Collaboration Mechanism in the Horizontal Logistics Collaboration

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COLLABORATION MECHANISM IN HORIZONTAL LOGISTICS COLLABORATION

(MECANISME DE COLLABORATION DANS LA COLLABORATION LOGISTIQUE HORIZONTALE)

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ABSTRACT

As the result of more and more ambitious production and marketing strategies, such as Just-In-Time and increasing product customization, current vertical logistics collaboration approaches based on a single supply chain seem insufficient to achieve further transportation efficiency improvements. Horizontal logistics collaboration (HLC), which has been proven an effective approach to efficiency improvement, has attracted both academics and practitioners. One of the main barriers to HLC implementation is the lack of feasible collaboration mechanism, in particular a gain-sharing mechanism. We identify two organizational forms of HLC: centralized and decentralized. For centralized HLC, we propose a collaboration model that is a collaboration-conducting process integrating decision-aiding tools to guide implementation of the collaboration. We also develop a generally applicable game-theoretic sharing mechanism for different categories of centralized HLCs modeled as super-additive and non-super-additive cooperative games. This sharing mechanism takes into account collaborator contribution, coalition stability and bargaining power to propose a credible sharing scheme for collaborators. The approach is illustrated by numerical examples taken from logistics cases. For implementation of decentralized HLCs, we propose an open collaborative logistics framework, and design the system protocols as the collaboration mechanism that specifies the combinatorial-auction-based request allocation and payment determination to foster the collaborations.

Keywords: Horizontal logistics collaboration, Collaboration mechanism, Centralized and decentralized collaboration, Supply network pooling, Cooperative game theory, Combinatorial auction

RÉSUMÉ

En raison des stratégies de production et de marketing de plus en plus ambitieuses telles que le Juste-à-Temps et la personnalisation au client, les approches de collaboration logistique verticale qui sont courantes atteignent une limite d'efficacité notamment en transport. La collaboration logistique horizontale (CLH) et plus particulièrement la mutualisation, dont l'efficacité a été prouvée dans la littérature et dans les cas réels, a attiré l'attention des chercheurs ainsi que des praticiens. Cependant, un des obstacles principaux à la mise en œuvre des CLHs est l'absence d'un mécanisme de collaboration raisonné, en particulier un mécanisme de partage des gains. Nous identifions deux formes d'organisation centralisée et décentralisée. La forme centralisée est limitée à de petites coalitions, celle décentralisée pouvant comprendre de nombreux participants. Pour des CLHs centralisées, nous proposons un modèle de collaboration qui est un processus de conduite qui intègre les outils d'aide à la décision. Nous développons également un mécanisme de partage par la théorie des jeux. Ce mécanisme est applicable aux différentes catégories des CLHs centralisées, qui peuvent être modélisées par des jeux coopératifs super-additif ou non. Afin de proposer un plan de partage crédible aux collaborateurs, ce mécanisme de partage prend en compte la contribution de chacun des collaborateurs, la stabilité de la coalition et leur pouvoir de négociation. Ce cadre est illustré par des exemples numériques issus de cas logistiques. Pour la mise en œuvre des CLHs décentralisées, nous proposons un cadre de travail de logistique collaborative qui est ouvert aux participants potentiels, et avons conçu des protocoles fondés sur le mécanisme d'enchère combinatoire, qui spécifient l'allocation de demande de livraison et la détermination de paiement pour faciliter les collaborations. Cette dernière partie s'appuie sur la théorie dite de Mechanism Design.

Mots clés: Collaboration Logistique horizontale, Mécanisme de collaboration, Collaborations centralisée et décentralisée, Mutualisation des réseaux d'approvisionnement, Théorie des jeux coopératifs, Enchère combinatoire

Description:

Le thème de recherche de cette thèse est "*mécanisme de collaboration dans la collaboration logistique horizontale*" (CLH), qui comprend l'organisation de collaboration et le partage des gains. Son application la plus courante est celle de la mutualisation des opérations de logistiques et en particulier de transport. L'objectif général des travaux présentés dans cette thèse est de proposer les mécanismes de collaboration pour les CLHs centralisées, correspondant à un faible nombre d'acteurs, ainsi que décentralisées pour le cas plus général. A cette fin, la théorie des jeux coopératifs et la théorie de la conception des mécanismes d'incitation (appelé aussi la théorie de la conception des mécanismes de marché) sont appliquées.

Dans le chapitre II, une introduction détaillée à la CLH est présentée. Nous identifions les avantages de la CLH (e.g. la réduction des coûts logistiques, l'amélioration du service client), les obstacles à la mis en œuvre (e.g. la difficulté à trouver des collaborateurs, l'absence du mécanisme de partage des gains), et les canevas présentés dans la littérature qui facilitent l'implémentation de cette approche. Deux types de forme organisationnelle de la CLH sont identifiés : les CLHs centralisées et celles décentralisées. La théorie des jeux coopératifs et la théorie de la conception de mécanisme d'incitation sont identifiées comme des outils théoriques pour construire les mécanismes de collaboration dans les deux types de CLH respectivement.

