et al., 2007). They outsource their transport needs to non-asset-based 3PLs or 4PLs who establish their mutual transport plans and send transport requests to carriers. The traditional transaction-based relationship is still used but nowadays, more companies like Mark's hypermarket are seeking the benefits of collaboration through partnerships and outsourcing. The ability to build partnerships is a critical advantage not just for a firm but also for a transport company or LSP. Partnerships with customers and suppliers are important, but so are alliances with other transport and logistics suppliers (Agarwal and Ergun, 2008; 2010; Albers and Klaas-Wissing, 2012). These alliances provide the strategic advantages of multiple partners to meet the demand for seamless, global, and comprehensive logistics services (Ihde, 2004; Houghtalen et al., 2011; Zhou et al., 2011).

There are notable examples of logistics and transport firms operating collaboratively. Companies such as *FedEx* and *DHL* have been partnering with national postal companies for many years. The idea of forming collaborations between carriers is well known in practice; in the European less-than-truckload market, six of the top ten carrier organizations are actually networks of collaborating small and medium-sized companies (KLAUS, 2003). There are many other examples of logistics companies sharing fleets and networks to use assets more efficiently. 'Collaborating' is a big story in logistics and transport now; from Uber-style approaches and last-mile delivery to more formal partnerships, the whole sector is redefining collaboration.

However, the multiplication of alliances and partnerships results in the partial optimization of the logistics and transport networks and, therefore, sub-optimal performance leading to inefficient allocation of resources and higher system costs. Moreover, the lack of coordination among the many actors involved results in losses in scale of logistics activities and poor use of resources. In Europe, for example, truck load factors vary from 47 % in Denmark to 63 % in the UK (excluding empty trips) and empty hauling makes up 30 % on average of total truck vehicle-kilometers (EEA, 2017). Fragmentation, accountability, and a lack of consistency make collaboration more difficult.

Today, the race is on to define the future of logistics and freight transport, and with an estimated revenue of €27.8 billion at stake in Europe (ECORYS and TCI, 2015), logistics and transport companies cannot afford to sit back and watch; they need to adapt to changes proactively. New solutions are emerging to help address the major logistics challenges by drastically increasing collaboration and cooperation between companies and across transport modes, and by making collaboration much more dynamic (Berger and Bierwirth, 2010). These solutions promise lower costs, improved efficiency and effectiveness (Agarwal and Ergun, 2008), and the opportunity to make genuine breakthroughs in the way logistics and freight transport work. However, for these solutions to work in practice, firms would need to be willing to collaborate and cooperate far more extensively than they do today.

That said, imagine the savings if all the distribution centers in Europe, which are standalone operations owned by different companies, were all connected, and physical flows were standardized for maximum efficiency. Imagine the increase in performance if the flow of goods was no longer controlled by a centralized body but found its way through the transport network to the destination while constantly communicating with conveyances and nodes and considering demands (e.g., delivery date and costs). So, imagine the advantages if logistics was organized via a collaborative, interconnected network that allowed sharing of resources and services, making logistics more collaborative and interoperable, and ensuring decentralized decision-making based on real-time data.

This dissertation addresses the freight transport service procurement problem in a collaborative, interconnected network, hereinafter called *Collaborative Transport Network* (CTN), as transport is the backbone of logistics and a large component of the economy. Freight transport plays an important role in today's economy and society, and has a large impact on growth and employment. It often accounts for between one-third and two-thirds of total logistics costs, between 9% and 10% of the gross domestic product (GDP) for the European economy, and between 10% and 20% of the price of the product (Transports, 2019). Moreover, freight transport is expected to further increase considerably over the next few years, while challenges are high and at the top of the political and societal agenda.

In the related literature, a CTN is generally defined as a common, shared, collaborative network for freight transport whose objective is to consolidate logistics flows from different stakeholders to improve freight transport efficiency and effectiveness (Agarwal and Ergun,

2008; 2010). The definition is vast enough to broadly cover different types of large scale collaboration in freight transport, including *vertical collaboration*, wherein different organizations such as suppliers, manufactures, LSPs, and retailers share their responsibilities, resources, and performance information to better serve their customers, *horizontal collaboration*, wherein two or more firms that operate at the same level of the supply chain cooperate actively to increase efficiency and effectiveness, *collaborative multi-modal transport*, or *collaborative city logistics* (Gonzalez-Feliu and Salanova, 2012; Ambra et al., 2019; Pan et al., 2019).

Given the importance of collaboration in transport systems generally and in CTN in particular, it is worth properly defining the term *Collaboration* to avoid any ambiguity about its difference with the inter-organizational relationships *cooperation* and *coordination*. In the related literature, these terms are sometimes regarded as interchangeable. Ring and Van de Ven (1992) established that collaboration is a cooperative relationship that is more intensive and has a common goal and higher level of trust. Compared with short-term cooperation, collaborations are based on the longer term, and often incur organizational restructuring. Spekman et al. (1998) explained that collaboration, cooperation, and coordination are different, require different levels of trust and commitment, and often lead to different outcomes. They explain that relationships that are both strategically important and complex to manage should be treated collaboratively. According to Nof et al. (2006), cooperation relationships only allow the exchange of information, whereas with collaborative relationships, task sharing and information exchange take place together. This means parts of a CTN may interact more intensively than those participating in cooperation. All these statements show that the term collaboration is used to describe a long-term inter-organizational relationship requiring a higher level of integration and more intensive interaction; it covers collaborative partnerships from operational level to strategic level.

However, sharing information and tasks in collaboration could be an issue and an impediment (Crujssen et al., 2007). For example, carriers are not willing to share information with their competitors. Collaboration needs to be very carefully handled so that it does not fall foul of competition law. There are several usage barriers that might result in the refusal to collaborate in real life: the difficulty to find a suitable partner with whom synergies can be established, profit sharing mechanisms, trust, information sharing, competitive issues, legal issues, enterprise culture, organizational structure, entry/exit rules, etc.

The reality is that the landscape of the emerging CTN is complex. It is promoted as a fast-growing area that is leading to actors re-imagining how they operate, and especially how to better utilize previously under-utilized assets. Thus, innovative, effective, and sustainable management of transport service procurement is needful. Moreover, new *collaborative incentive mechanisms* and rules are required to manage interactions between all the independent stakeholders in such networks (e.g., determine whether transactions are free or market-based, who is the sharing between, what is the governance model, etc.). By collaborative incentive mechanisms, we mean the organization, information exchange process, trading procedure, and sets of rules specifying how the freight transport collaborative network works and, more specifically, the permissible behavior of its participants.

With the current organization of freight transport, there are three major mechanisms that manage interactions between carriers in peer-to-peer collaborations or in alliances (Nandiraju and Regan, 2005; Caplice, 2007; Collignon, 2016): Catalogs (posted prices), Auctions, and Negotiations. Selecting the appropriate transport procurement mechanism is complicated; applying a “well-known mechanism”, which worked for one situation, to a second one, may not provide the same expected successful outcomes. In other words, a given mechanism may be very successful for one situation and may fail wholly for another. That said, applying one or a combination of these mechanisms to the CTN may have unintended repercussions and may fail. Consequently, this dissertation identifies the appropriate collaborative incentive mechanisms that lead to good performance in CTN.

## **1.2. Research questions and dissertation plan**

The variety of procurement mechanisms available in today’s freight transport markets in general, and more specifically in alliances and peer-to-peer collaborations shows that there is no single best solution for all freight transport service procurement problems. This fact provides the starting point to answer the question “*What major freight transport service procurement mechanisms are studied in research and used in practice and what are their performances?*” Chapter 2 answers this question. It provides a literature review of the current freight transport service procurement mechanisms studied in research, compares them with those used in practice, and investigates the challenges and opportunities regarding procurement mechanism design. Academic research can benefit from this review as it is one of the first to classify the existent freight transport service procurement mechanisms. For practitioners, it provides an overview of the state of the freight transport sector with regard to

incentive mechanisms, which can raise awareness of critical factors in the design of future freight transport service procurement mechanisms. A total of 78 articles published in academic journals between 1998 and 2017 were reviewed for this chapter. The systematic literature review (SLR) methodology recently studied in Durach et al. (2017) and in Koufteros et al. (2018) was adopted in order to create a tool for reviewing the literature on freight transport service procurement mechanisms. First, in an iterative process, a literature review was conducted and a framework was developed to guide the exploration of criteria that could impact adoption, use or success of a mechanism in the transport market. Seven main classification criteria were identified: procurement mechanism type, procurement mechanism ownership, transport mode, terms of agreement, participants on two sides, procurement mechanism outcomes, and article research methodology. The literature on freight transport service procurement mechanisms dealing with these criteria was reviewed. Second, the data collection process is detailed. Finally, some descriptive and categorization analyses regarding the data are provided (Lafkihi et al., 2019).

The first conclusion of the literature review that determines the most studied mechanism in freight transport markets in general, and more specifically in partnerships and alliances, leads us to wonder if these mechanisms are compatible with the constraints of emerging collaborative transport networks and what is needed to adapt them to this new structure. It provides the groundwork that is needed to answer the question: ***“What freight transport service procurement mechanisms are required in collaborative transport networks to facilitate interactions between stakeholders?”*** Chapter 3 focuses on the development of new collaborative mechanisms adapted to emerging CTN. First, the literature on collaborative freight transport networks was reviewed to identify all the specific constraints of these structures. Second, based on freight transport key performance indicators (KPI), a methodology is proposed to identify and design sets of collaborative rules to regulate interactions between individual carriers and guide them toward common goals: efficiency, effectiveness, and sustainability. Finally, two mechanisms integrating auction-based optimization models were developed and the rules for collaborative transport request assignment are proposed to increase the efficiency, effectiveness, and sustainability of CTN.

Using the new mechanisms developed in chapter 3, chapter 4 answers the following question: ***“How do collaborative freight transport networks perform when adopting the new***

*procurement mechanisms?”* After reviewing the literature on freight transport key performance indicators (KPIs), three freight transport objectives were identified to study the performance of CTN: Effectiveness, which is the degree to which a predetermined objective or target is met (Mentzer and Konrad, 1991); Efficiency, which is the degree to which expended resources are used to meet a goal (Mentzer and Konrad, 1991); and Sustainability, which is the ability of a system to protect, sustain, and enhance the human and natural resources that will be needed in the future while meeting a desired goal (Labuschagne et al., 2005). Second, a multi-agent simulation model is presented to evaluate the global performance of the proposed collaborative mechanisms and rules and to analyze their impact on the CTN. Third, an experimental analysis was conducted to verify if the pre-defined rules and mechanisms performed as predicted, and to evaluate the potential benefits to be gained by introducing them into various collaborative transport networks with different characteristics. Finally, the simulation model was used to analyze the decisions of individual carriers in order to verify if the proposed collaborative mechanisms and rules guide the self-interested decisions of individual carriers toward an optimal global solution.

The multi-agent simulation proved the theoretical success of the proposed collaborative mechanisms. However, the second conclusion drawn from the literature review reveals a gap between the mechanisms studied in the literature and those used in practice. This finding provides the groundwork needed to answer the following questions: ***“What are the obstacles to deploying the theoretically proven mechanisms and rules in an actual collaborative transport network, and how will the stakeholders behave in the face of these new mechanisms and rules?”*** Chapter 5 answers these questions. Gamification was used to realistically simulate the complex transport market and carrier decisions. First, a freight transport game was developed as a protected space where prospective actors can explore and try out the new collaborative mechanisms in a playful way. First, several sessions of the game were organized to observe player behavior and to study their impact on the global performance of the freight transport network. Second, the data from the game sessions were validated in order to use them to support the analysis. This step is fundamental before analyzing the game outputs. We used the same methodology as Smith et al. (2015) to collect and validate the data. Third, the innovative Game and Choice Based Simulation methodology (GCSM) created by (Caminada et al., 2020) was used to provide insights into player behavior.

Finally, based on these insights, a decision support tool for carriers was defined as a policy to optimize the performance of players. The proposed policy was tested in an experiment.

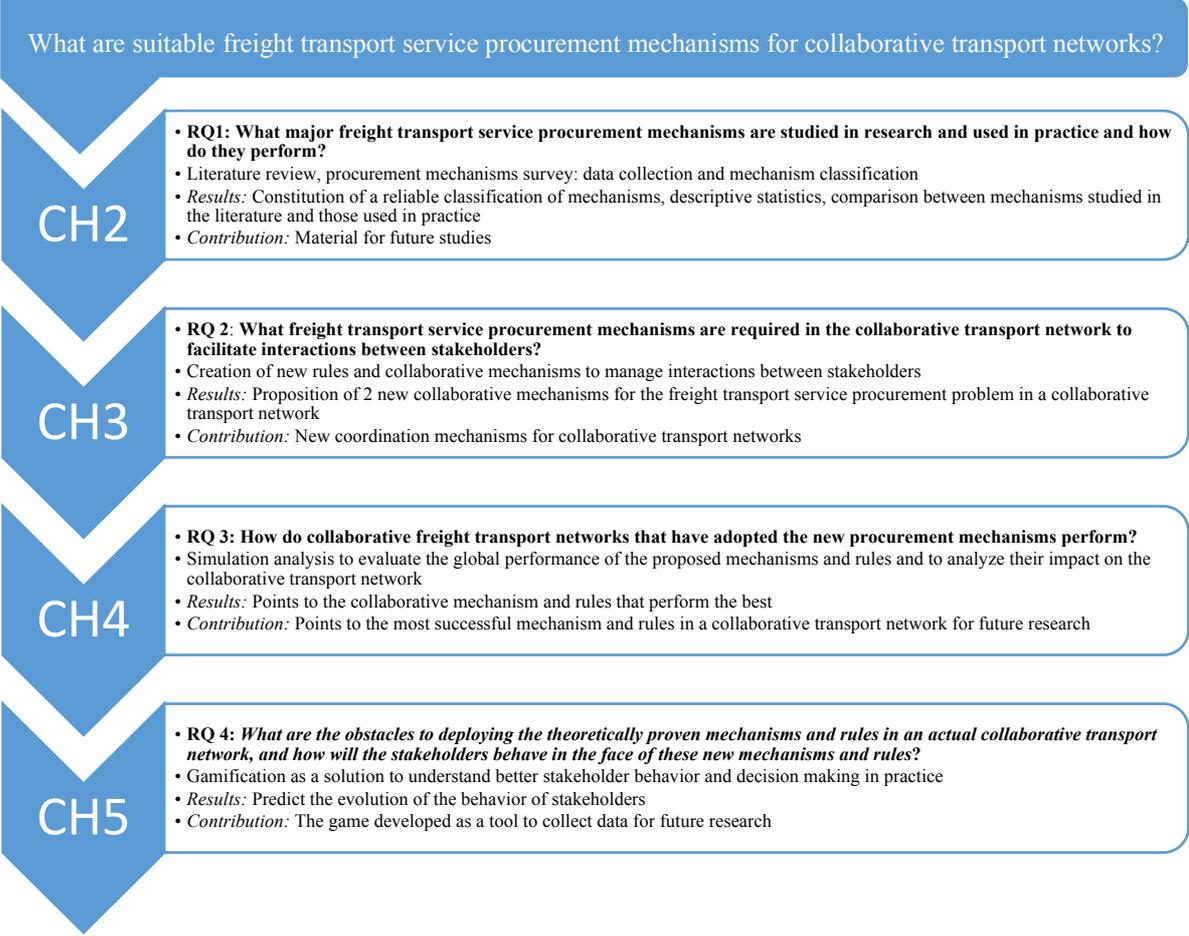


Figure 1: Dissertation plan

### 1.3. Research methodology

As discussed in chapter 1, the primary aim of this dissertation is to identify the appropriate collaborative procurement mechanisms that lead to good performance in collaborative transport networks, and implement them in real-life circumstances in order to analyze the barriers to these mechanisms.

To examine and understand the existent freight transport service procurement mechanisms, a combination of a literature review and the best practices survey method was adopted (Figure 2).

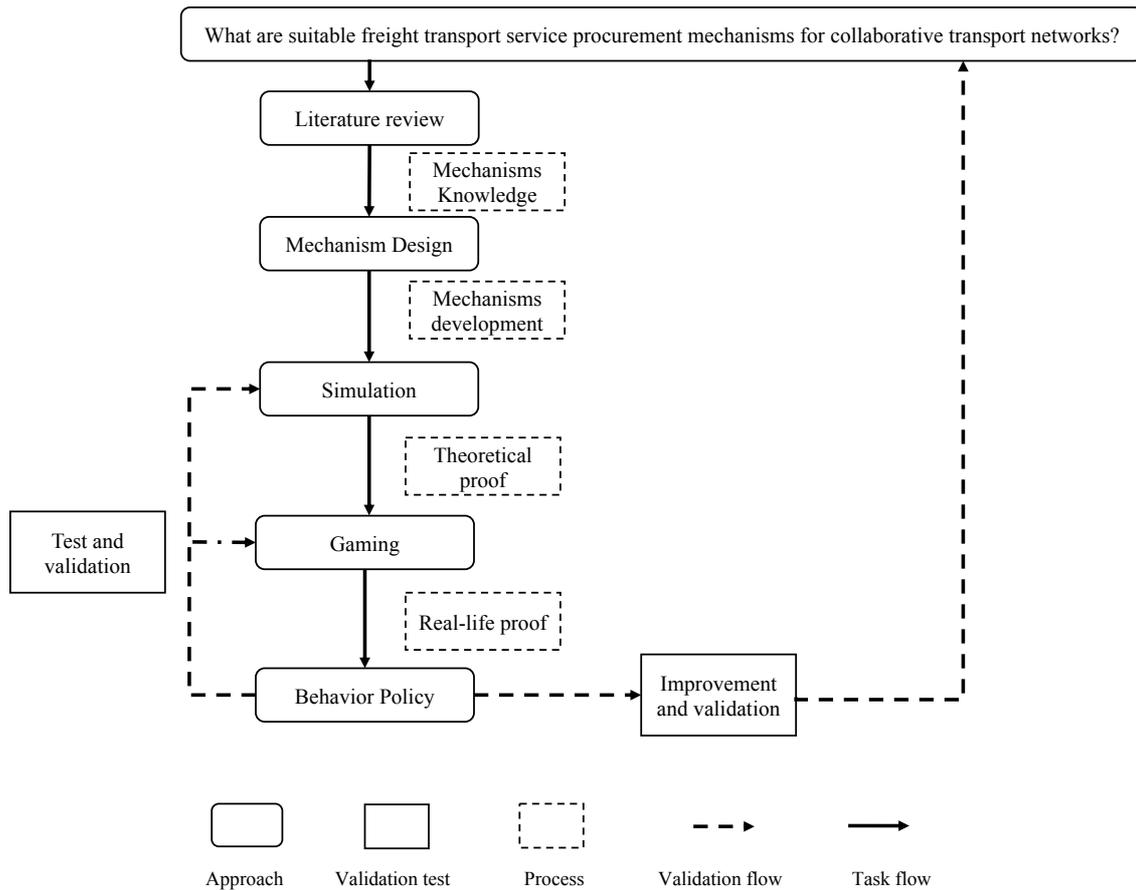


Figure 2: Research method

Based on the results of a survey presenting the pros and cons of the current best practices, mathematical modeling based on the Mechanism Design theory was adopted to design collaborative mechanisms and rules that increase the efficiency, effectiveness, and sustainability of freight transport systems without decreasing the individual profit of the independent stakeholders.

Then, a multi-agent simulation was used for performance analysis and assumption tests. The multi-agent simulation assessed the performance of the proposed mechanisms and rules.

Finally, gamification was adopted as an effective approach to simulate the highly complex freight transport market. A serious game was developed for behavior and decision-making analysis.

## **CHAPTER 2: Literature review and survey of existent freight transport service procurement mechanisms<sup>1</sup>**

### **Résumé**

Dans ce chapitre, nous créons un cadre théorique pour examiner la littérature scientifique sur les mécanismes d'achat de services de transport de marchandises. Un état de l'art complet de la littérature scientifique a été réalisé afin de comparer les mécanismes étudiés dans la littérature avec ceux utilisés dans la pratique.

Le cadre théorique qui a été créé comprend sept critères de classification :1) le type du mécanisme étudié, 2) la possession du mécanisme étudié, 3) le mode de transport utilisé, 4) les termes d'accord entre les différentes parties prenantes, 5) le nombre de participants dans le marché de transport, 6) les résultats et performances du mécanisme et enfin 7) la méthodologie de recherche utilisée pour étudier le mécanisme.

Nous examinons 78 articles publiés dans des revues académiques entre les années 1998 et 2017. Cette première étape d'analyse de la littérature permet une meilleure compréhension des mécanismes d'achat de services de transport de marchandises. Elle permet ainsi d'ouvrir la voie à de nouvelles études sur les mécanismes gérant les interactions entre les différents acteurs du système de transport.

### **Abstract**

In chapter 2, a framework was created to review existent freight transport service procurement mechanisms in research and compare them with those used in practice. This framework includes 7 classification criteria helping the adoption, use or success of a mechanism in a freight market and in studies: procurement mechanism type, procurement

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<sup>1</sup> This chapter is mainly based on the work and results that are presented in the article: Lafkihi, M., Pan, S., Ballot, E., 2019. Freight transportation service procurement: A literature review and future research opportunities in omnichannel E-commerce. *Transportation Research Part E: Logistics and Transportation Review*. 125, 348-365. <https://doi.org/10.1016/j.tre.2019.03.021>

mechanism ownership, transport mode, terms of agreement, participants on two sides, procurement mechanism outcomes, and article research methodology. A total of 78 articles published in academic journals between 1998 and 2017 were reviewed. This first reviewing step offers a way to reach a clearer understanding of freight transport service procurement mechanisms in current organizations and pave the way for future studies in need of elaborating new mechanisms for new freight transport markets and organizations. It also identifies the trends and gaps from the viewpoints of practitioners and researchers and provides insights into what types of mechanisms should be studied in the future and what are the obstacles to their use in practice.

## **2.1. Introduction**

The importance of freight transport is amplified today by the rapid boom in E-commerce (Verhoef et al., 2015; Savelsbergh and Van Woensel, 2016; Hübner et al., 2016a; Hübner et al., 2016b). In China, for instance, over 30 billion packages were delivered across the country in 2016, which is 53% more than in 2015 (data from the National Bureau of Statistics of China 2018). On 11 November 2018, the E-commerce festival in China generated more than 1 billion packages within only 24 hours, which is approximately 1/30 of the entire year.

Moreover, the performance of freight transport is becoming increasingly crucial to the sustainability of logistics and the Supply Chain. On the one hand, freight transport is the largest component of logistics costs for most shippers and can reach 60% of the total logistics costs of a firm. Cost-efficiency in transport is thus highly sensitive to logistics costs. On the other hand, the current state of freight transport is not sufficiently optimized and, therefore, is characterized by economic, social and environmental inefficiency and unsustainability. Despite efforts by transport companies, the frequency of empty trips remains high and average truck fill-rate is low. Overall, according to Eurostat (2017), at total transport level, most trucks in Europe fell within the range between 15 % and 30 % of empty journeys. Improving freight transport efficiency is therefore crucial to reduce logistics costs, as well as other negative environmental and social externalities.

To improve freight transport efficiency, the main research stream is applying Operations Research approaches to optimize transport operations, e.g., distribution network design, vehicle routing, transport planning. However, the appropriateness of the freight transport service procurement mechanism also significantly affects the efficiency and effectiveness of

freight transport operations (Caplice, 2007; Xu and Huang, 2013). But the problem has received relatively much less attention. The significance of freight transport service procurement can be understood by two facts regarding the freight market. On the one hand, the variety of procurement mechanisms available in today's freight transport markets, in theory or in practice, shows that there is no single best solution for all freight transport services procurement (FTSP) problems, e.g., combinatorial auctions, private or public exchanges, and electronic catalogs (Caplice, 2007). Applying a "well-known mechanism" may be very successful for one situation but totally fail for another with regards trading quantity, means utilization, service rate, etc. Selection of the appropriate transport procurement mechanism is worth investigating. On the other hand, the rapid evolution of the freight transport market requires guidance and guidelines for mechanism design and its applications. For example, spot markets have been increasing as more and more shippers are looking for short-term or one-shot services for their on-demand transport requests, in particular regarding less-than-truckload (LTL) or parcel shipments (see some online platforms such as uship.com, anyvan.com).

To have a comprehensive review of the state of the art, it was necessary to conduct a systematic review of recent research and applications on freight transport service procurement mechanisms. A relevant review was found in the literature (Jothi Basu et al., 2015). However, the study only focused on auction mechanisms for the Full Truck Load (FTL) sector. To the best of knowledge, no exhaustive and comprehensive review on FTSP mechanisms could be found in the literature. Therefore, this dissertation chapter looks to answer the following research question:

***What major freight transport service procurement mechanisms are studied in research and used in practice?***

Motivated by the research objectives and gaps in the literature, this chapter aims to exhaustively investigate all existing FTSP mechanisms in order to identify gaps from the viewpoints of practitioners and researchers and provides insights into what types of mechanisms should be studied in the future and what are the obstacles to their use in practice. It is worth mentioning that mechanism design has been studied considerably in other fields including computer science (Nisan, 2007; Parsons et al., 2011) and economics (Klemperer, 1999; Abdulkadiroğlu and Sönmez, 2003). However, this study focuses on a very different field that is logistics and transport. This chapter firstly focuses on reviewing the recent

relevant literature to show to what extent researchers have investigated the problem. To this end, we followed the guidance on writing literature reviews in Wee and Banister (2016), for the organization and structure of this chapter. For the review methodology, we adapted the systematic literature review (SLR) methodology discussed in Durach et al. (2017) and in Koufteros et al. (2018).

## **2.2. Systematic Literature Review**

### **2.2.1. Theoretical framework for studying procurement mechanisms**

This section defines the freight transport service procurement problem, explains the role of different actors in transport service procurement, and exposes the criteria helping the adoption, use or success of a mechanism in a freight market.

#### **2.2.1.1. What is the freight transport service procurement problem?**

Freight transport service procurement is the problem of matching shippers' transport needs and carriers' capacities. It generally refers to the problem of pricing transport services, determining delivery timing and quantity, and controlling costs and capacity to reduce empty trips and improve market efficiency (Song and Regan, 2003; Sheffi, 2004; Huang and Xu, 2013). This problem can be seen from different standpoints. From a shipper (carrier) standpoint, the problem is the selection (supply) of services and the choice of the proper methods of buying (selling) them. From a market standpoint, it is the determination of methods and settings that incite shippers (carriers) to buy (sell) services efficiently and effectively. There are two main questions concerned in the transport service procurement problem: how to procure and at what price. The former is investigated via a mechanism design approach, and the latter via a dynamic pricing approach. This dissertation will focus on the first point about how to procure transport services in a CTN and what are the appropriate mechanisms for that.

#### **2.2.1.2. Who are the actors in freight transport service procurement studies?**

Transport services always include at least three actors: the carrier who is the buyer of the transport service, the shipper who is either the buyer or supplier of the goods subject to transport, and the transport service provider.

- Carriers: offer the transport services to shippers. They could offer a vehicle or a fleet to a particular shipper with a customized service, or accept transport demands from different shippers.
- Shippers: propose the demand for freight transport. They decide whether to transport the goods by themselves or outsource them to carriers or intermediaries, through considering the availability and characteristics of the services provided on the market (e.g., price, quality).
- Transport service provider: a freight forwarder who manages the shipments of shippers by contracting one or several carriers. He provides services for shippers who do not own a fleet and do not want to make the planning decision either.

#### 2.2.1.3. What criteria help the adoption, use or success of a procurement mechanism?

With regard to the research questions, an initial framework is proposed, as shown in Figure 3, comprising four groups of criteria to categorize the literature. Firstly, we are interested in all procurement mechanisms that are applicable to the freight transport market and the holders of these mechanisms. Then, according to our expertise and experience, freight transport markets may vary, especially as regards transport mode (road, rail, or intermodal, etc.), terms of agreement (long-term, short-term, one shot, etc.), and participants on two sides (many-to-few, many-to-many, etc.). They are generally called market characteristics in the framework. The performance and impact of a mechanism can vary due to the different market characteristics. It is thus significant to study the outcome of the mechanisms regarding either stakeholder or market efficiency. In addition, we are also interested in the methodology used in the literature in order to identify the most common and powerful methodology for the research problem, as well as research trends.

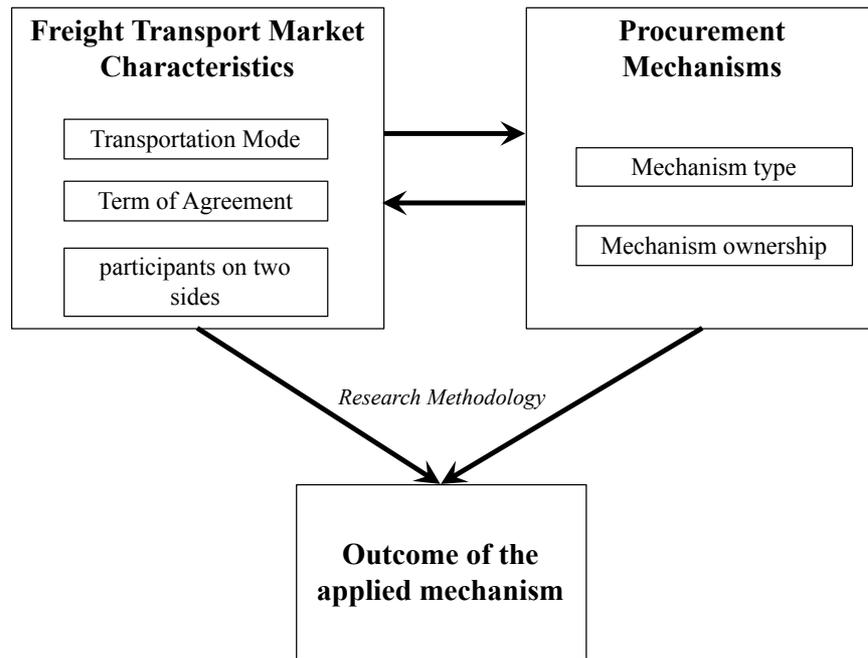


Figure 3: Theoretical review framework

### 2.2.2. Literature location and selection

The review adopts the systematic literature review (SLR) methodology recently studied in Durach et al. (2017) and Koufteros et al. (2018). According to the references, SLRs commonly comprise six steps: (1) define the research questions and theoretical framework, (2) determine the inclusion/exclusion criteria, (3) locate potentially relevant literature, (4) select the pertinent literature according to the inclusion/exclusion criteria, (5) summarize the literature and refine the initial framework, and (6) report and use the results.

The steps and criteria to locate and select studies, as well as the reasoning behind each criterion, are presented in Table 1.

<i><b>Inclusion &amp; Exclusion criteria</b></i>	<i><b>Reasoning</b></i>
Paper published between 1998 and 2017 (available online included)	Papers published in the past twenty years
Paper published in peer-reviewed academic journals	To focus on high-quality publications (Touboulic and Walker, 2015)
Paper written in English	English is the dominant language in SC and logistics research
Paper investigating freight transport service	This is the research problem in this paper

### ***Literature Location***

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This step involved two tasks. The first step was to locate relevant literature in the field of logistics and transport in well-known databases including Springer, Emerald, Science Direct, Informs, Wiley online library, Taylor & Francis, and JSTOR. We then completed the search with Web of Science, Scopus, and Google Scholar.

The second step was to define a list of keywords. The main keywords used were “mechanism”, “procurement”, “markets”, “freight”, and “transport(ation)”. In addition, keyword groupings such as “transport purchasing services”, “Freight transport procurement service mechanisms”, and “transport market mechanisms”, were used to complete the search. Moreover, to comprehensively cover all mechanisms addressed in the literature, the three keywords (negotiation, auction, and catalog) representing the three major mechanisms implemented in transport markets, according to a previous study (Caplice, 2007), were added. We applied multiple combinations of the keywords in an attempt to find an exhaustive list of all the relevant literature.

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### ***Study Selection***

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Using the keywords mentioned above and the databases chosen, 634 articles were located.

According to the inclusion criteria in Step 1, 409 articles were pre-selected.

All the remaining articles were saved in the reference management software Endnote in order to review the titles, abstracts, and content and only keep articles in which the clear focus of the research was FTSP mechanisms, including articles comparing and reviewing mechanisms. Finally, 78 articles were selected for review and analysis.

Other forms of publications such as conference papers, books, reports, theses, are discussed in this paper without being included in the review framework.

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*Table 1: Study selection steps and criteria*

#### 2.2.3. Data collection and determination of the classification

The 78 papers selected are classified in Appendix A according to the SLR methodology. After the initial analysis of the selected papers, this section aims to refine the theoretical framework as well as the categorization criteria (Figure 3).

**Procurement mechanism type:** Several articles (Nandiraju and Regan, 2005; Caplice, 2007) have classified FTSP mechanisms implemented in trading institutions into three major types: (a) Catalogs (posted prices), wherein carrier offers are posted and the sole choice of the shipper consists in picking the carrier that best fits its own needs. Several markets or platforms such as *Iship*, *Freightquote*, and *Smartship* use this mechanism. (b) Auctions, wherein one party (most often the shipper) posts its requirements and several players in the other party (most often the carriers) place bids. These automated on-line mechanisms such as *Uship* and *Anyvan* are widely used in transport service procurement (TSP). (c) Negotiations, wherein players on both sides of the market, shippers and carriers, bargain over the conditions of an exchange. Several transport procurement services such as *DAT Load Boards*, *The Internet Truck Stop*, and *Getloaded* use this mechanism.

**Procurement mechanism ownership:** indicates which of the trading parties manages and defines the rules of the mechanism (e.g., carrier, shipper, or a third party). As stated in Sharifi et al. (2006), the mechanism ownership categories are (a) carrier-owned, (b) shipper-owned, and (c) third-party-owned.

**Transport mode:** Transport systems catering to different transport modes have proliferated in recent years. The dominant mode is (a) road transport, which can be further divided into two sectors: Full Truckload (FTL) wherein carriers operate over irregular routes and move from origin to destination without any intermediate stops, and Less Than Truckload (LTL) wherein carriers require the use of terminals and scheduled routes to collect small-sized shipments and consolidate them into larger loads. Moreover, other transport modes such as (b) railway transport, (c) air transport, and (d) maritime transport are also considered in procurement mechanism design. Some freight marketplaces such as GoCargo (ocean shipping) and Global freight exchange have emerged in recent years.

**Terms of agreement:** refers to the nature of the contract used in different transport markets. According to the purpose of the service, there are two major modes of market: (a) spot market, wherein shippers are looking for one-time (one-shot) services for their on-

demand transport requests, and (b) contract market, wherein shippers are seeking to transport their requests over a specific time horizon (i.e., multiple services).

**Participants on two sides:** represents the number of participants on each side in the shipper-carrier relationship (Wang and Archer, 2007). In the literature several categories of shipper-carrier markets are considered: (a) many-to-few for a market with many shippers and few carriers, (b) many-to-many for a market with many shippers and many carriers, and (c) few-to-many for a market with few shippers and many carriers. In this review, the term few includes one, e.g., many-to-few markets include many-to-one markets.

**Procurement mechanism outcomes:** The FTSP mechanisms impact numerous variables and outcomes, e.g., transaction process, on-time performance, transport cost, relationships between agents, trust, achievements and satisfaction, ease of use and usefulness, perceived opportunism. These outcomes can be aggregated at two levels: individual outcomes or market outcomes. Individual outcomes contain: Objective Outcomes, which include utility value, values of different attributes, and time spent on the transaction, etc., and Subjective Outcomes, which include trust, relationships between agents, their achievements and satisfaction, perceived opportunism, etc., whereas market outcomes include allocation efficiency and social welfare.

**Article research methodology:** From the articles reviewed, 5 categories of methodology were observed: (a) conceptual analyses, which comprise theoretical studies reporting issues and challenges without any numerical or empirical studies, (b) case studies, which investigate real-world cases often with data and results, (c) literature reviews, (d) empirical studies based on observed and measured phenomena deriving knowledge from actual experiences rather than from theories or beliefs, and (e) numerical experiments, which involve studying approximation techniques for solving problems.

## 2.3. Descriptive Analysis

This section aims to analyze the literature according to the distribution of the papers in different journals over time and the different authors. All papers selected were positioned according to the categorization criteria presented in the initial framework. This classification allowed us to determine the areas of major interest to date and the areas where research gaps are evident.

### 2.3.1. Publications by year

Based on the 78 articles selected, the first observation is that the number of publications has been increasing in recent years, with 36 papers published in the last 5 years (see Figure 4) and only two papers published between 1998 and 2002. This trend reflects the increasing interest in research on innovative mechanisms and guidelines for mechanism design, stimulated by recent rapid changes in freight transport markets and the emergence of new freight markets.

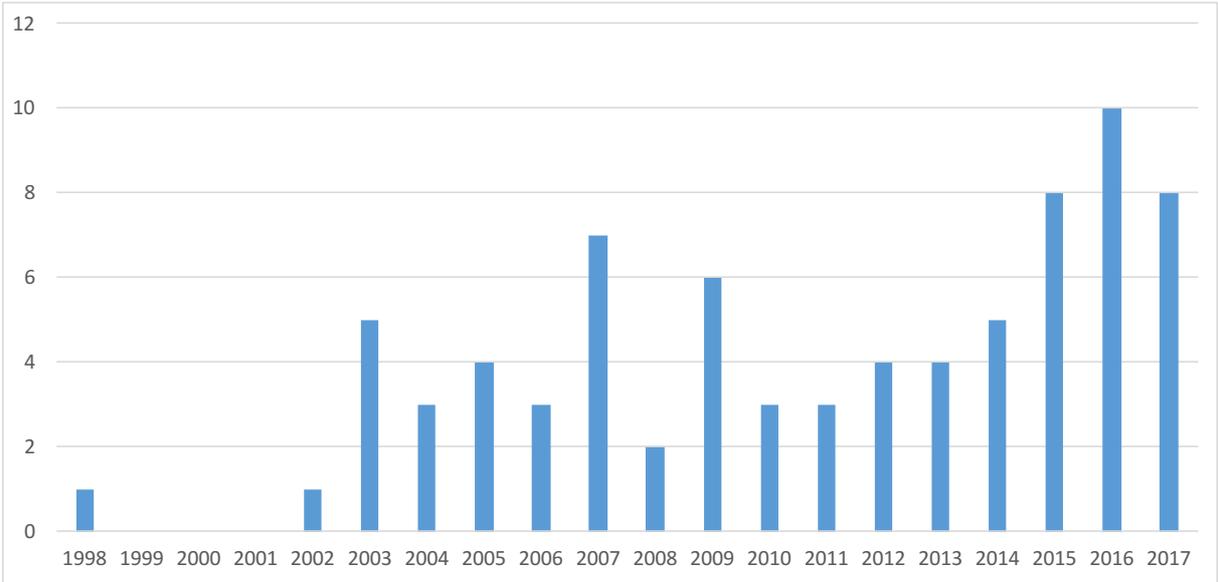


Figure 4: Distribution of articles per year

2.3.2. Publications by journal

The 78 articles selected were published in 35 different international journals in the field of logistics and transport, and particularly in Management Science and Operation Research. Six journals account for almost half of the articles (see Table 2), while the remaining articles were published in 29 different journals. Three journals made special contributions: Transportation Research Part B: Methodological published the most articles, followed by Transportation Research Part E: Logistics and Transportation Review, and Transportation Research Record: Journal of the Transportation Research Board.