Dans le chapitre III, afin de mettre en œuvre la CLH, nous proposons un modèle de collaboration général qui est un processus de conduite qui intègre des outils d'aide à la décision comme des modèles de planification et des mécanismes de collaboration qui sont variés selon des modalités de collaboration adoptées. En particulier, nous adoptons la mutualisation des réseaux d'approvisionnement (Pan et al., 2012), comme modalité spécifique de la CLH, et comme le contexte des travaux des chapitres 3 à 5 de cette thèse, qui est sur le mécanisme de collaboration dans les CLHs centralisées. Nous y proposons le cadre d'un modèle de collaboration pour la mutualisation des réseaux d'approvisionnement, qui intègre le modèle d'optimisation développé par Pan (2010) et le mécanisme de collaboration fondé sur la théorie des jeux coopératifs.

Afin de construire le mécanisme de collaboration pour des CLHs centralisées, nous examinons la théorie des jeux coopératifs et en présentons l'état de l'art dans le chapitre IV. Deux aspects du mécanisme de collaboration dans les CLHs centralisées, la stabilité de coalition et le partage des gains, sont identifiés. Nous nous concentrons sur les concepts importants dans la théorie qui peuvent être appliqués dans la conception de mécanisme de collaboration. Ayant examiné la littérature de la théorie des jeux coopératifs et de ses applications, nous nous rendons du compte que les concepts théoriques et les solutions présentes ne sont pas totalement appropriés à appliquer dans les cas logistiques réels où les coûts de coordination ne sont pas négligeables et où les intérêts individuels prennent le pas sur l'intérêt global.

Dans le chapitre V, tout d'abord, nous examinons la stabilité de coalition d'un cas pratique où des gains étant issus des synergies de la collaboration sont partagés proportionnellement, pour montrer l'infaisabilité du partage proportionnelle pourtant le plus répandu en pratique. Puis, nous distinguons quatre catégories de mutualisation des réseaux d'approvisionnement, à partir de la théorie des jeux. On montre en particulier qu'un seul de ces cas est traité dans la littérature, celui des jeux avec coût de coordination négligeable où l'on recherche l'intérêt global. Or les autres cas existent aussi. Dans ce cadre des 4 catégories et pour chacune d'elle, nous examinons la stabilité des coalitions et la partage des gains suivant la nature des jeux en cause et développons des mécanismes de partage des gains. Nous proposons un modèle de partage des gains qui est généralement applicable pour tous les CLHs faisables et démontrons ces propriétés. Ce modèle de partage des gains prenant en compte la contribution de chacun des collaborateurs, recherchant la stabilité de coalition, et prenant en compte le pouvoir de négociation des partenaires peut générer un plan de partage des gains équitable. Nous présentons en suite un cas de la mutualisation dans une chaîne de distribution française où quatre fournisseurs mutualisent leurs réseaux d'approvisionnement. Nous adoptons le modèle général de partage des gains comme le mécanisme de partage pour distribuer les gains acquis dans la collaboration (la réduction de coût de transport). Ce cas est modélisé par un jeu coopératif, et traité sous des hypothèses différentes de coût de coordination qui conduisent à des jeux aux propriétés différentes. En comparant le plan de partage généré par notre modèle général et celui obtenu par l'application de la valeur de Shapley, nous montrons l'adaptation de notre modèle général quand appliqué dans la CLH.

Dans les chapitres III-V, nous avons proposé un mécanisme de collaboration pour la mis en œuvre des CLHs centralisées. Dans le chapitre VI, nous proposons un mécanisme de collaboration fondé sur l'enchère combinatoire pour un cas spécifique : un système logistique collaboratif qui est ouvert et décentralisé. Nous présentons d'abord une vue d'ensemble de la théorie de la conception de mécanisme d'incitation. Particulièrement, nous nous concentrons sur la théorie des enchères combinatoires et son application dans les CLHs décentralisées. En suite, nous présentons la conception du mécanisme de collaboration d'un système de la CLH décentralisé, qui est fondé sur l'interconnexion des réseaux logistiques présentée par Sarraj et al. (2012). Les protocoles généraux, la stratégie d'évaluation des commandes, la génération des offres, et la formulation du processus décisionnel sont précisés en détail. Nous proposons les algorithmes et les formulations afin de construire un mécanisme de collaboration qui facilite l'implémentation du système de la CLH décentralisée et peut garantir le bon fonctionnement du système.

Dans chapitre VII, nous concluons cette thèse et présentons les perspectives de recherche à venir.

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List of Abbreviations

AHP: Analytic Hierarchy Process

BMC: Business Model Canvas

CA: Combinatorial Auction

CC: Coordination Cost

CPWV: Contribution-and-Power-Weighted Value

CS: Coalition Structure

CS Core: Coalition-Structure Core

CS CPWV: Coalition-Structure Contribution-and-Power-Weighted Value

CS SV: Coalition Structure Shapley Value

DC: Distribution center

EDI: Electronic Data Interchange

ELM: Electronic Logistics Marketplaces

EPCF: Equilibrium Process of Coalition Formation

EPM: Equal Profit Method

FMCG: Fast Moving Consumer Goods

G-Core: General Core

HLC: Horizontal Logistics Collaboration

ILN: Interconnected Logistics Network

IOS: Inter-Organizational System

LCS: Largest Consistent Set

LP: Linear Programming

LSP: Logistics Service Provider

LTL: Less than Truck Load

MD: Mechanism Design

MILP: Mixed Integer Linear Programming

MWSV: Modified Weighted Shapley Value

PCF: Process of Coalition Formation

PDM: Physical Distribution Management

PI: Physical Internet

RCMP: Rational Shapley Monotonic Path

SME: Small and Medium Enterprises

SNP: Supply Network Pooling

SV: Shapley Value

TU game: Transferable-Utility game

VCG mechanism: Vickrey-Clarke-Groves mechanism

WDP: Winner Determination Problem

WH: Warehouse

WLC: Weak Least Core

WLCSC: Weak Least Coalition Structure Core

WSV: Weighted Shapley Value

3PL: 3rd Party Logistics

4PL: 4th Party Logistics

CHAPTER 1

Introduction

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1.1 Research Context

As an important link in the national economy, logistics is intimately tied to economic development. Logistics system efficiency is vital for stable economic growth, and has thus drawn the interest of both academics and practitioners. Over the last decades, great emphasis has been placed on logistics collaboration. It has been widely addressed and proven to be an effective approach for businesses to obtain a competitive edge. In logistics collaboration, partners collaborate to share information, logistics facilities, and resources to improve cost efficiency without compromising service level. Logistics collaborations are categorized as vertical, horizontal, or lateral, according to the collaboration scope (Simatupang and Sridharan, 2002). Vertical collaboration aims to integrate one supply chain consisting of suppliers, retailers and customers. Horizontal collaboration occurs among logistics actors in the same level of the supply chain, for example, collaboration among suppliers. Lateral collaboration is a combination of the two latter approaches.

The term *supply chain management* refers to vertical collaboration and integration among parties in deferent levels of the supply chain. It aims to establish collaborative relations and seamless integration throughout the supply chain to improve logistics efficiency. The key drivers of such costs savings are inventory and transport reductions, logistics facilities or equipment rationalization, and better information usage (Cruijssen, 2006). Representative vertical collaborations include collaborative planning, forecasting and replenishment (CPFR), vendor-managed inventory (VMI) and efficient consumer response (ECR).

In the past few years, the *horizontal logistics collaboration* (HLC) has been studied and experimented with in supply chains (Cruijssen et al., 2007a,b). This form of collaboration takes place between companies operating at the same level of the supply chain. Some examples are manufacturer consolidation centers (MCCs) pooling, joint route planning, and purchasing groups. As a complement to traditional vertical collaboration, HLC has proven effective at reducing overall costs and improving logistics service quality, but actual applications are still rare. The gap between the logistics-horizontal-collaboration initiative and its implementation is due to the lack of an appropriate collaboration model, in particular a sharing mechanism for different collaboration cases (Cruijssen et al., 2007a).

There are two approaches to HLCs: the centralized collaboration group, and the decentralized collaboration system. The centralized collaboration group, where a centralized collaboration organizer coordinates and schedules logistics activities for all collaborators, is suitable only for collaborations with a limited number of participants. On the other hand, the decentralized approach allows a large number of agents to take part in the system, and an open collaborative system can even be even established. Since collaboration issues in centralized collaboration groups (eg gain-sharing mechanism and coalition formation) are widely addressed in cooperative game theory, we choose game-theoretic approaches to construct suitable collaboration mechanisms for centralized HLCs. In order to implement the decentralized collaboration system, mechanism design theory, especially combinatorial auction theory, can serve as the collaboration mechanism.

We focus on generally applicable collaboration mechanisms for all kinds of centralized HLCs. However, to develop such collaboration mechanisms, a concrete collaboration modality is needed to conduct a computational case study and thereby verify our mechanisms. In the overall logistics cost, transportation cost remains the top consideration since it accounts for half of the logistics cost, and road freight transport accounts for 73% of all inland freight transport activities in the EU (FTA and PwC, 2012). Thus we choose *supply network pooling*, a specific horizontal collaboration modality applied in road transportation consolidation as the context of our collaboration-mechanism investigations.

For the development of the collaboration mechanism in decentralized HLCs, we use a combinatorial-auction-based approach. We propose an open logistics system consisting of carriers that collaboratively deliver shippers' requests, and specify the protocols in such a decentralized HLC system. These protocols implement the combinatorial-auction-based-request-allocation and gain-sharing mechanisms in the collaboration.

The intermediate results of this dissertation have been published in three conferences(Xu et al., 2012a,b, 2013).

1.2 Research Objectives

The main objectif of this dissertation is to develop collaboration mechanisms aiming to facilitate the implementation of HLCs, no matter in centralized or decentralized way. We expect that the developed mechanisms can give helpful guidance from a theoretical point of view to decision makers (i.e. collaborators, orchestrators or trustees) when implementing collaboration, as well as help them resolve some problems from practical side. To this end, several tasks have been done and the objectives of the tasks are as follows:

- **Develop a feasible collaboration model**: In order to promote the implementability of the centralized HLC, a collaboration model is needed. It is a collaboration process integrating different decision-aiding tools to support the conducting of centralized collaborations and provide valid propositions for further bargaining among partners.