<i>Journals</i>	<i>Number of papers</i>	<i>Percentage</i>
Transportation Research Part B: Methodological	11	14.10%
Transportation Research Part E: Logistics and Transportation Review	9	11.54%
Transportation Research Record: Journal of the Transportation Research	6	7.69%

European Journal of Operational Research	5	6.41%
Transportation Science	5	6.41%
Interfaces	3	3.85%
Computers & Industrial Engineering	2	2.56%
Computers & Operations Research	2	2.56%
Journal of Intelligent Manufacturing	2	2.56%
Journal of Operations Management	2	2.56%
Journal of the Operational Research Society	2	2.56%
OR Spectrum	2	2.56%
Production and Operations Management	2	2.56%
Transportation Research Part C: Emerging Technologies	2	2.56%
Transportation Research Procedia	2	2.56%
European Journal of Operational Research	1	1.28%
Annals of Operations Research	1	1.28%
Decision Analysis	1	1.28%
Decision Support Systems	1	1.28%
Expert Systems with Applications	1	1.28%
Industrial Marketing Management	1	1.28%
Information Systems and e-Business Management	1	1.28%
Journal of Business Logistics	1	1.28%
Journal of Environmental Economics and Management	1	1.28%
Journal of Rail Transport Planning & Management	1	1.28%
Logistics Research	1	1.28%
Marketing Science	1	1.28%
Networks and Spatial Economics	1	1.28%
Omega-International Journal of Management Science	1	1.28%
Operations Research	1	1.28%
Optimization Letters	1	1.28%
The International Journal of Logistics Management	1	1.28%
Transport Reviews	1	1.28%
Transportation Research Part A: Policy and Practice	1	1.28%
Transportation Research Part B: Methodological	1	1.28%

Table 2: Distribution of articles in journals

### 2.3.3. Publications by author

Table 3 represents the top ten contributing authors and the number of contributions in the field of FTSP mechanisms. Su Xiu Xu and George Q. Huang from the University of Hong-Kong have been the most productive in this field with 8 and 6 papers, respectively. The next most prolific have been Mahmassani Hani with 6 publications, and Jaillet Patrick, Lim Andrew, and Figliozzi Miguel with 5 publications each.

<i>Authors</i>	<i>Number of contributions</i>	<i>Percentage</i>
Su Xiu Xu	8	10.39%
George Q. Huang	6	7.79%

Mahmassani Hani	6	7.79%
Jaillet Patrick	5	6.49%
Lim Andrew	5	6.49%
Figliozi Miguel	5	6.49%
Chen Haoxun	4	5.19%
Meng Cheng	3	3.90%
Regan Amelia	3	3.90%
Triki Chefi	3	3.90%

Table 3: Ten leading authors in the field

## 2.4. Classification Analysis

This section reports the key findings from the literature review. Derived from the categorization criteria, the discussion is based mainly on one table and two figures. Appendix A shows the classification of the papers studied according to the categorization criteria. Figure 5 shows the distribution of the literature according to the categorization criteria. Figure 6 shows the number of papers per classification criterion and per period of 5 years, i.e., 1998-2002, 2003-2007, 2008-2012, and 2013-2017.

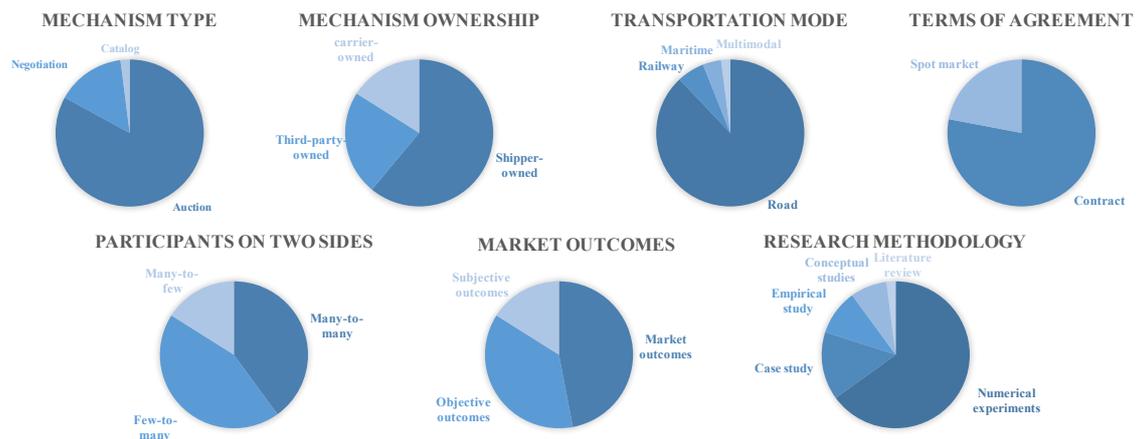


Figure 5: Distribution of papers according to the classification criteria (in percentage)

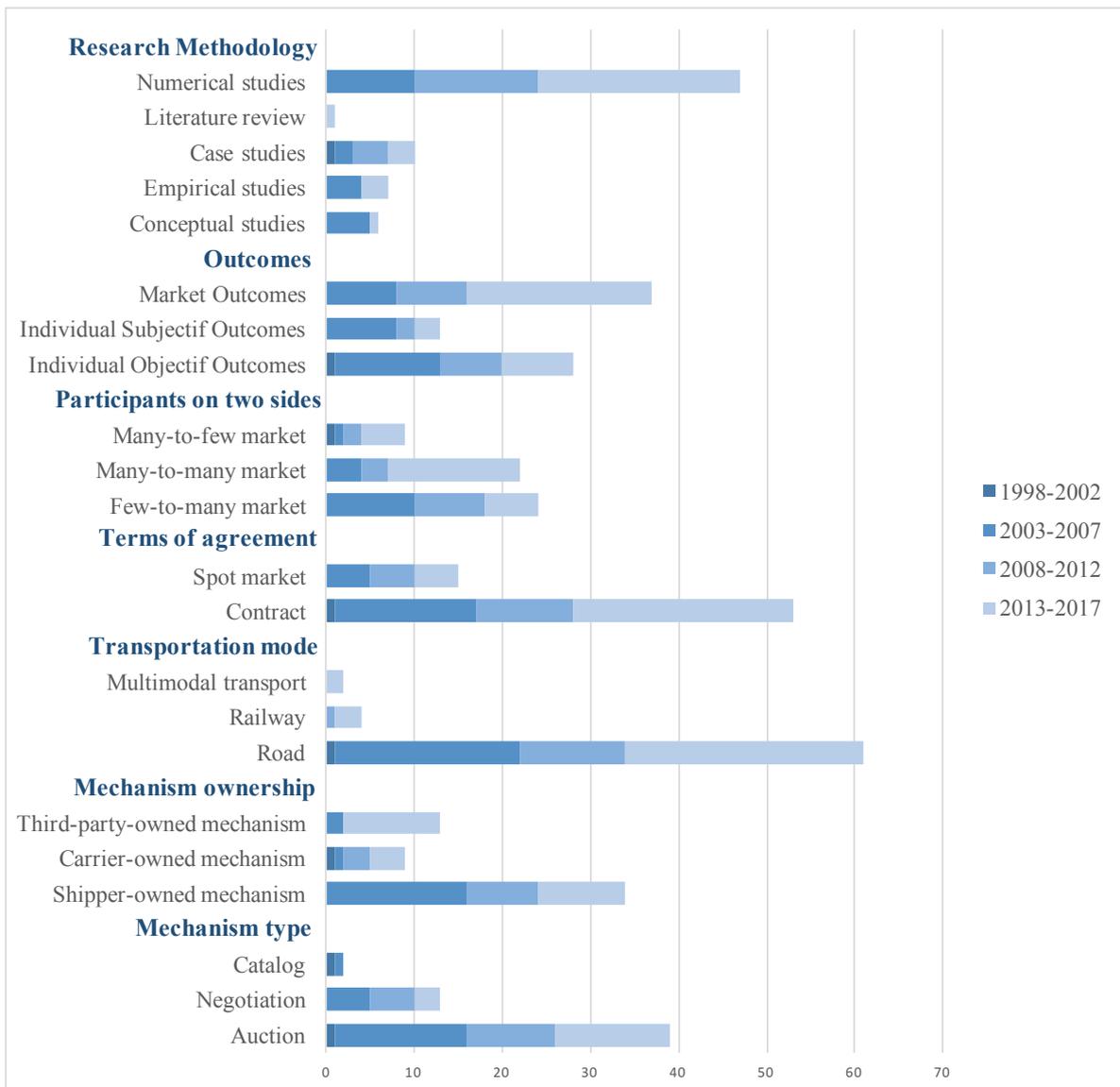


Figure 6: Number of papers per criterion and per period

**Procurement mechanism type:** The first notable conclusion drawn from Appendix A and Figure 5 is that auctions are the mechanism addressed the most by academia - 83% of articles in this review deal with auction mechanisms, while 15% deal with negotiation and only 2% deal with catalogs.

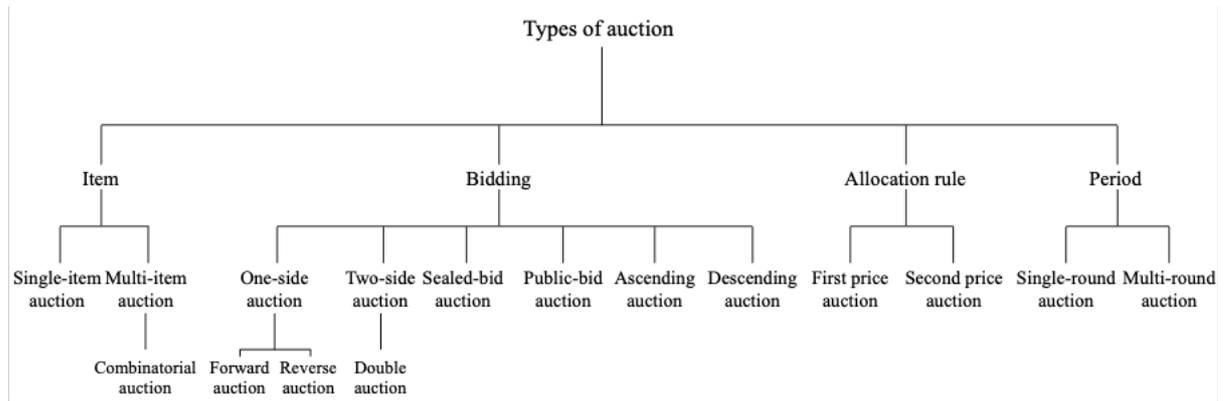


Figure 7: Classification of auction types in the freight transport literature

Different auction mechanisms have been studied in the freight transport literature. Here we propose a classification framework according to four criteria: trading item (single-item, multi-item or combinatorial auctions), bidding strategy (one-side, two-side, sealed-bid, public-bid, ascending or descending auctions), allocation rule (first price or second price auctions), and auction period (single-round or multi-round auctions) (see Figure 7).

Regarding the trading item, Caplice and Sheffi (2003) explained that shippers traditionally use single-item auctions to procure transport services for a set of lanes (or for an entire region) from a single carrier. Advantages of such a mechanism include allowing the carrier to provide coverage during a surge in demand or allowing easier carrier selection at the operational stage. In recent years, the development of technologies used in freight transport markets allows shippers to use multi-item (or multiunit) auctions wherein they assign more than one carrier to a lane. Similarly, the rise in online marketplaces allows shippers to put all lanes simultaneously online so that carriers can simultaneously bid on combinations of lanes, i.e. using combinatorial auctions. The pertinence of combinatorial auctions in FTSP is argued in Özener et al. (2011) as they enable synergies between requests/lanes, and particularly for exploiting the economies of scope in transport as stated in Sheffi (2004). A review of practical issues relating to the execution of combinatorial auctions can be found in Caplice and Sheffi (2003).

Several papers in the freight transport literature have studied different bidding strategies of auction mechanisms. The bidding strategy discussed here involves three questions - who can bid, how to bid, and at what price. One-sided auctions mean either the buyer or the seller can bid. This includes forward auctions wherein shippers (service buyer) bid on carrier capacities (seller), and reverse auctions in a contrary way. During the last twenty years, reverse auctions

have been the dominant research interest in this field (Ledyard et al., 2002; Song and Regan, 2003; Sheffi, 2004; Song and Regan, 2005; Figliozzi et al., 2007; Chen et al., 2009). In recent years, researchers have begun to address two-sided auctions (also called double auctions) that require both the buyer and the seller to name a price, see Xu and Huang (2013) and Xu and Huang (2014) for example. According to Xu and Huang (2013) and Cheng et al. (2016), the use of double auctions is promising for FTSP, as it allows shippers and carriers to bid simultaneously and reduces trading inefficiency. In addition, double auctions could reduce the opportunism perceived with reverse auctions that could lead to a loss of trust. Some other papers have addressed the question of how to bid. For example, carriers as bidders may have visibility of the price submitted by their competitors or not, i.e., public-bid auctions or sealed-bid auctions, respectively (Cheng, 2011). Due to the issue of information privacy, sealed-bid auctions have been the most used in freight transport markets (Carter et al., 2004; Berger and Bierwirth, 2010; Mesa-Arango and Ukkusuri, 2013; Jothi Basu et al., 2015). The third question concerns the bidding strategy, for example ascending/descending auctions. This type of auction is represented little in the freight transport markets, however, some papers have tried to highlight its advantages compared to sealed-bid auctions. (Xu and Huang, 2014) explained that the implementation of descending auctions (like Dutch auction) seems to be simpler and more transparent for carriers. Moreover, in descending auctions, carriers are allowed to decrease their bids, so a carrier can start by placing a high bid and revise it when competitors' bids are revealed. Cheng et al. (2016) claimed that both ascending and descending auctions seem simple enough to be understood by any carrier. The problem may extend to the dynamic pricing problem for carriers as studied in (Qiao et al., 2016; 2018).

In the freight transport literature, there are two plausible allocation rules for an auction. First-price auctions in which the carrier making the lowest bid claims the item and receives the amount he has bid, and second-price auctions (e.g., Vickrey auction) in which the lowest bid wins the auction, but the winning carrier only receives the amount of the second-lowest bid. Even though second-price auctions have been proven to be truthful bidding mechanisms, they are rare in the freight transport literature, contrary to first-price auctions (Brewer and Plott, 2002; Figliozzi et al., 2007; Kuo and Miller-Hooks, 2012). This could be due to the information privacy issue in real-life applications.

Regarding the auction period in freight transport markets, we can distinguish two forms. Single-round auctions involve a one-time submission of bids by carriers, and then the

auctioneer determines the final allocation decisions (Elmaghraby and Keskinocak, 2004). Whereas with multi-round auctions involve several iterations of submitting bids by carriers and updating allocation decisions by the auctioneer until some stopping criteria are met (Wang and Kopfer, 2014; Li and Zhang, 2015). There is continuing debate over the benefit of having multiple round auctions. Kwon et al. (2005) argued that multi-round formats provide information feedback for carriers whereby they can adjust their bids so that better allocations can be made. Ledyard et al. (2002) presented their experience of using multi-round combinatorial auctions for Sears Logistics Services. The company had been savings millions of dollars annually by providing rate visibility to carriers based on the information received from previous rounds. Elmaghraby and Keskinocak (2004) described the experience of Home Depot using a single round combinatorial auction mechanism for procuring FTL transport services to ship freight to its thousands of stores. Home Depot favored a single round bid in order to reduce the probability of a “damaging price war between carriers” that would result in lower overall service levels.

Besides, all the types of auction mentioned below have been studied for both FTL and LTL industries. Each type of auction could be studied alone or in combination with other types. Wang and Kopfer (2014) proposed a route-based multi-round iterative combinatorial auction for collaborative freight transport of LTL carriers. Recently, Li and Zhang (2015) studied a multi-round auction of the carrier collaboration problem in FTL transport with pickup and delivery requests by proposing a single request auction mechanism for request exchange.

Negotiation mechanisms were studied in fifteen percent of the articles in the survey. Negotiations appear in a multitude of forms in FTSP. The most traditional one is face-to-face negotiations, and others could include using e-mail, fax, and telephone. Nowadays, several electronic marketplaces propose negotiation mechanisms (Collignon, 2016), wherein shippers post their loads and carriers post their residual capacities. When one party is interested in the other party’s offer, one-on-one negotiations start. There are also bilateral and multi-bilateral negotiations (i.e. negotiations between one shipper and several carriers or vice versa). In transport markets, a negotiation mechanism could be implemented alone or with other mechanisms. Caplice (2007) argued that in any truckload auction there is usually a final soft negotiation round after the WDP is solved. Pontrandolfo et al. (2010) conducted an experiment to compare auction and negotiation mechanisms for TSP. They concluded that the choice of the FTSP mechanism may not be determined solely by the economic performance.

The type of mechanism alone has no significant effect on the economic outcomes. Nevertheless, the mechanism type could affect the participants' perceptions in evaluating their own outcomes and performance.

Finally, only two percent of the articles in the survey deal with catalogs. They are not widely considered in freight transport research as catalog services and prices are normally pre-defined and static (sometimes negotiable). (Caplice, 2007) explained that catalogs are used by large shippers to manage their FTL operations and are replaced by auctions for emergency distraught or distressed freight.

**Procurement mechanism ownership:** A second observation drawn from Figure 5 is that shipper-owned mechanisms are dominant compared to carrier-owned or third-party-owned mechanisms. The result is consistent with the dominant studies in the literature on reverse auction mechanisms wherein shippers manage the rules (Carter et al., 2004; Carter and Stevens, 2007).

**Transport mode:** A third observation concerns transport modes. Figure 5 shows that road transport is dominant compared to other transport modes (it represents 88% of transport modes studied). Indeed, many articles deal with road transport auction mechanisms. The term bundle is widely used in the literature on combinatorial auction mechanisms for road transport, whether for FTL or LTL, to estimate the transport synergy between the requests. Among the selected papers, only one (Xu et al., 2015) addresses multimodal transport.

**Terms of agreement:** According to Appendix A and Figure 5, both long-term procurement plans and short-term practices (spot markets) have been adequately studied, although long-term contract mechanisms have received more attention. Rekik and Mellouli (2012) introduced the concept of reputation-based allocation of lanes for long-term contracts for carriers in truckload transport procurement auctions. Schwind et al. (2009) proposed a long-term combinatorial exchange for medium-sized food delivery industries. Nandiraju and Regan (2005) and Sheffi (2004) claimed that in most cases, shippers prefer long- to mid-term transport service procurement contracts to transport goods to avoid volatility in future prices and to ensure capacity availability and quality of service. However, in some cases, uncertainties (e.g., evolution in shipper flow or demand, transport market evolution, fuel price fluctuation) may destabilize or disrupt these long- to mid-term contracts, forcing shippers to improvise at the last minute and use short-term contracts. The latter helps to eliminate some

of the complexities of long-term contracts when procurement criteria are clearly defined (Nandiraju and Regan, 2005). Besides, the terms of agreement also depend on the relationships between the actors. Grieger (2003) and Kwon et al. (2009) showed that spot markets are more adapted to situations where no close relationship is necessary, whereas Sharifi et al. (2006) suggested that markets owned by a third-party are more adapted to short-term practices. Various researchers have also addressed the spot market. Figliozzi et al. (2004) introduced a sequential auction format and discussed the truckload procurement in spot markets. Garrido (2007) exploited spot market opportunities by studying the procurement of transport services with real time information. Mes et al. (2009) developed profit maximization strategies for shippers in the spot market. Xu and Huang (2013) proposed a methodology in the spot market to address TSP with asymmetric demand.

***Participants on two sides:*** According to Figure 6, many-to-few markets (i.e. many shippers-to-few carriers) have received much less attention than others over the last twenty years. Few-to-many markets were obviously the main research stream between 2003 and 2012. However, research interests have gradually evolved to many-to-many markets in the last 5 years. This observation implies that carriers have been in increasing competition over the past few years due to the globalization and opening of local markets, resulting in primarily shipper-led freight markets. Nevertheless, to avoid the winner-take-all scenario, researchers have been looking for win-win mechanisms in many-to-many markets to maximize social welfare.

***Procurement mechanism outcomes:*** Many articles focused on individual objective outcomes. For example, references (Ledyard et al., 2002; Alp et al., 2003; Andres Figliozzi et al., 2003; Figliozzi et al., 2005; Lee et al., 2007) stated that the use of reverse auctions minimizes (maximizes) the expected total cost (profits) for shippers (carriers), and Kersten (2009) reported that multi-attribute reverse auctions are efficient mechanisms producing efficient solutions that maximize the buyers' utility. Conversely, some articles focused on individual subjective outcomes. Carter and Stevens (2007) studied the benefits and drawbacks of using reverse auctions in transport procurement from different perspectives. On the one hand, some participating suppliers are aware of opportunistic suppliers; on the other hand, from the buyer's perspective, reverse auctions can yield lower purchase prices. Moreover, Gattiker et al. (2007) underlined that sellers who use negotiation always report greater trust in their buyer counterparts than sellers using reverse auctions. Finally, there are also some

articles that focused on market outcomes and proposed efficient resource allocation mechanisms that minimize the total transport cost, see (Xu and Huang, 2013; 2014; Xu et al., 2015). Figure 5 shows that any subjective outcomes are given less importance and less attention compared to objective outcomes and market outcomes.

**Article research methodology:** Figure 5 shows that computational and numerical experiments are by far the most common in the literature. Most of the studies attempted to use mathematical models or simulation techniques. Berger and Bierwirth (2010) proposed a mathematical model for collaborative carrier networks wherein carriers exchange lanes in order to maximize the total profit without decreasing the individual profit. Guo et al. (2006) developed a mathematical model for the carrier assignment problem (CAP). Lee et al. (2007) developed a nonlinear integer programming model for the bid generation problem (BGP) to maximize the profit. Ma et al. (2010) formulated a two-stage integer programming model for CAP. Chang (2009) developed a bidding advisor for solving the bids generation problem for carriers by using a heuristic procedure. Figliozzi et al. (2006) used a simulation framework to evaluate different strategies adopted in sequential auctions for TSP. Ağralı et al. (2008) used a simulation study to evaluate the performance of the spot market. Zhang et al. (2014) used a Monte Carlo Approximation method to solve a two-stage stochastic WDP under volume uncertainty. Mes et al. (2009) conducted a simulation study to analyze the performance of the dynamic threshold policy adopted by the shipper in the spot market. Song and Regan (2005) conducted a simulation-based experiment to examine the performance of the proposed bid construction method involved in BGP. Moreover, multi-agent systems could be used as an important tool in FTSP. Robu et al. (2011) shed light on the effectiveness of agent-based systems in day-to-day transport outsourcing activities.

Fifteen percent of the articles studied in the literature review operated case studies. Ağralı et al. (2008) considered the logistics spot market in Turkey to evaluate its performance. Hedvall et al. (2017) considered three case studies to explore the variety in FTSP approaches and the impact of these on vehicle utilization.

Eight percent of the articles studied in the literature review comprised conceptual studies that reported issues and challenges in FTSP without any simulation or mathematical models. Caplice and Sheffi (2003) discussed FTSP as a whole by giving a detailed review of important issues related to combinatorial auctions. Sheffi (2004) studied the benefits of combinatorial auctions in FTSP.

Surprisingly, few researchers carried out empirical evaluations. Kuyzu et al. (2015) empirically evaluated the value of bid price optimization for carriers simulating a real-life environment. Song and Regan (2003) suggested “co-opetition” as a strategy option, which is a combination of competition and cooperation between ports, and explained empirically the case of co-opetition between container ports in South China and Hong Kong. (Marin and Sicotte, 2003) showed through an empirical study that contracts increase carrier profits and market power. Only 10% of the articles studied in the literature review comprised empirical evaluations.

**2.5. Research trends and gaps**

The first remark from the survey is that the application of mechanism design theory has become a popular approach to design auction mechanisms for FTSP. According to the theory, there are four principles as the main goals for an auction mechanism: incentive compatible (IC), allocatively efficient (AE), individual rationality (IR), and budget balance (BB), see Klemperer (1999) for the definitions. The study by Huang and Xu (2013) was one of the first to propose three truthful multi-unit trade auction mechanisms in freight transport that ensure IC, IR, BB, and AE. Further studies would be of great interest in this field.

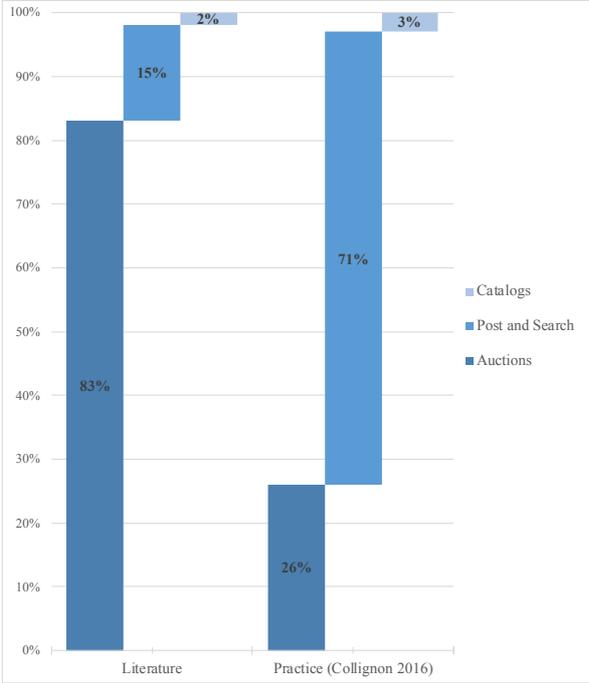


Figure 8: Mechanisms studied in the literature and used in practice

Second, very few papers in the survey have studied the applications of FTSP mechanisms in practice. Some contradictory findings have been revealed with regard to the types of mechanisms studied in the literature compared to those that exist in practice, as shown in Figure 8. In practice, the most popular mechanism is negotiation, which is way ahead of auctions (see Collignon (2016)); however, auctions are the most addressed mechanisms in the literature. Additional studies should be carried out in this direction to explain the reasons for this gap. One of the reasons for this difference could be the link between mechanism and fee structure. Mechanisms relying on intermediaries would generate additional fees (e.g., commission of the intermediary). Another reason could also be the added complexity of implementing auction mechanisms as a market broker is usually present at the auctions. Moreover, the complexity of procurement could also influence seller trust. In this thesis, the obstacles to successful mechanisms are studied to explain the reasons for this gap.

Third, research interests have gradually expanded to third-party-owned mechanisms, especially over the last five years, as depicted in Figure 6. Early studies (1998-2007) were limited to reverse auction mechanisms managed by shippers. However, studies in recent years have focused more on mechanisms based on trust and sharing responsibilities between all the trading parties to achieve effectiveness and efficiency. As mentioned above, research is trending toward assessing cooperative or collaborative transport systems that require new mechanisms managed by a third-party to avoid shipper/carrier opportunism and loss of trust between shippers and carriers.

Fourth, mechanisms for multimodal transport deserve more attention. Numerous studies have focused on auction-based single-mode transport whereas little attention has been paid to auction-based multimodal transport (Crainic and Kim, 2007; Caris et al., 2013; SteadieSeifi et al., 2014). Further studies would be necessary due to the increasing importance of multimodal transport.

Fifth, in recent years, the emergence of new online decentralized freight marketplaces (for short-term services in particular) has led to the need to study many-to-many markets. Moreover, with the emergence of horizontal collaborative transport systems, it is necessary to study many carriers-to-few shipper markets that require cooperation between carriers as well as new procurement mechanisms.

Sixth, regarding outcomes, the literature addressing collaboration issues as a new way of procuring transport services needs to focus more on non-financial outcomes such as on-time performance and pick-up performance in order to maintain the collaboration. It also needs researchers to focus more on the question of who will organize the auction mechanism, the shipper or the carrier.

Finally, concerning the research methodology, the emergence of new markets and organizational models will need empirical research to study how a change in the actors' structures will affect their behavior. Empirical studies are necessary to estimate the effectiveness, the efficiency, and the usability of a procurement mechanism in a transport market.

## **2.6. Conclusion**

This chapter presents a review based on the related literature and real-world practices that gives insights into the organization and procurement mechanisms in current freight transport markets. Some evolving and disrupting trends can be observed, especially the emergence of (online) intermediary and horizontal cooperative transport. The observations and gaps are therefore motivating new research questions in this field. The next chapters are devoted to such questions. In particular, the next chapter 3 is aimed at investigating the elaboration of new collaborative mechanisms for freight transport service procurement in collaborative transport networks. Then, the proposed mechanisms are evaluated through different approaches in order to gain insights from theoretical or practical points of view, (e.g., multi-agent simulation in Chapter 4 and serious gaming in Chapter 5).

## **CHAPTER 3: Design of new collaborative mechanisms for freight transport service procurement in collaborative transport networks<sup>2</sup>**

### **Résumé**

Dans ce chapitre, nous développons et modélisons de nouveaux mécanismes d'achat de services de transport de marchandises. Ces mécanismes inciteront les entreprises de transport à collaborer afin de profiter des avantages de la mutualisation des moyens de transport. Ainsi, les acteurs de la logistique bénéficieront d'une meilleure utilisation des ressources et se rapprocheront *in fine* d'un optimum sociétal.

Dans ce cadre, nous proposons une méthodologie innovante et efficace de combinaison de modèles d'enchères et d'ensemble de règles de collaboration pour gérer les interactions entre les différents acteurs du réseau de transport.

L'objectif des mécanismes de collaboration proposés est d'améliorer l'efficacité, l'efficacité et la durabilité du réseau de transport sans diminuer le profit individuel des parties prenantes indépendantes.

Afin d'atteindre cet objectif, nous proposons deux mécanismes collaboratifs intégrant des modèles d'optimisation basés sur les enchères et des règles collaboratives assurant l'intérêt individuel des participants.

### **Abstract**

This chapter proposes novel collaborative mechanisms for collaborative transport service procurement based on auction mechanisms (i.e. reverse and double auctions), which are the most studied in the literature, as proven in chapter 2. More particularly, the mechanisms are coupled with sets of collaborative rules designed for collaborative transport networks. The goal of the proposed collaborative mechanisms is to increase the efficiency, effectiveness, and sustainability of the network without decreasing the individual profit of the independent

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<sup>2</sup> This chapter partially contains the work presented in the article: Lafkihi, M., Pan, S., Ballot, E., 2019. Rule-based incentive mechanism design for a decentralised collaborative transport network. International Journal of Production Research. 1-17. 10.1080/00207543.2019.1693658.

stakeholders. To this end, the literature on collaborative transport networks was reviewed to identify the perspectives academics have adopted to analyze interactions between stakeholders. An effective methodology for designing mechanisms and rules in collaborative transport networks, as well as for assessing performance is provided. Two collaborative mechanisms integrating auction-based optimization models and rules for collaborative transport request assignment are proposed.

### **3.1. Introduction**

In recent years, freight transport has grown dramatically due to increasing global trade and economic development. Freight transport organizations have also undergone rapid changes. New markets and new technologies have emerged that will probably require innovative solutions as efficiency is still low. There is thus strong motivation involving economic, social, and environmental objectives, to develop more sustainable and efficient freight transport systems (Tavasszy and Piecyk, 2018; Zhu et al., 2018).

In this vein, horizontal collaboration has been largely studied, and its effectiveness and efficiency in freight transport have been proven in the recent literature (see a recent literature review in (Pan et al., 2019)). In particular, CTN are a horizontal collaboration solution attracting increasing attention (Berger and Bierwirth, 2010). According to Agarwal and Ergun (2008), CTN may help carriers to reduce costs and empty runs, improve truck utilization, and improve the overall level of service. More recently, a broader concept was proposed, namely the Physical Internet (PI) (Montreuil, 2011; Ballot et al., 2014). From a transport system perspective, PI can be described as an interoperable, decentralized CTN, aimed at seamlessly interconnecting currently independent transport networks and markets to increase profitability and efficiency. In this chapter, a PI network is used as an example of a CTN.

Carriers involved in fragmented markets make self-interested decisions to maximize their individual profit, which could eventually be harmful to overall market optimality. According to Agarwal and Ergun (2010), collaborative rules and incentive mechanisms must be carefully designed to guide the self-interested decisions of individual carriers toward an optimal global solution in such a way that the individual carriers are motivated to choose optimal, rational solutions.

Following the same logic, this chapter investigates the incentive mechanisms and collaborative rules design problem in a collaborative transport network to manage interactions between stakeholders. It answers the following research question:

***Which freight transport service procurement mechanisms are required in the collaborative transport network to facilitate interactions between stakeholders?***

Many studies use *Mechanism Design Theory* (Narahari et al., 2009) or *Game Theory* (Shapley, 1953) to investigate mechanisms to manage interactions between collaborating carriers (Xu et al., 2016) and share the benefits and costs of the collaboration whereby all carriers are motivated to collaborate (Zhang et al., 2019). However, these mechanisms have often been studied in a specific transport market with local decision making (e.g., for a given marketplace), and they have no vision at network level. Nevertheless, it is essential to consider collaboration at network level, as it interconnects different heterogeneous transport networks as well as markets with hubs.

This dissertation is among the first to investigate collaborative mechanisms and rules for collaborative transport networks and takes PI as an example. It aims to make two contributions to the literature. First, based on freight transport key performance indicators (KPI), a methodology is proposed to identify and design sets of collaborative rules to organize interactions between actors to increase the efficiency, effectiveness, and sustainability of the CTN. Second, two collaborative mechanisms integrating auction-based optimization models and rules for collaborative transport request assignment are proposed. By that, this chapter aims to provide a theoretical and methodological framework for the problem of collaborative rules and mechanism design for collaborative transport networks.

## **3.2. Background literature**

This part briefly reviews two main branches of the related literature: collaborative transport networks and rule-based incentive mechanism design.

### **3.2.1. Collaborative transport networks**

In the related literature, a CTN is generally defined as a common, shared, collaborative network for freight transport whose objective is to consolidate logistics flows from different stakeholders to improve freight transport efficiency and effectiveness (Agarwal and Ergun, 2008; 2010). The definition is vast enough to broadly cover different types of collaboration in

freight transport, including vertical and/or horizontal collaboration, collaborative multi-modal transport, or collaborative city logistics (Gonzalez-Feliu and Salanova, 2012; Ambra et al., 2019; Pan et al., 2019). More precisely, this dissertation focuses on decentralized horizontal collaborative transport, wherein carrier-to-carrier collaborations and/or collaboration between shippers are allowed. The Physical Internet is a recent paradigm in logistics for this type of collaboration.

In the freight transport literature, many experimental studies deal with the design of such collaborative transport networks to highlight their synergies; (Hernández et al., 2012; Wang et al., 2014) presented the collaborative Hub-and-Spoke network design, (Pan et al., 2013) studied the pooled network design for multi-suppliers and multi-retailers, and (Pan et al., 2013) studied the location of collaborative hubs for small and medium-sized regional food suppliers. Moreover, other studies revealed their potential to improve freight transport efficiency and effectiveness. According to Özener et al. (2011), lane-exchange between carriers in a CTN may reduce asset repositioning costs (i.e. economies of scope), and according to Zhou et al. (2011) and Houghtalen et al. (2011), forming an alliance between carriers may improve truck utilization (i.e. economies of scale). Moreover, Berger and Bierwirth (2010) showed that carrier collaboration in a collaborative carrier network (CCN) is advantageous even in highly competitive environments. Such CTN provide a new level of performance unattainable with traditional markets.

#### 3.2.1.1. Evolving from centralized to decentralized freight transport networks

In freight transport, centralization and decentralization are the two common systems of organization used in practice (Klaas-Wissing and Albers, 2010; Gansterer et al., 2018). Centralization relies on a central authority that optimizes and establishes transport plans for all carriers within the organization for global interest. For the sake of optimization, the authority should collect full information about the market and participants. In a centralized transport network, an LSP optimizes the transport plans for carriers in the network. Differently, decentralized organization lets carriers optimize their own transport plans for their own interests - selfish decisions, and the carriers do not have to give out private information. Several LSPs could exist in such a network; each LSP optimizes the transport plans for their carriers. The outcome of the two models could be very different in terms of efficiency and effectiveness (Li et al., 2015). The two models perform differently (Lafkihi et al., 2019). Centralization may perform much better in terms of efficiency and effectiveness,

whereas decentralization may improve flexibility, acceptance, scalability, and agility. Therefore, companies have to select the appropriate organization in accordance with their business model and activities.

Decentralization is one of the recent observable trends in logistics and freight transport. This is because, on the one hand, logistics is coming under increasing pressure from omnichannel distribution and fast delivery to customers. As a result, decision making in logistics should be agile and closer to demands. On the other hand, recent logistics paradigms such as the Physical Internet (Ballot et al., 2014), Cyber Physical Systems (Cardin et al., 2017), and Smart Logistics (Wong et al., 2002) also aim to decentralize logistics management to improve agility and sustainability. Finally, centralized optimization is not tractable from a computational point of view or accepted by independent companies. These paradigms are catalyzed by new techniques and technologies such as online transport marketplaces, IoT/ICT, or Big Data analytics.

Despite the aforementioned theoretical advantages, the performance - efficiency and effectiveness - of decentralization still needs to be further investigated for freight transport and compared with centralization.

Many of the CTN studied operate in a decentralized manner, where decisions are made according to local self-interested information instead of an advanced centralized schedule (Sternberg and Andersson, 2014). For example, Sarraj et al. (2014) studied the PI network as a decentralized, interconnected CTN, and Agarwal and Ergun (2010) examined carrier alliances as a partially decentralized transport network. According to Choi et al. (2001), decentralized systems are an effective solution to cope with the high dynamic complexity of CTN, as a centralized authority imposing too much control detracts from reactivity and innovation. However, Agarwal and Ergun (2010) present two major challenges for managing such decentralized systems: (1) designing collaborative rules that provide incentives to guide individual self-interested decisions of carriers toward a system-wide common goal; and (2) designing a mechanism that regulates interactions between carriers (i.e. exchange of capacity). In this chapter, we will focus on decentralized collaborative transport networks.

### 3.2.1.2. The Physical Internet as an example of a decentralized CTN

Development of the Physical Internet (PI), a collaborative transport paradigm for sustainability, began in 2010. This concept proposes to interconnect logistics services on a

global scale, gathering transport systems (trucks, railroads, etc.), facilities (warehouses, hubs, etc.), and information systems (ERP, TMS, etc.) to supply or distribute freight from shippers to their clients (Montreuil, 2011). It is proposed for the purpose of developing a shared, highly modularized, standardized, and interoperable CTN of which the aim is to interconnect currently independent transport networks, and is a metaphor of the digital internet (Montreuil, 2011; Ballot et al., 2014; Sarraj et al., 2014; Pan, 2017). It is also called “the network of independent logistics networks” in Ballot et al. (2014).

By such definition, PI advocates the exchange of transport orders between carriers throughout a shared network and hubs (i.e. where carriers can acquire transport orders or exchange in-hand orders for transport efficiency and effectiveness). The request allocation process is very dynamic due to stochastic demands and offers (including request exchanges). This will lead to a profound reorganization of transport and will create enormous needs for new means of transport service procurement.

In this chapter, we take PI as an example of a CTN and develop two collaborative mechanisms adapted to this new structure. First, we propose a collaborative mechanism based on the combinatorial reverse auction; without upsetting the current transport organization, we use the existing mechanism that we supplemented with collaborative rules to make it suitable for the CTN. The purpose of this first step is to adapt the existing mechanism to the CTN without upsetting the current transport organization. Second, we imagine a new transport organization and develop a collaborative mechanism based on combinatorial double auctions as an effective and more suitable mechanism for new transport structures.

### 3.2.2. Rule-based Incentive Mechanism

In the freight transport literature, research on decentralized schemes focuses mainly on using mechanism design theory, especially auctions to reassign requests between self-interested carriers in a collaborative network. Song and Regan (2003) developed a framework for an auction-based collaborative carrier network wherein a carrier can subcontract costly or inefficient requests to other carriers in the network if they are profitable for them. Figliozzi et al. (2006) studied a dynamic collaborative carrier network and used the Vickrey second-price auction to induce truthful bidding from carriers. Moreover, numerous studies consider combinatorial auction mechanisms in decentralized CTN to facilitate carrier collaboration and

allow greater synergy (Gansterer et al., 2018). It is known from the literature that combinatorial auctions could improve efficiency in transport.

All the combinatorial auction mechanisms studied in decentralized CTN focus on carrier interactions and propose collaborative rules to provide carriers with incentives to pursue the optimal collaborative solution (Agarwal and Ergun, 2010; Gansterer and Hartl, 2018). These studies disregard the interests of shippers, the level of service (i.e. the level of service must be maintained after the exchange), and the market positioning. However, in a CTN, the interests of all the actors should be protected; common collaborative rules that every individual must respect while being free to make their own decisions (e.g., rules to harmonize services and costs, or rules for modal shifting) should be combined with the incentive mechanism to constitute the collaborative mechanism. Xu (2013) developed a game-theoretic model as a collaborative mechanism for the implementation of centralized and decentralized horizontal logistics collaborations.