- **Develop feasible collaboration mechanisms for centralized HLCs**: The collaboration mechanism is indispensable in the collaboration model, which provides a solid basis for establishing the collaborative relationship. We adopt optimization model developed in the literature as the cost and contribution evaluation tool. Based on the contribution evaluation, we focus on the construction of collaboration mechanism. The collaboration mechanism should specify two important issues: coalition formation and gain allocation. In constructing the collaboration mechanism, we should also take into account some practical considerations for industrial application.

- **Develop feasible collaboration mechanisms for decentralized HLCs**: We define system protocols as the collaboration mechanisms in a decentralized HLC system. The protocols implement a market mechanism (combinatorial-auction-based transportation request market) to carry out request allocation and gain-sharing in the decentralized HLC system.

1.3 Research Methodology

In order to develop collaboration mechanisms to HLCs, we have adopted a theoretical approach rather than a practical approach. We try to extract the most essential factors from different collaboration modalities, and propose robust and incentive-compatible solutions as these factors fluctuate. Thus the theoretical study on collaboration mechanism provides tools that can be used to evaluate the performance of practical collaboration mechanisms from a strategic point of view.

In the first place, we have carried through an in-depth literature review of HLCs of both research papers and practical cases, in order to understand the drivers and barriers to HLC. The outcome points out the important factors that should be considered in the mechanism to be developed. From the literature we further recognized that two types of organization of HLC are possible: centralization type for small-scale collaboration, and decentralization type for medium and large scale. Accordingly we should study the problem in two directions that are somewhat separate.

We then adopt game theoretic approach to construct collaboration mechanisms, since it investigates the strategic decision making among intelligent agents, which is the main research question of this dissertation. Game theory is well recognized as an appropriate tool to address this question from a theoretical point of view. Different from the simulation approach that construct case-specific collaboration mechanisms (Albino et al., 2007; Fischer et al., 1999; Prakash and Deshmukh, 2010), game-theoretic approach is able to propose general collaboration mechanisms for different collaboration modalities, since the modality-related operational details (optimization of network, modality of co-delivery, action-related transaction) are hidden into the contribution evaluation result.

For decentralized HLC, we adopt cooperative game theoretic approach to develop a new gain sharing model that is a very important tool in the collaboration mechanism. Since it investigates the coalition formation and gain sharing issues with a strategic perspective. In order to construct the collaboration mechanism for decentralized HLCs, we investigate a branch of game theory: Mechanism Design (MD). After comparing different MD approaches, we choose logistics combinatorial auction as the basis of the collaboration mechanism framework, due to its ability to achieve high efficiency. Then we develop the technical details and system protocols based on the framework.

To validate the developed collaboration mechanisms, we have conducted two experimental cases and the scope of both is limited to transport. The first case, which is the centralized one, was based on real-world data from a case of pooling. We used the developed gain sharing model to divide the common gain. The results show that, differing from the existent models, our model is generally applicable to different pooling categories under variation of collaboration environment. The second case, which is the decentralized one, was based on an illustrative case of auction. We illustrated how the developed auction process works in an open logistics platform. However, it is difficult to validate the obtained result since no comparable reference is available. A simulation work is therefore needed in the next step.

1.4 Summary of Contribution

The contribution of this dissertation is as follows:

- First, we identify two organizational forms of HLCs: centralized and decentralized. For each of the organizational forms, we identify cooperative game theory and mechanism design theory respectively as feasible tools to construct the collaboration mechanisms.
- Secondly, we identify different categories of centralized HLCs from the cooperative-game-theoretic perspective. Rising coordination costs in collaborations and different collaboration preferences are considered, providing a valid basis for game-theoretic investigations in all cases.
- Thirdly, we model HLCs as cooperative games, investigate coalition formation and gain-sharing issues in different categories of HLC games, and then propose a set of generally applicable gain-sharing mechanisms that consider players' contribution and bargaining power, as well as coalition stability (a major requirement in pooling). In light of the rarity

of non-super-additive game investigation in current logistics collaboration literature, our collaboration mechanism is generalized to non-super-additive HLC games to improve its general applicability in different logistics situations.

- Fourthly, after proving a set of theorems, we propose a general collaboration mechanism that is valid for all feasible HLCs by integrating the super-additive cover in the theoretic framework that we have established.

- Last of all, we develop protocol frameworks for a decentralized HLC system. A combinatorial auction mechanism is integrated in this collaboration system by these protocols to achieve the incentive compatibility goal, and thus the systematical logistics efficiency improvement.

1.5 Outline of the Dissertation

This dissertation is organized as follows:

Chapter 2 is dedicated to an explicit review of HLC literature. HLC drivers and barriers are identified, and we propose directive frameworks for HLC implementation. Two organizational forms of HLCs are identified. Cooperative game theory and mechanism design theory are identified as feasible theoretic tools to construct the collaboration mechanisms for each respective case.

In Chapter 3, we propose a general collaboration model for centralized HLCs, which can be adopted by the organizers of centralized HLCs as collaboration-conducting guidelines. We introduce supply network pooling, and specify the details in the general model to propose a collaboration model for this HLC modality. We identify important factors that should be considered in constructing the collaboration mechanisms in this model, and justify the importance of our work.

Chapter 4 is an exploration of cooperative-game-theory literature. We identify useful solutions in constructing the HLC collaboration mechanism, and indicate the ineffectiveness of current solutions for the HLC implementation.

In Chapter 5, we conduct game-theoretic investigations in the context of supply-network-pooling collaboration. Four categories of pooling games are identified, and feasible collaboration mechanisms are proposed for pooling games in each category, considering player contribution, bargaining power, and coalition stability. By integrating the super-additive cover concept, we propose a general collaboration mechanism that is valid for all feasible collaborations. The performance of the general collaboration mechanism and that of SV are compared using a French-retail-chain case study and a simple computational example.

Chapter 6 proposes a framework for the mechanism design approach to decentralized HLC. We generally introduce the mechanism design theory, identify two mechanism design approaches to HLC, and then focus on the application of combinatorial auction theory in decentralized HLC cases. We propose a decentralized HLC organization of the interconnected logistics network. Protocols and mathematical models are developed, and we give a simple illustration of the auction process to show how this system works.

Chapter 7 concludes this dissertation, indicating the limits of the works presented, and proposing perspectives for further research.

CHAPTER 2

Horizontal Collaboration in Logistics

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2.1 Introduction

The most dominant definition of logistics is given by Council of Logistics Management (2004): "Logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements". According to the definition, logistics services play the roles of vital links among raw material suppliers, manufactures, and consumers. Among logistics services, freight transportation represents 29.4% of the total logistics costs (Chang, 1998), thus improving transportation efficiency becomes one of the major objectives for enterprises to keep competitive in global market.

Traditional researches to this end are based on single supply chain or single network, such as the logistics network design, transportation planning, fleet management, etc. The existent solutions have brought about good improvements in transportation efficiency. However, with using the traditional solutions, further improvement seems to be difficult to achieve because of those more and more ambitious marketing and production strategies, for example the increasing customization of products and just-in-time. These strategies induce the fragmentation of deliveries and the rise of delivery frequency, which result in less opportunity for effective consolidation.

New researches show interest in open logistics, which attempts to interconnect those independent chains or networks in order to globally optimize the logistics activities. Concretely, the open logistics could be carried out by horizontal cooperation between different networks (Cruijssen et al., 2010, 2007a), supply network pooling (Pan et al., 2013, 2012), or more ambitiously a universal open and interconnected transportation network namely the Physical Internet (PI)(Montreuil, 2011; Sarraj et al., 2012). The advantages could appear in reducing inventory, increasing delivery frequency, improving the transportation efficiency, and thus reducing the cost and environment footprint.

However, the implementations of *horizontal logistics collaboration* (HLC) are still rare. One of the impediments is the lack of suitable sharing mechanisms. Thus in order to improve the logistics efficiency within the delivery frequency constraints, this dissertation investigates the collaboration mechanisms for the HLC, an effective approach towards both cost efficiency and customer service improvement.

This chapter is devoted to a comprehensive introduction to HLC. The chapter is structured as follows:

Section 2 introduces why enterprises need to collaborate horizontally in logistics. The economic context and the global trends driving the demand for logistics are introduced.

Section 3 gives the definition of HLC. Horizontal and vertical collaborations are illustrated and we give a descriptive definition of HLC after comparing different definitions of logistics collaborations in the literature.

In the following two sections, we answer two most important questions on HLCs. Section 4 introduces the main drivers of such collaboration identified in the literature, and Section 5 demonstrates the possible barriers that may inhibit the successful implementation of the collaboration scheme.

Section 6 introduces the frameworks for horizontal collaboration implementation in the literature, which can serve as guiding tools. These frameworks should be referred to at the very beginning of the collaboration project.

Section 7 introduces two organizational forms of HLCs, the centralized and decentralized collaboration systems, and the corresponding theoretic tools used to construct the collaboration mechanisms.

Section 8 points out the research objectives of this dissertation, which can be mainly divided into two parts: the collaboration mechanism for centralized collaborations and that for decentralized collaboration systems.

Section 9 concludes this chapter.

2.2 Why We Need Horizontal Collaboration?

The European logistics market size (27 EU countries plus Norway and Switzerland) accounted in 2007 for about 860 billion EUR (Klaus and Kille, 2007). As the "backbone" of the economy growth, it provides an essential link between production, distribution and consumption. Estimates put the share of the logistics industry in Europe at close to 14% of GDP (Eurostat, 2012).

Table 2.1 lists the employment and value added created by sub sectors of logistics, where road transport contribute 39% of total employment and 32.5% of value added in 27 EU countries.

Table 2.1: Weight of sub sectors of logistics in employment and value added in 2005, EU27 (Meyer-Rühle et al., 2008)

EU27	Persons employed	Value added	Value added per employee
Rail	5.4%	2.6%	19'400
Road	39.0%	32.5%	33'100
Sea	2.0%	7.0%	137'400
IWW	0.5%	0.7%	47'600
Air	0.6%	1.2%	84'800
All Transport	47.5%	44.0%	36'800
Supporting activities	25.6%	34.3%	53'200
Post and courier activities	26.8%	21.7%	32'100
Total logistics sector	100.0%	100.0%	39'700

Source: Eurostat, national statistics and own estimates

Especially in the inland freight transport sector, due to the flexibility and door-to-door delivery ability, the road transport is adopted for 73% merchandise deliveries, as illustrated in Figure 2.1. Thus the road transport is the main application area of the collaboration model developed in this dissertation.