These common collaborative rules are used in a wide variety of fields such as internet routing, telecommunications, and postal services (Beam and Segev, 1997; Shi et al., 2012). However, in the freight transport literature, we were unable to find any research combining incentive mechanisms and collaborative rules in decentralized CTN to regulate interactions between selfish participants that we can use directly.

### **3.3. Methodology**

This chapter deals with the collaborative mechanism design problem for resource allocation in a freight CTN for which a two-step methodology is proposed. The first step is to model carrier bidding price strategies (i.e. setting resource costs and prices) and shipper reservation prices (i.e. setting prices they are willing to pay to transport requests), and incorporate them into two different combinatorial auction mechanisms that manage actor interactions such that “optimal” resource allocation is attained. The second step is to extend the traditional auction mechanisms with collaborative rules; assuming that individuals may have different constraints and objectives (e.g., improvement in service rate or cost reduction), a mechanism should have the ability to respect these individual constraints and interests while guiding them toward common goals: efficiency, effectiveness, and sustainability.

Nonetheless, we propose rules based on three freight transport objectives depicted by some significant key performance indicators (KPIs). The three main objectives observed in the literature are considered and defined as follows:

- *Effectiveness*: the degree to which a predetermined objective or target is met (Mentzer and Konrad, 1991).
- *Efficiency*: the degree to which expended resources are used to meet a goal (Mentzer and Konrad, 1991).
- *Sustainability*: the ability of a system to protect, sustain, and enhance the human and natural resources that will be needed in the future while meeting a desired goal (Labuschagne et al., 2005).

Thus, seven KPIs corresponding to the three objectives are studied in this chapter and refined as follows:

#### ***For Efficiency***

- Total transport cost (€) is the classical, most significant KPI to calculate the efficiency of a freight transport network. Nowadays, even if there is a trend in the freight transport industry toward the use of more operational performance indicators and more strategic behavior, the transport cost is still an important KPI that indicates the overall optimization of transport efficiency.
- Total carrier profit (€) represents the objective of the freight transport system to maximize the global profit.
- Loading Factor (%) is the average load to total truck freight capacity ratio. Empty runs are excluded from the calculation. The relevance of this indicator is contingent on the fact that efficient vehicle loading results in fewer vehicle-kilometers being needed to transport the same number of tonnes.
- Total transport (tonne-kilometer or tkm) represents the sum of the volumes transported by the vehicles.

#### ***For Effectiveness***

- The total number of delays measures the number of order shipments delivered to customers on time and in full. It helps determine how effectively a carrier is meeting the deadlines agreed with the shipper.

- The number of unallocated requests is an important KPI of effectiveness that can be seen as the network service rate. Theoretically, when the capacity of the network (of carriers) is sufficient, all requests can be allocated. However, in some cases, requests may not be fulfilled because no one was interested in them due to a short lead-time or a long distance, for example.

### ***For Sustainability***

- Vehicle-kilometers is the total number of kilometers travelled by the vehicles within a given period of time. It is an important variable in the analysis of environmental quality. Reducing the vehicle-kilometers could improve freight sustainability and efficiency leading to several benefits including reduced congestion and reduced carbon and air pollutants.

## **3.4. Designing new collaborative mechanisms and rules**

In this step, we develop two collaborative mechanisms integrating combinatorial auction-based optimization models and rules for collaborative transport request assignment, that is to say reverse auctions and double auctions. In reverse auctions, only carrier-to-carrier collaboration is taken into consideration; shipper collaboration is not considered, as the decisions or strategies of shippers are not taken into account; they are the managers of the reverse auction mechanism and rules. However, in double auctions, shipper collaboration is considered. We propose using a multi-agent system to model the combinatorial auction process. In the combinatorial auction mechanisms used, we assume agents bid truthfully.

### **3.4.1. Collaborative mechanism based on combinatorial reverse auctions**

The first collaborative mechanism used for CTN is based on a *combinatorial reverse auction* in which the shipper puts up a request for a required service. Carriers then place bids for the amount they are willing to be paid for the service, and at the end of the auction the carrier with the lowest bid wins.

Combinatorial reverse auctions gained popularity with the emergence of internet-based online auction tools that enabled multiple carriers to connect with a shipper in real-time. It is known that combinatorial reverse auctions improve efficiency in transport (Cramton et al., 2006). Considering the economies of scope, the cost of serving a group of lanes in a bundle is less than the sum of individual costs of the lanes (Caplice and Sheffi, 2003; Sheffi, 2004) that

Song and Regan (2005) call the complementary effect. Bundling various lanes into a single bid enables carriers to generate tours. For example, consider two different loads: one load must be moved from A to B and the other load must be moved from B to A. Thus, bundling these two loads together as an atomic bid in a combinatorial auction leads to zero empty mileage when necessary constraints are satisfied. As argued by Özener et al. (2011), this is indeed an example of economies of scope, as a carrier can use the same vehicle for complementary services in different lanes to reduce empty movement costs. Conversely, combinatorial reverse auctions make carriers bid for multiple LTL shipments as bundles to maximize the fill rate of the means of transport and to reduce the unit cost for the shipments. Consequently, it leads to lower payments for shippers.

In this mechanism, all carriers submit their sealed bids at the same time in order to respect carrier information privacy (Kleijnen and Van Schaik, 2011). If we assume that requests are repeated on a periodic basis (e.g., a day or an hour), then the auction process should take place at the same frequency. Generally, at the beginning of every predetermined time interval, one combinatorial auction is carried out in the CTN to allocate the requests to the carriers present. The model is then applied for several periods. In each period, the carriers must place bids on bundles of requests within a combinatorial auction process. We assume that requests can be bundled for cost reduction thanks to economies of scale (Gansterer and Hartl, 2018). We propose using a multi-agent system to model the combinatorial auction process.

In this mechanism, the carriers would likely encounter difficulties when making bidding decisions (i.e. BGP) due to the exponential number of possible bundles. In addition to the complexity of evaluating all possible bundles, the carriers need to decide which bundles to submit. Evaluating and submitting all possible bundles would be prohibitively time consuming for the bidders. Therefore, we propose using autonomous proxy agents to facilitate and assist the bidding decision-making process of carriers. These agents are widely discussed in the literature on auction theory (Parkes and Ungar, 2000; Plummer, 2003; Cramton et al., 2006). The mission of the proxy bidding agent is to provide its customer carrier with the best bidding strategy, taking the private information of its customer into consideration (unit cost, expected revenue, services, capacity, etc.). This is achieved in two steps: *Determining the feasible request bundles* and *Bidding for each feasible request bundle*.

The agents present in each period are carriers linked to bidding agents (sellers), shippers (buyers), and the auctioneer who may be a third-party facilitating communication between the shippers and the carriers. We assume that a single auctioneer runs the auction in each period.

Within a given period, the process of each combinatorial auction is as follows. Initially, carriers submit the in-transit request information (i.e. reallocation requests) to the auctioneer. Meanwhile, shippers submit the new request information to the auctioneer (Step 1). The auctioneer pools all the requests and then sends the information (volume and route of request, etc.) to the proxy agents of the carriers who then analyze the requests to determine which request bundles (i.e. sets of individual requests) from the pool are feasible for them insofar as they meet route compatibility and carrier capacity. Based on the private information of the carriers and the feasible request bundles generated, the proxy agents of the carriers make decisions regarding which request bundles to bid for and at what price to maximize their profits (Step 2). Once the carriers have validated the bids, they are submitted to the auctioneer and a WDP takes place to make the decision. Finally, the decision is sent to the carriers and the auction process is closed (Step 3). Figure 9 presents the cross-functional flow chart of the three actors involved in the auction process.

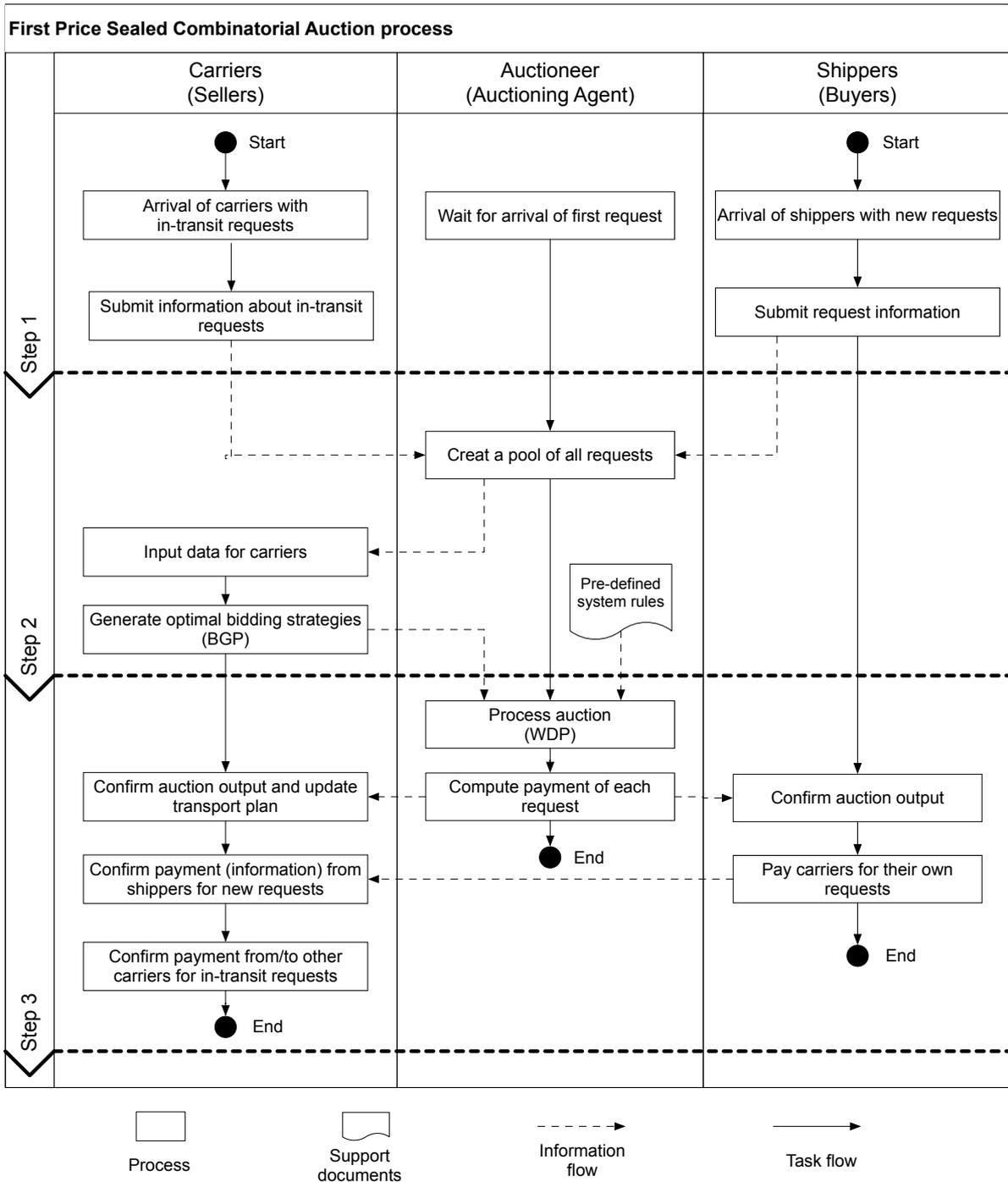


Figure 9: Cross-functional flow chart of the combinatorial reverse auction process

Today, combinatorial reverse auctions are used by large suppliers as a competitive procurement method to drive the prices down. However, it creates perceptions of opportunism among participating suppliers and leads to a loss of trust. We then extend this traditional mechanism with a set of collaborative rules to respect all the individual constraints and

interests, and create the collaborative mechanism adapted to the CTN. Assuming that individuals may have different constraints and objectives (e.g., improvement in service rate or cost reduction), a collaborative mechanism should have the ability to respect these individual constraints and interests while guiding them toward common goals: efficiency, effectiveness, and sustainability. Then, the proposed collaborative mechanism provides actors with incentives to pursue the optimal collaborative solution (Agarwal and Ergun, 2010; Gansterer and Hartl, 2018) and protect their interests (i.e. level of service, market positioning, etc.).

In what follows, we define the set of collaborative rules and show their impact on each of the KPIs presented.

<i>Rules</i>	<i>Definitions</i>
<b>Rule 1:</b> En-route reallocation	Reallocation is allowed at hubs in the network. When reallocation happens, shipments must be reallocated to other carriers proposing a lower price.
<b>Rule 2:</b> Lowest price and best reputation win	If there is competition, shipments must be allocated/reallocated to the carrier proposing the lowest price. If two carriers are tied for the lowest price, then the carrier with the best reputation will win the shipment auction.
<b>Rule 3:</b> No price increase	Once a price is promised to the shipper, it cannot be increased when transferring the request(s) from one carrier to another in the event of reallocation.
<b>Rule 4:</b> Individual responsibility	Each carrier is responsible for any delays they cause and pay the associated penalty.
<b>Rule 5:</b> No halfway drop-out	If there is no possibility of reallocation, the carrier in charge must transport the request acquired from the origin to the destination. Reallocation occurs if and only if the request is taken over by another carrier to the destination.

*Table 4: Definitions of the set of collaborative rules (reverse auctions)*

- *Rule 1* allows reallocation and enables the co-delivery of requests. This is the core activity and advantage of flow consolidation enabled by the PI collaborative network. At transit hubs in the network, carriers exchange requests to motivate a carrier to sell

any unused capacity to a carrier who can use it to transfer their own cargo. This improves vehicle use by reducing empty runs and making better use of the capacity of each vehicle as the same goods can be carried with fewer vehicle journeys. Reallocation allows carriers to exchange their capacity and thus improve their efficiency. More precisely, a carrier can subcontract its shipments to other carriers who can provide lower prices for the remainder of the routes. This can produce profits/savings; however, after subcontracting, it has the capacity available for other, more economically attractive requests. Thus, reallocation provides side payments for carriers in addition to the revenue generated from delivering other requests. Hence, carriers will have a strong incentive to exchange their capacities. In this chapter, we claim that all requests that arrive at in-transit hubs are systematically added to the auction pool (and the price of each is assumed to be known as private information) for reallocation; we are not dealing with “request selection and pricing problems” wherein carriers choose to exchange their capacities based on their pricing strategies (Qiao et al., 2016). We especially mention here that the profit to be shared after reallocation is the profit after deducting all extra costs generated by reallocation (unloading/loading costs, handling costs, etc.). In this way, carriers involved in reallocation share the extra costs by sharing the profit to avoid discussions regarding who pays the extra cost resulting from the reallocation. This rule has an impact on several KPIs that are strongly related to each other and helps to reduce total freight transport costs and total vehicle traffic, measured in vehicle-kilometers, thereby reducing congestion, emissions, accidents, and other environmental impacts of freight transport.

- *Rule 2* is proposed to maximize the global profit of the network by motivating carriers to optimize their prices and reputation.
- *Rule 3* aims to protect the interests of shippers, as the ultimate objective of a carrier is to increase their profit while satisfying shipper demands (transport order shipments on time at the best price with a good quality of service). In the case of reallocation, it is not possible to increase the price promised to a shipper when transferring the request(s) from one carrier to another.
- *Rule 4* is proposed to ensure quality of service for shippers, for example by minimizing the cumulative delays. The fact that each carrier is responsible for their

delays makes them more cautious about the lead times and their route choices, especially in the case of reallocation (subcontracting).

- *Rule 5* also aims to ensure the quality of service by ensuring the end-to-end service for each shipment in the network. To do this, a bidder (carrier) must submit a price (for allocation or reallocation) that covers the entire route from the origin to the final destination. In other words, if there is no reallocation to improve the efficiency, the carrier must be able to deliver the shipment to its final destination at the proposed price.

### 3.4.2. Collaborative mechanism based on combinatorial double auctions

Another collaborative mechanism that we propose for CTN is based on *combinatorial double auctions* in which shippers post their loads and reservation prices, carriers post their availabilities and bids, and the market intermediary (e.g., auctioneer) allocates the resources and determines the prices dynamically as the players update their information in real time (Viswanadham et al., 2012; Miyashita, 2014). The mechanism aims to facilitate order consolidation; an order served by one carrier can be transferred and hence delivered by another carrier with the same or higher level of service.

In recent years, researchers have begun to address double auctions in freight transport service procurement that require both the buyer and the seller to name a price, see Xu and Huang (2013) and Xu and Huang (2014), for example. According to Xu and Huang (2013) and Cheng et al. (2016), the use of double auctions is promising for FTSP, as it allows shippers and carriers to bid simultaneously and reduces trading inefficiency. In addition, double auctions could reduce the opportunism perceived with reverse auctions that could lead to a loss of trust. Some other papers have addressed the question of how to bid. For example, carriers as bidders may be able to see the price submitted by their competitors or not, i.e. sealed-bid auctions or public-bid auctions, respectively (Cheng, 2011).

In this chapter, we consider a CTN with dynamic demand, multiple carriers and shippers, and a third-party auctioneer (e.g., a logistics e-marketplace). Shippers make transport service requests available to multiple carriers simultaneously, and they are assigned for immediate payment and delivery within a period of time (e.g., one day). Double auctions are conducted by the auctioneer in order to better match the supply and demand. This CTN is cleared every unit of time (e.g., a day or an hour); at least one auction is executed during each unit of time.

Transport service requests are accumulated during this time interval and wait to be cleared. Accordingly, a periodic combinatorial double auction mechanism is devised in such a context.

We assume that each agent is a self-interested player attempting to maximize his own utility. We also assume all agents have quasi-linear utility. That is, if an agent does no trade, his utility is zero; otherwise, his utility is the difference between the valuation of the agent and the amount of payment transferred. The auctioneer's monetary payoff is the difference between the total payments from the shippers and the total revenues of the carriers. The social welfare is the summation of the utility of each agent and the auctioneer's payoff.

In this mechanism, all the agents submit their sealed bids at the same time in order to respect carrier and shipper information privacy (Kleijnen and Van Schaik, 2011). The auction process takes place at the same frequency. Generally, at the beginning of every predetermined time interval, one combinatorial double auction is carried out in the CTN to allocate the requests to the carriers present. The model is then applied for several periods. We assume that requests can be bundled for cost reduction thanks to economies of scale (Gansterer and Hartl, 2018). We propose using a multi-agent system to model the combinatorial double auction process.

Furthermore, we propose the use of the proxy agents of autonomous carriers to facilitate and assist the bidding decision-making process of carriers, and the proxy agents of autonomous shipper to facilitate and assist the determination of request reservation prices. The mission of the proxy bidding agent is to provide its customer carrier with the best bidding strategy, taking the private information of its customer into account (unit cost, expected revenue, capacity, etc.). This is achieved in two steps: *Determining the feasible request bundles* and *Bidding for each feasible request bundle*. The mission of the shipper proxy agent is to determine the reservation prices of request bundles taking the reservation prices provided by its customer shippers into consideration.

The agents present in each period are carriers linked to bidding proxy agents (sellers), shippers linked to proxy agents (buyers), and the auctioneer who may be a third-party facilitating communication between the shippers and the carriers. We assume that a single auctioneer runs the auction in each period.

Within a given period, the process of each combinatorial double auction is as follows. As soon as the auction starts, the participating carriers post the private information about their

shareable requests to the auctioneer. This includes the volumes and destination zones. Meanwhile, shippers submit the new request information (i.e. volumes, origins, destinations etc.) to the auctioneer (Step 1). The auctioneer pools all the requests and generates the feasible request bundles, then sends the information (volume and route of request, etc.) to the local proxy agents of the carriers and the shippers. Next, the proxy agents of the carriers analyze the requests and bid according to the personalized configuration of the carriers (BGP). Decisions need to be made regarding which request bundles to bid for and at what price, and which requests to outsource at what reservation price to maximize carrier profit. Meanwhile, the proxy agents of the shippers analyze and determine the reservation prices of request bundles according to the personalized reservation prices of the shippers (Step 2). Once the proxy agents of the carriers have validated the bids and the proxy agents of the shippers have validated the reservation prices, they are submitted to the auctioneer and a WDP takes place to make the decision. Finally, the decision is sent to the carriers and shippers and the auction process is closed (Step 3). At the end of the bidding phase, all bids with a reservation price higher than the carrier bidding price are eliminated and the winners are then determined. Figure 10 presents the cross-functional flow chart of the three actors involved in the combinatorial double auction process.

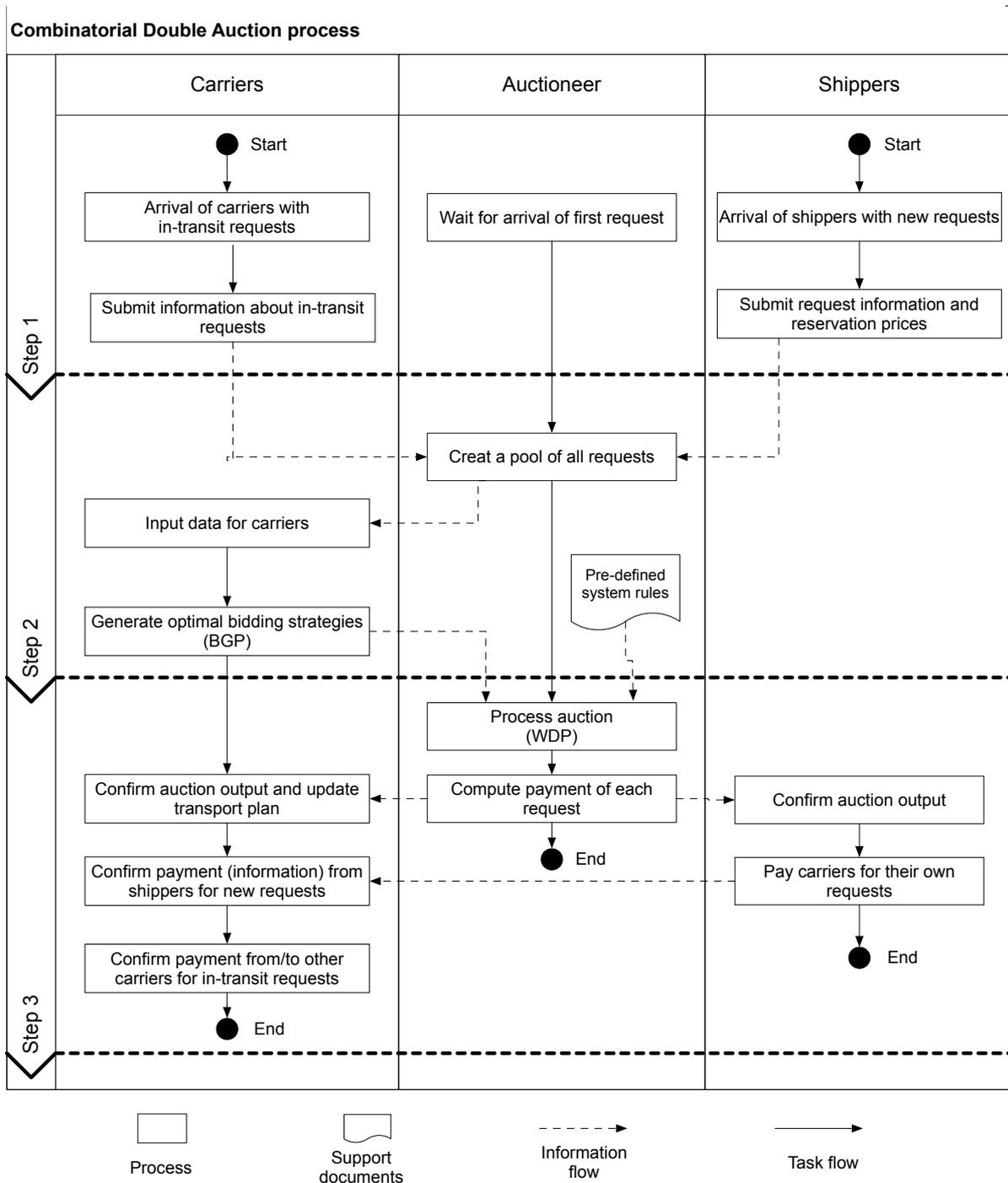


Figure 10: Cross-functional flow chart of the combinatorial double auction process

We extend the traditional double auction mechanism with a set of collaborative rules to respect all the individual constraints and interests. A collaborative mechanism should have the ability to respect the individual constraints and interests of actors while guiding them toward common goals: efficiency, effectiveness, and sustainability.

In what follows, we define the set of collaborative rules and show their impact on each of the KPIs presented.

<i>Rules</i>	<i>Definitions</i>
<b>Rule 1:</b> En-route reallocation	Reallocation is allowed at hubs in the network. When reallocation happens, shipments must be reallocated to other carriers proposing a lower price.
<b>Rule 2:</b> No price increase	Once a price is promised to the shipper, it cannot be increased when transferring the request(s) from one carrier to another in the event of reallocation. With this rule we respect the individual constraints but it could weaken the maximization of global social welfare.
<b>Rule 3:</b> Individual responsibility	Each carrier is responsible for any delays they cause and pay the associated penalty.
<b>Rule 4:</b> No halfway drop-out	If there is no possibility of reallocation, the carrier in charge must transport the request acquired from the origin to the destination. Reallocation occurs if and only if the request is taken over by another carrier to the destination.

*Table 5: Definitions of the set of collaborative rules (double auctions)*

### 3.5. Problem Formulation and Notation

The combinatorial reverse and double auction mechanisms were implemented in Matlab®. The two algorithms comprise the simultaneous generation of vehicle routes and lanes, the calculation scheme to determine cost and profit, and the allocation and reassignment of transport requests in the CTN.

A carrier-to-carrier CTN was considered. In this network, carriers receive new transport requests either from shippers for contracting or from other carriers for subcontracting. For the latter, the term reallocation process is used. Carriers plan their operations and routes on this basis.

The freight transport collaborative network consists of multiple shippers and carriers, multiple hubs (normal hubs and in-transit hubs wherein the reallocation of requests is allowed), and multiple lanes (see Figure 11).

All order shipments, that is to say transport requests, are less than truckload (LTL). They are generated randomly and repeated regularly on a periodic basis (e.g., a day). To determine prices of requests, carriers and shippers rely on transport costs. Without loss of generality, we assume that the transport costs of a given order are the same for all the carriers and shippers and are calculated according to the same non-linear function depending on the volume of orders and the distances travelled (see Figure 12).

We assume that each carrier has the same maximal capacity, and if a carrier is represented by a truck, then the capacity of each carrier is limited to a truckload. Hereinafter, we maintain the assumption that a truck is equivalent to a carrier. Furthermore, we do not focus on transactions between carriers and shippers; it is assumed that if a carrier wins an order, there are no transaction errors.

The models are based on a network portrayed by a graph composed of 9 vertices and 40 edges. The vertices represent the transport hubs and the edges represent the routes between the vertices to transport services. The weights assigned to each edge represent the distance between the hubs (see Figure 11).

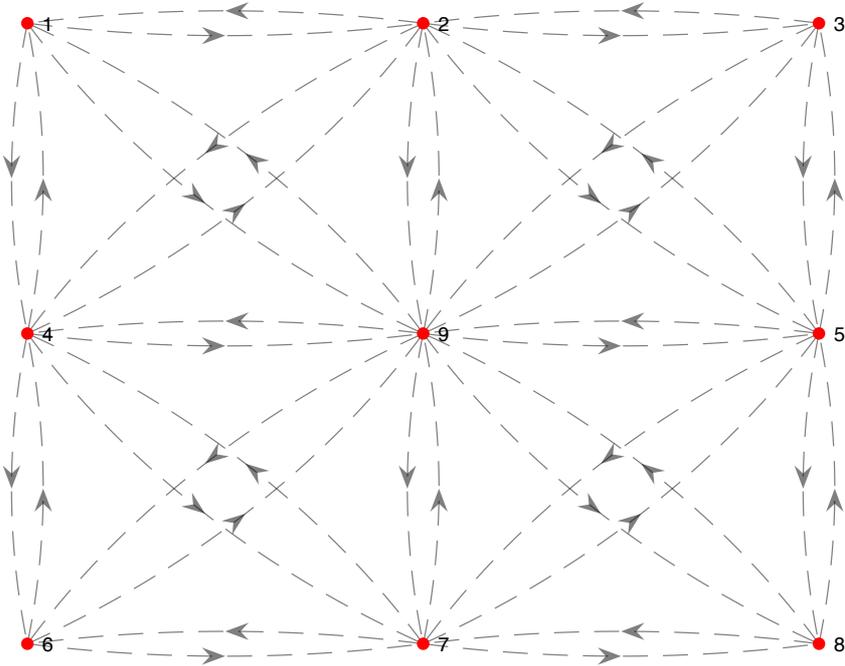


Figure 11: Freight transport network

The request capacity of shippers for origin-destination pairs is given in terms of pickup and delivery locations. We focus on a service with request lead time compliance.

### 3.5.1. Reverse auctions

In this model, the decisions or strategies of shippers are not considered, as they are the managers of the reverse auction mechanism and rules. We assume that after the allocation, shippers will accept to pay the price of winner carriers.

Let  $m$  denote the independent carrier companies that form the network member set  $M$ . Each carrier has a limited capacity (truckload carriers)  $C_{\max}$ . We assume that all carriers have the same maximal capacity. Carriers are considered as homogeneous agents that compete to obtain order shipments based on a defined cost function.

Let  $R^n$  denote the set of all transport service requests in a period  $n \in N$  (e.g., a day).  $R^n$  is composed of 2 subsets:  $R^n = NR^n \cup OR^n$

- $NR^n$  denotes the set of all new transport service requests generated randomly within a period  $n \in N$ .
- $OR^n$  denotes the set of all previous transport requests generated within previous periods that have not yet arrived at their destinations.

Each  $O - D$  demand corresponds to an individual indivisible request  $r \in R^n$ . For a given  $r$ ,  $o(r)$  and  $d(r)$  denote its origin and destination hubs, respectively.  $V_r$  denotes its volume and  $LT_r$  denotes its delivery lead time, which represents the number of periods after which the request should be delivered. If a delivery is delayed, the carrier pays a penalty cost of  $PC_{rt,r}^m$  for this request. We assume that the request  $r \in R^n$  can take any route between its origin and destination.

We assume that the request routes are not predetermined: each carrier can choose any route in the network to transport requests.  $Rt$  denotes the set of all request routes. A route  $rt \in Rt$  can be composed of several arcs, for example, route  $1 - 2 - 3 - 4$  is composed of 3 arcs  $\{1 - 2; 2 - 3; 3 - 4\}$ .  $A_{rt} = \{a_1, \dots, a_k\}$  denotes the set of arcs comprising route  $rt$ .  $CR_{a_i \in A_{rt}}^m$  defines the residual capacity of a carrier  $m$  in the arc  $a_i \in A_{rt}$  of route  $rt$ . Let  $T_{rt,r}^m$  denote the transport time of request  $r \in R^n$  on route  $rt \in Rt$  by carrier  $m$ .

We define a detour for a carrier  $m$  as a route change to transport new requests. For example, if, in the period  $n - 1$ , a carrier has a determined route to transport request  $r_1$ , and in

period  $n$  they propose to transport the request bundles  $\{r_1, r_2\}$  on route  $1 - 2 - 3$ , then the arc  $1 - 2$  is considered as a detour. The transport cost and efficiency are computed accordingly.

$M$	The set of all carriers in the network
$m \in M$	An independent carrier company
$C_{\max}$	The maximal capacity of a carrier
$N$	The set of all periods
$n \in N$	One period (e.g., a day)
$R^n$	The set of all transport service requests (commodities)
$NR^n$	The set of all new transport service requests generated randomly during a period $n$
$OR^n$	The set of all previous transport requests generated during previous periods, transported by carriers, and that have not yet arrived at their destination.
$r \in R^n$	An individual indivisible request $r$
$o(r)$	The origin of the request $r$
$d(r)$	The destination of the request $r$
$V_r$	The volume of the request $r$
$LT_r$	The delivery lead time of the request $r$
$PC_{rt,r}^m$	The penalty cost of the request $r$ if delivery is delayed
$R_t$	The set of all request routes
$rt \in R_t$	A route
$A_{rt} = \{a_1, \dots, a_k\}$	The set of arcs of a route $rt$
$a_i \in A_{rt}$	An arc
$d_i$	The distance of arc $a_i$
$CR_{a_i \in A_{rt}}^m$	The residual capacity for a carrier per arc

$T_{rt,r}^m$	The transport time of request $r \in R^n$ on a route $rt \in Rt$ by carrier $m$
$RB_{rt}^m$	The set of all feasible RBs for carrier $m$ on route $rt$
$Rb_i$	A request bundle
$V_{a_k,Rb_i}$	The volume of the request bundle $Rb_i \in RB_{rt}$ on arc $a_k$
$V_{rt,Rb_i}$	The volume of the request bundle $Rb_i \in RB_{rt}$ on route $rt$
$Ctr_{a_k,Rb_i}^m$	The cost of transporting the request bundle $Rb_i \in RB_{rt}$ on arc $a_k$ by carrier $m$
$Ctr_{rt,Rb_i}^m$	The cost of transporting the request bundle $Rb_i \in RB_{rt}$ on route $rt$ by carrier $m$
$P_{a_k,Rb_i}^m$	The price of the request bundle $Rb_i$ proposed by carrier $m$ in arc $a_k$
$P_{rt,Rb_i}^m$	The price of the request bundle $Rb_i$ proposed by carrier $m$ for route $rt$
$PC_{rt,Rb_i}^m$	The penalty cost of the request bundle $Rb_i$ to be paid by carrier $m$ for route $rt$ due to delays
$mr_m$	The profit margin for carrier $m$ in each period $n$
$RP_{rt,r}^m$	The unit price of request $r \in NR^n$ for route $rt$ proposed by carrier $m$

Table 6: List of notations in the combinatorial reverse auction model

In each period  $n$ , the mission of a carrier  $m$  is to provide the best bidding strategy according to their private information (position, expected revenue, capacity, etc.). Each carrier proposes a price to transport a bundle on a determined route. This can be done in two steps: determining the feasible request bundles and bidding for each feasible request bundle. The mission of a shipper is to confirm the allocation and pay the winning carrier at the end of the process.

### 3.5.1.1. Feasible Request bundles

According to rule 5, a carrier must be able to transport its shipments to the final destination if no adequate reallocation is possible. This means that only requests with origins and destinations along the same route that can be delivered by one truck are compatible. An  $RB$  is transported on a route  $rt$  if, and only if, the route contains the origins and the destinations of all the requests in the bundle, and with the constraint that, for each request, the position of its

origin along the route is prior to its destination. If we assume that during the period  $n$ , a carrier  $m$  is still transporting the requests from previous periods to their destinations ( $OR_m^n \subseteq OR^n$ ), the feasible request bundles should contain these previous requests, and the carrier should consider the determined route and the previous requests when choosing feasible  $RBs$ .

Considering each carrier in a period  $n$  has a limited capacity (maximal or residual capacity), they will only consider the  $RBs$  they can handle (as task reservation is not allowed here). The total volume of requests transported by a carrier should not exceed the capacity of the carrier in all the arcs of the determined route.

Finally, only  $RBs$  that meet both conditions are considered feasible. For a carrier  $m$ , let  $RB_{rt}^m$  denote the set of all feasible  $RBs$  on route  $rt$ , then  $RB_{rt}^m = \{Rb_1, Rb_2, \dots, Rb_k\}$ .

Let  $V_{rt, Rb_i}$  denote the volume of the request bundle  $Rb_i \in RB_{rt}$  on route  $rt$ , then

$$\forall rt \in Rt, V_{rt, Rb_i} = \sum_{a_k \in A_{rt}} \sum_{r \in R^n, r \in Rb_i} V_r y_{k,i}$$

Where  $y_{k,i}$  is a binary variable with  $y_{k,i} = 1$  if the request  $r \in Rb_i$  is transported in the arc  $a_k \in A_{rt}$  and  $y_{k,i} = 0$  otherwise.

All the feasible request bundles on route  $rt$  verified the two conditions:

$$\forall m \in M, \text{if } OR_m^n \neq \emptyset \text{ then } \forall Rb_i \in RB_{rt}^m, \quad OR_m^n \subseteq Rb_i$$

$$\forall m \in M, \forall a_k \in A_{rt}, \forall Rb_i \in RB_{rt}^m \quad \sum_{r \in R^n, r \in Rb_i} V_r y_{k,i} \leq CR_{a_k \in A_{rt}}^m$$

Let  $Ctr_{a_k, Rb_i}^m$  denote the cost for transporting the request bundle  $Rb_i \in RB_{rt}$  on route  $rt$  by carrier  $m$ . We use a concave nonlinear function of volume per unit distance (i.e. €/RB-km) to calculate the transport cost in each arc of route  $rt$  (see Figure 12):

$$Ctr_{a_k, Rb_i}^m = f(V_{a_k, Rb_i}); \quad \forall m \in M, \forall a_k \in A_{rt}, \forall Rb_i \in RB_{rt}^m$$

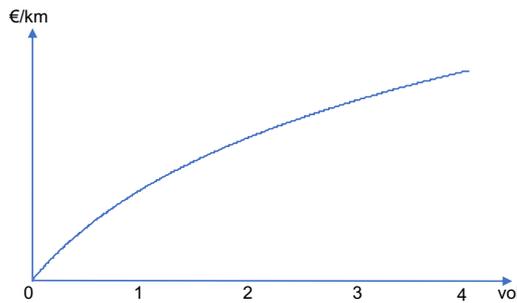


Figure 12: Transport Cost function (€/km)

The nonlinearity is due to transport synergies (i.e. economies of scale) generated by bundling requests.  $Ctr_{a_k, Rb_i}^m$  is the transport cost per kilometer of the bundle  $Rb_i \in RB_{rt}^m$  proposed by carrier  $m$  in the arc  $a_k \in A_{rt}$ .  $V_{a_k, Rb_i}$  is the volume of the request bundle  $Rb_i \in RB_{rt}^m$  in the arc  $a_k \in A_{rt}$ .  $f$  is a nonlinear function.

Then, the transport cost of the request bundle  $Rb_i \in RB_{rt}^m$  proposed by carrier  $m$  for route  $rt$  can be written as follows:

$$Ctr_{rt, Rb_i}^m = \sum_{a_k \in A_{rt}} Ctr_{a_k, Rb_i}^m * d_k; \quad \forall m \in M, \forall rt \in Rt, \forall Rb_i \in RB_{rt}^m$$

### 3.5.1.2. Bidding price function

Once the feasible RBs are determined, carriers establish a bidding price for each interesting bundle based on the transport cost. The price for a request bundle depends on the transport cost and the penalty cost of the bundle. We use a nonlinear function  $g$  to define the price of an RB knowing its transport cost. The function depends on the volume of the RB and the distance travelled.

Let  $P_{a_k, Rb_i}^m$  denote the price of the request bundle  $Rb_i \in RB_{rt}^m$  proposed by carrier  $m$  in the arc  $a_k \in A_{rt}$ .

$$P_{a_k, Rb_i}^m = g(Ctr_{a_k, Rb_i}^m); \quad \forall m \in M, \forall a_k \in A_{rt}, \forall Rb_i \in RB_{rt}^m$$

The price of the request bundle  $Rb_i \in RB_{rt}^m$  proposed by carrier  $m$  for route  $rt$  can be written as follows:

$$\forall m \in M, \forall rt \in Rt, \forall Rb_i \in RB_{rt}^m \quad P_{rt, Rb_i}^m = \sum_{a_k \in A_{rt}} g(Cost_{a_k, Rb_i}^m) + PC_{rt, Rb_i}^m$$

Where  $PC_{rt, Rb_i}^m$  is the penalty cost of the request bundle  $Rb_i \in RB_{rt}^m$  to be paid by carrier  $m$  for route  $rt$  due to delays. It is equal to the sum of the penalty costs for each request in the RB:

$$\forall m \in M, \forall rt \in Rt, \quad PC_{rt, Rb_i}^m = \sum_{r \in R^m, r \in Rb_i} PC_{rt, r}^m$$

The parameters of the function  $g$  will be defined later in the simulation in chapter 4 to depict different bidding price strategies.

Let  $mr_m$  denote the profit margin for carrier  $m$  in each period  $n$ :

$$mr_m = \frac{P_{rt,Rb_i}^m}{Cost_{rt,Rb_i}^m} - 1; \quad \forall m \in M, \forall rt \in Rt, \forall Rb_i \in RB_{rt}^m$$

Specifically, we define here  $mr_m$  as the expected profit margin for carrier  $m$ . Normally,  $mr$  is positive, as the carrier submits a higher price than the theoretical cost to make a profit.

As carriers submit prices for  $RBs$ , we propose a numerical model to calculate the unit price of each request in the bundle. We assume that the unit price is proportional to the total price of the bundle to which it belongs in terms of distance-volume. This calculation is necessary for the reallocation of requests; we need the price of each request in the bundle for the reallocation. For each request, we calculate the unit price in each arc of the route. The price on the route is the sum of the unit prices per arc. Let  $RP_{rt,r}^m$  denote the unit price of request  $r \in NR^n$  for route  $rt$  proposed by carrier  $m$ .

$$\forall r \in NR^n, \quad RP_{rt,r}^m = \sum_{a_k \in A_{rt}} RP_{a_k,r}^m$$

Where  $RP_{a_k,r}^m$  is the unit price in the arc  $a_k \in A_{rt}$ :

$$\forall r \in Rb_i, \quad RP_{a_k,r}^m = P_{rt,Rb_i}^m \cdot \frac{V_r}{\sum_{r \in Rb_i, r \in NR^n} V_r}$$

### 3.5.1.3. Allocation model

According to the rules, once a carrier has won a request, they must handle the request all the way to the final destination. Considering that carriers have a limited capacity; no more than one feasible request bundle should be allocated to each carrier and the request bundle should have the highest volume and thus the lowest unit cost. This is the XOR bidding language, as defined by (Lehmann et al., 2006). For example, a carrier submitting a bid  $(Rb_1, P_{rt,Rb_1}^m) \text{ XOR } (Rb_2, P_{rt,Rb_2}^m) \dots \text{ XOR } (Rb_k, P_{rt,Rb_k}^m)$  means that the carrier only wants to deliver one of the bundles  $Rb_1$  to  $Rb_k$ . In other words, even though carriers bid for each bundle in an auction, they can only win one bundle. To solve this problem, a Winner Determination Program is needed. We used the most studied winner determination formulation in the literature (Lehmann et al., 2006; Chen et al., 2009) and adapted it to the

specific context of horizontal collaboration. This formulation, often combined with combinatorial auctions, is widely used in the literature for the freight transport service procurement problem because it is considered as a solution that helps to achieve economies of scope and scale and to reduce the total transport cost (see Caplice and Sheffi (2003), Song and Regan (2005), Chen et al. (2009) and Huang and Xu (2013)). Moreover, adding the possibility of reassigning/reallocating the requests in this mathematical model (constraint (5)) enhances the advantages of economies of scope and scale (Krajewska and Kopfer, 2006; Berger and Bierwirth, 2010; Özener et al., 2011). The model used for request allocation and reallocation is defined as follows:

$$\min \sum_{m \in M} \sum_{rt \in Rt} \sum_{Rb_k \subseteq RB_{rt}^m} P_{rt, Rb_k}^m y_{rt, Rb_k}^m \quad 1$$

**Subject to**

$$\sum_{rt \in Rt} \sum_{Rb_k \subseteq RB_{rt}^m} y_{rt, Rb_k}^m \leq 1, \forall m \in M, \quad 2$$

$$\sum_{m \in M} \sum_{rt \in Rt} \sum_{Rb_k \subseteq RB_{rt}^m; r_i \in Rb_k} y_{rt, Rb_k}^m = 1, \forall r_i \in NR^n \quad 3$$

$$\sum_{r \in RR^n} \sum_{m \in M} \sum_{rt \in Rt} \sum_{Rb_k \subseteq RB_{rt}^m; r \in Rb_k} RP_{rt, r}^m y_{rt, Rb_k}^m \leq RC_{rt, r}^{m'} \quad 4$$

$$y_{rt, Rb_k}^m \in \{0, 1\}, \forall m \in M, \forall rt \in Rt, \forall Rb_k \subseteq RB_{rt}^m \quad 5$$

Where  $RR^n$  denotes the set of requests with the possibility of reallocation in period  $n$  and  $RC_{rt, r}^{m'}$  denotes the transport cost of request  $r$  in period  $n - 1$  by carrier  $m'$ .  $y_{rt, Rb_k}^m$  are binary decision variables with  $y_{rt, Rb_k}^m = 1$  if for route  $rt$  the request bundle  $Rb_k$  is allocated to the carrier  $m$  and 0 otherwise. Equation (1) is the objective function to minimize the total price for allocating all  $RB$ s. Constraint (2) guarantees that each carrier transports at most one bundle. Constraint (3) guarantees that each request is allocated, at most, once on one route. Constraint (4) is imposed to ensure that an in-transit request (those at in-transit hubs) can only be reallocated if it is distributed at a lower unit cost/price. Without this constraint, an overall optimal solution may impose a higher unit price on an in-transit request.

### 3.5.2. Double auctions

Let  $s$  denote the independent shippers that form the member set  $S$ . Each shipper determines the reservation price that they are willing to pay to transport their request.

Let  $R^n$  denote the set of all transport service requests in a period  $n \in N$  (e.g., a day).  $R^n$  is composed of 2 subsets:  $R^n = NR^n \cup OR^n$

- $NR^n$  denotes the set of all new transport service requests generated in a period  $n \in N$  by shippers (i.e. shipments directly from shippers).
- $OR^n$  denotes the set of all previous transport requests generated in previous periods that have not yet arrived at their destinations (i.e. in-hand shipments from carriers for reallocation).

Let  $r_s \in NR^n$  denote a new transport service request generated by shipper  $s$ .  $o(r_s)$  and  $d(r_s)$  denote its origin and final destination, respectively.  $V_{r_s}$  denotes its volume and  $LT_{r_s}$  denotes its delivery lead time (i.e. time constraint to be respected).

Once shippers and carriers have sent the transport service requests and capacity to the auctioneer, the latter pools them and generates the feasible request bundles  $RBS = \{Rbs_1, Rbs_2, \dots, Rbs_k\}$  for the shippers, and the feasible request bundles for the carriers. The total volume of requests transported in a feasible request bundle should not exceed the maximal capacity of the carriers in all the arcs of the route.

After constituting the feasible request bundles, the mission of a shipper proxy agent is to determine their reservation prices. Let  $Pr_{Rbs_i}$  denote the reservation price of the request bundle  $Rbs_i \subseteq RBS$ . Without loss of generality, we assume that  $Pr_{Rbs_i}$  is equal to the sum of the reservation prices of the requests contained in the request bundle:

$$\forall Rbs_i \subseteq RBS, \quad Pr_{Rbs_i} = \sum_{r_s \in Rbs_i} P_{r_s}$$

Where  $P_{r_s}$  denotes the reservation price determined by shipper  $s$  for an individual request  $r_s$ . It can be written as follows:

$$P_{r_s} = Ctr_{r_s} * (1 + \overline{marg}_{r_s}) * SQ_{r_s}$$

Where  $Ctr_{r_s}$  is the cost of transporting request  $r_s$  from its origin to its final destination via the shortest route. We use a concave nonlinear function of volume per unit distance (i.e. €/V-km) to calculate the transport cost in each arc of the shortest route (see Figure 12):

$$Ctr_{rs} = \sum_{a_k \in A_{short\_rt}} f(V_{a_k, r_s}); \quad \forall a_k \in A_{short\_rt}, \forall r_s \in R^n$$

$V_{a_k, r_s}$  is the volume of the request  $r_s \in R^n$  in the arc  $a_k \in A_{short\_rt}$ .  $f$  is a nonlinear function.

$\overline{marg}_{r_s}$  is the market average margin for request  $r_s$  estimated by the shippers. In this model, the average margin forms a reference for shippers to help them determine the reservation price of the request. This margin is introduced here to avoid the situation in which shippers name a reservation price that is too low for a request (e.g., equal to the transport cost) so that no carrier will bid for it.

$SQ_{r_s}$  is a constant representing the quality of service associated with request  $r_s$ . This means, for shipper  $s$  shipping  $r_s$ , the quality of service is a significant parameter in determining its reservation price. For example, a shipper will be willing to pay more for urgent requests (i.e. requests with a short lead time). This parameter is assumed to be known and given by the shippers when they submit requests.

The set  $R^n$  of transport service requests could be composed of 2 subsets:  $R^n = InR^n \cup OutR^n$

- $OutR^n$ : outsourced requests denote the set of new requests from shippers plus the set of requests that carriers are willing to subcontract to other carriers.
- $InR^n$ : insourced requests denote the set of requests offered by other carriers that the carrier is willing to perform.

We assume that each carrier chooses the shortest route in the network to transport requests from their origin to their destination.  $Rt$  denotes the set of all the shortest routes. A shortest route  $short\_rt \in Rt$  can be composed of several arcs; for example, route 1 – 2 – 3 – 4 is composed of 3 arcs {1 – 2; 2 – 3; 3 – 4}.  $A_{short\_rt} = \{a_1, \dots, a_k\}$  denotes the set of arcs of the shortest route  $short\_rt$ .  $CR_{a_i \in A_{short\_rt}}^m$  defines the residual capacity of a carrier  $m$  in the arc  $a_i \in A_{short\_rt}$  of the shortest route  $short\_rt$ .

$M$	The set of all carriers in the network
$m \in M$	An independent carrier company

$S$	The set of all shippers in the network
$s \in S$	An independent shipper
$C_{\max}$	The maximal capacity of a carrier
$N$	The set of all periods
$n \in N$	One period (e.g., a day)
$R^n$	The set of all transport service requests (commodities)
$NR^n$	The set of all new transport service requests generated randomly during a period
$OR^n$	The set of all previous transport requests generated during previous periods, transported by carriers, and that have not yet arrived at their destination.
$OutR^n$	The set of new requests from shippers, or requests that carriers are willing to pass on to other carriers (outsourced requests)
$InR^n$	The set of requests offered by other carriers that the carrier is willing to perform (insourced requests)
$r_s \in R^n$	An individual indivisible request $r_s$
$o(r_s)$	The origin of the request $r_s$
$d(r_s)$	The destination of the request $r_s$
$V_{r_s}$	The volume of the request $r_s$
$LT_{r_s}$	The delivery lead time of the request $r_s$
$OutRB^m$	The set of all outsourced request bundles for a carrier $m$
$OutRb_i$	An outsourced request bundle
$InRB^m$	The set of all insourced request bundles for a carrier $m$
$InRb_i$	An insourced request bundle
$A_{\text{short\_rt}} = \{a_1, \dots, a_k\}$	The set of arcs of the shortest route

$a_i \in A_{short\_rt}$	An arc
$d_i$	The distance of arc $a_i$
$CR_{a_i \in A_{short\_rt}}^m$	The residual capacity for a carrier $m$ per arc
$V_{InRb_i}$	The volume of the insourced request bundle $InRb_i$
$Ctt_{InRb_i}^m$	The cost for transporting the insourced request bundle $InRb_i$ by carrier $m$
$Ctr_{a_k, InRb_i}^m$	The transport cost of the bundle $InRb_i$ proposed by carrier $m$ in arc $a_k$
$Ctr_{InRb_i}^m$	The transport cost of the request bundle $InRb_i$
$P_{a_k, InRb_i}^m$	The price of the request bundle $InRb_i$ proposed by carrier $m$ in arc $a_k$
$P_{InRb_i}^m$	The price of the insourced request bundle $InRb_i$ proposed by carrier $m$
$P_{OutRb_i}^m$	The price of the outsourced request bundle $OutRb_i$ proposed by carrier $m$
$PC_{short\_rt, Rb_i}^m$	The penalty cost of the request bundle $InRb_i$ to be paid by carrier $m$ to transport the request bundle in the shortest route
$RP_r^m$	The unit price of request $r$ proposed by carrier $m$
$RP_{a_k, r}^m$	The unit price of request $r$ in the arc $a_k$ proposed by carrier $m$

Table 7: List of notations in the combinatorial double auction model

In each period  $n$ , a carrier  $m$  has two distinct missions. The first mission is to provide the best bidding strategy according to their private information (position, expected revenue, capacity, etc.). Each carrier proposes a price to transport an insourced request bundle on a determined route. This can be done in two steps: *determining the feasible request bundles* and *bidding for each feasible request bundle*. The second mission is to determine the outsourced requests and their reservation prices.

### 3.5.2.1. Feasible Request bundles

A carrier must be able to transport its shipments to the final destination. This means that only requests with origins and destinations along the same route that can be delivered by one truck are compatible. An  $RB$  is transported on a route if, and only if, this route contains the

origins and the destinations of all the requests in the bundle, and with the constraint that, for each request, the position of its origin along the route is prior to its destination.

Considering each carrier in a period  $n$  has a limited capacity (maximal or residual capacity), they will only consider the RBs they can handle (as task reservation is not allowed here). The total volume of requests transported by a carrier should not exceed the capacity of the carrier in all the arcs of the route. Finally, only RBs that meet both conditions are considered feasible.

For a carrier  $m$ , let  $InRB^m$  denote the set of all insourced feasible RBs, then  $InRB^m = \{InRb_1, InRb_2, \dots, InRb_k\}$ . Let  $V_{InRb_i}$  denote the volume of the insourced request bundle  $InRb_i \in InRB^m$ , then

$$V_{InRb_i} = \sum_{a_k \in A_{short\_rt}} \sum_{r \in InR^n, r \in InRb_i} V_r y_{k,i}$$

Where  $y_{k,i}$  is a binary variable with  $y_{k,i} = 1$  if the request  $r \in InRb_i$  is transported in the arc  $a_k \in A_{short\_rt}$  and  $y_{k,i} = 0$  otherwise.  $A_{short\_rt}$  is the set of arcs of the shortest route to transport the request bundle  $InRb_i$ .

All the insourced feasible request bundles verified the condition:

$$\forall m \in M, \forall a_k \in A_{short\_rt}, \forall InRb_i \in InRB^m \quad \sum_{r \in InR^n, r \in InRb_i} V_r y_{k,i} \leq CR_{a_k \in A_{short\_rt}}^m$$

Let  $Ctr_{InRb_i}^m$  denote the cost of transporting the insourced request bundle  $InRb_i \in InRB^m$  by carrier  $m$ . We use a concave nonlinear function of volume per unit distance (i.e. €/RB-km) to calculate the transport cost in each arc of the shortest route (see Figure 12):

$$Ctr_{a_k, InRb_i}^m = f(V_{a_k, InRb_i}); \quad \forall m \in M, \forall a_k \in A_{short\_rt}, \forall InRb_i \in InRB^m$$

The nonlinearity is due to transport synergies (i.e. economies of scale) generated by bundling requests.  $Ctr_{a_k, InRb_i}^m$  is the transport cost per kilometer of the bundle  $InRb_i \in InRB^m$  proposed by carrier  $m$  in the arc  $a_k \in A_{short\_rt}$ .  $V_{a_k, InRb_i}$  is the volume of the request bundle  $InRb_i \in InRB^m$  in the arc  $a_k \in A_{short\_rt}$ .  $f$  is a nonlinear function.

Then, the transport cost of request bundle  $InRb_i \in InRB^m$  proposed by carrier  $m$  can be written as follows:

$$Ctr_{InRb_i}^m = \sum_{a_k \in A_{short\_rt}} Ctr_{a_k, InRb_i}^m * d_k; \quad \forall m \in M, \forall InRb_i \in InRB^m$$

### 3.5.2.2. Bidding price function

Once the insourced feasible RBs are determined, carriers establish a bidding price for each interesting bundle based on the transport cost. The price for a request bundle depends on the transport cost and the penalty cost of the bundle. We use a nonlinear function  $g$  to define the price of an insourced  $RB$  knowing its transport cost. The function depends on the volume of the  $RB$  and the distance travelled.

Let  $P_{a_k, InRb_i}^m$  denote the price of the request bundle  $InRb_i \in InRB^m$  proposed by carrier  $m$  in the arc  $a_k \in A_{short\_rt}$ .

$$P_{a_k, InRb_i}^m = g(Ctr_{a_k, InRb_i}^m); \quad \forall m \in M, \forall a_k \in A_{short\_rt}, \forall InRb_i \in InRB^m$$

The price of the request bundle  $InRb_i \in InRB^m$  proposed by carrier  $m$  can be written as follows:

$$\forall m \in M, \forall InRb_i \in InRB^m \quad P_{InRb_i}^m = \sum_{a_k \in A_{short\_rt}} g(Cost_{a_k, InRb_i}^m) + PC_{short\_rt, InRb_i}^m$$

Where  $PC_{short\_rt, Rb_i}^m$  is the penalty cost of the request bundle  $InRb_i \in InRB^m$  to be paid by carrier  $m$  to transport the request bundle via the shortest route. This price is paid in the event of any delays and is equal to the sum of the penalty costs for each request in the  $RB$ :

$$\forall m \in M, \quad PC_{short\_rt, InRb_i}^m = \sum_{r \in InR^n, r \in InRb_i} PC_{short\_rt, r}^m$$

The parameters of the function  $g$  will be defined later in the simulation in chapter 4 to depict different bidding price strategies.

As the carriers submit prices for  $RBs$ , we propose a numerical model to calculate the unit price of each request in the bundle. We assume that the unit price is proportional to the total price of the bundle to which it belongs in terms of distance-volume. For each request, we calculate the unit price in each arc of the shortest route. The price on the route is the sum of the unit prices per arc. Let  $RP_r^m$  denote the unit price of request  $r \in R^n$  on the shortest route proposed by carrier  $m$ .

$$\forall r \in R^n, \quad RP_r^m = \sum_{a_k \in A_{short\_rt}} RP_{a_k,r}^m$$

Where  $RP_{a_k,r}^m$  is the unit price in the arc  $a_k \in A_{short\_rt}$ :

$$\forall r \in InRb_i, \quad RP_{a_k,r}^m = P_{InRb_i}^m \cdot \frac{V_r}{\sum_{r \in InRb_i, r \in R^n} V_r}$$

### 3.5.2.3. Reservation prices of outsourced requests

In each period  $n$ , the second mission of a carrier  $m$  is to determine the reservation prices of the outsourced requests.

For carrier  $m$ , let  $OutRB^m$  denote the set of all outsourced request bundles, then  $OutRB^m = \{OutRb_1, OutRb_2, \dots, OutRb_k\}$ .

Let  $P_{OutRb_i}^m$  denote the reservation price of the outsourced request bundle  $OutRb_i \subseteq OutRB^m$  determined by carrier  $m$ . Without loss of generality, we assume that this reservation price is calculated using the same function as the one used to calculate the reservation price proposed by the shippers.

### 3.5.2.4. Allocation model

Considering that carriers have a limited capacity, no more than one feasible request bundle should be allocated to each carrier and the request bundle should have the highest volume and thus the lowest unit cost. This is the XOR bidding language, as defined by (Lehmann et al., 2006). For example, a carrier submitting a bid  $(Rb_1, P_{rt,Rb_1}^m) \text{ XOR } (Rb_2, P_{rt,Rb_2}^m) \dots \text{ XOR } (Rb_k, P_{rt,Rb_k}^m)$  means that the carrier only wants to deliver one of the bundles  $Rb_1$  to  $Rb_k$ . In other words, even though carriers bid for each bundle in an auction, they can only win one bundle. To solve this problem, a Winner Determination Program is needed. We used the following winner determination program:

$$\max \sum_{m \in M} \left( \sum_{OutRb_i \subseteq OutRB^m} P_{OutRb_i}^m y_{OutRb_i}^m - \sum_{InRb_i \subseteq InRB^m} P_{InRb_i}^m y_{InRb_i}^m \right) - \sum_{Rbs_i \subseteq RBS} Pr_{Rbs_i} y_{Rbs_i} \quad 1$$

**Subject to**

$$\sum_{InRb_k \subseteq InRB^m} y_{InRb_k}^m \leq 1, \quad \forall m \in M \quad 2$$

$$\sum_{m \in M} \sum_{\substack{InRb_k \subseteq InRB^m \\ r_i \in InRb_k}} y_{InRb_k}^m = \sum_{m \in M} \sum_{\substack{OutRb_k \subseteq OutRB^m; \\ r_i \in OutRb_k}} y_{OutRb_k}^m + \sum_{Rbs_i \subseteq RBS; r_i \in Rbs_i} y_{Rbs_i}, \quad \forall r_i \in R^n \quad 3$$

$$\sum_{m \in M} \sum_{\substack{InRb_k \subseteq InRB^m \\ r \in InRb_k}} RP_r^m y_{InRb_k}^m \leq \sum_{m \in M} \sum_{\substack{OutRb_k \subseteq OutRB^m \\ r \in OutRb_k}} RP_r^m y_{OutRb_k}^m + \sum_{\substack{Rbs_i \subseteq RBS \\ r \in Rbs_i}} P_r y_{Rbs_i}, \quad \forall r \in R^n \quad 4$$

$$y_{InRb_k}^m \in \{0,1\}, \quad \forall m \in M, \forall InRb_k \subseteq InRB^m \quad 5$$

$$y_{OutRb_k}^m \in \{0,1\}, \quad \forall m \in M, \forall OutRb_k \subseteq OutRB^m \quad 6$$

$$y_{Rbs_i} \in \{0,1\}, \quad \forall Rbs_i \subseteq RBS \quad 7$$

$y_{InRb_k}^m$ ,  $y_{OutRb_k}^m$ , and  $y_{Rbs_i}$  are binary decision variables with  $y_{InRb_k}^m = 1$  if the insourced request bundle  $InRb_k$  is allocated to the carrier  $m$  and 0 otherwise.  $y_{OutRb_k}^m = 1$  if the outsourced request bundle  $OutRb_k$  is insourced by another carrier and 0 otherwise.  $y_{Rbs_i} = 1$  if the insourced request bundle from the shipper is allocated and 0 otherwise. Equation (1) is the objective function to maximize the social welfare. Constraint (2) guarantees that each carrier transports at most one insourced bundle. Constraint (3) guarantees that each request that is outsourced by shippers or some carriers is insourced by another carrier and vice versa. Constraint (4) is imposed to ensure that an insourced request can only be reallocated if it is distributed at a lower unit price.

### 3.6. Discussion and implications

This chapter considers two collaborative mechanisms with sets of collaborative rules in a CTN, taking the Physical Internet as an example. The goal was to increase the efficiency, effectiveness, and sustainability of the network without decreasing the individual profit of the independent carriers. We propose two rule-based, combinatorial auction-based mechanisms to resolve the problem. The mechanisms developed may be generalized as decision-making tools for other collaborations between carriers or as routing protocols between multiple networks.

Some improvements relating to the model can be expected in the next phases. For example, the collaborative mechanisms between carriers such as side payments or gain sharing mechanisms should be refined. Another relevant issue is who covers the extra costs of reallocation (handling, loading/unloading, etc.). Moreover, some practical and operational issues such as the responsibility for damaged products (which can be related to insurance issues) should also be discussed in more detail. To go further, more research is needed.

### **3.7. Conclusion**

This chapter proposes novel collaborative mechanisms for freight transport service procurement based on auction mechanisms. The collaborative mechanisms developed were modeled and coupled with sets of collaborative rules designed to increase the efficiency, effectiveness, and sustainability of the network without decreasing the individual profit of the independent stakeholders. To test and evaluate the performance of the collaborative mechanisms, two approaches are used in the following chapters to obtain theoretical and practical insights. In chapter 4, the multi-agent simulation approach is presented to evaluate the theoretical performance of the collaborative mechanisms, and in chapter 5, the Serious Game approach is presented to analyze the practicability and usage barriers of the innovative collaborative mechanisms in the real world.

## **CHAPTER 4: Multi-agent simulation approach to assess the performance of the designed mechanisms<sup>3</sup>**

### **Résumé**

Dans ce chapitre, nous développons un modèle de simulation multi-agents pour évaluer les performances théoriques des mécanismes proposés dans un cadre contrôlé en terme de comportement des acteurs.

Nous démontrons la supériorité de la méthode proposée sur un panel de scénarios et réalisons une analyse de sensibilité conduite à l'aide de plusieurs expérimentations.

Nous analysons les résultats à l'aide d'un ensemble d'indicateurs de performances clés. Les résultats indiquent que les mécanismes de collaboration sont avantageux pour tous types de marchés et ce quelle que soit la concurrence dans le marché.

### **Abstract**

In this chapter, a multi-agent-based simulation model was developed to assess the performance and practicability of the collaborative mechanisms developed. First, a set of key performance indicators was used to study the global performance of the collaborative mechanisms. Second, experimental analyses were conducted to evaluate the potential benefits to be gained by introducing collaborative mechanisms into various network fleet capacities with varying competition between carriers in carrier-to-carrier collaboration. Finally, numerical studies were executed to quantify the differences in performance caused by shipper collaboration and the strategy convergence of the participants in the CTN. The results indicate that collaborative mechanisms are advantageous for all market types regardless of the competition in the network. This chapter provides an effective methodology for assessing CTN performance.

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<sup>3</sup> This chapter partially contains the work presented in the article: Lafkihi, M., Pan, S., Ballot, E., 2019. The Price of Anarchy for Centralising or Decentralising Freight Transport Organisation Through Serious Gaming. IFAC-PapersOnLine. 52 (13), 1657-1662. <https://doi.org/10.1016/j.ifacol.2019.11.438>.

## 4.1. Introduction

Freight transport has different positive and negative effects on society. Positive effects typically relate to economy and social welfare, whereas negative effects relate primarily to social and environmental impacts (e.g., congestion, emissions, pollution, and accidents). As policy makers, public authorities often aspire to reach certain governmental goals such as obtaining sustainable transport systems, meeting emission targets, and obtaining an economically effective and efficient transport system. A typical ambition of a public authority is to increase the global performance of transport systems. However, increasing global performance may have negative effects on individual goals.

For individual companies, both shippers and carriers are “desperately” searching for ways to operate more efficiently. Shippers are under continuous pressure from the market to increase logistics performance while reducing costs. Meanwhile, carriers are facing challenges with profitability too. The goal of individual actors is typically to maximize profit by optimizing their activities (either individually or in collaboration), reducing lead times, lowering transport costs, improving delivery accuracy, and so forth. They make self-interested decisions to maximize their individual profit without regard for overall market optimality.

In any freight transport system there is a natural conflict between the interest of individuals and the interest of the group as a whole. There is a conflict between what individuals want and what serves their interests and what is needed for the welfare, safety, and security of the entire system. In this dissertation, collaborative mechanisms are proposed to deal with this conflict. They have been designed to guide the self-interested decisions of individual actors toward an optimal global solution in such a way that the individual actors are motivated to choose the optimal and rational solutions in a CTN. The collaborative mechanisms developed give shippers and carriers visibility to optimize their own activities by respecting the global interests in a CTN.

To assess the practicability of the proposed collaborative mechanisms, and evaluate their performance and their impact on the global and individual profit of independent actors under different market circumstances, we present a multi-agent freight transport simulation to study the theoretical performance of the collaborative transport network using the collaborative mechanisms developed. Based on key performance indicators, this chapter answers the following research question:

***“How do collaborative freight transport networks perform when adopting the new collaborative procurement mechanisms?”***

To answer this research question in a structured way, we have divided it into four sub-questions.

*SQ1: What is the impact of the collaborative mechanisms developed on the collaborative transport network performance measured in terms of KPIs?*

This sub-question studies the impact of the collaborative mechanisms developed on the performance of the CTN. It is known from the freight transport literature that collaboration generates more efficiency and sustainability in a freight transport network. It may help carriers to reduce transport costs and empty runs, improve truck utilization, and improve the overall level of service (Ergun et al., 2007). This statement was confirmed in this chapter by measuring the performance of the CTN using the proposed multi-agent simulation model.

*SQ2: How do changes in network characteristics and carrier competition affect the performance of the collaborative rules in a collaborative transport network?*

The second sub-question aims to evaluate the potential benefits of carrier collaboration in the CTN with various network characteristics (e.g., demand to supply ratio), and competition between carriers. The idea of forming networks of collaborating carriers is well known in the freight transport literature and has been recognized as one of the most effective approaches to improve freight transport efficiency and sustainability (Goldsby et al., 2014). However, this collaboration has often been studied in a specific transport market with local decision making (e.g., for a given marketplace) and with no vision at network level. Nevertheless, it is essential to consider carrier collaboration at network level where different heterogeneous transport networks as well as markets are interconnected with hubs.

We conducted experimental analyses to evaluate the potential benefits to be gained by introducing the collaborative mechanisms developed into various network fleet capacities with varying competition between carriers. We then propose a supply and demand sensitivity analysis to explore how this parameter could affect the performance of the transport system.

*SQ3: What is the impact of shipper collaboration on the performance of collaborative transport networks?*

In addition to carrier collaboration, sub-question 3 studies the potential benefits to be gained by adding the possibility for shippers to collaborate using the collaborative mechanisms developed; searching for more favorable rates, shippers could collaborate to identify sets of requests that can be submitted to carriers as bundles, rather than individually. We conducted experimental analyses to study the difference in performance caused by shipper collaboration in the CTN. This performance was studied in terms of global system efficiency, effectiveness, and sustainability, and individual profit of independent actors.

*SQ4: How will the strategy convergence affect the performance of the collaborative transport network?*

The last sub-question studies the impact of participant strategy convergence on the performance of the CTN. Through collaboration, participants in CTN can implement strategies specifically designed to reduce costs. We are interested in the impact of collaborative mechanisms on network performance if participants use the same strategy. This can be reflected in the sharing of information between shippers and carriers via a digital platform managed by a third party. We conducted experimental analyses to study the impact of strategy convergence and information sharing on CTN performance.

## **4.2. Background literature**

### **4.2.1. Measuring the performance of collaborative transport networks**

Morash (2000) explained that there are five categories of freight transport performance measurement: asset management, customer service, productivity, cost, and quality. Furthermore, there are several categories of freight stakeholders (e.g., the freight infrastructure provider, the producer of goods, the shipper, and the customer). Each category of measurement is subject to a different interpretation by each of the stakeholder groups. Thus, it is possible to develop many sets of performance measures related to the given measurement category and stakeholder group.

In the freight transport literature, performance measurement has attracted two realms of interest: that of the global system and that of individuals (Cottrell, 2008). The global system is keenly interested in measures such as asset productivity, total shipments, total flow, total cost, and total fleet emissions. Individuals are interested in economic measures such as aspects of financial performance, load, haul, and customer service measures. Many researchers have been interested in one or a group of these objectives for freight transport systems and

proposed several indicators and measurements for each objective. Australia's Bureau of Industry Economics (1992c) published a research report for road freight transport and suggested two types of indicators: customer service and operational efficiency. The report identified four key customer service measures: on-time pickup (% of pickups), on-time delivery (% of deliveries), proportion of claims paid, and loss and damage rate, as well as six operational efficiency measures: total kilometers per vehicle per year, total tonne-kilometers per vehicle per year, kilometers travelled empty as a proportion of the total kilometers travelled, average actual load as a proportion of full load capacity, number of kilometers per driver per year, and fuel usage by vehicle type. Stewart (1995) discussed four key measures: delivery performance, flexibility and responsiveness, logistics cost, and asset management. Based on the literature addressing freight transport KPIs, a categorization proposed by Pan (2017) was used in this dissertation to propose freight transport KPIs and define the rules and policies that have an impact on these KPIs. The categorization contains mainly *effectiveness*, which is the degree to which a predetermined objective or target is met (Mentzer and Konrad, 1991), *efficiency*, which is the degree to which expended resources are used to meet a goal (Mentzer and Konrad, 1991), and *sustainability*, which is the ability of a system to protect, sustain, and enhance the human and natural resources that will be needed in the future while meeting a desired goal (Labuschagne et al., 2005).

#### 4.2.2. Multi-agent simulation

A multi-agent-based simulation was adopted to model the actual complexity of the freight transport system (e.g., decisions of different actors, their interaction, time aspects). The simulation used the models developed to understand how the actors behave and to estimate and evaluate the freight transport performances. Multi-agent based simulation allows complicated freight transport systems with multiple actors to be investigated (Ferber and Weiss, 1999; Weiss, 1999; Wooldridge, 2009). This is a powerful method to get accurate results when assessing the impact of transport measures (Holmgren et al., 2011). Anand et al. (2016) denoted that agent-based simulation is the most natural and flexible technique to model complex systems involving several agents and in which establishing general rules for their interactions is difficult. For further understanding of the main advantages of multi-agent based simulation compared to other techniques, refer to Siebers et al. (2010).

Multi-agent models generally deal with behavior and interactions among multiple agents and their response to policy measures. Davidsson et al. (2005) provided a survey of existing

research on agent-based approaches in freight transport and noted that agent-based approaches seem very suitable for this domain. Schroeder et al. (2012) justified the use of agent-based simulation as it allows the agents (shipper, transport service provider, carrier, and driver) to act as independent decision-makers or behave as single entities. Ossowski et al. (2005) presented multi-agent approaches to decision support systems in traffic management.

The literature shows a number of interesting examples of multi-agent simulation studying the performances of freight transport systems. van Heeswijk et al. (2016) highlighted that agent-based simulation techniques are suitable to evaluate the effectiveness of urban logistics schemes, as they are capable of monitoring and altering the behavior of autonomous agents under varying conditions. Tamagawa et al. (2010) presented a methodology for evaluating city logistics measures considering the behavior of several independent stakeholders with their own objectives.

The literature contains a number of agent-based simulations for freight transport analysis (Jlassi et al., 2017). However, logistics decisions and the complex relationships between freight actors make the proliferation of these approaches a challenging task. Some characteristics of multi-agent-based simulations such as their micro-level of operations and the need for explicit interactions can make them difficult to apply and to validate.

### **4.3. Methodology and scenario design**

Simulation was used as it is relatively easy and faster to change parameters, apply a sensitivity analysis, and identify the results. Multi-agent simulation models can also be easily applied in real-life circumstances in which the parameters need to be adjusted according to actual values and strategies of the participating actors. In what follows, we present the methodology used to answer each of the research sub-questions.

#### **4.3.1. The impact of collaborative mechanisms on the global performance of the CTN**

As the collaborative mechanisms developed are based on the auctions and optimization models defined previously, we used the simulation to simulate the decisions and outputs of a sequence of auctions, and to study the impact of the collaborative mechanisms on the performance of the CTN. We conducted an experimental study to compare the transport plans of carriers between two scenarios. Scenario 1 is a baseline scenario with no collaboration (the scenario is based on the optimization model defined above without collaboration rules) and Scenario 2 is the scenario of carrier-to-carrier collaboration.

For both scenarios, we used the same inputs (transport requests and capacity, see Appendix B). For each scenario, 33 rounds were played with 4 players (carriers). The maximal capacity of a truck was 4 units, and the penalty cost of a delay was 5€/order/period.

The outcomes of both scenarios were compared using the KPIs defined (see section 3.3) in order to quantify the impact of collaborative mechanisms on the performance of the CTN.

#### 4.3.2. The impact of market and carrier characteristics on CTN performance

The performance was compared using the KPIs defined to examine if the collaborative rules achieve the desired performance in the CTN. Furthermore, two factors that were assumed to influence the performance of the CTN were studied: carrier bidding strategy and market characteristics.

The allocation of resources achieved by the collaborative mechanisms depends heavily on the bidding price strategy employed. Thus, it is important to consider the impact of the strategy selected on the overall performance of the mechanism. We simulated three different carrier bidding price strategies that represent three different cases of carrier competition (see Figure 13). In Case No.1, we considered that all carriers had the same non-linear pricing function. In Case No.2, carriers had different non-linear pricing functions with close margins. In Case No.3, we considered that one of the carriers had a much lower margin than the others.

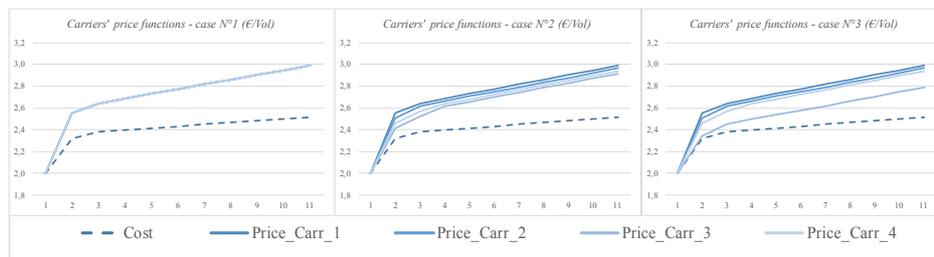


Figure 13: Cost function and cases of carrier competition

In the freight transport literature, the demand to supply (D/S) ratio is important for price determination and resource allocation and has an impact on the performance of the freight transport market. For this reason, we conducted a supply and demand sensitivity analysis to explore how this parameter could affect the performance of the transport system. For that, we changed the maximal truck capacity to define different supply and demand ratios. As demand is the same and supply is the sum of the theoretical maximal capacity, the D/S ratio differs depending on the maximal capacity chosen (e.g., a high D/S ratio representing a seller

(carrier) dominated market, a balanced market, and a low D/S ratio representing a buyer (shipper) dominated market). In this step, we defined five markets (see Table 8).

Market	Maximal Capacity	Demand/Supply ratio
Market 1	2	300%
Market 2	4	160%
Market 3	7	100%
Market 4	8	80%
Market 5	10	60%

Table 8: Maximal truck capacity and demand to supply ratio for different markets

Sensitivity analysis was used for supply and demand and carrier competition to assess the robustness of the impact of pre-defined collaborative rules on the CTN.

#### 4.3.3. The impact of shipper collaboration and strategy convergence on CTN performance

To study the impact of shipper collaboration in addition to carrier-to-carrier collaboration on the performance of the CTN, we set up three scenarios of collaborative mechanisms. The first scenario (ScShipper.1) adopts the collaborative mechanisms with carrier-to-carrier collaboration and no possibility of shipper collaboration, the second scenario (ScShipper.2) adopts the collaborative mechanisms with carrier-to-carrier collaboration and the possibility of shipper collaboration, and the third scenario (ScShipper.3) adopts the collaborative mechanisms enabling shippers to collaborate and use the same price strategy as the carriers. The only difference between ScShipper.2 and ScShipper.3 is that in ScShipper.3 the third party passes the reference prices of the transport market on to the carriers and shippers and lets them take this information into consideration when proposing prices and reservation prices for request bundles.

In the simulation model, shipper collaboration reflects the possibility for shippers to combine their requests on request bundles in order to get more favorable rates. They do this with the help of a proxy shipper agent that calculates the transport cost of request bundles using a non-linear function of volume and distance. Moreover, strategy convergence in the

model reflects the use of the same strategy to determine prices and reservation prices by carriers and shippers, respectively.

**4.4. Simulation results**

It should be noted that it is not reasonable to directly compare reverse and double auction mechanisms in terms of KPIs because shipper bids (reservation price) are not considered in reverse auctions. Readers may refer to Chapter 2 reviewing different procurement mechanisms for a comparison in terms of outcomes for the two mechanisms.

**4.4.1. With a reverse auction mechanism**

**4.4.1.1. Impact of a collaborative mechanism with reverse auctions on CTN performance**

The analysis of the global network performance with reverse auctions was based on Figure 14, which compares the global performance indicators of the collaborative mechanism. According to this figure, the performance of a CTN is better with collaborative mechanisms. This finding confirms the results in the freight transport literature indicating that the performance of transport systems increases with collaboration.