Figure 2.2 shows that in both national and international road transport, a substantial part of transport services are outsourced, which means the transport service orders will be able to be consolidated by third party logistics or shippers on their own. However, the statistics in Table 2.2 presents the inefficiency of the vehicle utilization, which is unsatisfactory for both own account and outsourced fleets.

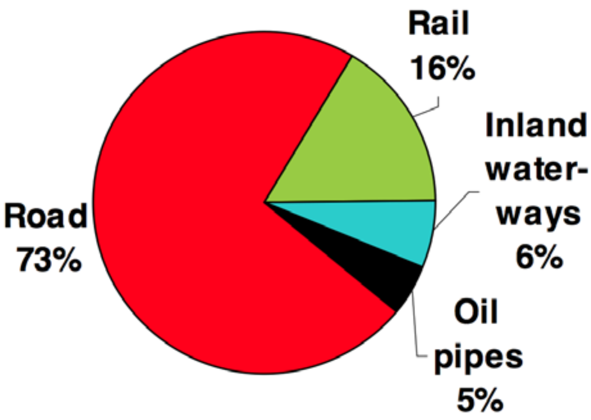

Figure 2.1: Modal split in inland freight transport in the EU in 2010 (based on ton-km) (Directorate-General for Mobility and Transport, 2011)

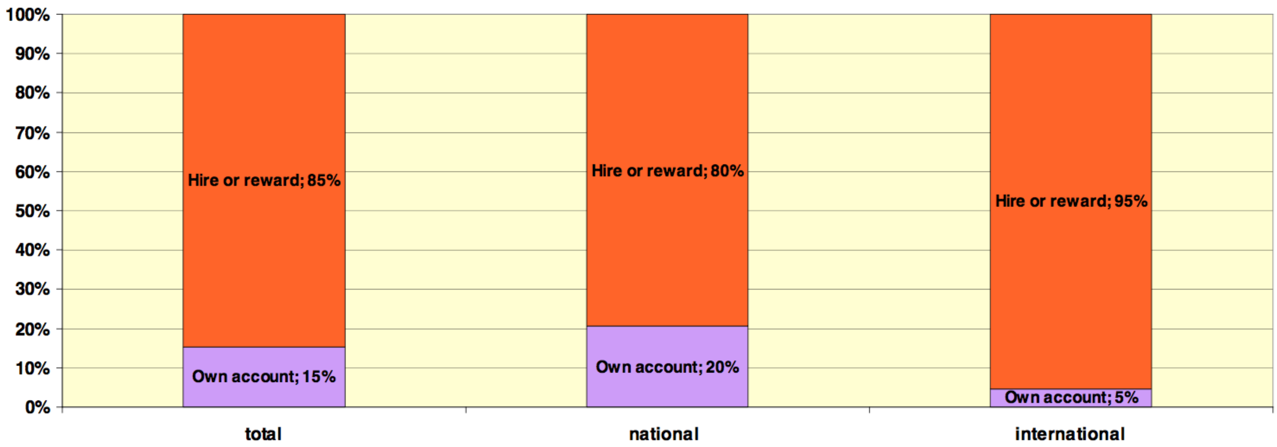

Figure 2.2: Breakdown of road freight transport in the EU by type of transport in 2010 (Directorate-General for Mobility and Transport, 2011)

Table 2.2: Share of empty vehicle-km in the EU in 2010 (Directorate-General for Mobility and Transport, 2011)

	own account	hire or reward	total
national	30.9%	25.5%	27.3%
international	26.8%	12.8%	13.6%
total	30.6%	21.4%	23.9%

Further more, Eurostat (2012) shows that about 24% of all road freight kilometers driven in the European Union (27 countries) are by empty vehicles, and that the average vehicle is loaded to 56% of its capacity in terms of weight (European Environment Agency, 2010). The cost of this inefficiency has been estimated at about €160 billion (Cruijssen, 2012). Why logistics service providers (LSPs) are not able to well consolidate client transport orders? That's is because the production and commerce strategies adopted by manufacturers and retailers in response to the fierce competition and the accelerating business rhythm induce constraints for the further consolidation of freight flows.

Klaus and Kille (2007) summarize four "megatrends" transforming the general "external" conditions for doing business in the global economy. They account for the rapid growth in the demand for professional and modern logistics services and the way they are changing. The evaluating external conditions would further expose the inefficiency of current logistics system.