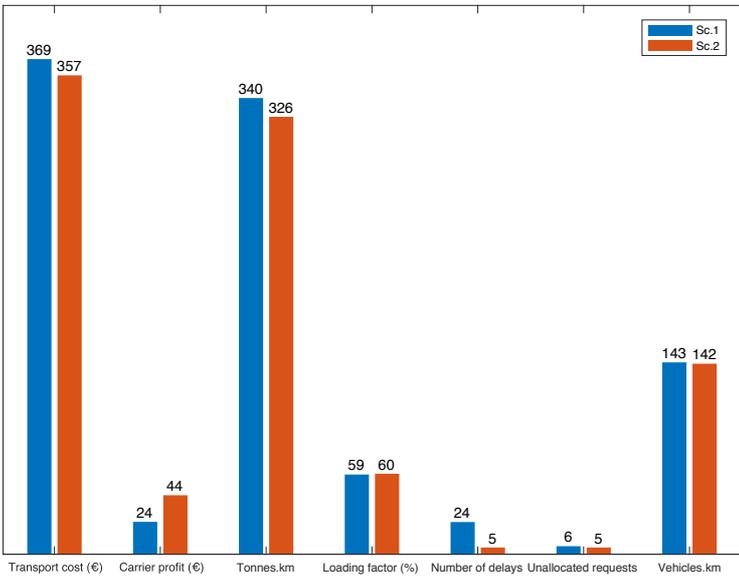


Figure 14: Global performance of CTN (reverse auctions)

We can see from the figure that all freight transport KPIs are better in scenario 2 compared to scenario 1. In terms of efficiency, scenario 2 generated minimum transport costs compared to scenario 1. In addition, the total carrier profits were better in scenario 2, as well as the transport tonne-kilometers and vehicle-kilometers. Regarding effectiveness, again, scenario 2

outperformed scenario 1 with fewer delays and fewer unlocated requests; the quality of service in the network with collaborative mechanisms was better.

#### 4.4.1.2. Impact of network and carrier characteristics on CTN performance

All the KPIs in Sc.1 (i.e. without carrier-to-carrier collaboration) and Sc.2 (i.e. carrier-to-carrier collaboration with rules) were compared according to the three freight transport objectives presented (i.e. effectiveness, efficiency, and sustainability). The figures in this section represent the gap between Sc.1 and Sc.2 in terms of the KPIs defined. Depending on each KPI (e.g., loading factor or vehicle-kilometers), the difference between Sc.1 and Sc.2 could be positive or negative. In what follows, we consider the absolute value of this difference.

Considering the *effectiveness* of the network (see Figure 15), the service rate is represented by the number of unallocated requests in our model. It depends on the type of market (e.g., under-capacity, balanced, and overcapacity markets). The service rate for balanced and overcapacity markets (i.e. markets 3, 4, and 5) was 100% for both scenarios, whereas the service rate for under-capacity markets (1 and 2) was better in Sc.2 than in Sc.1. A relative increase in service rate of up to 33% was observed in Sc.2 compared to Sc.1. Moreover, the total number of carrier delays was more significant in Sc.1 compared to Sc.2 (see Figure 15). The reallocation and exchange of requests in Sc.2 allowed carriers to increase the service rate. After subcontracting a request to another carrier with unused capacity, a carrier has capacity anew to transport other requests within shorter times, thus avoiding possible delays.

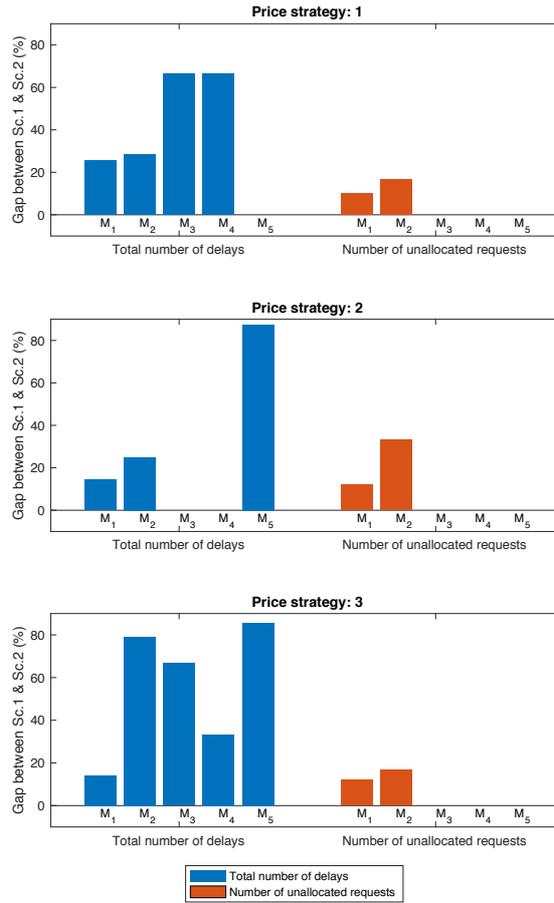


Figure 15: Effectiveness of the CTN (reverse auction): Gap between Sc.1 & Sc.2

The introduction of new collaborative rules that favor the reallocation and the exchange of orders without changing the current structure of the transport market considerably improve the quality of service of the CTN.

In what follows, it is assumed that if a request has not been allocated in the network, it will be allocated to a dummy carrier, which delivers it with no detour (i.e. shortest route) and at a more expensive price. This assumption allows us to compare the efficiency indicators between the two scenarios.

Considering the *efficiency* of the network, Figure 16 represents the gap between the two scenarios in terms of total profits for carriers, and Figure 17 represents the gap between the two scenarios in terms of market objectives (i.e. total transport costs, total distances travelled, and total tkm).

According to the figures, all the indicators were better in Sc.2 compared to Sc.1; the gap between Sc.1 and Sc.2 was greater than zero. Reallocation allows carriers to exchange their

capacity to improve their profits. More precisely, to derive profits/savings, a carrier can subcontract its shipments to other carriers who can provide lower prices for the remainder of the routes; the carrier then has capacity anew for other, more economically attractive requests. Thus, reallocation provides side payments for carriers in addition to the revenue generated by delivering other requests.

According to Figure 16, the total carrier profit was optimized in Sc.2. We can observe that Sc.2 yielded a higher total profit than Sc.1. In other words, Sc.2 based on collaborative mechanisms with reverse auctions would be more interesting for carriers to participate in. The incentive is, therefore, more individual.

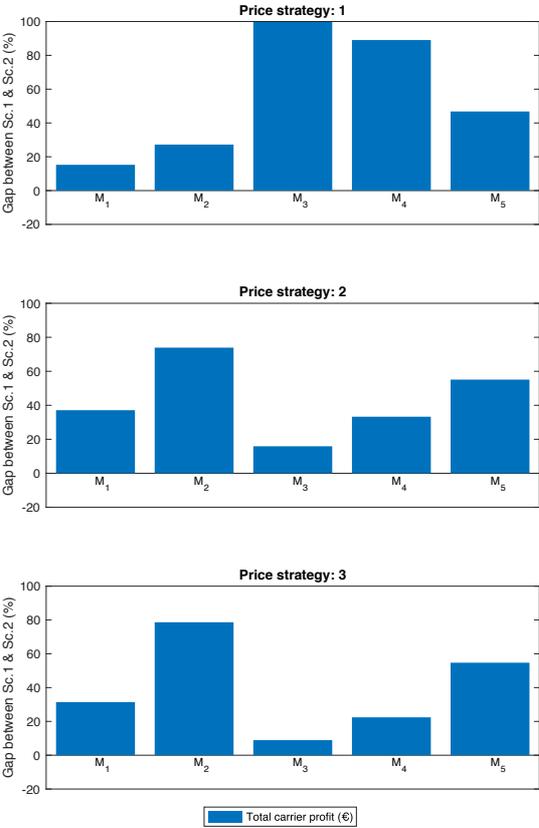


Figure 16: Total carrier profit (reverse auction): Gap between Sc.1& Sc.2

According to Figure 17, pre-defined collaborative rules significantly increase the performance of the decentralized CTN; a relative reduction in the total transport cost of up to 15% was observed. Moreover, in Sc.2, requests travelled shorter distances; a relative reduction between 3% and 22% was observed in Sc.2 compared to Sc.1. In the same way, the total transport tonne-kilometers indicator was better in Sc.2 compared to Sc.1.

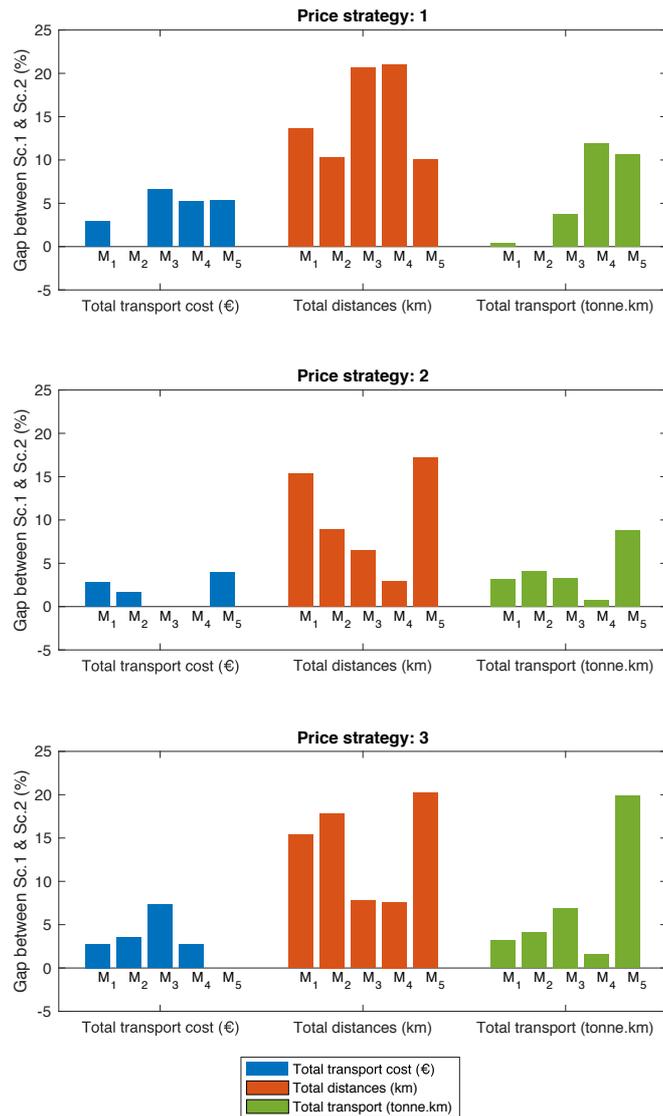


Figure 17: Efficiency of CTN (reverse auction): Gap between Sc.1 & Sc.2

Considering the *sustainability* of the network, Figure 18 shows that the collaborative mechanism with a reverse auction had a small impact on the vehicle-kilometers indicator. However, the greater freight efficiency and effectiveness due to the collaborative mechanism also improved the sustainability of the CTN. By reducing distances travelled and total transport (tkm), the collaborative mechanism improves vehicle utilization and makes better use of the capacity of each vehicle. Then, the same goods can be carried with fewer vehicle journeys.

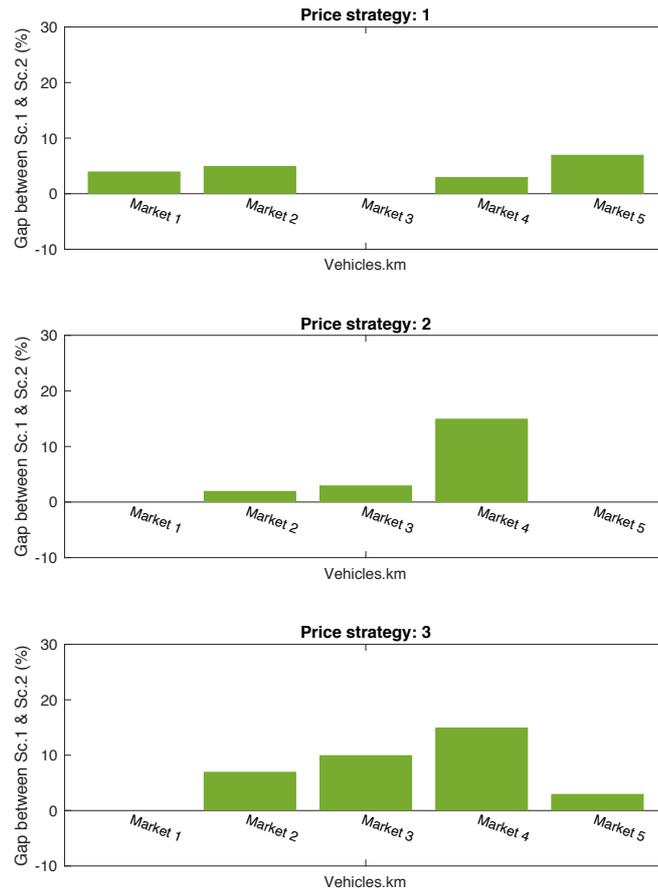


Figure 18: Sustainability of CTN (reverse auction): Gap between Sc.1&Sc.2

According to the *sensitivity analysis*, both factors—pricing strategy and market type—had a significant impact on the collaboration results. Several conclusions can be derived from the figures above regarding managerial implications. First, there is no clearly dominant pricing strategy that simultaneously meets all the global performance indicators, especially with respect to different market types. Second, pricing strategy No.1 (all carriers had the same non-linear pricing function that could be considered the extreme case of transport price stability) performed very differently from pricing strategies No.2 and No.3 that had almost the same results in different market types. When the D/S ratio is low (i.e. shipper markets such as 4 & 5 where carriers are in high competition), collaboration between carriers leads to high efficiency and profits. Third, the fact that the results of strategies No.2 and No.3 were very similar means that when few players have very different pricing strategies to the others, the consequences on the market are limited. However, it should be noted that the discussion here concerns the qualitative analysis. Due to the difficulty and complexity of the real business world, pricing is one of the most important issues and requires more quantitative studies.

## 4.4.2. With a double auction mechanism

### 4.4.2.1. Impact of a collaborative mechanism with a double auction on CTN performance

According to Figure 19, the performance of the CTN is better with a collaborative mechanism based on a double auction; scenario 2 generated a minimum transport cost, and the total carrier profits and the transport tonne-kilometers and vehicle-kilometers were better. Moreover, fewer delays were generated and more requests were allocated.

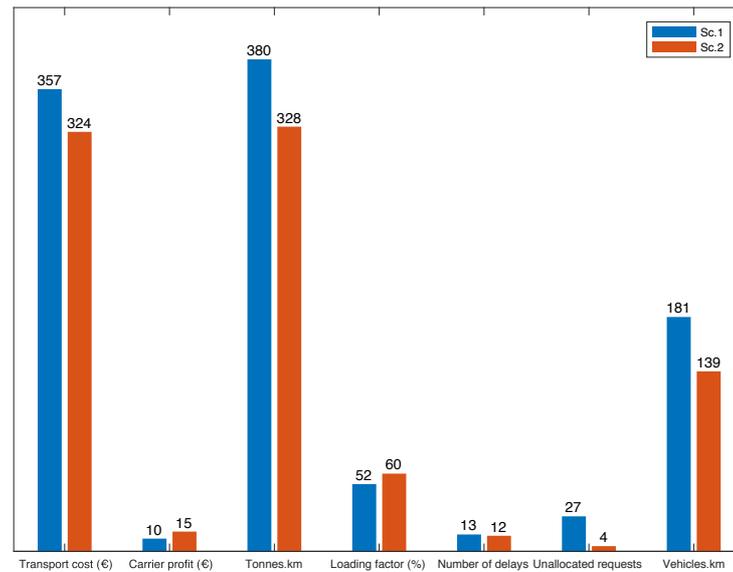


Figure 19: Global performance of CTN (double auction)

This finding confirms the results in the freight transport literature showing that the performance of transport systems increases with collaboration and with double auction mechanisms.

### 4.4.2.2. Impact of network and carrier characteristics on CTN performance

Considering the *effectiveness* of the network (see Figure 20), the service rate was much better in Sc.2 compared to Sc.1 whatever the type of market (e.g., under-capacity, balanced, and overcapacity markets). Moreover, the total number of delays by carriers was higher in Sc.1 compared to Sc.2.

Collaborative mechanisms based on double auctions offer a high quality of service at low cost (see Figure 22); for all the price strategies, the quality of service was higher in CTN with double auction-based collaborative mechanisms.

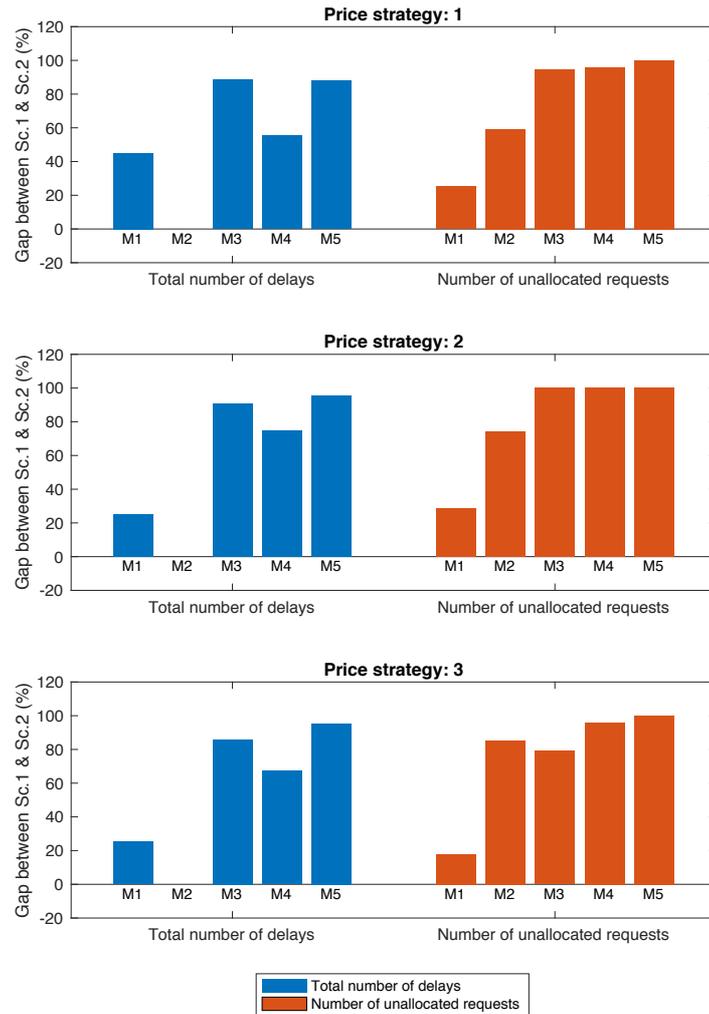


Figure 20: Effectiveness of the CTN (double auction): Gap between Sc.1&Sc.2

Differently to the gain in quality of service of collaborative mechanisms with reverse auctions, the gain with double auctions does not depend on the price strategies of the carriers; the curve representing the gap between Sc.1 and Sc.2 is the same for all the price strategies. In collaborative mechanisms with double auctions, shippers propose reservation prices by taking into consideration the quality of service of their shipments (for instance, a shipper could propose a higher reservation price for urgent shipments). The quality of service depends more on shipper reservation prices than on carrier price strategies.

Considering the *efficiency* of the network, the gap between Sc.1 and Sc.2 was greater than zero; all the indicators were better in Sc.2 compared to Sc.1. According to [Figure 21](#), the total carrier profit was much better in Sc.2; carriers gain more because the network is more optimized with a collaborative mechanism based on double auctions; the CTN is more

interesting in Sc.2 based on a collaborative mechanism with double auctions and carriers are more motivated to participate.

In this section, we focus on the total carrier profit. To study the individual profit of each carrier, side payments or gain sharing mechanisms need to be refined; a good sharing mechanism can give actors more incentives to participate in the collaborative mechanism.

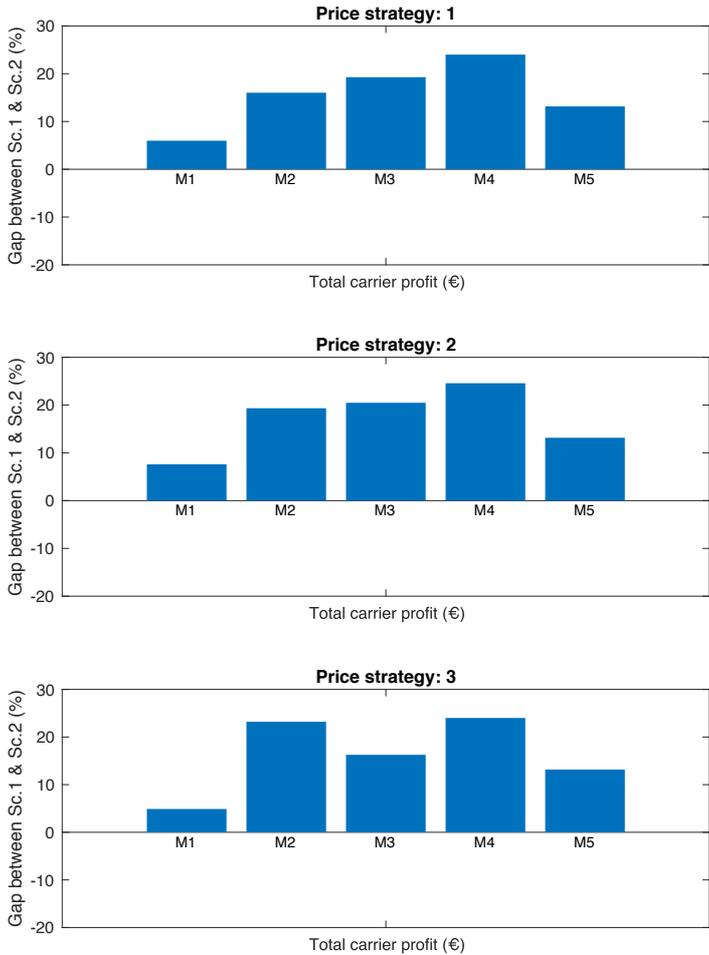


Figure 21: Total carrier profit (double auction): Gap between Sc.1&Sc.2

Once again, and differently to the total carrier profit of collaborative mechanisms with reverse auctions, the total carrier profit with double auctions does not depend on the price strategies of carriers.

According to Figure 22, the collaborative mechanisms developed with double auctions significantly increase the performance of the CTN; a relative reduction in the total transport cost of up to 25% was observed. Moreover, in Sc.2, requests travelled shorter distances. In the same way, the total transport tonne-kilometers indicator was better in Sc.2 compared to Sc.1.

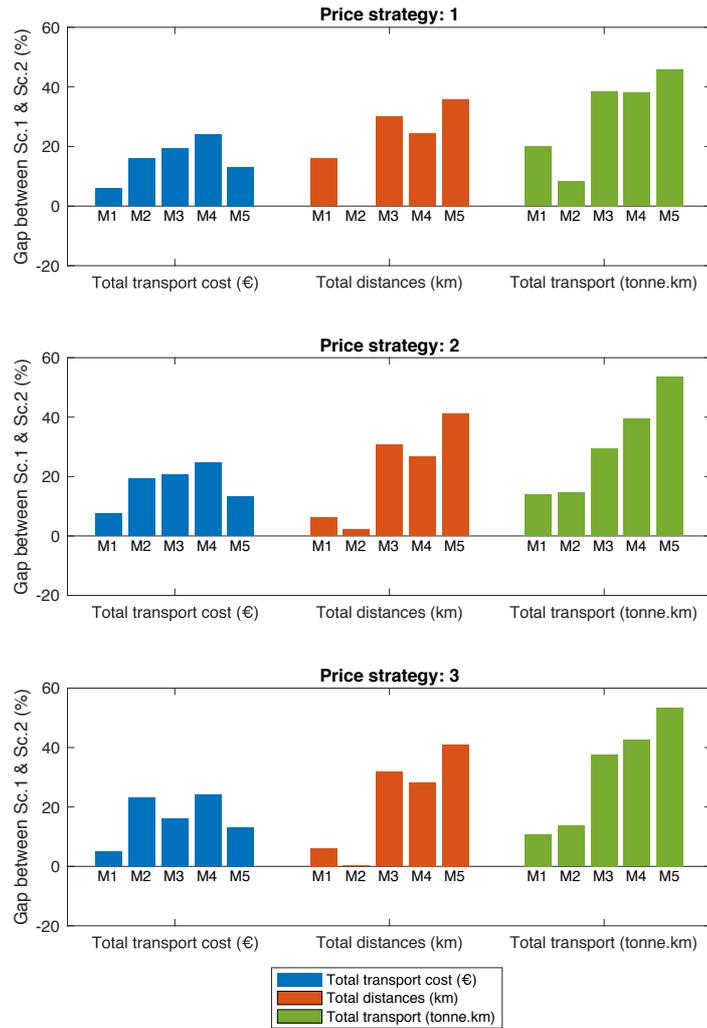


Figure 22: Efficiency of CTN (double auction): Gap between Sc.1&Sc.2

We can conclude that a CTN based on a collaborative mechanism with double auctions is more efficient; truck use is better, requests travel shorter distances, and carriers gain more.

Considering the *sustainability* of the CTN, Figure 23 shows that a collaborative mechanism with double auctions has a significant impact on the vehicle-kilometers indicator. In a CTN with double auctions, the vehicles cover less kilometers and therefore can reduce CO<sub>2</sub> emissions and congestion.

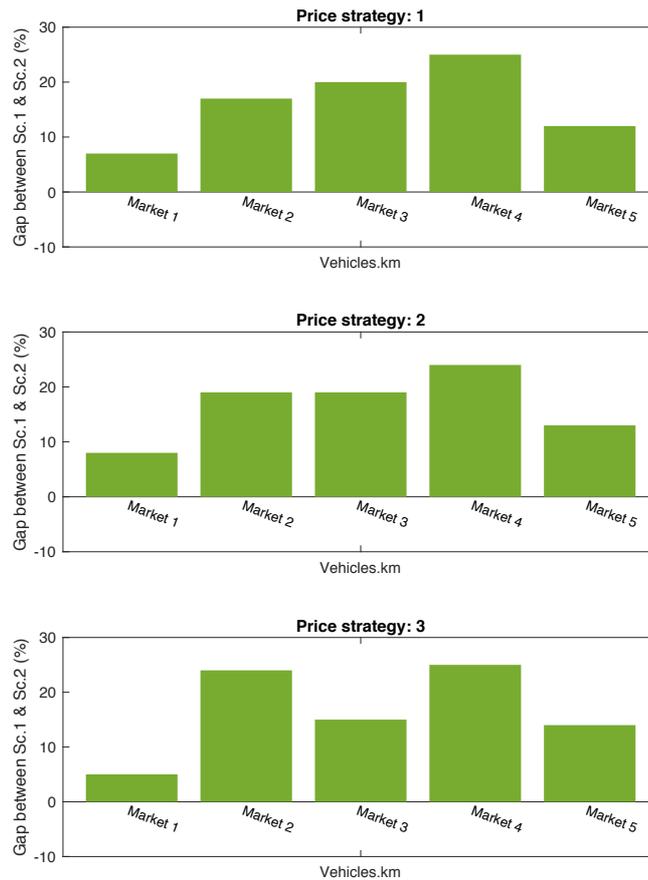


Figure 23: Sustainability of CTN (double auction): Gap between Sc.1&Sc.2

According to the *sensitivity analysis*, both pricing strategy and market type do not have a significant impact on the collaboration results with double auctions. First, the change in pricing strategy does not seem to change the results. Second, there is no clearly dominant pricing strategy that simultaneously meets all the global performance indicators, especially with respect to different market types.

#### 4.4.2.3. Impact of shipper collaboration and strategy convergence on CTN performance

According to Table 9, the performance of the CTN was better in ScShipper.2 (scenario allowing collaboration between shippers) than in ScShipper.1; through collaboration, shippers could propose more interesting request bundles and benefit from lower prices or better services.

KPI		<i>ScShipper.1: without shipper collaboration</i>	<i>ScShipper.2: with shipper collaboration</i>	<i>ScShipper.3: strategy convergence</i>
<i>Effectiveness</i>	<i>Unallocated requests</i>	5	3	3
	<i>Total delays</i>	4	2	1
<i>Efficiency</i>	<i>Total price</i>	287.43	335.57	340.1
	<i>Mean filling rate</i>	53.15%	58.06%	61.04%
	<i>Total transport (tonne.km)</i>	350	329	318
<i>Sustainability</i>	<i>Total Vehicle.km</i>	181	174	171

Table 9: Comparison of CTN performance – Shipper collaboration

Moreover, as a result of the strategy convergence in ScShipper.3, the CTN prices converged toward reference prices thus increasing the performance of the CTN.

The adoption of a digital platform as a way of sharing information could create new opportunities to improve freight transport performance.

#### 4.5. Conclusion

This chapter looked at the theoretical analysis of the performance of the collaborative mechanisms in a CTN. We conducted a multi-agent simulation to demonstrate the theoretical performance of the collaborative mechanisms and assess the influence of the proposed collaborative rules. This chapter also aimed to provide evidence of potential applications of CTN in real practice. As a hot topic in Europe and on other continents, CTN are often considered as effective and efficient organizational solutions for sustainable freight transport, as proven by a considerable number of studies and projects (especially the European H2020 projects). Furthermore, this dissertation extends the scope of collaboration to make it more appropriate for large transport networks. From a practical point of view, the study presents a new line of research in CTN research that is designing collaborative rules to achieve efficiency in CTN. In the next chapter, it is expected that more managerial implications can be obtained by implementing the study in real-life circumstances in order to close the gap between theory and practice.

## **CHAPTER 5: Serious Gaming approach to analyze the practicability of the designed mechanisms in a real-world scenario**

### **Résumé**

Ce chapitre décrit la conception et le développement du «Freight Transportation Game», un jeu sérieux dans lequel chaque joueur incarne un transporteur dans un système de transport collaboratif. Dans ce cadre, le joueur qui gagne la partie est celui qui empêche le plus de revenus.

Le jeu propose des simulations très fines des systèmes de transport. Il est très ouvert car il pousse les joueurs à l'expérimentation dans une démarche d'investigation : un transporteur doit analyser le marché ainsi que les comportements de ses concurrents et optimiser son plan de transport. Comme il est assez peu guidé, il doit être dans une vraie démarche d'essai/erreur.

Le jeu a été joué des centaines de fois par des vrais transporteurs, mais aussi par des personnes non initiées (notamment de jeunes étudiants). Chaque partie du jeu permet d'analyser la faisabilité et les barrières d'utilisation des mécanismes proposés.

Ainsi, nous analysons le comportement des joueurs à l'aide de la méthodologie innovante de simulation créée par Caminada et al., 2020. Cette méthodologie permet de fournir des informations sur le comportement des joueurs afin de leur proposer des outils d'aide à la décision.

### **Abstract**

This chapter describes the design and development of the “Freight Transport Game”, a serious game that represents a protected space where prospective actors can explore and try out the new collaborative mechanisms in a playful way. The results of the assessment of the game are summarized and the usage barriers that might result in the refusal of the collaborative mechanisms in real life are analyzed. First, the data from the game sessions were validated in order to use them to support the analysis. This step is fundamental before analyzing the game outputs. We used the same methodology as Smith et al. (2015) to collect and validate data from the game sessions organized. Second, player performance was studied in terms of the KPI defined. Third, the innovative Game and Choice Based Simulation methodology (GCSM) created by (Caminada et al., 2020) was used to provide insights into

player behavior. Finally, based on these insights, a decision support tool for carriers was defined as a policy to optimize the performance of players. The proposed policy was tested in an experiment.

## **5.1. Introduction**

Collaborative transport networks are a new and innovative horizontal collaboration solution attracting increasing attention (Berger and Bierwirth, 2010) of which the effectiveness and efficiency in freight transport have been proven in the recent literature. However, examples in real practice are still rare, especially in large scale networks (Pan et al., 2019). Insufficient provision of information about how to use the new collaborative mechanisms or the absence of a comprehensible information environment could create usage barriers that might result in the refusal of the collaborative mechanisms in real life. Additionally, the complexity of the current transport market, which is very dynamic and involves multiple stakeholders, makes it difficult to analyze the behavior of actors within the CTN.

Creating a model of a real CTN with collaborative mechanisms could be an effective solution to overcome these difficulties (Holguín-Veras et al., 2011). In the freight transport literature, there are several ways of modeling a real transport market, of which multi-agent simulations are the most important methodology.

There are a number of multi-agent based simulations for freight transport analysis in the freight transport literature (Jlassi et al., 2017). Multi-agent simulation allows complicated freight transport systems with multiple actors to be investigated (Ferber and Weiss, 1999; Weiss, 1999; Wooldridge, 2009). Holmgren et al. (2011) indicated that multi-agent based simulation is a powerful method to get accurate results when assessing the impact of transport measures. Anand et al. (2016) denoted that it is the most natural and flexible technique to model complex systems where several agents are involved and in which establishing general rules for their interactions is difficult.

However, logistics decisions and the complex relationships between freight actors make the proliferation of multi-agent simulation a challenging task. Some characteristics of this approach such as its micro-level of operations and the need for explicit interactions can make it difficult to apply and to validate. Moreover, considering the dynamism of the freight transport market, with too many (known & unknown) complex factors, it is difficult to

simulate it. For example, carrier behavior varies dramatically and changes over time. In reality, freight transport systems most often involve human agents with potentially irrational behavior, subjective choices, and complex psychology (i.e. soft factors that are difficult to quantify, calibrate, and sometimes justify).

Over the last decade, a new approach has captured the attention of researchers and professionals in the domain of transport and logistics: Serious Games. In contrast to simulations, serious games allow a simplified representation of a complex reality where the human factor and dynamic relationships are addressed. In the transport domain, several serious games have been developed and used to analyze, understand, and change decision making and behavior of participants. For example, Kelpin et al. (2016) successfully used a serious game approach based on a mobility application to convince people to use “greener” modes of transport such as bicycles. Gabrielli et al. (2013) used the Eco-Dealer game to promote awareness of sustainable transport systems. In logistics and SCM, the beer game is one of the most famous serious games and it has a twofold objective, on the one hand for teaching purposes, and on the other hand for empirical research.

Serious games seem to be an excellent approach, in our case, to complement the theoretical results of the multi-agent simulation and analyze the practicability and usage barriers of the innovative collaborative mechanisms in practice. Moreover, Serious games have been proven to enhance learning and knowledge acquisition (Breuer and Bente, 2010; Wouters et al., 2013), and prompt behavioral change (Klimmt, 2009). Therefore, they will be an excellent way of explaining and teaching the complex concept of a CTN with collaborative mechanisms.

This chapter describes the design and development of the “Freight Transport Game”, a serious game that represents a protected space where prospective actors can explore and try out the new collaborative mechanisms in a playful way before the actual large-scale implementation of the CTN. The results of the assessment of the game are summarized and usage barriers that might result in the refusal of the collaborative mechanisms in real life are analyzed. This chapter answers the following research question:

***“What are the obstacles to using the theoretically proven mechanisms and rules in an actual collaborative transport network, and how do the stakeholders behave in the face of these new mechanisms and rules?”***

To answer the research question in a structured way, it has been divided into four sub-questions.

*SQ.1: How to assess the performance of theoretically proven mechanisms and rules via serious gaming, and how to collect and validate data from participants to this end?*

The first sub-question aims to validate game session data in order to use it to support the analysis. The answer to this sub-question is fundamental before conducting any analysis of the game outputs. We used the same methodology as Smith et al. (2015) to collect and validate data from the game sessions organized.

*SQ.2: How well do participants perform when using the new proposed collaborative mechanisms?*

Before analyzing player behavior during the game (i.e. a representation of the CTN with the new collaborative mechanisms), it is necessary to study the performance of the player. We organized two game sessions with the same players (i.e. a game session with the collaborative mechanism and the possibility of players collaborating and a game session without the collaborative mechanism), and we compared the performance of each player in the two scenarios in terms of the KPIs used in theory (see Section 3.3).

*SQ.3: How do players react to the new proposed collaborative mechanisms?*

To answer this sub-question, the innovative Game and Choice Based Simulation methodology (GCSM) created by (Caminada et al., 2020) was used to provide an insight into the behavior of the players. As part of this PhD, a master's student at Delft University of Technology (TU Delft) conducted research regarding the analysis of player behavior in serious games. The team at TU Delft proposed an innovative methodology that was applied to the "Freight Transport Game" to analyze player behavior when using the new collaborative mechanisms (Caminada, 2019).

*SQ.4: How can player decision making and performance be improved in the face of the new rules?*

Based on the insights into player behavior obtained from the GCSM methodology, a decision support tool for carriers was defined as a policy to optimize system performance. The proposed policy was tested in an experiment.

## 5.2. Related literature on gamification in freight transport

It was assumed that designing a CTN with the appropriate collaborative mechanisms that meets actor requirements to a high degree was necessary but insufficient to achieve excellent acceptance and willingness of the actors to use the collaborative mechanisms. According to Rogers (2010), the first two steps that precede the actual motivation to use an innovative concept are knowledge acquisition and persuasion. Thus, the adoption of the collaborative mechanisms developed in a CTN is expected to face two major challenges when introduced to the actors.

The challenge of comprehension implies participant understanding of the concept of the new CTN and how to use the collaborative mechanisms. Awareness and ease-of-use for participants are critical factors for the successful introduction of an innovative concept, according to Finn et al. (2003). Thus, new collaborative mechanisms should be introduced to the prospective participants in a comprehensive manner to reduce feelings of uncertainty.

The next step after comprehension is to achieve a favorable evaluation of the new collaborative mechanisms within the system. To achieve a positive attitude toward the new collaborative mechanisms, it thus seems necessary to increase its perceived usefulness by underlining the individual, societal, and environmental benefits of the new CTN. Consequently, it is a necessary step to encourage participants to try out and actively deal with the collaborative mechanisms.

An interactive digital approach based on serious gaming appeared to be a promising way of managing the previous challenges of comprehension, attitude, and acceptance that are an inherent part of introducing new CTN with innovative collaborative mechanisms. A serious game is defined as “an activity that has an explicit *goal* or *challenge*, *rules* that guide achievement of the goal, *interactivity* with either other players or the game environment (or both), and *feedback mechanisms* that give clear cues as to how well or poorly you are performing. It results in a *quantifiable outcome* (you win/you lose, you hit the target, etc.). Usually, it generates an *emotional reaction* in players” (Boller, March 26, 2014).

Serious games are valuable as they provide the opportunity to effectively study future-oriented complex systems (Duke and Greenblat, 1981). Compared to experimenting in reality, serious games are a relatively easy and cheap way to study and experiment with an innovative

new concept. Moreover, they make a particular phenomenon more visible for observation and enable the design of controlled experiments in a safe environment (Kurapati et al., 2017).

In addition, serious games have been proven to enhance learning and knowledge acquisition (Breuer and Bente, 2010; Wouters et al., 2013). They are motivating, provide continuous feedback, maintain learner/player attention, and provide an appropriate level of challenge (Shute, 2011).

### 5.3. Freight transport Game: description, implementation, and output validation

#### 5.3.1. Game description

This part briefly describes the "Freight Transport Game". More details and the game guidelines can be found in Appendix C.

The "Freight Transport Game" is a serious game developed as part of my doctoral research at MINES ParisTech – PSL to investigate the collaborative mechanisms within a CTN in real practice. The aim of the serious game is to measure and explain the divergence with the optimal allocation of resources that optimizes the overall performance of the CTN by considering the interests of each player.

The game is played online or on a board portraying the CTN (Figure 24). Regions are represented by a map and requests are manipulated by the players (i.e. carriers).



Figure 24: Collaborative transport network

The game is coordinated by an organizer who is responsible for explaining the rules to the players, creating the game sessions, inviting the players to the sessions, ending the game, and coordinating the debriefing with the players at the end. The organizer has the unique global vision of all the players and their dashboard. They can see the overall ranking of the players and all the information about the winner.

In the game, each player has a truck with a maximum capacity, and they are initially positioned at the central node. The CTN (Figure 24) contains nine cities the truck can pass through to make its deliveries. Each player optimizes the journey of their truck to submit the best rates, win the maximum number of requests to transport, and maximize their profit. The winner is the player with the highest profit at the end of the game.

The game is played in several rounds and three requests are generated in each round. Each request contains an origin, a destination, a volume, and a lead time (see Figure 25). Each player has to create their own route in order to bid for a request.