- **Globalization of production and commerce**
  Increasing transport distances, new communication and integration requirements, growing competitive pressure

- **The transition to a post-industrial society**
  The end of growth in industrial manufacturing in the countries of Western Europe, compensated by an increasing demand for product individualization and more services

- **Acceleration of the clock speeds of economic activity in an "on demand" world**
  Stockpile production is replaced by just-in-time responses to customer demand, the compression of technology and product cycles, time-based competition and the atomization of contract and shipment sizes

- **Growing external risks and environmental awareness**
  Growing threats of the logistics systems by terrorism and political impact, increasing awareness on the consumption of energy and area, respectively the climbing emissions by logistics, resulting in more requirements in security, prevention and sustainability. More recycling, extended logistics chains and more complex logistics chains

As the megatrends suggest, on one hand, the globalization of production and commerce requires more transport services than before in terms of ton-km; while on the other hand, the demand for individualized products and services, along with the accelerating business rhythm and shorter product life cycle, impose higher delivery frequency and more fragmented orders on LSPs, which resulted in limited consolidation possibilities. Dornier (1997) lists four strategies of suppliers and three strategies of retailers in the context of previously mentioned "megatrends", their impacts on the delivery quantity, the total distance, and the frequency are in Table 2.3.

Table 2.3: Supplier and retailer strategies and their impacts on logistics (Dornier, 1997)

Supplier strategies	Volume per delivery	total distance	delivery frequency
Delocalization of production	increase	increase	
Delayed differentiation	decrease		
Just-in-time	decrease		increase
Specialization of production	increase	increase	
Retailer strategies			
Organization according to retail store size	variate	increase	
Assortment management	decrease		increase
Acceleration of stock rotation	decrease		increase

The trend of these adaptive strategies is to atomize the delivery volume and increase delivery frequency in order to cut inventory costs and increase responsiveness to dynamic market environment. All these strategies pose obstacles for further improvement of logistics efficiency at different levels, which cannot be overcome by current logistics system. Therefore, we investigate the HLC, an approach that can improve the logistics efficiency and the delivery frequency at the same time by volume consolidation.

The EU-funded project CO^3 (Collaboration Concepts for Co-modality) aims to develop, professionalize and disseminate information on the business strategy of logistics collaboration in Europe. The goal of the project is to deliver a concrete contribution to increasing vehicle load factors, reducing empty movements and stimulate co-modality, through the implementation of HLCs between industry partners, thereby reducing cost and transport externalities such as congestion and greenhouse gas emissions without compromising the service level (Palmer et al., 2013). In this framework, we focus on the collaboration mechanism design part.

2.3 Definition of Horizontal Logistics Collaboration

2.3.1 Categorization of logistics collaboration

There lies ambiguousness between the following three inter-organizational relationships: co-operation, coordination and collaboration. Sometimes these terms are regarded as interchangeable, since we can see many papers in this field that have not made a distinction between them. Ring and Van de Ven (1992) distinguish cooperation and collaboration as follows: collaboration is a cooperative relationship that is more intensive and has higher level of trust and common goal. Compared with short-term cooperation, collaborations are based on long-term horizon, and often incur organizational restructure. Spekman et al. (1998) summarize the requisite role transition from being an important supplier to becoming a supply chain partner in Figure 2.3.

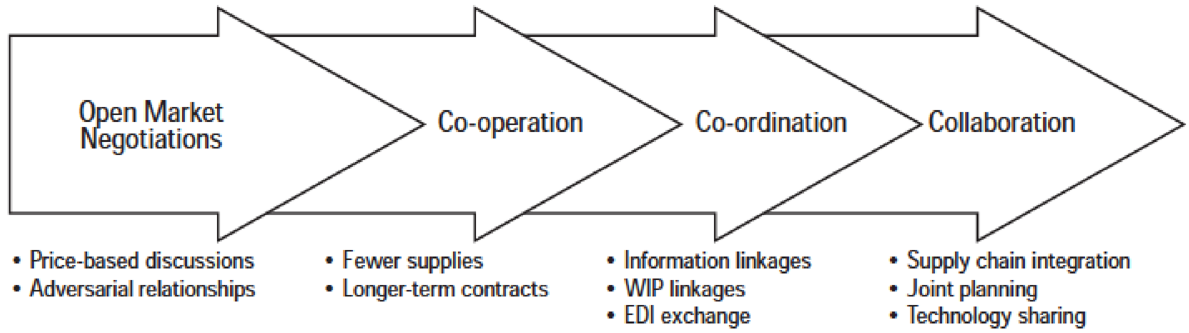

Figure 2.3: The key transition from open-market negotiations to collaboration (Spekman et al., 1998)

In this transition process, collaboration is considered an advanced phase in higher level of supply chain integration than cooperation and coordination. Mejias-Sacaluga and Prado-Prado (2002) also consider that collaboration is of more strategic importance and complexity than cooperation. According to Nof et al. (2006), in logistics cooperation, only information exchange occurs, whilst in collaborative relationship, task sharing, such as joint planning behavior, takes places alongside information exchange. That means parties of a collaborative alliance may have more intensive interaction among them than those who take part in cooperation. All these statements show that the term collaboration is used to describe a long-term inter-organizational relationship requiring higher level of integration and more intensive interaction than cooperation and coordination. It is the logistics collaboration that can generate more synergy profit for all members, at the same time, the requirements for full integration, both strategic and operational coordination between collaborators make it more complicated to conduct.