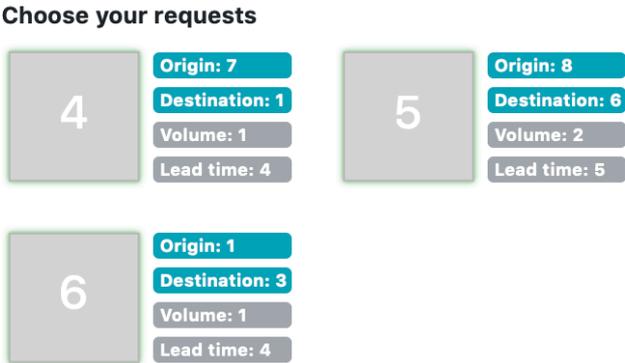


Figure 25: Requests generated in the game

Once a player has chosen the route and the request bundle to be transported, the cost of transporting this request bundle on this route is displayed for the appropriate player. The player can then propose a price to transport the chosen request bundle.

The prices proposed by the players (carriers) are sent to the organizer and an optimization model allocates requests to the winners by minimizing the total price. A general ranking of the players is displayed at the end of each round to determine the winners (see Figure 26).



Figure 26: General ranking of players in the game

In the game, players (carriers) are allowed to exchange requests for economies of scale and scope (i.e. shipment reallocation is allowed). A carrier can submit their requests for reallocation when they arrive at the central node (i.e. node nine). These are called reallocated requests and are visible for other carriers to bid on.

When players view reallocation proposals, they may offer a price to pick them up. If the proposed price is lower than the former cost of the reallocated request, the former carrier wins the price difference, time, and capacity, and the new carrier wins the request and profit. However, if the new price is higher than the former cost, nothing happens. Reallocation therefore occurs when there is a win-win situation for the former and new carriers. If no one makes a proposal for a reallocated request, the former player is forced to make the delivery. Thus, players should go through the central node (i.e. node 9) to increase their chances of winning. **For more information about the “Freight Transport Game” see Appendix C.**

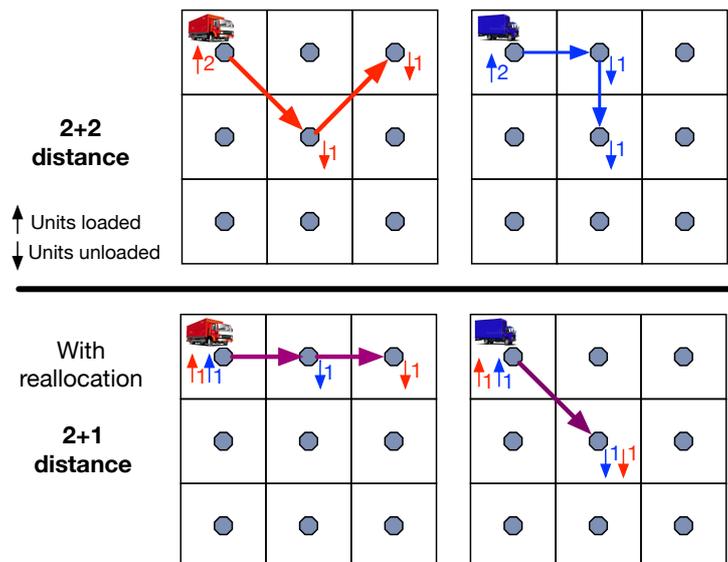


Figure 27: Reallocation of requests in the game

It is worth mentioning that in this dissertation, all the game sessions are based on the collaborative mechanism with reverse auctions; the collaborative mechanism with double auctions is not considered. All the results and player behavior were analyzed for a CTN based on a collaborative mechanism with reverse auctions.

**5.3.2. Game implementation**

To collect data from the game for future research, several game sessions were organized based on three major phases (Smith et al., 2015).

**5.3.2.1. Learning phase: pre-game**

The learning phase is a process where the players enter with no understanding of the game and at the end they are able to play correctly. Therefore, a key challenge for game designers in the learning phase is to explain clearly and concisely the purpose and the rules of the game. The results of the game are fully aligned with how well players understood the purpose and the rules of the game. This learning phase depends on several elements that could directly influence player understanding (i.e. player characteristics, organizer characteristics, and methodology used) (see Figure 28).

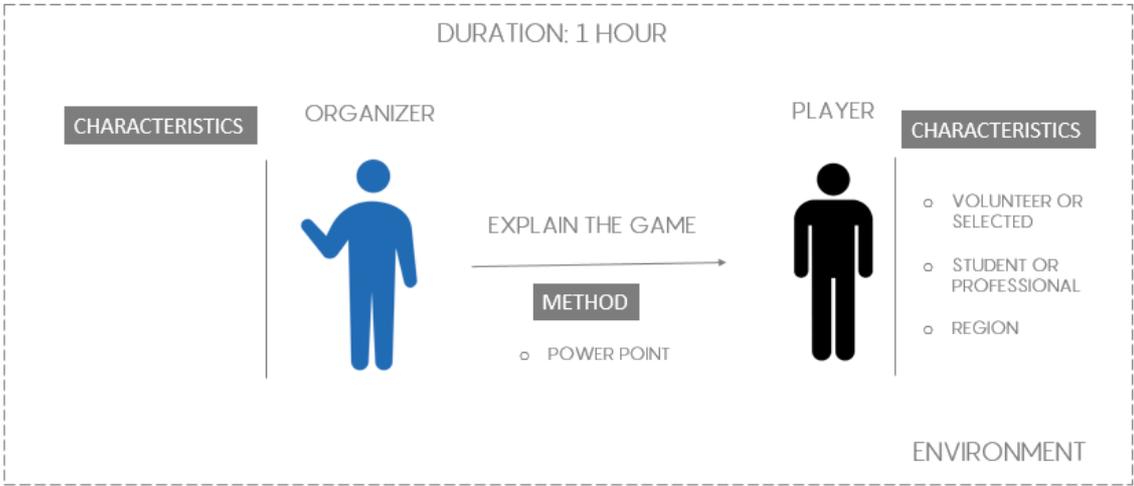


Figure 28: Learning phase

**5.3.2.2. Game play phase**

In the game play phase, the organizer answers any doubts players may have about the game and controls the time of each round. The organizer plays a passive role in this phase; the players have the main role by interacting directly with the game (see Figure 29 and Figure

30). This is the most important phase in the serious game, as all the future research relies on the data collected during this phase.

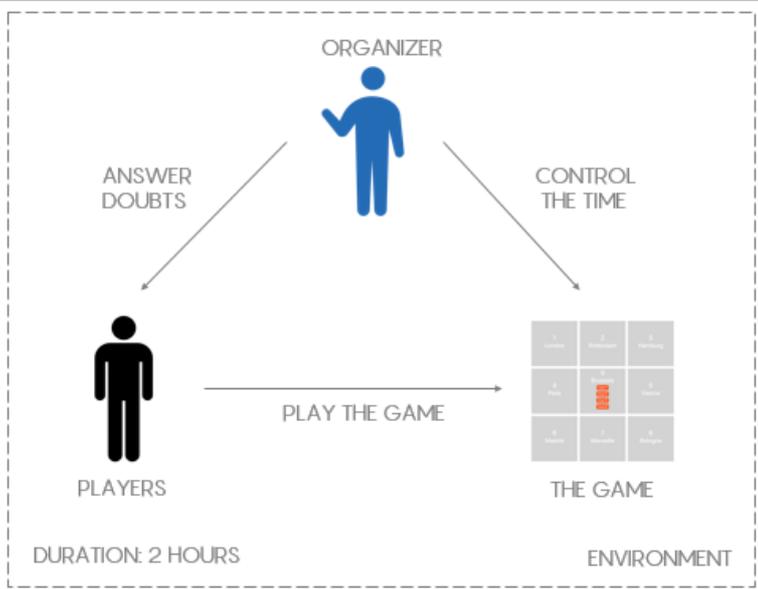


Figure 29: Game play phase



Figure 30: Player view

5.3.2.3. Debriefing phase: post-game

The role of an effective debriefing is emphasized as post-game information allows players to draw parallels between the game and the real world and to transfer the learning patterns to real life (Crookall, 2010).

In the debriefing phase, the organizer is responsible for showing the results obtained in the game, and conducting a discussion about the game data (see Figure 31).

Feedback and propositions collected from the participants could be used to make improvements to the game (Mayer et al., 2014). After the debriefing and discussion phase, the

game organizer submits a questionnaire to the players and collects their feedback and some qualitative information that could be useful for further analysis.

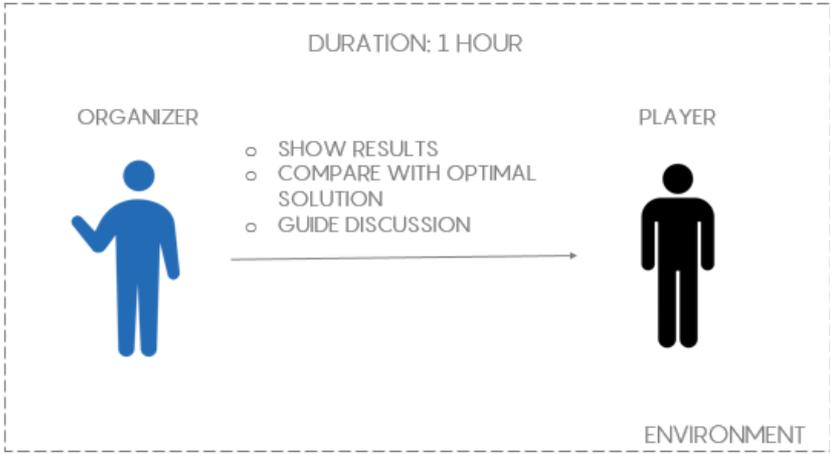


Figure 31: Debriefing phase

5.3.3. Data collection and validation process

It is worth mentioning that the collection and validation of the data from the game session organized was conducted as a part of a research internship under my supervision completed by Renan DE ALENCAR from ENSTA ParisTech.

The accuracy of the information and research heavily depends on the quality and validity of the data to support the analysis. If poor quality data is initially collected, then its progress through the latter stages of the analytics pipeline will be compromised and the validity of any identified patterns weakened (Smith et al., 2015).

In this step, we followed the methodology by Smith et al. (2015) to collect the useful data from each phase of the sessions organized to support the analysis. Table 10 represents the data set from the organized sessions and the characteristics of each session. In what follows, the sessions are represented by the session number (e.g., session 98 refers to the first session in Table 10 played in France with volunteer students).

<i>Sessions played</i>	98	106	107	108	109	114	115	116	117	119	120	121	135	142
<i>Location</i>	FR	FR	FR	FR	FR	NL	FR	FR	FR	FR	FR	FR	AU	FR

<b>Participants</b>	Vol.	Sel.	Sel.	Sel.	Sel.	Vo	Sel.	Sel.	Sel.	Sel.	Sel.	Sel.	Vol.	Vol.
<b>Profession</b>	St.	St.	St.	St.	St.	Pr.	St.	Pr.						
<b># Rounds</b>	10	10	10	10	20	26	10	19	19	10	10	10	10	10

Table 10: Data set from the game sessions organized (Vol: volunteer; Sel: selected; St: students, Pr: professional)

Then, based on these data sets, we formulated a list of hypotheses to validate and evaluate their impact on the game results (see Table 11).

	<i>A volunteer has different results compared to a selected person</i>
<b>Pre-game phase</b>	<i>Professionals and Students have different results in the game</i>
	<i>The region affects the results of the game</i>
	<i>Players generally gain more confidence in proposing prices over time</i>
<b>Game play phase</b>	<i>The market capacity has an influence on the results</i>
	<i>The gain for each proposal depends on the cost</i>
<b>Post-game phase</b>	<i>The playing time is very long</i>

Table 11: List of hypotheses by game phase

The hypotheses were tested and their impact on the game results analyzed.

### ***H.1: “Players generally gain more confidence in proposing prices over time”***

To analyze the confidence of players to propose prices over time, we used the value the players gain when they transport a request bundle, which is the difference between the proposed price and the real cost to transport the request bundle. We analyzed the average minimum gain of the players in each round when determining the price of the request bundle (see Figure 32). We emphasize here that the minimum gain in each round represents the conservatism of the players.

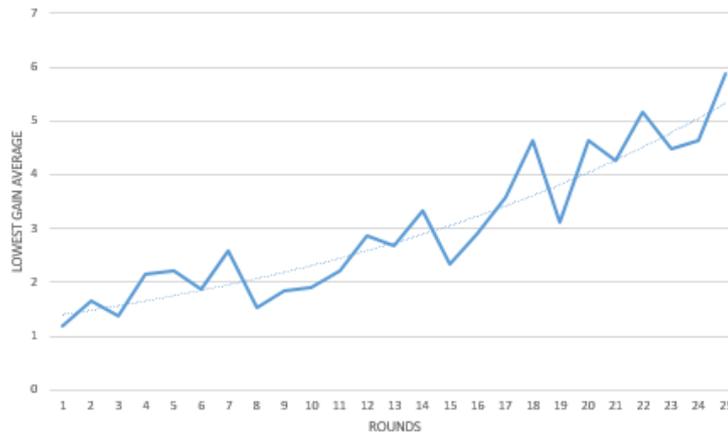


Figure 32: Evolution of average minimum player gain

According to Figure 32, the evolution in the average minimum player gain closely resembles an exponential evolution. We used the EViews® software to test how well the data can be approximated to an exponential curve through the least squares method (Figure 33).

For the interpretation of the results obtained, we looked at the  $F - static$  value and the  $Prob(F - static)$  value:

$$F - static = 11.39 \text{ and } Prob(F - static) = 0.0026.$$

Dependent Variable: MED\_MIN\_  
Method: Least Squares (Gauss-Newton / Marquardt steps)  
Date: 08/17/19 Time: 22:44  
Sample: 2001 2025  
Included observations: 25  
MED\_MIN\_ = C(1) + C(2)\*EXP(ROUNDS)

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	2.774043	0.229839	12.06951	0.0000
C(2)	5.01E-11	1.48E-11	3.374954	0.0026

R-squared	0.331207	Mean dependent var	3.002258
Adjusted R-squared	0.302129	S.D. dependent var	1.314760
S.E. of regression	1.098333	Akaike info criterion	3.102083
Sum squared resid	27.74572	Schwarz criterion	3.199593
Log likelihood	-36.77604	Hannan-Quinn criter.	3.129128
F-statistic	11.39031	Durbin-Watson stat	0.525995
Prob(F-statistic)	0.002612		

Figure 33: Average minimum player gain – exponential evolution

We can infer that the curve presented fits the exponential equation proposed very well. This behavior closely resembles the learning curve first proposed by Ebbinghaus (1885) (Figure 34). As can be seen, the learning curve presents a region where the learning levels off.

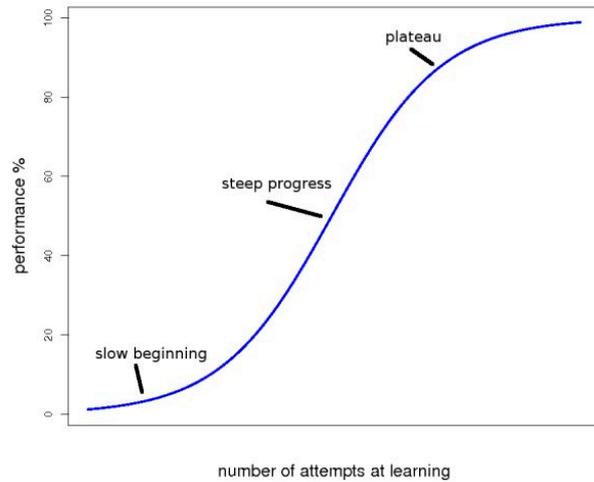


Figure 34: The learning curve proposed by Ebbinghaus (1885)

After several rounds, players understand the game better and propose more appropriate prices to increase their profit.

**H.2: A volunteer has different results compared to a selected person**

According to Rosnow and Rosenthal (1976), volunteers are probably smarter, they come from higher social classes, and they are more motivated. Based on those facts, it is believed that volunteers are more reasonable in proposing prices compared to the selected people.

We started by looking at the average evolution of the lowest gain over the rounds (Figure 35) to see if we could extract any insight. The players in “game session 98” (i.e. game with volunteers) did not have the greatest or the lowest capacity for risk, nor did they seem to be the "greediest".

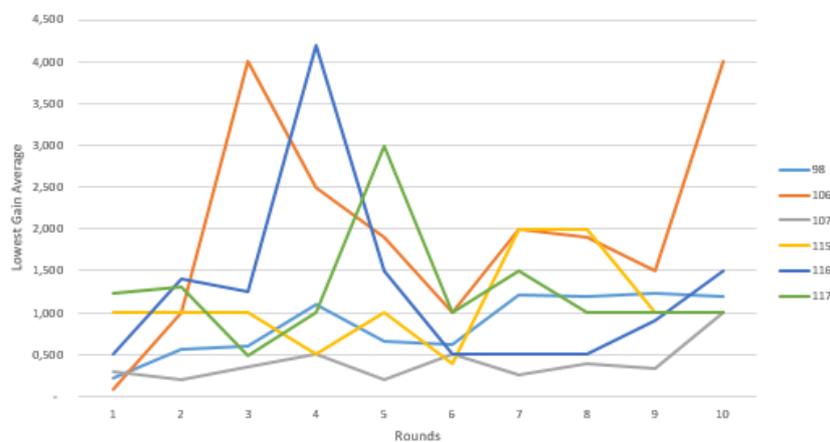


Figure 35: Average minimum player gain over several game sessions

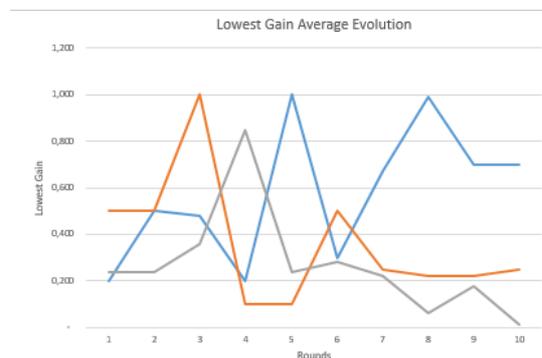
Moreover, by looking at the minimum gain of each player within each game session (see Table 12), we can see that the players in “game session 98” had the most conservative propositions compared to the propositions of selected players in the other game sessions. Thus, we can induce that volunteers are more reasonable in proposing prices than selected people.

<i>Players/ Game sessions</i>	<b>98</b>	<b>106</b>	<b>107</b>	<b>115</b>	<b>116</b>	<b>117</b>
<b>1</b>	0.220	0.100	0.300	0.400	0.200	0.490
<b>2</b>	0.230	0.090	0.200	1.000	0.500	1.000
<b>3</b>	0.600	0.010	0.200	1.000	0.500	1.000
<b>4</b>	0.940	4.000	0.200	0.500	2.00	0.600

*Table 12: Minimum gain per player*

### ***H.3: Professionals and Students have different results in the game***

According to Babb et al. (1966), businessmen were found to be more stable and conservative than a contrasting group of students. To check this hypothesis, we analyzed the minimum gain of professionals compared to students.



*Figure 36: Average minimum gain of students (blue curve) vs. professionals (grey curve)*

According to Figure 36, we noticed that until round six the conservatism of professionals (i.e. grey curve) and students (i.e. blue curve) seemed to be the same. However, from round six, the average minimum gain of professionals was lower than that of the students. The professionals were more realistic; they knew the transport market with its low margins better than the students who took more risks.

#### H.4: The region affects the results of the game

To the best of the author's knowledge, no studies on the behavior of people by region were found. Any hypothesis regarding the behavior of participants by region is not easy to make. Thus, we tried to study the evolution of the average gain of players over the rounds.

According to the availability of the data from the organized sessions, it was only possible to analyze France vs. Austria and France vs. the Netherlands.

##### France vs. Austria

We started by analyzing data from sessions organized in France and in Austria (see game sessions 135 and 98 in Table 10).

According to Figure 37, we noticed that the average profit of players in Austria over time was higher than the profit of players in France, although its growth seemed slower.

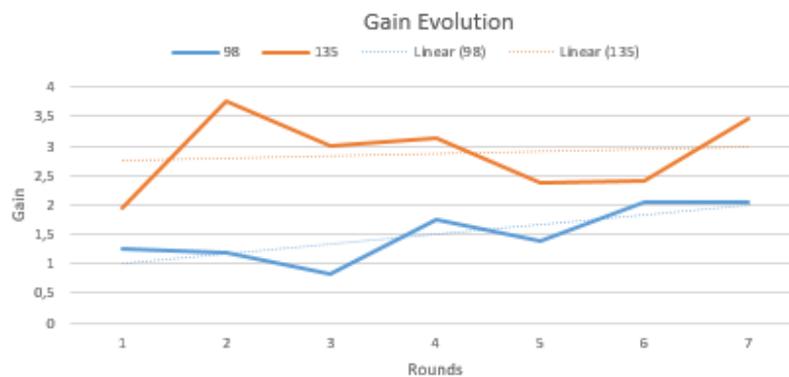


Figure 37: Average minimum gain for France (blue curve) vs. Austria (red curve)

To understand this behavior, we plotted the evolution of each player separately within each game. We can see from Figure 38 that the “y” axis values of all the gain graphics in Austria seem to be lower than the games in France. It can be noted that the average winning values of the Austrian players were generally higher than those of the players in France.

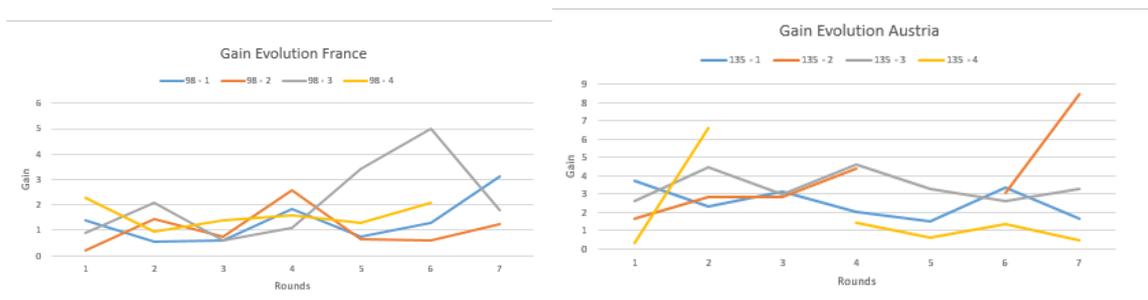


Figure 38: Minimum gain for each player in France (left) vs. Austria (right)

To confirm this hypothesis, we analyzed the data from a game session in Austria with data not only from one game session in France but from several game sessions in France.

Compared with other similar games in France, no characteristic was highlighted for the game in Austria; the average gain in Austria was neither the highest nor the lowest compared to other games in France.

As we only have one game session in Austria, the confidence is lower for the analyses performed. More game sessions should be played to draw more accurate conclusions.

### France vs. the Netherlands

We started by analyzing data from sessions organized in France and in the Netherlands (see game sessions 114 and 142 in Table 10).



Figure 39: Average minimum gain for France (blue curve) vs. the Netherlands (red curve)

According to Figure 39, we cannot see any discrepant behavior between the games. According to the average gain of each player during the game, we see that changing the region did not seem to affect the game data.

### ***H.5: The market capacity has an influence on the results***

It is believed that with a larger number of players, the market is more competitive and so profit margins are lower. To verify this hypothesis, we analyzed the average minimum gain of players in two different types of market (i.e. a market with four players and a market with two players). Of the game sessions organized, two sessions could be used (game session 106 and game session 121).

	Game session 106 with four players				Game session 121 with two players	
Average minimum gain	Player 1	Player 2	Player 3	Player 4	Player 1	Player 2
	1.05	1.18	1.75	3.83	1.21	3.50

Table 13: Average minimum gain of players

According to Table 13, we see that game 121 had a larger gain, as expected. However, we must consider a number of factors that may hinder our analysis such as insufficient data. It would therefore be interesting to play more games with different numbers of players so that the hypothesis can actually be refuted or accepted with a high degree of statistical confidence.

### H.6: The gain for each proposal depends on the cost

In this step, we used the value of  $R_2$  as an indicator to analyze if there was a correlation between the player's gain and the real cost of each request bundle. The coefficient of determination  $R_2$  is a statistical measure of how close the data are to the fitted regression curve. The value of  $R_2$  is always between 0 and 1, and the closer it is to 1, the better the regression.

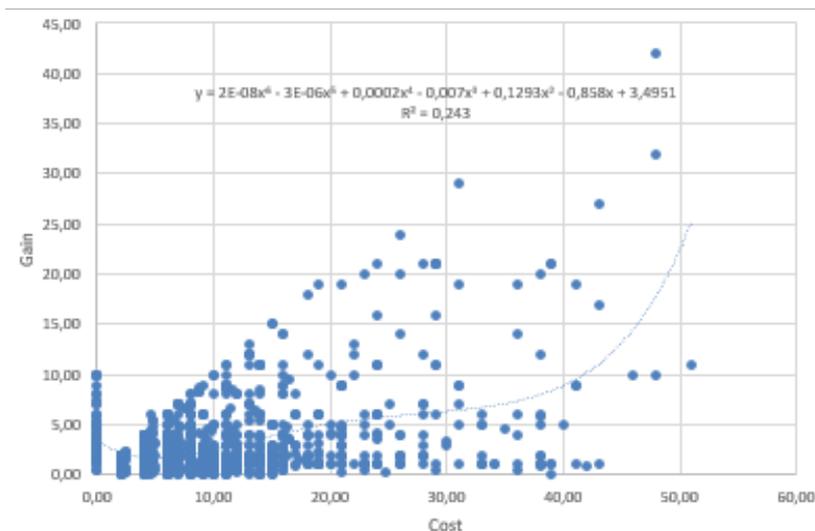


Figure 40: Correlation between player gain and request bundle costs

It is noticeable from Figure 40 that there is no correlation between the player's gain and the real cost for a request bundle.  $R_2 = 0.243 \ll 1$  for a sixth order polynomial.

However, it would be interesting to analyze if we are able to find a correlation between some specific player characteristics (Table 14).

	<i>Participants</i>		<i>Profession</i>		<i>Region</i>		
	Volunteer	Selected	Student	Professional	Austria	France	Netherlands
R2	0.47	0.33	0.28	0.52	0.65	0.28	0.56

Table 14: R2 values for different data types

According to Table 14, there is no correlation between gain and cost for any of the player characteristics. Although some values were greater than 0.5, a 6-order polynomial was required for the regression, which does not present much physical sense. Consequently, we can consider that the proposed price for a request bundle is independent of its real cost.

### ***H.7: The playing time is very long***

A very common problem in behavioral research is tiredness. As it is very difficult to quantitatively measure tiredness, a question was included in the debriefing phase to ask players if they were tired during the game.

However, some researchers have indicated that 1 to 2 hours of game play per session is a much more appropriate time frame for serious games research - without participants getting bored or tired (Loh et al., 2015).

## **5.4. Results**

### **5.4.1. Analysis of player performance in the game**

To analyze player performance, two different game sessions with the same players were organized. The first game session represented the CTN without the collaborative mechanism developed and the second game session represented the CTN with the collaborative mechanism developed. We compared, in terms of the KPIs defined in section 3.3, the performance of the players using the collaborative mechanism with the performance of the same players without the collaborative mechanism.

Here, we discuss the results of the two scenarios played (Sc.1 without the collaborative mechanism and Sc.2 with the collaborative mechanism). It is important to note that only the

preliminary results obtained over 10 rounds of games are discussed at this stage. More experiments are expected to further enhance the results and conclusions.

	<i>KPI</i>	<i>Sc.1</i>	<i>Sc.2</i>
<i>Effectiveness</i>	<i>Unallocated Requests</i>	1	0
	<i>Total delays</i>	0	0
<i>Efficiency</i>	<i>Total cost</i>	95	92
	<i>Total price</i>	103	105
	<i>Total gain</i>	13	15
	<i>Mean fill rate</i>	42.36%	43.47%

Table 15: Player performance in terms of KPIs

According to Table 15, the efficiency and effectiveness of the CTN are a little better in the second game session with the collaborative mechanism. However, in theory, we stated that the scenario with the collaborative mechanism was much better in terms of efficiency, effectiveness, and sustainability.

To understand the reason why players cannot match the theoretical performance, we studied how players react to the collaborative mechanism. This could be translated as the number of reallocations during the game. According to the results of the game session with the collaborative mechanism, we noticed that the players did not collaborate many times. We analyzed their behavior to understand the barriers to using the collaborative mechanism.

#### 5.4.2. Analysis of player behavior

The methodology used in this section is the result of our collaboration with a research team at TU Delft University. The team created an innovative methodology to combine serious games and Discrete Choice Modeling to provide insights into player behavior and create a realistic simulation. This innovative Game and Choice Based Simulation methodology (GCSM) was implemented and evaluated through the “Freight Transport Game”.

The innovative GCSM is visualized in terms of modeling types in Figure 41, based on the modeling typology of McCarl and Spreen (1997).

The real world was simulated using a calculation model from which a game was developed (1) that can be played with participants. A DCM was created based on player decisions in the game (2), then a Game and Choice Based Simulation was developed from the model/game calculation (3) and the DCM (4).

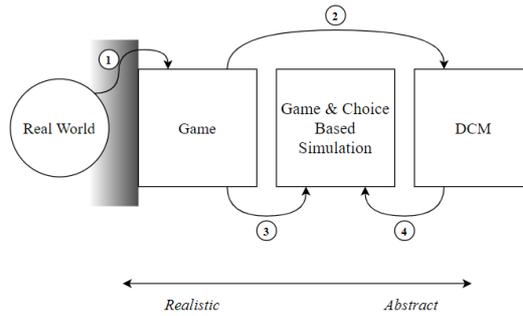


Figure 41: GCBS in terms of modeling types (from (Caminada et al., 2020))

To implement the innovative methodology, a valid DCM was created that captures the choice behavior of players and provides quantitative and statistically rigorous insight into this behavior.

Based on the literature and experience of playing the game, the attributes to capture the **“complexity of finding a feasible alternative”** behavior were selected. At first, *“Game Round”* is selected, as it is possible that players learn to play the game while playing it (Ryu, 2013) making it less complex to find feasible bundles as the game progresses. Additionally, *“Total/Bundle of Request”* and *“Route Length”* are selected as more requests need to be considered and connected the longer the feasible route is and the more difficult it is to find that bundle.

Moreover, attributes to capture **“choice to bid or not bid for a feasible bundle”** behavior were selected as follows. The effect of the possibility of setting competitive prices, making a profit, and the profit already won, as described by Van Duin et al. (2007), were taken into account by selecting a constant for *“Bidding”* (i.e. the effect of potentially making a profit), *“Total/Penalty Costs”* (i.e. the extent to which a competitive price can be set), *“Current load”* (i.e. the effect of profit already won), and *“Player Ranking”* (i.e. the relative effect of profit already won).

With the data collected, several multinomial logit (MNL) models were estimated to check whether evidence could be found that the attributes affect bidding behavior. Herewith the goodness-of-fit (rho squared value) of the model, significance of parameter values, the hypothesis of the model, and the interpretability of the utility function composition were used as criteria for selecting the specification. Therefrom, the following attributes were used:

*Number of Requests in a bundle (BNR), Penalty Costs (PC), and the constant for Bidding ( $ASC_{bid}$ ).* The random parameter  $\varepsilon$  was added to represent the (general independent) unobserved utility. It is distributed i.i.d. Extreme Value type I,  $\text{var} = \pi^2/6$ . More sophisticated ML models that captured panel effects, nesting effects, and random taste heterogeneity were tested as well. Eventually, an MNL was chosen with the following utility functions:

$$U_{bid} = \beta_{BNR} * BNR + \beta_{PC} * PC + ASC_{bid} + \varepsilon$$

$$U_{Notbid} = 0 + \varepsilon$$

This MNL model was chosen because it performs as well as the ML models (in terms of Rho squared value), and it is parsimonious and relatively straight forward to simulate. The estimated parameters are presented in Table 16. The initial log-likelihood of the model was -336.176 and the final log-likelihood of the model was -250.256. The Rho squared value of the model is 0.256.

<i>Attribute</i>	<i>Notation</i>	<i>Value</i>	<i>Std err.</i>	<i>p- value</i>
<b><i>Beta Bundle Number of Requests</i></b>	$\beta_{BNR}$	- 1.22	0.196	0.00
<b><i>Beta Penalty Costs</i></b>	$\beta_{PC}$	- 0.0242	0.0118	0.04
<b><i>Constant for Bidding</i></b>	$ASC_{bid}$	1.37	0.313	0.00

*Table 16: Estimated parameters for DCM*

To check how reliable this model is regarding its ability to predict the right choices, a validation of the model was conducted. Herewith, the percentage of choices correctly predicted by the model was calculated (i.e. hit rate). This validation consisted in calculating the hit rate using out-of-sample testing. For this, the data set of 485 observations was split into two parts. The first 2/3 of the observations were randomly selected to develop the model. Then, this model was applied to the remaining 1/3 of the observations. The percentage of correctly predicted choices is the hit rate. To obtain robust results, the hit rate was calculated ten times, each time with different randomly selected data sets.

The hit rate of the model was found to be quite stable over the ten replications, and on average, 73%. Therefore, it is concluded that the bidding behavior can be realistically represented.

Based on the experience of playing the game, it is considered plausible that players have difficulties with the complexity of creating a feasible bid. It looks like players are not able to consider all their bidding options to make a fully rational bidding decision. There are too many possibilities making it highly unlikely that players are able to create a full overview of their options and make a rational decision to bid or not to bid on a bundle. Left alone, a player is able to strategically incorporate the option of reallocation within his bidding process as this possibility creates even more bidding options. Game data shows that sometimes players have the possibility of bidding on more than a thousand unique possible combinations of request bundles and routes. Conversely, a player could sometimes even be glad to have found an option to bid on, as the restrictions of previously won bids and their corresponding routing obligations greatly limit the possibilities. Consequently, there could be too many options to find and oversee them all, or too few to be able to catch them. This phenomenon of bounded rationality of carriers could decrease the effectiveness and efficiency of the transport market.

Based on the DCM of the bidding choices, some careful conclusions could be drawn about the bidding behavior of players. It can be stated that players prefer making a bid (i.e.  $U_{bid} > U_{Notbid}$ ). However, when a player wants to bid on a request, this effect is almost entirely abolished due to the negative effect of the parameter *number of requests (BNR)*. Players presumably find it difficult to deal with the complexity of combining a bundle and a feasible route when more requests need to be considered. This attribute of complexity has relatively the most substantial influence on the systematic bidding behavior found by estimating the DCM (see Table 16). The other attribute of which evidence was found that it influences player bidding behavior is penalty cost. The higher the penalty cost a player has to pay when bidding on the corresponding request bundle, the less likely they will bid on it. However, this influence is logical, and it only really affects bidding behavior with hefty penalties. However, even then this effect is relatively small compared to the previously mentioned complexity effect (see Table 16).

Based on the DCM conclusions, it can be stated that the players have difficulties with the complexity of combining requests with a feasible route in order to place a bid. Additionally, game data shows that it could be plausible that players experience too many options to find and oversee them all or too few options to be able to catch them. This phenomenon of bounded rationality of carriers could decrease the effectiveness and efficiency of the transport market and weaken the position of an independent carrier. A solution can be found in the concept of a decision support system. All the information regarding routing, load size, start and end time, reallocation, and so on, can logically not be processed by a human. Therefore, a digital platform that helps carriers to process all that information to improve their decision making, without them losing control, could make the transport market more efficient and effective.

In a transport market, two aspects are essential for an optimized transport system. At first, carriers want to bid on bundles with the lowest cost; in this way, they can set competitive prices. Additionally, carriers want to exchange requests more as it provides them with a win-win situation. To capture the two aspects in one policy, a decision support tool for carriers is proposed that processes all the transportation information for each individual carrier and calculates their optimal bid compositions. These optimal bids per carrier consist of request bundles that have the lowest total cost and pass through the reallocation point (i.e. central node). In this way, carriers can set more competitive prices and utilize reallocation more.

#### **5.4.3. Analysis of the proposed policy**

To test the effect of the policy, an experiment with two different scenarios was created. Scenario.1 represents a freight transport market with the collaborative mechanism with reverse auctions allowing collaboration between carriers (i.e. exchange and reallocation of requests), where carriers bid on all the possible feasible request bundles. In Scenario.2, carriers bid on bundles that have the lowest total cost and pass by the reallocation point (i.e. central node). The two different scenarios were run *ceteris paribus* and the results were compared with the KPIs presented in Section 3.3. This indicates whether the policy produces the desired effect and in what aspects it performs better or worse.

The results of the experiment are presented in Table 17. It shows the mean and the standard deviations of the sessions conducted.

KPI		<i>Scenario.1: without policy</i>		<i>Scenario.2: with policy</i>	
		Mean	Std.	Mean	Std.
<i>Effectiveness</i>	<i>Unallocated requests</i>	35.22	1.55	1	0.94
	<i>Total delays</i>	0	0	0	0
<i>Efficiency</i>	<i>Total price</i>	287.43	10.49	335.57	53.04
	<i>Price allocated requests</i>	4,51	0.21	3.42	0.53
	<i>Mean filling rate</i>	10.15%	0.89%	53.06%	3.64%
	<i>Number of reallocations</i>	0	0	4	2.79

Table 17: Simulation results, mean and standard deviation

The results show that the filling rate of the trucks in Scenario.1 is low (10%). This is presumably because carriers likely do not bid on bundles with multiple requests because of the complexity. The proposed policy was partly aimed at solving this complex issue for carriers. Scenario.2 shows that the policy works in this respect, as the filling rate is much higher. The other aim of the policy was to create more reallocations, which it did well. So, the policy creates a much more efficient market situation. Additionally, almost all the requests were allocated in Scenario.2, which was definitely not the case in Scenario.1. Therefore, the policy also creates a more effective market. In general, it can be stated that the policy of providing the player with decision-support for their most “attractive” potential bids, results in a much more efficient and effective game performance.

## 5.5. Discussion and implications

Other than in the game, carriers in real life could have other incentives than only making a profit. They may also care about the region in which they conduct their transport, the length of the route or finding a suitable trustworthy partner for collaboration. These criteria have to be part of the game and the attributes in the DCM to be taken into consideration. This will change the model and increase the complexity of developing the DCM.

Moreover, in real life there are usage barriers other than complexity that might result in the refusal of the collaborative mechanisms; finding a suitable partner with whom synergies can

be established, profit sharing mechanisms, trust, information sharing, competitive issues, legal issues, enterprise culture, organizational structure, and entry/exit rules, etc. Additional cases need to apply the GCBS framework to investigate these barriers in detail.

## **5.6. Conclusion**

The research conducted in this chapter has provided some valuable insights into and contributions to the existing literature. *At first*, the “Freight Transport Game” was developed allowing players to explore and try out the new collaborative mechanisms in a playful way. *Second*, an innovative method of creating a game and choice-based simulation was tested. This method proved to be successful in gaining quantitative and statistically rigorous insight into the behavior of the actors and creating a realistic simulation. *Third*, by using the GCBS method, it was discovered that a decision support tool (i.e. digital platform) could create not only an efficient and effective market in terms of performance but also create a more firm and "in control" position of the independent carrier in a CTN.

Knowing that the “Freight Transport Game” has also been serving as a teaching tool for courses in logistics and transport, more real-life experiments and data are expected to validate and improve the proposed methodology. The work can also be followed by empirical research to investigate customer policies for CTN, as the game can provide a virtual laboratory for studying empirical evidence.

## **CHAPTER 6: Conclusions and research prospects**

Despite the growing popularity of collaboration in freight transport (i.e. vertical and/or horizontal collaboration, collaborative multi-modal transport, or collaborative city logistics), research on the collaborative mechanisms regulating the interactions of actors in this collaboration has been scant. Thus, this dissertation aimed to advance our understanding of the application of collaborative mechanisms in freight transport service procurement in general and in CTN in particular.

The research conducted in this dissertation has provided some valuable insights into and contributions to the existing literature. *First*, a literature review is provided as a way to better understand the strengths and limits of the existing freight transport service procurement mechanisms. Based on quantitative and qualitative analyses and the comparison between research and real-world practices, this first step provides a clear review to help improve understanding of procurement mechanisms and to guide practitioners and researchers in this field, identifies some promising research lines and prospects that deserve further attention, and develops a research agenda for freight transport service procurement mechanisms.

### **6.1. Mechanisms for omnichannel and O2O E-commerce**

The current organization of freight transport has been forced to confront the new challenges from omnichannel E-commerce logistics and the trucking industry. Simply speaking, omnichannel E-commerce can be described as a business strategy that aims to reach customers by means of a variety of marketing methods, distribution channels, and touchpoints (Verhoef et al., 2015; Savelsbergh and Van Woensel, 2016). The O2O strategy in particular aims to bring online customers to bricks-and-mortar locations. It also involves designing fulfillment channels that mutually improve online web-based and offline bricks-and-mortar sales, e.g., brick-and-click service (Agatz et al., 2008; Hübner et al., 2016a; Paul et al., 2019). To enhance the shopping experience of consumers, the strategy relies on fast and direct-to-consumer fulfillment, and multi-channel delivery such as home delivery, pickup points, or auto lockers. As a result, the logistic flows of omnichannel E-commerce are characterized as fragmented and fluctuant, high speed, and with variable delivery points. These flows are therefore extremely difficult to consolidate in shipments under the traditional freight transport organization models. Conversely, recent trends in the trucking industry

also question the traditional models. Currently, trucking companies are facing many difficulties, such as fiercer international competition and low margins in the industry, in addition to demanding services required by shippers and strict regulations imposed by governments. Consequently, truck driver shortages will be likely in the near future.

To cope with the challenges, innovative organizational models for freight transportation have recently been proposed and investigated by practitioners and researchers. Examples include sharing economies in freight transportation (e.g., ride-sharing or crowd shipping), horizontal cooperation between carriers, real-time dynamic vehicle routing, or online freight marketplaces. The effectiveness and efficiency of such models have already been proven in the literature (Andres Figliozzi et al., 2003; Archetti et al., 2016; Wang et al., 2016; Chen et al., 2017; Pan et al., 2019). Nevertheless, the perspectives of freight transportation service procurement mechanisms have been rarely addressed.

## **6.2. Mechanisms for on-demand transportation in E-commerce**

On-demand transport requests have been thoroughly investigated for passenger transportation (e.g., taxis) but not for freight transport (Egan and Jakob, 2016). However, it has become an important trend in E-commerce and last mile delivery in particular. Like Amazon Prime Now, more and more e-tailers are proposing same-day delivery. Short lead times and narrow time windows make it very difficult to consolidate deliveries and optimize the transport plan for all of them. Consequently, in most cases, each order is delivered independently thus rendering the transport unsustainable. Some innovative solutions have been studied to deal with the issue, for example, dynamic vehicle routing, transport autonomy (e.g., AGV, drone), or crowdsourced delivery services (e.g., Uber, Deliveroo, Stuart). Currently, a popular procurement mechanism for on-demand services is that the shipper (or client) pays a known price via a platform for each on-demand service, i.e., spot markets with a service catalog. The major drawback is that resource utilization efficiency and trading effectiveness are not optimized by such mechanisms, despite the use of surge pricing proposed by some platforms such as Uber. As proven in the literature, double auctions could be more efficient and effective in such contexts (Xu and Huang, 2017). However, it is important to understand why the mechanism is still rarely applied in real practice, and how it can be put into practice.

### **6.3. Mechanisms for sharing economies**

The rise of sharing economies in freight transport also requires innovations in procurement mechanisms. Savelsbergh and Van Woensel (2016) defined two models of sharing economies. The first is collaborative consumption in Consumer to Consumer (C2C) networks, for example crowdsourcing shipping or freight and people ride-sharing. The second is collaborative business in Business to Business (B2B) networks that could be horizontal cooperation or interconnection of logistics services (Pan et al., 2019). Both could be applied to logistics services, including national and city-wide transportation that are crucial to E-commerce. But the procurement mechanism could be different, and impacts differently the feasibility and performance of the solution. For example, in collaborative consumption, third party organizers (such as *Uber*) would prefer to use a catalog with surge pricing rather than auction mechanisms to avoid price competition and instability. In collaborative business, collaborating companies would prefer to adapt a gain sharing mechanism rather than procurement for each occasional sharing. As sharing economies will become more and more important in logistics and freight transport, it is worth further investigating the appropriateness of the existing mechanisms for different collaboration and sharing models or developing new ones.

### **6.4. Intermodality and synchronomodality**

Recent challenges in omnichannel or O2O E-commerce transportation reveal the great potential of intermodal and synchronomodal transportation. This is particularly important for global E-commerce (Xu et al., 2015), as the end-to-end supply chain includes cross-board, national, and city-wide transportation. Some logistics planning services (LPS) provide global logistics services but how the transportation services involved can be synchronized and optimized is still an issue, especially with regards to cost-efficiency and sustainability. Synchronomodal freight transportation is a recent concept to this end. It is a network of interconnected, well-synchronized transport modes that, together, cater dynamically for the demands and instantaneous needs of shippers (Ambra et al., 2018). To achieve win-win situations in synchronomodal business, cooperation among players is essential, and there is a need to introduce new mechanisms that ensure risk sharing and trust between actors that may feel reluctant to cooperate with each other for fear of competition. Mechanisms managed by a third-party are needed to avoid shipper/carrier opportunism and loss of trust between actors.

Moreover, new mechanisms have to be introduced to assess actor preferences and support the flexibility and reliability of synchromodal systems. Synchronized transport systems have even evolved into decentralized, highly distributed systems (e.g., Physical Internet) to improve interoperability between transportation modes, optimize capacity utilization, and tailor services to the needs of shippers (Montreuil, 2011). This concept, resulting in collaborative, highly distributed and leveraged logistics needs new procurement mechanisms to handle the flexible door-to-door arrangements between the different actors.

### **6.5. Procurement mechanism for sustainable city logistics**

It is foreseeable that procurement mechanisms should take sustainability into account as it is becoming a major constraint in transportation, especially with regards to city logistics. However, until now only a few studies have investigated the problem (Jothi Basu et al., 2015; Jothi Basu et al., 2017). These studies question how to integrate sustainability criteria (e.g., transport emissions) into procurement mechanisms and decisions. For example, using auction mechanisms to assign carriers while considering emissions saved through the auction (Jothi Basu et al., 2015). Furthermore, it is important to study the efficiency and effectiveness of the well-known mechanisms (i.e., auction, catalog, negotiation) for sustainability purposes. These studies are still lacking in the literature.

*The second contribution of the research conducted in this dissertation is the proposition of an innovative method for combining multi-agent simulation and serious games. In this method, different approaches were proposed to investigate the development and design of novel collaborative mechanisms for freight transport service procurement that are appropriate for emerging collaborative transport networks; starting with the design and development of collaborative mechanisms via “Mechanism Design” theory, then performance assessment and evaluation via multi-agent simulation, and finally applicability and behavior analysis via gamification.*

The proposed collaborative mechanisms may be generalized as a decision-making tool for other forms of collaboration or as a routing protocol between multiple freight transport networks that ensure risk sharing and trust between actors that may feel reluctant to cooperate with each other for fear of competition.

Several studies in the related literature investigated the theoretical performance of collaborative mechanisms without studying their practicability in the real world. They

propose complicated mathematical models that are successful in theory but are difficult if not impossible to implement in real life. This study goes a step further and proposes collaborative mechanisms that have the potential to be implemented in a real freight transport market and study their practicability with a serious game, which is a close representation of the freight transport system. Based on the case at hand, we conclude that the proposed collaborative mechanisms proved to be successful in increasing the efficiency, effectiveness, and sustainability of a CTN without decreasing the individual interests of actors.

Despite the success of the proposed method, it has potential limitations. *First*, the multi-agent simulation experiments assess the theoretical performance of collaborative mechanisms but do not take into consideration all the parameters of the freight transport system. *Second*, the mathematical model is not tested for large instances; more studies should be conducted to test the model with large instances. *Third*, not all the proposed collaborative mechanisms were tested in the serious game due to a lack of data; more game sessions have to be organized in the future to collect the data necessary for more studies. *Finally*, one step is still missing before the practical implementation of the proposed collaborative mechanisms in a real freight transport market: field tests.

Moreover, some improvements relating to the model can be expected in the next phases. For example, the collaborative mechanisms between carriers such as side payments or gain sharing mechanisms should be refined. Who covers the extra costs of reallocation (handling, loading/unloading, etc.) is also a relevant issue. Moreover, some practical and operational issues such as the responsibility for damaged products (which can be related to insurance issues), etc., should also be discussed further. To go further, more research is needed. The proposed method helps by providing a macro-perspective of collaboration in freight transport systems but more research is needed to understand the collaborative mechanisms down to the specific option level.

Overall, the insights revealed and condensed in this dissertation are crucial for both academics and practitioners as they provide a method for further studies concerned with the elaboration of novel collaboration mechanisms in a new freight transport system.

For academics, the serious game developed, available online, could be used as a tool for teaching and explaining the complex concept of Collaborative Transport Networks with collaborative mechanisms and rules. Moreover, it could be used as a tool to perform more

empirical studies in order to analyze decision biases of players and propose policies to avoid these biases. It could also be used to test other mechanisms in different freight transport markets (e.g., negotiations, opaque mechanisms), and to test other market objectives (e.g., sustainability, actor reputation, resilience).

For practitioners, this study and the use of the “Freight Transport Game” could help them to better understand the mechanisms and rules of collaboration and make them aware of its usage barriers. For example, “l’Autorité de la concurrence” [French Competition Authority] recently fined the Astre transport group, which comprises small and medium-size road transport companies collaborating to increase efficiency and effectiveness, €3.8 million for anticompetitive practices. Collaboration needs to be very carefully handled so that it does not fall foul of competition law, and practitioners should be aware of all these barriers. Moreover, the proposed collaborative mechanisms could be used by some platforms such as *Urby*, a global urban logistics system based on the pooling and optimization of deliveries, or *CRC*, a platform that offers an innovative multi-industrial and multi-distributor transport pooling service.

These research avenues are certainly of utmost importance for the future of freight transport systems. With the emerging new collaborative transport networks, the complete understanding of collaborative transport service procurement mechanisms is essential but so far relatively ignored. Therefore, this dissertation can serve as a corner stone for future research.

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## APPENDIX A: Classification of papers studied in the literature review

### *The procurement mechanisms*

<b><i>Mechanism type</i></b>	Auction	(Ağralı et al., 2008), (Alp et al., 2003), (Andres Figliozzi et al., 2003), (Jothi Basu et al., 2017), (Berger and Bierwirth, 2010), (Buer and Kopfer, 2014), (Buer and Pankratz, 2010), (Caplice, 2007), (Caplice and Sheffi, 2003), (Carter et al., 2004), (Carter and Stevens, 2007), (Chang, 2009), (Chen, 2016), (Chen et al., 2009), (Cheng, 2011), (Cheng et al., 2016), (Dahl and Derigs, 2011), (Figliozzi et al., 2004), (Figliozzi et al., 2005), (Figliozzi et al., 2006), (Figliozzi et al., 2007), (Gansterer and Hartl, 2016), (Garrido, 2007), (Gattiker et al., 2007), (Goldsby and Eckert, 2003), (Guo et
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		al., 2006), (Handoko and Lau, 2016), (Hu et al., 2016), (Huang and Xu, 2013), (Jothi Basu et al., 2015), (Jothi Basu et al., 2015), (Kersten, 2009), (Kuo and Miller-Hooks, 2012), (Kuo and Miller-Hooks, 2015), (Kuyzu et al., 2015), (Lalive et al., 2017), (Ledyard et al., 2002), (Lee et al., 2007), (Li and Zhang, 2015), (Li et al., 2016), (Lim et al., 2012), (Lim et al., 2008), (Lindsey and Mahmassani, 2017), (Ma et al., 2010), (Mes et al., 2009), (Mesa-Arango and Ukkusuri, 2013), (Özener et al., 2011), (Park and Rothkopf, 2005), (Qiao et al., 2016), (Qin et al., 2012), (Rekik and Mellouli, 2012), (Remli and Rekik, 2013), (Robu et al., 2011), (Sandholm et al., 2006), (Schwind et al., 2009), (Sheffi, 2004), (Song and Regan, 2003), (Song and Regan, 2005), (Triki et al., 2017), (Triki et al., 2014), (van Duin et al., 2007), (Wang and Wang, 2015), (Wang and Kopfer, 2014), (Wang and Xia, 2005), (Xu and Huang, 2013), (Xu and Huang, 2014), (Xu and Huang, 2017), (Xu et al., 2015), (Xu et al., 2016), (Zhang et al., 2014), (Zhang et al., 2015), (Zhang et al., 2016)
	Negotiation	(Caplice, 2007), (Cheng, 2011), (Gattiker et al., 2007), (Goldsby and Eckert, 2003), (Hedvall et al., 2017), (Lalive et al., 2017), (Lim et al., 2012), (Lim et al., 2008), (Mes et al., 2009), (Remli and Rekik, 2013), (Robu et al., 2011), (Song and Regan, 2003), (van Duin et al., 2007)
	Catalog	(Balasubramanian, 1998), (Caplice, 2007)
<b><i>Mechanism ownership</i></b>	Carrier-owned	(Berger and Bierwirth, 2010), (Gansterer and Hartl, 2016), (Kuo and Miller-Hooks, 2012), (Ledyard et al., 2002), (Li et al., 2016), (Özener et al., 2011), (Park and Rothkopf, 2005), (Wang and Wang, 2015), (Xu and Huang, 2017)

	Shipper-owned	(Ağralı et al., 2008), (Alp et al., 2003), (Jothi Basu et al., 2017), (Buer and Pankratz, 2010), (Caplice and Sheffi, 2003), (Carter et al., 2004), (Carter and Stevens, 2007), (Chang, 2009), (Chen et al., 2009), (Figliozzi et al., 2004), (Figliozzi et al., 2005), (Figliozzi et al., 2006), (Figliozzi et al., 2007), (Gattiker et al., 2007), (Goldsby and Eckert, 2003), (Hu et al., 2016), (Huang and Xu, 2013), (Kersten, 2009), (Kuyzu, 2017), (Lee et al., 2007), (Lim et al., 2008), (Ma et al., 2010), (Mes et al., 2009), (Mesa-Arango and Ukkusuri, 2013), (Remli and Rekik, 2013), (Sandholm et al., 2006), (Sheffi, 2004), (Song and Regan, 2003), (Song and Regan, 2005), (Triki et al., 2014), (van Duin et al., 2007), (Wang and Kopfer, 2014), (Zhang et al., 2014), (Zhang et al., 2015)
	Third-party-owned	(Buer and Kopfer, 2014), (Chen, 2016), (Cheng et al., 2016), (Garrido, 2007), (Handoko and Lau, 2016), (Li and Zhang, 2015), (Lindsey and Mahmassani, 2017), (Wang and Xia, 2005), (Xu and Huang, 2013), (Xu and Huang, 2014), (Xu et al., 2015), (Xu et al., 2016), (Zhang et al., 2016)

***The market characteristics***

<b><i>Transport mode</i></b>	Road	(Ağralı et al., 2008), (Alp et al., 2003), (Andres Figliozzi et al., 2003), (Jothi Basu et al., 2017), (Berger and Bierwirth, 2010), (Buer and Kopfer, 2014), (Buer and Pankratz, 2010), (Caplice, 2007), (Caplice and Sheffi, 2003), (Carter et al., 2004), (Carter and Stevens, 2007), (Chang, 2009), (Chen, 2016), (Chen et al., 2009), (Cheng et al., 2016), (Figliozzi et al., 2004), (Figliozzi et al., 2005), (Figliozzi et al., 2006), (Figliozzi et al., 2007), (Gansterer and Hartl, 2016), (Garrido, 2007), (Goldsby and Eckert, 2003), (Guo et al., 2006), (Handoko and Lau, 2016), (Hedvall et al., 2017), (Hu et al., 2016), (Huang and Xu, 2013), (Jothi Basu et al., 2015),
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		(Kersten, 2009), (Kuyzu, 2017), (Kuyzu et al., 2015), (Ledyard et al., 2002), (Lee et al., 2007), (Li et al., 2016), (Lim et al., 2008), (Lindsey and Mahmassani, 2017), (Ma et al., 2010), (Mes et al., 2009), (Mesa-Arango and Ukkusuri, 2013), (Özener et al., 2011), (Park and Rothkopf, 2005), (Qiao et al., 2016), (Rekik and Mellouli, 2012), (Remli and Rekik, 2013), (Robu et al., 2011), (Sandholm et al., 2006), (Sheffi, 2004), (Song and Regan, 2003), (Song and Regan, 2005), (Triki et al., 2014), (van Duin et al., 2007), (Wang and Wang, 2015), (Wang and Kopfer, 2014), (Wang and Xia, 2005), (Xu and Huang, 2013), (Xu and Huang, 2014), (Xu and Huang, 2017), (Xu et al., 2015), (Zhang et al., 2014), (Zhang et al., 2015), (Zhang et al., 2016)
	Railway	(Hu et al., 2016), (Kuo and Miller-Hooks, 2012), (Kuo and Miller-Hooks, 2015), (Lalive et al., 2017)
	Maritime	(Hu et al., 2016), (Li and Zhang, 2015), (Lim et al., 2012)
	Multimodal	(Xu et al., 2015)
<i>Terms of agreement</i>	Contract	(Alp et al., 2003), (Jothi Basu et al., 2017), (Berger and Bierwirth, 2010), (Buer and Kopfer, 2014), (Buer and Pankratz, 2010), (Caplice, 2007), (Caplice and Sheffi, 2003), (Carter et al., 2004), (Carter and Stevens, 2007), (Chen, 2016), (Chen et al., 2009), (Cheng, 2011), (Gansterer and Hartl, 2016), (Goldsby and Eckert, 2003), (Guo et al., 2006), (Hedvall et al., 2017), (Hu et al., 2016), (Huang and Xu, 2013), (Jothi Basu et al., 2015), (Kersten, 2009), (Kuo and Miller-Hooks, 2015), (Kuyzu, 2017), (Kuyzu et al., 2015), (Lalive et al., 2017), (Ledyard et al., 2002), (Lee et al., 2007), (Li and Zhang, 2015), (Li et al., 2016), (Lim et al., 2012), (Lim et al., 2008), (Ma et al., 2010), (Mesa-Arango and Ukkusuri, 2013), (Özener et al., 2011), (Park and Rothkopf,

		2005), (Qin et al., 2012), (Rekik and Mellouli, 2012), (Remli and Rekik, 2013), (Robu et al., 2011), (Sandholm et al., 2006), (Sheffi, 2004), (Song and Regan, 2003), (Song and Regan, 2005), (Triki et al., 2014), (van Duin et al., 2007), (Wang and Wang, 2015), (Wang and Kopfer, 2014), (Wang and Xia, 2005), (Xu and Huang, 2014), (Xu and Huang, 2017), (Xu et al., 2015), (Zhang et al., 2014), (Zhang et al., 2015), (Zhang et al., 2016)
	Spot market	(Ağrali et al., 2008), (Chang, 2009), (Figliozzi et al., 2004), (Figliozzi et al., 2005), (Figliozzi et al., 2006), (Figliozzi et al., 2007), (Garrido, 2007), (Kuo and Miller-Hooks, 2012), (Kuyzu et al., 2015), (Lindsey and Mahmassani, 2017), (Mes et al., 2009), (Qiao et al., 2016), (Schwind et al., 2009), (Xu and Huang, 2013), (Xu and Huang, 2017)
<i>Participants on two sides</i>	Few-to-many	(Ağrali et al., 2008), (Alp et al., 2003), (Jothi Basu et al., 2017), (Buer and Pankratz, 2010), (Chang, 2009), (Cheng, 2011), (Figliozzi et al., 2004), (Figliozzi et al., 2005), (Figliozzi et al., 2006), (Figliozzi et al., 2007), (Goldsby and Eckert, 2003), (Hu et al., 2016), (Huang and Xu, 2013), (Lee et al., 2007), (Lim et al., 2012), (Lim et al., 2008), (Ma et al., 2010), (Mes et al., 2009), (Remli and Rekik, 2013), (Sandholm et al., 2006), (Sheffi, 2004), (Song and Regan, 2005), (Wang and Kopfer, 2014), (Zhang et al., 2014)
	Many-to-few	(Gansterer and Hartl, 2016), (Kuo and Miller-Hooks, 2012), (Ledyard et al., 2002), (Li and Zhang, 2015), (Li et al., 2016), (Özener et al., 2011), (Park and Rothkopf, 2005), (Wang and Wang, 2015), (Xu and Huang, 2017)
	Many-to-many	(Andres Figliozzi et al., 2003), (Buer and Kopfer, 2014), (Chang, 2009), (Chen, 2016), (Chen et al., 2009), (Cheng et

	al., 2016), (Garrido, 2007), (Guo et al., 2006), (Handoko and Lau, 2016), (Jothi Basu et al., 2015), (Kuyzu et al., 2015), (Lalive et al., 2017), (Lindsey and Mahmassani, 2017), (Qiao et al., 2016), (Schwind et al., 2009), (Wang and Xia, 2005), (Xu and Huang, 2013), (Xu and Huang, 2014), (Xu and Huang, 2017), (Xu et al., 2015), (Xu et al., 2016), (Zhang et al., 2016)
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***The procurement mechanism outcomes***

<b><i>Individual Objective Outcomes</i></b>	(Ağralı et al., 2008), (Andres Figliozzi et al., 2003), (Carter et al., 2004), (Chang, 2009), (Cheng, 2011), (Figliozzi et al., 2004), (Figliozzi et al., 2006), (Figliozzi et al., 2007), (Gansterer and Hartl, 2016), (Guo et al., 2006), (Kuyzu, 2017), (Kuyzu et al., 2015), (Ledyard et al., 2002), (Lee et al., 2007), (Li and Zhang, 2015), (Li et al., 2016), (Lim et al., 2012), (Ma et al., 2010), (Özener et al., 2011), (Park and Rothkopf, 2005), (Qiao et al., 2016), (Rekik and Mellouli, 2012), (Sandholm et al., 2006), (Sheffi, 2004), (Song and Regan, 2003), (Song and Regan, 2005), (Triki et al., 2017), (Triki et al., 2014)
<b><i>Individual Subjective Outcomes</i></b>	(Andres Figliozzi et al., 2003), (Jothi Basu et al., 2017), (Berger and Bierwirth, 2010), (Buer and Kopfer, 2014), (Caplice, 2007), (Caplice and Sheffi, 2003), (Carter and Stevens, 2007), (Figliozzi et al., 2005), (Gattiker et al., 2007), (Guo et al., 2006), (Hu et al., 2016), (Rekik and Mellouli, 2012), (Sheffi, 2004)
<b><i>Market Outcomes</i></b>	(Ağralı et al., 2008), (Alp et al., 2003), (Andres Figliozzi et al., 2003), (Berger and Bierwirth, 2010), (Buer and Kopfer, 2014), (Buer and Pankratz, 2010), (Cheng et al., 2016), (Dahl and Derigs, 2011), (Garrido, 2007), (Goldsby and Eckert, 2003), (Handoko and Lau, 2016), (Hedvall et al., 2017), (Hu

	et al., 2016), (Huang and Xu, 2013), (Jothi Basu et al., 2015), (Kersten, 2009), (Kuo and Miller-Hooks, 2012), (Kuo and Miller-Hooks, 2015), (Lalive et al., 2017), (Lim et al., 2008), (Mesa-Arango and Ukkusuri, 2013), (Schwind et al., 2009), (Song and Regan, 2005), (van Duin et al., 2007), (Wang and Wang, 2015), (Wang and Kopfer, 2014), (Wang and Xia, 2005), (Xu and Huang, 2013), (Xu and Huang, 2014), (Xu and Huang, 2017), (Xu et al., 2015), (Xu et al., 2016), (Zhang et al., 2014), (Zhang et al., 2015), (Zhang et al., 2016)
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***The research methodologies***

<b><i>Conceptual studies</i></b>	(Caplice, 2007), (Caplice and Sheffi, 2003), (Garrido, 2007), (Goldsby and Eckert, 2003), (Lindsey and Mahmassani, 2017), (Sheffi, 2004)
<b><i>Empirical studies</i></b>	(Alp et al., 2003), (Buer and Kopfer, 2014), (Kuyzu et al., 2015), (Park and Rothkopf, 2005),
<b><i>Case studies</i></b>	(Ağralı et al., 2008), (Jothi Basu et al., 2017), (Carter and Stevens, 2007), (Hedvall et al., 2017), (Lalive et al., 2017), (Ledyard et al., 2002), (Lim et al., 2012), (Robu et al., 2011), (Sandholm et al., 2006), (Schwind et al., 2009)
<b><i>Literature reviews</i></b>	(Jothi Basu et al., 2015)
<b><i>Numerical experiments</i></b>	(Andres Figliozzi et al., 2003), (Berger and Bierwirth, 2010), (Buer and Pankratz, 2010), (Chang, 2009), (Chen, 2016), (Chen et al., 2009), (Cheng, 2011), (Cheng et al., 2016), (Dahl and Derigs, 2011), (Figliozzi et al., 2004), (Figliozzi et al., 2005), (Figliozzi et al., 2006), (Figliozzi et al., 2007), (Gansterer and Hartl, 2016), (Garrido, 2007), (Guo et al., 2006), (Huang and Xu, 2013), (Jothi Basu et al., 2015), (Kuo and Miller-Hooks, 2012), (Kuo and Miller-Hooks, 2015), (Lee et al., 2007), (Li et al., 2016), (Lim et al., 2008),

(Ma et al., 2010), (Mes et al., 2009), (Mesa-Arango and Ukkusuri, 2013), (Özener et al., 2011), (Qiao et al., 2016), (Qin et al., 2012), (Rekik and Mellouli, 2012), (Remli and Rekik, 2013), (Song and Regan, 2003), (Song and Regan, 2005), (Triki et al., 2017), (Triki et al., 2014), (Wang and Wang, 2015), (Wang and Xia, 2005), (Xu and Huang, 2013), (Xu and Huang, 2014), (Xu and Huang, 2017), (Xu et al., 2015), (Xu et al., 2016), (Zhang et al., 2014), (Zhang et al., 2015), (Zhang et al., 2016)

*Appendix A: Classification of papers studied in the literature review*

## **APPENDIX B: Input transport requests for simulation model**

<b>Requests</b>	<b>Origins</b>	<b>Destinations</b>	<b>Volumes</b>	<b>Lead times</b>	<b>Requests</b>	<b>Origins</b>	<b>Destinations</b>	<b>Volumes</b>	<b>Lead times</b>
1	2	6	1	5	51	1	5	2	9
2	2	6	1	6	52	3	1	1	6
3	4	8	2	7	53	8	2	2	5
4	7	1	1	4	54	4	5	1	7
5	8	6	2	5	55	6	8	2	7
6	1	3	1	4	56	8	1	1	8
7	4	8	1	9	57	7	2	1	6
8	5	4	1	5	58	3	6	1	8
9	3	8	1	6	59	2	7	2	7
10	3	6	1	6	60	1	3	1	5
11	1	5	1	8	61	1	8	2	9
12	1	8	2	7	62	2	8	1	6
13	6	3	1	7	63	4	7	2	8
14	6	5	1	7	64	2	7	1	5
15	7	2	2	6	65	3	8	2	5
16	4	5	1	5	66	6	5	1	5
17	2	8	1	10	67	3	7	2	6
18	7	2	1	9	68	1	8	1	5
19	1	7	2	6	69	6	3	1	7
20	6	3	1	6	70	3	6	1	7
21	4	8	2	7	71	6	8	2	8
22	1	5	1	5	72	8	1	1	6
23	8	1	1	8	73	4	8	2	8
24	9	2	1	9	74	1	7	1	7
25	1	7	2	5	75	5	1	2	5
26	4	3	2	7	76	3	7	1	9
27	9	8	1	6	77	2	8	1	6
28	2	8	1	8	78	6	1	1	8
29	5	7	1	4	79	8	1	2	5
30	1	7	2	3	80	2	6	1	5
31	4	3	1	4	81	5	3	1	9
32	8	1	2	3	82	4	9	1	6
33	2	7	1	4	83	6	2	2	9
34	8	3	1	4	84	3	1	2	7
35	7	2	2	5	85	7	1	2	4
36	8	1	2	5	86	1	8	1	8
37	3	4	1	6	87	5	1	1	6
38	2	8	1	4	88	3	2	2	5
39	4	8	2	7	89	5	6	2	7

40	7	1	1	7	90	7	1	2	5
41	8	6	2	4	91	5	7	1	6
42	1	3	1	6	92	7	2	2	6
43	1	8	2	8	93	6	3	2	8
44	5	4	2	7	94	2	8	2	7
45	5	6	1	5	95	3	6	1	5
46	3	6	1	5	96	7	2	2	9
47	4	3	2	6	97	4	6	1	8
48	1	8	1	8	98	4	8	1	9
49	9	2	2	5	99	8	1	1	5
50	7	1	1	5					

*Appendix B: Input transport requests for 33 rounds (3 new requests in each round)*

## APPENDIX C: Freight Transport Game

### Player's Guide

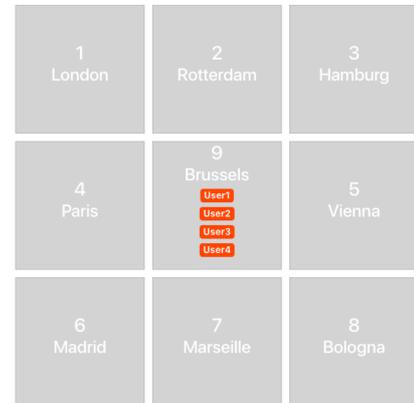
#### Goal – How to win



- Each player optimizes the journey of their truck to submit the best rates, win the maximum number of requests to transport, and maximize their profit
- The winner is the player with the highest profit at the end of the game

## Presentation - Map

- 4 players are initially positioned at node 9
- A map with 9 cities
- Several rounds
- 3 new requests per round (one round = one period)
- Each player has a truck with a maximum capacity of 4 units
- In each round, the players must submit the best prices for the requests they want to take
- Each player submits their own profit (no communication allowed between players – competitors)



## Presentation – Requests

- For each period, 3 new requests are generated randomly on the map

- A request is defined by:

- Origin: from 1 to 9

- Destination: from 1 to 9

- Volume: 1 to 2 units

- Lead time: the number of rounds after which the request should be delivered, otherwise the carrier pays a penalty

### Requests



## Presentation – Useful information

### ○ Moves: duration, distance, lead time, penalties...

- Each player is located at node 9 at the beginning
- The duration of each move (horizontal, vertical or diagonal) is 1 round
- The distance between neighboring nodes is 1 unit
- For each move, the volume of transported requests should not exceed the capacity of the truck (controlled by the game)
- After each move, the delivery lead time decreases by 1
- Each delivery delay generates a penalty of \$5

## How the game works

### ○ Steps

#### A. Market analysis

1. Controlling your position and capacity
2. Controlling requests (origin, destination, volume and lead time)

#### B. Proposal submissions

1. The route
2. The feasible request bundles
3. Your best price for the bundle

#### C. Submit

- Submit several propositions to increase your chances of winning

#### D. Next round

## How the game works

### ○ For each round

1. The prices proposed by the carriers are sent to the organizer
2. An optimization model allocates requests to winners by minimizing the total price
3. Results: The profit is calculated for each player as follows:

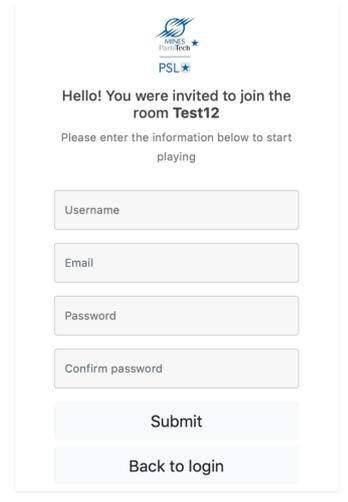
$$\text{Profit}_{\text{round/carrier}} = \text{Proposed Price} - \text{Cost}$$

## How to join the game ?

- Each player will receive an invitation by e-mail
- Each player must follow the link, register and log in
- Each player has a unique username
- Each player must choose a number for their truck

Choose your carrier

1	2	3	4
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Hello! You were invited to join the room **Test12**

Please enter the information below to start playing

Username

Email

Password

Confirm password

Submit

[Back to login](#)

## How it works

### ○ B. Proposal submissions : 1. Choose the appropriate route

The appropriate route should contain the origins and destinations of all the requests a player wants to transport (origins before destinations)

CARRIER	POSITION	+ \$ CUMUL GAIN	CUMUL DELAY
1	9	0.00	0

Choose your road (Road cost: 6 \$) 9-2-9-6 ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

1  
Origin: 2  
Destination: 6  
Volume: 1  
Lead time: 6

2  
Origin: 2  
Destination: 6  
Volume: 1  
Lead time: 6

3  
Origin: 4  
Destination: 8  
Volume: 2  
Lead time: 4

**(Total cost: 6 \$)**  
Request bundle price

Finish Round

## How it works

### ○ B. Proposal submissions : 1. Choose the appropriate route

The appropriate routes are in green

CARRIER	POSITION	+ \$ CUMUL GAIN	CUMUL DELAY
1	9	0.00	0

Choose your road (Road cost: 6 \$) 9-2-9-6 ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

1  
Origin: 2  
Destination: 6  
Volume: 1  
Lead time: 6

2  
Origin: 2  
Destination: 6  
Volume: 1  
Lead time: 6

3  
Origin: 4  
Destination: 8  
Volume: 2  
Lead time: 4

**(Total cost: 6 \$)**  
Request bundle price

Finish Round

## How it works

### ○ B. Proposal submissions : 1. Choose the appropriate route

CARRIER: 1   POSITION: 9   CUMUL GAIN: 0.00   CUMUL DELAY: 0

Choose your road 9-2-9-4

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

If a route is red it means that it is not valid

Choose your requests

1	Origin: 2 Destination: 6 Volume: 1 Lead time: 5	2	Origin: 2 Destination: 6 Volume: 1 Lead time: 6
3	Origin: 4 Destination: 8 Volume: 2 Lead time: 4		

Request bundle price: 0

Finish Round

## How it works

### ○ B. Proposal submissions : 1. Choose the appropriate route

CARRIER: 1   POSITION: 9   CUMUL GAIN: 0.00   CUMUL DELAY: 0

Choose your road 9-2-9-4

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

A player can delete a route if they want to change it

Choose your requests

1	Origin: 2 Destination: 6 Volume: 1 Lead time: 5	2	Origin: 2 Destination: 6 Volume: 1 Lead time: 6
3	Origin: 4 Destination: 8 Volume: 2 Lead time: 4		

Request bundle price: 0

Finish Round

## How it works

### ○ B. Proposal submissions : 1. Choose the appropriate route

CARRIER <b>1</b>	POSITION <b>9</b>	CUMUL GAIN <b>0.00</b>	CUMUL DELAY <b>0</b>
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**Choose your requests**

1

Origin: 2  
Destination: 8  
Volume: 1  
Lead time: 5

2

Origin: 2  
Destination: 6  
Volume: 1  
Lead time: 6

3

Origin: 4  
Destination: 8  
Volume: 2  
Lead time: 4

Request bundle price

**Choose your road**

9-2-9-4

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Finish Round

The player can choose green nodes; red nodes are blocked so they cannot be chosen

## How it works

### ○ B. Proposal submissions : 1. Choose the appropriate route

CARRIER <b>1</b>	POSITION <b>9</b>	CUMUL GAIN <b>0.00</b>	CUMUL DELAY <b>0</b>
---------------------	----------------------	---------------------------	-------------------------

**Choose your requests**

1

Origin: 2  
Destination: 8  
Volume: 1  
Lead time: 5

2

Origin: 2  
Destination: 6  
Volume: 1  
Lead time: 6

3

Origin: 4  
Destination: 8  
Volume: 2  
Lead time: 4

Request bundle price

**Choose your road**

9-2-9-6 ✓

Road cost: 6 \$!

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Finish Round

The route cost is

## How it works

### ○ B. Proposal submissions : 2. Choose the appropriate requests

Select the requests to be transported on the route chosen

Choose your road (Road cost: 6 \$) 9-2-9-6 ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

- 1: Origin: 2, Destination: 0, Volume: 1, Lead time: 0
- 2: Origin: 2, Destination: 0, Volume: 1, Lead time: 0
- 3: Origin: 4, Destination: 8, Volume: 2, Lead time: 4

(Total cost: 6 \$)  
Request bundle price: 0

Finish Round

## How it works

### ○ B. Proposal submissions : 3. Propose a price for the request bundle chosen

The proposed price must take the total cost into consideration

The difference between the proposed price and the total cost is the potential profit for the carrier in this round if they are allocated the bundle

Choose your road (Road cost: 6 \$) 9-2-9-6 ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

- 1: Origin: 2, Destination: 0, Volume: 1, Lead time: 0
- 2: Origin: 2, Destination: 0, Volume: 1, Lead time: 0
- 3: Origin: 4, Destination: 8, Volume: 2, Lead time: 4

(Total cost: 6 \$)  
Request bundle price: 7,24

Submit

Finish Round

## How it works

### B. Proposal submissions : 3. Propose a price for the request bundle chosen

When the price is proposed selected requests turn "green"

The screenshot shows the game interface with the following elements:

- Carrier Status:** CARRIER 1, POSITION 9, CUMUL GAIN 0.00, CUMUL DELAY 0.
- Choose your road:** Road cost: 6 \$, route 9-2-9-6.
- Request Grid:**

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna
- Choose your requests:** Three request cards are shown: 1 (Origin: 2, Destination: 6, Volume: 1, Lead time: 6), 2 (Origin: 2, Destination: 6, Volume: 1, Lead time: 6), and 3 (Origin: 4, Destination: 8, Volume: 2, Lead time: 4). Requests 1 and 2 are highlighted in green.
- Price Submission:** (Total cost: 6 \$), Request bundle price: 7,24, Submit button.
- Finish Round** button.

## How it works (specific case: penalty)

### B. Proposal submissions : 3. Propose a price for a request bundle with penalty

This route takes 5 rounds

The lead time of request "3" is 4 periods

If a player decides to transport request "3" on this route they will have a delay of 1 round

The screenshot shows the game interface with the following elements:

- Carrier Status:** CARRIER 1, POSITION 9, CUMUL GAIN 0.00, CUMUL DELAY 0.
- Choose your road:** Road cost: 6 \$, route 9-2-1-4-7-8.
- Request Grid:**

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna
- Choose your requests:** Three request cards are shown: 1 (Origin: 2, Destination: 6, Volume: 3, Lead time: 5), 2 (Origin: 2, Destination: 6, Volume: 3, Lead time: 6), and 3 (Origin: 4, Destination: 8, Volume: 2, Lead time: 4). Request 3 is highlighted in green.
- Price Submission:** (Total cost: 15 \$), Request bundle price: 18,45, Submit button.
- Finish Round** button.

## How it works (specific case: penalty)

- B. Proposal submissions : 3. Propose a price for a request bundle with penalty

The penalty for one delay is \$5 -> To transport request "3" on the chosen route, the player will pay a penalty cost of \$5

The screenshot shows the game interface. At the top, a status bar displays: CARRIER 1, POSITION 9, CUMUL GAIN 0.00, and CUMUL DELAY 0. Below this, a route selection bar shows '9-2-1-4-7-8' with a checkmark. A grid of 9 cities is shown: 1 London, 2 Rotterdam, 3 Hamburg, 4 Paris, 9 Brussels, 5 Vienna, 6 Madrid, 7 Marseille, 8 Bologna. To the right, a 'Choose your requests' panel shows three request cards. Request 3 is selected. Below the requests, a 'Request bundle price' input field contains '18,45' and a 'Submit' button. A red circle highlights the 'Total cost: 15 \$' label. A 'Finish Round' button is at the bottom right.

## How it works (specific case: penalty)

- B. Proposal submissions : 3. Propose a price for a request bundle with penalty

The total cost = Route cost + Penalty cost

This screenshot is identical to the one on slide 23, showing the same route grid, route selection, and request bundle selection interface. A blue arrow points from the text 'The total cost = Route cost + Penalty cost' to the 'Total cost: 15 \$' label in the interface.

## How it works (particular case: penalty)

### ○ B. Proposal submissions : 3. Propose a price for a request bundle with penalty

CARRIER: 1, POSITION: 9, CUMUL. GAIN: 0.00, CUMUL. DELAY: 0

Choose your road (Road cost: 10 \$) **9-2-1-4-7-8** ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests (Penalty: 5 \$)

1	Origin: 2, Destination: 6, Volume: 1, Lead time: 5
2	Origin: 2, Destination: 6, Volume: 1, Lead time: 6
3	Origin: 4, Destination: 8, Volume: 2, Lead time: 4

(Total cost: 15 \$)  
Request bundle price: 18,45 € Submit ✓

Finish Round

The proposed price must take the total cost into consideration!

## How it works

### ○ C. Submit

CARRIER: 1, POSITION: 9, CUMUL. GAIN: 0.00, CUMUL. DELAY: 0

Choose your road (Road cost: 6 \$) **9-2-9-6** ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

1	Origin: 2, Destination: 6, Volume: 1, Lead time: 6
2	Origin: 2, Destination: 6, Volume: 1, Lead time: 6
3	Origin: 4, Destination: 8, Volume: 2, Lead time: 4

(Total cost: 6 \$)  
Request bundle price: 7,24 € Submit ✓

Finish Round

Click on "submit" to register the proposition

## How it works

### ○ Summary of propositions

#### Summary

Road	
<b>9-2-9-6</b>	
Road cost	
6 \$	
Request	
<b>1-2</b>	
Price	
7.24 \$	

Click on “New requests” if you want to make other propositions

New requests

Finish Round

## How it works

### ○ Summary of propositions

#### Summary

Road	
<b>9-2-9-6</b>	
Road cost	
6 \$	
Request	
<b>1-2</b>	
Price	
7.24 \$	

Click on “Finish Round” if you do not have any other propositions

New requests

Finish Round

## How it works

### ○ Summary of propositions

**Summary**

A player can delete a proposition if it is not right

Road 🗑️

**9-2-1-4-7-8**

Road cost  
15 \$

Request  
**3**

Price  
18.45 \$

Road 🗑️

**9-2-9-6**

Road cost  
6 \$

Request  
**1-2**

Price  
7.24 \$

**New requests**

**Finish Round**

## View of next round

### ○ For each round

To choose new routes, the player must take the route remaining from the previous round into consideration.

The player can either:

CARRIER: 1    POSITION: 2    + \$ CUMUL GAIN: 1.24    CUMUL DELAY: 0

**Loads**

Request Bundles	Volumes	Origins	Destinations
<b>2-8-2</b>	1-2	1-1	2-2
		6-6	

**Choose your road**

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

**Choose your requests**

4

Origin: 7  
Destination: 1  
Volume: 1  
Lead time: 4

5

Origin: 8  
Destination: 6  
Volume: 2  
Lead time: 5

6

Origin: 1  
Destination: 3  
Volume: 3  
Lead time: 4

Request bundle price  
0

**Finish Round**

## How it works

### ○ Summary of propositions

**Summary**

A player can delete a proposition if it is not right

Road 🗑️

**9-2-1-4-7-8**

Road cost  
15 \$

Request  
**3**

Price  
18.45 \$

Road 🗑️

**9-2-9-6**

Road cost  
6 \$

Request  
**1-2**

Price  
7.24 \$

New requests

Finish Round

## View of next round

### ○ For each round

1. Change the remaining route but they must check that it goes through all the nodes on the remaining route

Choose your road (Road cost: 4 \$)

**2-9-8-7-6 ✓**

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

4 Origin: 7 Destination: 1 Volume: 1 Lead time: 6	5 Origin: 8 Destination: 6 Volume: 1 Lead time: 6
6 Origin: 1 Destination: 3 Volume: 1 Lead time: 4	

**(Total cost: 4 \$)**

Request bundle price  
6

Finish Round

## View of next round

○ For each round

2. Choose the remaining route and continue the route

## View of next round

○ For each round

On the proposed route, the player must take the information about their loads from previous rounds into consideration and must deliver all the previous loads with the new ones

## Specific case - Reallocations

---



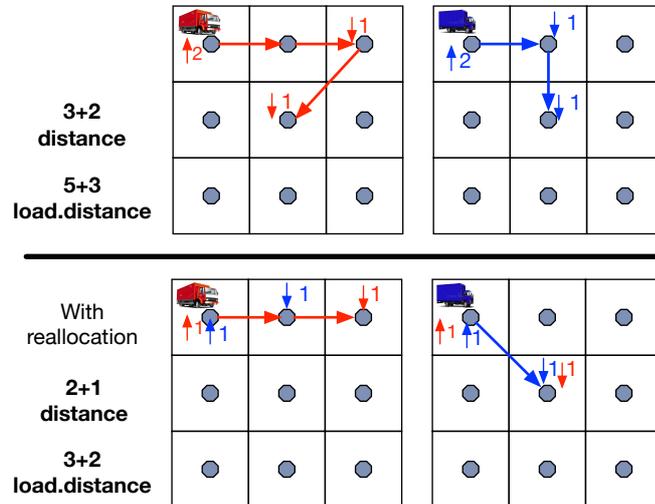
### Reallocation

#### ○ Possibility of reallocation at node 9

- When a carrier arrives at node 9, they can offer their requests for reallocation
  - These requests are called reallocated requests
  - These requests will be visible for other carriers to bid on

# Reallocation

○ Example



# Reallocation

○ Condition for reallocation

- If new price < former cost
  - Former carrier wins:  $\Delta\epsilon$ , time, capacity
  - New carrier wins: requests and profit
- If new price > former cost
  - Nothing happens  $\rightarrow$  play as usual

**$\rightarrow$  A win-win situation for the former and new carriers**

**$\rightarrow$  Should go through the central node (9) to increase chance of winning** (more requests at node 9 and possibility of reallocation)

## Reallocation

### ○ Useful information

A player's reallocated requests are displayed and are private information

The screenshot shows the 'Reallocations' interface. At the top, a summary bar includes: CARRIER 1, POSITION 9, CUMUL. GAIN 3.26, and CUMUL. DELAY 0. Below this, a 'Reallocations' section has a 'Loads' button. A table below shows: Remaining roads (0-8-7-6), Request Bundles (3), Volumes (2), Origins (8), and Destinations (6). The main area is divided into 'Choose your road' and 'Choose your requests'. 'Choose your road' shows a 3x3 grid of nodes: 1 London, 2 Rotterdam, 3 Hamburg, 4 Paris, 9 Brussels (highlighted in red), 5 Vienna, 6 Madrid, 7 Marseille, 8 Bologna. 'Choose your requests' shows several bundles: 1 (Origin: 9, Destination: 0, Volume: 1, Lead time: 3), 2 (Origin: 9, Destination: 0, Volume: 1, Lead time: 4), 3 (Origin: 9, Destination: 8, Volume: 2, Lead time: 2), 7 (Origin: 4, Destination: 8, Volume: 1, Lead time: 5), 8 (Origin: 5, Destination: 4, Volume: 3, Lead time: 5), 9 (Origin: 3, Destination: 8, Volume: 1, Lead time: 6). A 'Request bundle price' input field is set to 0. A 'Finish Round' button is at the bottom right.

## Reallocation

### ○ Condition for reallocation

- If new price < former cost
  - Former carrier wins:  $\Delta\epsilon$ , time, capacity
  - New carrier wins: requests and profit
- If new price > former cost
  - Nothing happens  $\rightarrow$  play as usual

**$\rightarrow$  A win-win situation for the former and new carriers**

**$\rightarrow$  Should go through the central node (9) to increase chance of winning** (more requests at node 9 and possibility of reallocation)

# Reallocation

## Useful information

CARRIER	POSITION	CUMUL. GAIN	CUMUL. DELAY
1	9	3.26	0
<b>Reallocations</b>			
1 2			
<b>Loads</b>			
Remaining roads	Request Bundles	Volumes	Origins Destinations
0-3-7-8	3	2 8	6

Reallocated requests are in yellow

Choose your road

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

1 Origin: 9 Destination: 6 Volume: 1 Lead time: 3 <b>(-1 \$)</b>	2 Origin: 9 Destination: 6 Volume: 1 Lead time: 4 <b>(-1 \$)</b>
3 Origin: 9 Destination: 8 Volume: 2 Lead time: 2 <b>(-2 \$)</b>	7 Origin: 4 Destination: 8 Volume: 1 Lead time: 5
8 Origin: 5 Destination: 4 Volume: 1 Lead time: 5	9 Origin: 3 Destination: 8 Volume: 1 Lead time: 6

Request bundle price: 0

Finish Round

# Reallocation

## Useful information

CARRIER	POSITION	CUMUL. GAIN	CUMUL. DELAY
1	9	3.26	0
<b>Reallocations</b>			
1 2			
<b>Loads</b>			
Remaining roads	Request Bundles	Volumes	Origins Destinations
0-3-7-8	3	2 8	6

All Requests = Reallocated requests + New requests for the round

Choose your road

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

1 Origin: 9 Destination: 6 Volume: 1 Lead time: 3 <b>(-1 \$)</b>	2 Origin: 9 Destination: 6 Volume: 1 Lead time: 4 <b>(-1 \$)</b>
3 Origin: 9 Destination: 8 Volume: 2 Lead time: 2 <b>(-2 \$)</b>	7 Origin: 4 Destination: 8 Volume: 1 Lead time: 5
8 Origin: 5 Destination: 4 Volume: 1 Lead time: 5	9 Origin: 3 Destination: 8 Volume: 1 Lead time: 6

Request bundle price: 0

Finish Round

# Reallocation

## ○ Useful information

The players can see all the reallocated requests (theirs and those of other players). E.g. request "3" belongs to another player but it is proposed to all players.

The screenshot shows a carrier's status at the top: CARRIER 1, POSITION 9, CUMUL GAIN 3.26, CUMUL DELAY 0. Below this, there are sections for 'Reallocations' (with a '3' icon) and 'Loads' (with a '2' icon). A table shows 'Remaining roads' (0-3, 7-8), 'Request Bundles' (3), 'Volumes' (2), 'Origins' (8), and 'Destinations' (6). The main interface is divided into 'Choose your road' and 'Choose your requests'. The road grid has 9 cells: 1 London, 2 Rotterdam, 3 Hamburg, 4 Paris, 9 Brussels (highlighted in red), 5 Vienna, 6 Madrid, 7 Marseille, 8 Bologna. The 'Choose your requests' section shows 9 request bundles with details like Origin, Destination, Volume, and Lead time. A blue circle highlights request 3, and a blue arrow points from the text to it. A 'Request bundle price' input field is set to 0, and a 'Finish Round' button is at the bottom right.

# Reallocation

## ○ Useful information

Former carrier cost of reallocated request

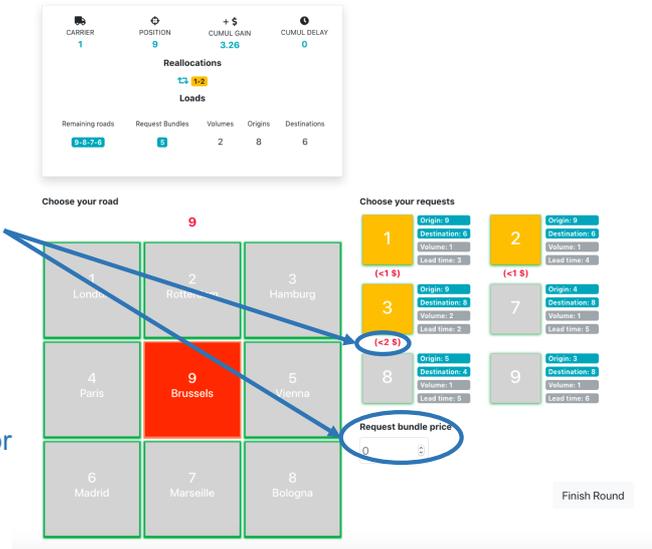
This screenshot is identical to the one on slide 43, showing the same carrier status, road grid, and request bundles. However, a blue circle is drawn around request bundle 3 in the 'Choose your requests' section, and a blue arrow points from the text 'Former carrier cost of reallocated request' to this circle.

# Reallocation

## ○ Useful information

The price\* proposed by the new player for this request should be less than the cost of the former carrier; this price is calculated automatically in the game depending on the request bundle price proposed.

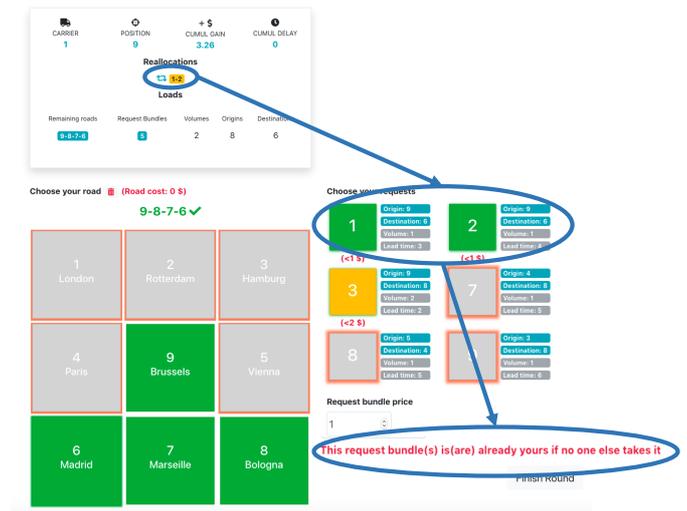
\*Price = the total price normalized for each request (depends on distance traveled by each request and its volume); it is calculated automatically in the game



# Reallocation

## ○ Useful information

A player cannot choose the reallocated requests they had in the previous round as they are already theirs. If no one else makes an offer for these requests, they will be forced to transport them



# Reallocation

## ○ A case study

A player responsible for reallocated requests can only make a proposition for new requests but in this case:

⚠ If no other player has made an offer for the reallocated requests -> the player will lose the new request (request 7) and will just transport the old reallocated requests (1 & 2) because they are responsible for these requests

Reallocations

CARRIER: 1, POSITION: 9, CUMUL. GAIN: 3.26, CUMUL. DELAY: 0

Remaining roads: 9-8-7-6, Request Bundles: 5, Volumes: 2, 8, Origins: 2, Destinations: 6

Choose your road (Road cost: 4 \$): 9-4-9-8-7-6 ✓

Choose your requests (Penalty: 5 \$):

1	2	3
4	9	5
6	7	8

(Total cost: 9 \$)  
Request bundle price: 10,5

# Reallocation

## ○ Solution to the case study: make 2 propositions instead of one

### 1. A proposition only for the new request

Reallocations

CARRIER: 1, POSITION: 9, CUMUL. GAIN: 3.26, CUMUL. DELAY: 0

Remaining roads: 9-8-7-6, Request Bundles: 5, Volumes: 2, 8, Origins: 2, Destinations: 6

Choose your road (Road cost: 4 \$): 9-4-9-8-7-6 ✓

Choose your requests (Penalty: 5 \$):

1	2	3
4	9	5
6	7	8

(Total cost: 9 \$)  
Request bundle price: 10,5

Reallocations

CARRIER: 1, POSITION: 9, CUMUL. GAIN: 3.26, CUMUL. DELAY: 0

Remaining roads: 9-8-7-6, Request Bundles: 5, Volumes: 2, 8, Origins: 2, Destinations: 6

Choose your road (Road cost: 4 \$): 9-4-9-8-7-6 ✓

Choose your requests (Penalty: 20 \$):

1	2	3
4	9	5
6	7	8

(Total cost: 24 \$)  
Request bundle price: 21

# Reallocation

○ Solution to the case study: make 2 propositions instead of one

## 1. A proposition only for the new request

## 2. The same proposition with the new requests and the reallocated ones

# Reallocation

○ Example

The route cost is "0" because the proposed route is the same as the remaining route -> No detour made -> Route Cost = 0

# Reallocation

## ○ Example

The destination of request “3” is on the remaining route of this player -> it will cost them nothing to transport it

Choose your road (Road cost: 0 \$) 9-8-7-6 ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

1 (€1 \$)	2 (€1 \$)
3 (€2 \$)	7
8	9

Request bundle price: 2.01 \$ Submit ✓

Finish Round

# Reallocation

## ○ Example

The request bundle price proposed “2.01” will be divided between the 3 reallocated requests selected -> the unit price of each request will be less than the cost displayed -> the condition of reallocation is verified

Choose your road (Road cost: 0 \$) 9-8-7-6 ✓

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels	5 Vienna
6 Madrid	7 Marseille	8 Bologna

Choose your requests

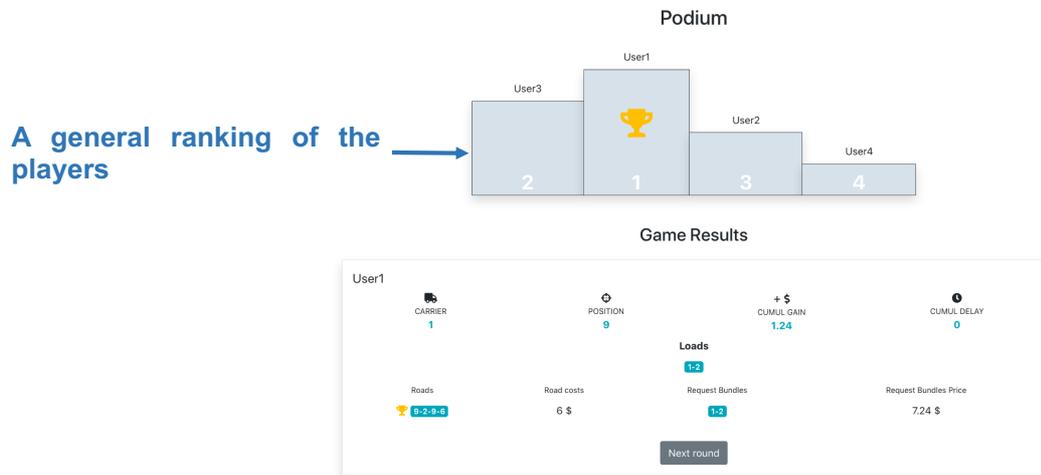
1 (€1 \$)	2 (€1 \$)
3 (€2 \$)	7
8	9

Request bundle price: 2.01 \$ Submit ✓

Finish Round

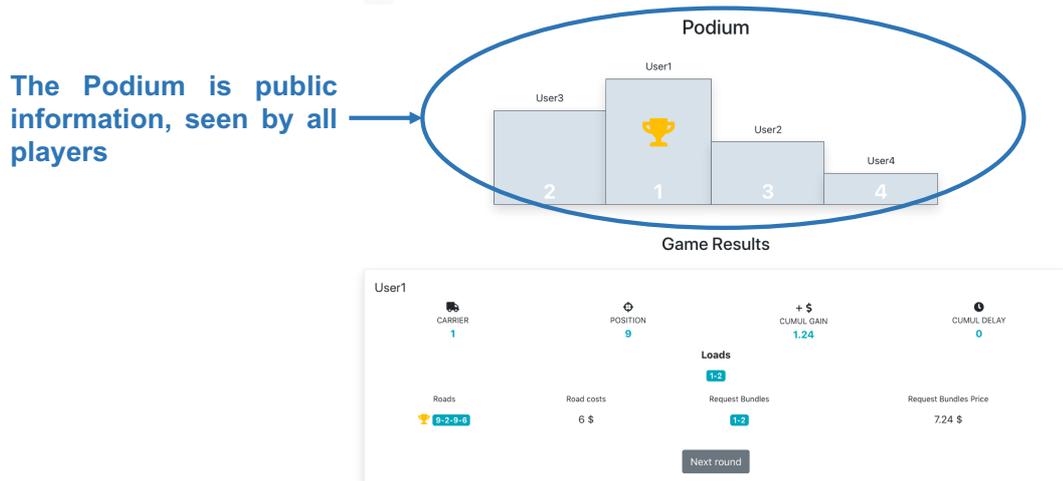
# Results

○ For each round



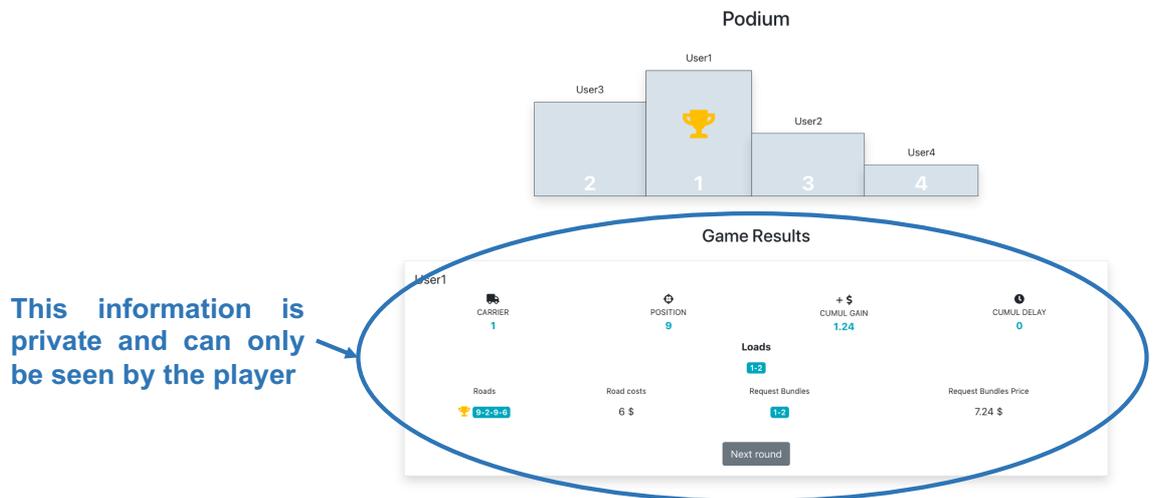
# Results

○ For each round



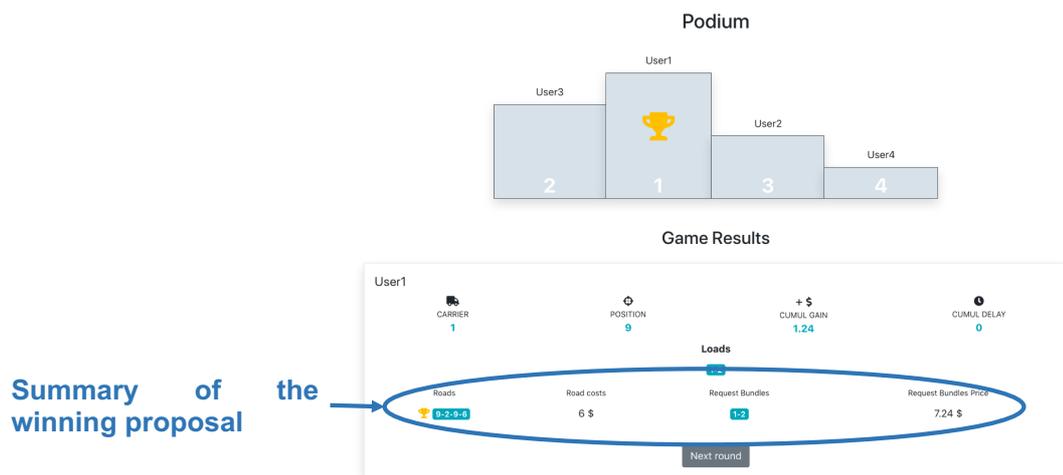
# Results

○ For each round



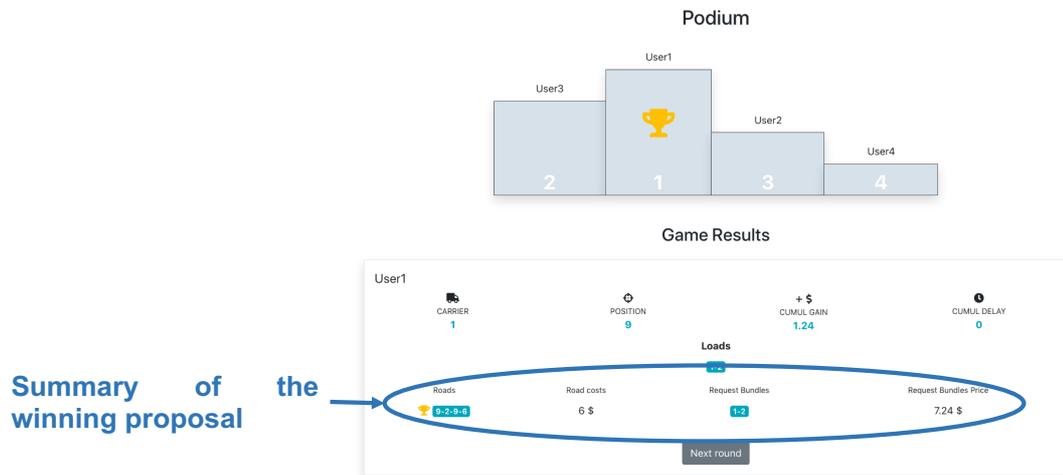
# Results

○ For each round



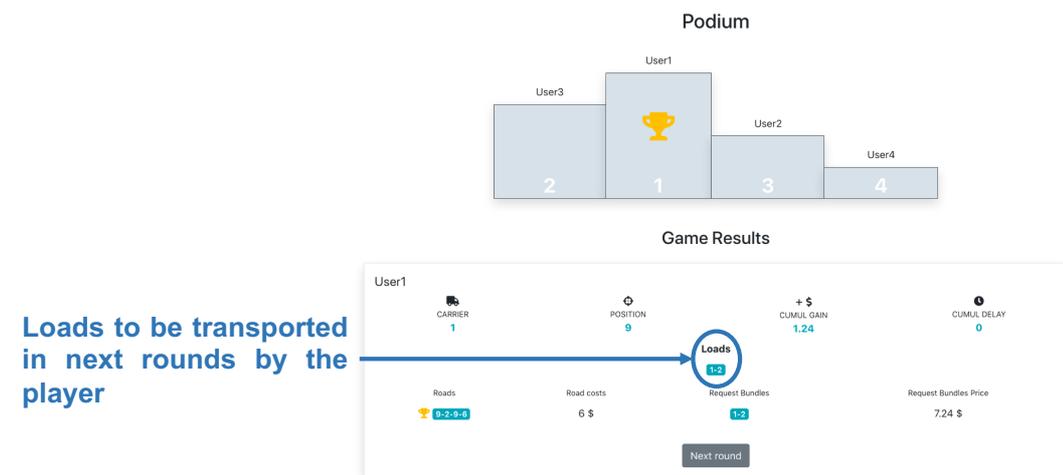
# Results

○ For each round



# Results

○ For each round



# Organizer's Guide

## Useful information



-  • Bachelor or Master's level students, supply chain professionals, carriers or logistics providers
-  • 3 hours are needed to inform the players, play a game, and analyze the results
  - Presentation of the game (~ 30 min)
  - Gaming (~ 2 h) -> (2 h = ~ 25 rounds) -> Each round ~ 5 min
  - Debriefing (~ 30min)
-  • 4 simultaneous players (possible to team up for each); parallel sessions can be managed simultaneously
  - Each session must have an organizer
  - An organizer is advised to manage at most 3 sessions simultaneously
-  • The game can be played via a web interface on a computer or mobile device. The game can also be reproduced on a physical board

## Accessing the game



- MINES ParisTech will create an account for your university/company and send you the "Access ID" and "Access Password" by e-mail so you can access the game
- The game organizer must follow this link <http://freight-transport.mines-paristech.fr/login>

## Accessing the game

- When accessing the game for the first time, the organizer must:
  - “Register” (click on “Register” button)
  - Enter the Access ID sent by MINES ParisTech in the field “Type your company or university”
  - Select the role “Game Administrator” in the list
  - Enter your own username (to be chosen by the organizer)
  - Enter your own e-mail
  - Choose your own password and “Submit”
- If the organizer already has an account, they can login directly using the username and password chosen when they registered

Login

Register

MINES ParisTech | PSL

Freight transportation game

Please enter the information below to register

Type your company or university...

PLAYER  
GAME ADMINISTRATOR

Username

Email

Password

Confirm password

Submit

Back to login

## Accessing the game

Enter university/ company password

Name

Authenticate

Once all the information has been submitted, the organizer must enter the “Access Password” received from MINES ParisTech by e-mail to access the game

## Creating a game session

- To create a new game session, the organizer must
  - Create the session name
  - Choose the scenario, either current market scenario (by default) or the Physical Internet scenario (check the box)
- The organizer can also continue an existing session

Enter a room name

Name

Physical Internet Scenario

New game

Or

Select an existing room

## Inviting players to join a session

Invite new players

Email

Send invitation

The organizer can invite players to join a session created by entering their e-mails here

# Inviting players to join a session

Invite new players

Email

Send invitation

The organizer can invite players to join a session created by entering their e-mails here

# Tasks of the organizer

## ○ Coordination of the game

The organizer has a global vision of all the players

The screenshot displays the game interface for an organizer. On the left, three user profiles are shown:

- User1:** CARRIER 1, POSITION 9, CUMUL GAIN 1.24, CUMUL DELAY 0. Gameset: Roads 9-2-1-4-7-8, Road costs 15 \$, Request Bundles 3, Request Bundles Price 18.45 \$.
- User2:** CARRIER 2, POSITION 9, CUMUL GAIN 0.00, CUMUL DELAY 0. Gameset: Roads 6-2-9-9, Road costs 6 \$, Request Bundles 1-2, Request Bundles Price 7.24 \$.
- User3:** CARRIER 3, POSITION 9, CUMUL GAIN 0.99, CUMUL DELAY 0. Gameset: Roads 9-4-9-8, Road costs 6 \$, Request Bundles 3, Request Bundles Price 6.99 \$.

On the right, a 3x3 grid of cities is shown:

- 1 London, 2 Rotterdam, 3 Hamburg
- 4 Paris, 9 Brussels (circled in blue), 5 Vienna
- 6 Madrid, 7 Marseille, 8 Bologna

Below the grid are buttons for "Allocation" and "Download .m file".

# Tasks of the organizer

## ○ Coordination of the game

The organizer can see the dashboard of all the players with all their information

The dashboard displays information for three users (User1, User2, User3) and a grid of cities. Each user's information includes their carrier, position, cumulative gain, and cumulative delay. The 'Gameset' section shows road costs, request bundles, and request bundles prices. The city grid includes London, Rotterdam, Hamburg, Paris, Brussels, Vienna, Madrid, Marseille, and Bologna. A 'Download .m file' button is visible at the bottom.

User	Carrier	Position	Cumul. Gain	Cumul. Delay
User1	1	9	1.24	0
User2	2	9	0.00	0
User3	3	9	0.99	0

Roads	Road costs	Request Bundles	Request Bundles Price
9-2-1-4-7-8	15 \$	3	18.45 \$
9-2-9-9	6 \$	1-2	7.24 \$
9-4-9-8	6 \$	3	6.99 \$

# Tasks of the organizer

## ○ Coordination of the game

The organizer can see all the propositions of the players

The dashboard is identical to the previous slide, but a blue circle highlights the 'Roads' section of the 'Gameset' for User1, which contains the proposition '9-2-1-4-7-8'. This indicates that the organizer can view all player propositions.

# Tasks of the organizer

## ○ Coordination of the game

When a player clicks on “Finish round”, the organizer will see them in green

The screenshot displays the game interface for three users (User1, User2, User3) and a grid of cities. User1's statistics are: CARRIER 1, POSITION 9, CUMUL GAIN 1.24, CUMUL DELAY 0. User2's statistics are: CARRIER 2, POSITION 9, CUMUL GAIN 0.00, CUMUL DELAY 0. User3's statistics are: CARRIER 3, POSITION 9, CUMUL GAIN 0.99, CUMUL DELAY 0. The city grid includes London, Rotterdam, Hamburg, Paris, Brussels, Vienna, Madrid, Marseille, and Bologna. The 'Brussels' cell is highlighted with a red circle and contains icons for User1, User2, User3, and User4. Below the grid are buttons for 'Allocation' and 'Download .m file'.

# Tasks of the organizer

## ○ Coordination of the game

When all the players have finished their propositions in a round (all are in green), the organizer can launch the "Allocation".

One round takes 5 minutes on average; if a player cannot finish his propositions, the organizer can decide to launch the allocation or wait

The screenshot displays the game interface for three users (User1, User2, User3) and a grid of cities. User1's statistics are: CARRIER 1, POSITION 9, CUMUL GAIN 1.24, CUMUL DELAY 0. User2's statistics are: CARRIER 2, POSITION 9, CUMUL GAIN 0.00, CUMUL DELAY 0. User3's statistics are: CARRIER 3, POSITION 9, CUMUL GAIN 0.99, CUMUL DELAY 0. The city grid includes London, Rotterdam, Hamburg, Paris, Brussels, Vienna, Madrid, Marseille, and Bologna. The 'Brussels' cell is highlighted with a red circle and contains icons for User1, User2, User3, and User4. Below the grid are buttons for 'Allocation' and 'Download .m file'.

# Tasks of the organizer

## ○ Coordination of the game

When the allocation is completed, the results (the winners and prices) are displayed on the dashboard

The dashboard displays three user profiles (User1, User2, User3) with their carrier numbers, positions, cumulative gains, and delays. A map shows 9 cities: London, Rotterdam, Hamburg, Paris, Brussels, Vienna, Madrid, Marseille, and Bologna. Brussels is highlighted with user icons. Below the map are 'Allocation' and 'Download .m file' buttons. A 'Gameset' table is also visible.

Carrier	Position	Cumul Gain	Cumul Delay
User1: 1	9	1.24	0
User2: 2	9	0.00	0
User3: 3	9	0.99	0

Roads	Road costs	Request Bundles	Request Bundles Price
9-2-1-4-7-8	15 \$	3	18.45 \$
9-2-9-9	6 \$	1-2	7.24 \$

# Tasks of the organizer

## ○ Coordination of the game

The organizer can see the overall ranking of the players after each round

The podium shows the overall ranking of four users: User3 (2nd), User1 (1st), User2 (3rd), and User4 (4th). Below it, the 'Game Results' for User1 are shown, including carrier, position, cumulative gain, delay, loads, roads, road costs, request bundles, and request bundles price.

**Podium**

User1 (1st), User3 (2nd), User2 (3rd), User4 (4th)

**Game Results**

Carrier	Position	Cumul Gain	Cumul Delay
User1: 1	9	1.24	0

Roads	Road costs	Request Bundles	Request Bundles Price
9-2-9-9	6 \$	1-2	7.24 \$

# Tasks of the organizer

## ○ Coordination of the game



### Game Results

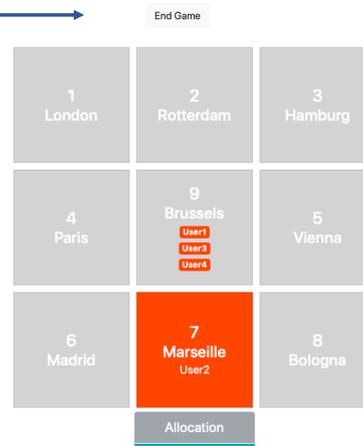
**User1**

- CARRIER: 1
- POSITION: 9
- CUMUL GAIN: + \$ 1.24
- CUMUL DELAY: 0
- Roads: 9-2-9-8
- Road costs: 6 \$
- Request Bundles: 1-2
- Request Bundles Price: 7.24 \$

The organizer can see all the information about the winner on the dashboard

# Ending the game

When the time is up, the organizer can decide to stop the game by clicking on "End game" and obtain the final results.



## Ending the game

A message will be displayed asking the organizer if they are sure they want to finish the game and show the results

Are you sure you want to finish ?

Yes No

1 London	2 Rotterdam	3 Hamburg
4 Paris	9 Brussels User1 User2 User3	5 Vienna
6 Madrid	7 Marseille User 2	8 Bologna
Allocation		

After selecting "Yes", the players will be able to see the final results.

## Debriefing

### ○ Suggestions for coordinating the debriefing with the players at the end of the game

- Ask the players how they felt about the game
  - Did they have a strategy or did they propose prices randomly?
  - Why do they think they had the right or wrong strategy? What was it based on?
  - Did they play seriously?
- Compare their results with those of the optimal solution (these results are in the player's guide)
  - Why was the optimal solution not attained?
  - What was missing to reach it?

## RÉSUMÉ

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La logistique est une dimension croissante et déterminante du management et de la compétitivité des entreprises qui entraîne avec elle une part importante de la performance de l'économie et de l'emploi en Europe. Sans le développement de la logistique, toutes les innovations des deux derniers siècles n'auraient pas été possibles. Nous sommes certes arrivés à un niveau de performance extrême, avec notamment des livraisons en moins de 2 heures, mais cela a un coût : 25 % des trajets des transporteurs se font à vide et le taux moyen de remplissage des poids lourds ne dépasse pas les 65% dans les pays développés. Le transport de marchandises est actuellement piégé par un système peu utilisé et peu respectueux de l'environnement. Ce dilemme peut être résumé par : comment continuer à satisfaire les exigences toujours plus pointues tout en maîtrisant les coûts et en respectant des normes environnementales et sociales plus exigeantes ? Au-delà d'une transition énergétique nécessaire mais insuffisante, des solutions émergent, notamment la mutualisation et l'interconnexion des transports de marchandises à grande échelle.

La mutualisation en transport et logistique est un accord de partenariat qui consiste à la mise en commun volontariste de moyens physiques, d'informations et de compétences dans le but d'obtenir à long terme des gains économiques, écologiques et financiers. Le cadre de cette coopération peut revêtir des formes juridiques et organisationnelles variables en fonction de la nature des parties, des moyens et des produits ou services (Chai et al., 2013).

Depuis quelques années, les grands distributeurs ont compris rapidement l'intérêt de partager des capacités de transport ou de stockage en recourant notamment à des prestataires de services logistiques communs. Ce partage est une source d'avantage concurrentiel dans la mesure où il permet à la grande distribution, alimentaire ou spécialisée, de bénéficier d'économies d'échelle, et d'optimiser l'usage de ressources logistiques rares.

Les démarches de mutualisation connaissent toutefois aujourd'hui une réelle accélération. Des solutions de mutualisation logistique et de transport multimodal voient le jour dans plusieurs régions où les industriels travaillent ensemble en collaboration avec les clients et les transporteurs. Sur cette base, l'objectif de cette thèse est de proposer des mécanismes de collaboration, sur la base de la théorie des « Mechanism Design », permettant la gestion des relations entre les différents acteurs d'un réseau de transport collaboratif, d'évaluer leur potentiel économique et écologique et d'étudier leur applicabilité dans un réseau de transport collaboratif.

## MOTS CLÉS

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Mécanismes de collaboration; Mechanism Design; Simulation multi-agent; Gamification; Réseau de transport collaboratif

## ABSTRACT

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The importance of freight transport is amplified today by the rapid boom in E-commerce, and in particular new online-to-offline business strategies. To boost competitiveness, e-tailers and logistics service providers have devoted adequate efforts to managing express fulfillment services, e.g., same-day delivery (one or two-hour delivery), and various distribution and delivery channels. This has resulted in massive, high-frequency shipments with short lead times and fluctuating volumes. Moreover, freight transport organizations have undergone rapid changes. New markets and new technologies have emerged that will probably require innovative solutions as efficiency is still low. There is thus a strong motivation, involving economic, social, and environmental objectives, to develop more sustainable and efficient freight transport systems.

In this vein, horizontal collaboration has been largely studied, and its effectiveness and efficiency in freight transport have been proven in the recent literature (Pan et al., 2019). In particular, Collaborative Transport Networks are a horizontal collaboration solution attracting increasing attention. Given the important role of freight transport in logistics and the multiple, compounding challenges faced by actors, an innovative, effective, and sustainable management of transport services procurement is needful for the emerging new collaborative transport networks. Moreover, new collaborative incentive mechanisms and rules are required to manage interactions between all the independent stakeholders in such networks.

This dissertation intends to explore collaborative mechanisms that manage the interactions between actors and guide the self-interested decisions of individuals toward an optimal global solution in such a way that these individuals are motivated to choose the optimal and rational solutions. This dissertation provides a picture of existing mechanisms for freight transport service procurement, challenges components of existing research, and provides ground for further research.

## KEYWORDS

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Collaborative mechanisms; collaborative transport network; Mechanism Design; multi-agent simulation; Gamification