As for collaborative structures, Simatupang and Sridharan (2002) propose to differentiate logistics collaborations into three categories: vertical, horizontal and lateral. Vertical collaboration occurs when different organizations such as suppliers, manufactures, LSPs, and retailers share their responsibilities, resources, and performance information to better serve relatively similar end customers. For example, Wal-Mart collaborate with his suppliers by sharing up-to-date sales and inventory information, which enable Wal-Mart to reduce order-cycle time, lost sales and stocking cost, and at the same time, suppliers are able to replenish goods according to sales information, hence minimize stock-outs and improve brand loyalty. Horizontal collaboration occurs when unrelated or competing firms share their private information or resources to promote their productivity. For example suppliers' joint replenishment, or retailers' joint distribution. Lateral collaboration aims to gain more flexibility by combining and sharing capabilities in both vertical and horizontal manners. It can be regarded as a combination of vertical and horizontal collaboration. Visser (2007) gives the definitions of vertical and horizontal collaborations as follows: vertical collaboration is defined as collaboration between parties that succeed each other in a particular generation process and therefore have different activities; horizontal collaboration is characterized by collaboration between (potential) competitors: parties at the same level(s) in the market. Examples of vertical and HLCs are illustrated in Figure 2.4.

Simchi-Levi et al. (1999) define supply chain management as "the set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed in the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements." From this definition, we can see that it shares the same objective and approaches as vertical collaboration, to promote logistics efficiency by integrating supply chain members in different levels. Examples of vertical collaboration are vendor managed inventory (VMI), efficient customer response (ECR), collaborative planning, forecasting, and replenishment (CPFR), and collaborative trans-

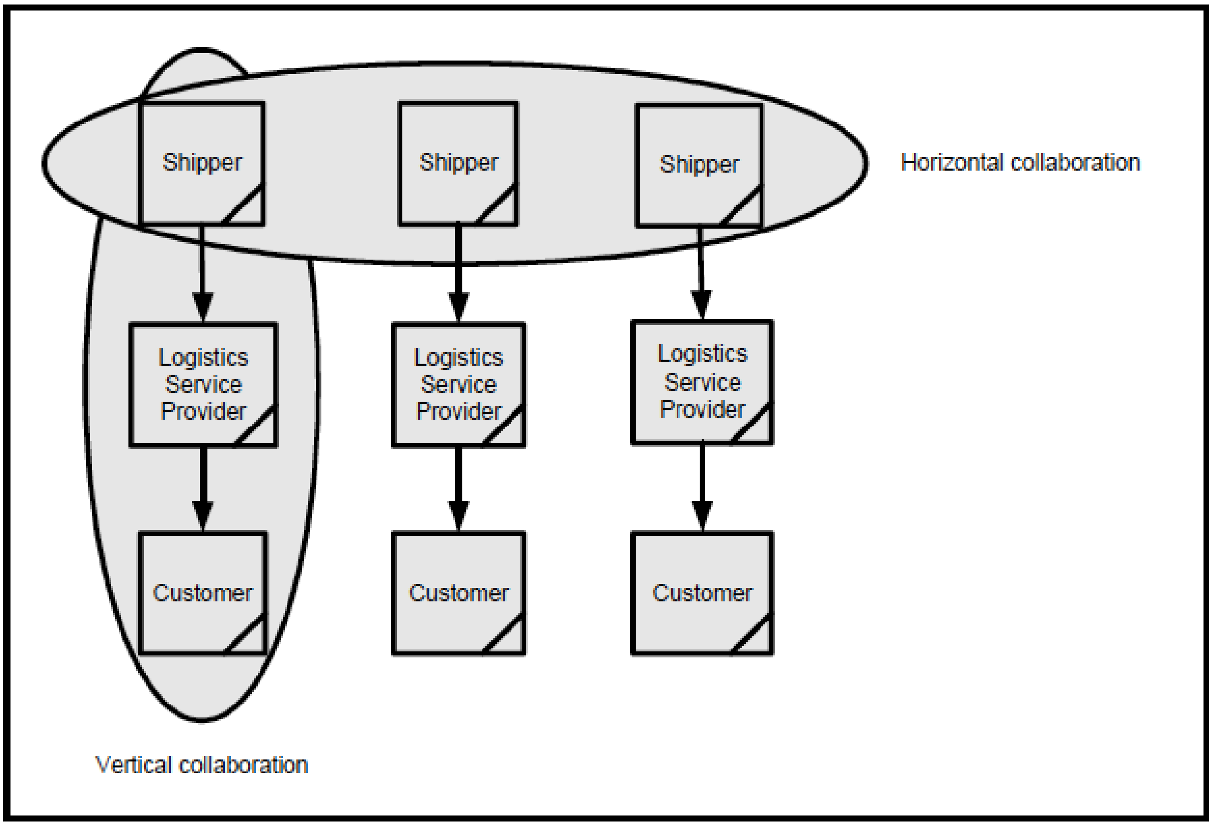

Figure 2.4: Horizontal and Vertical Collaboration Combined (Visser, 2007)

portation management (CTM).

Compared with vertical collaboration, HLC is still in its infancy. Examples of horizontal collaboration are manufacturers consolidation centers (MCCs), joint route planning, and purchasing groups. The successful implementation of horizontal collaboration is scarce since there are many operational obstacles that have not been overcome yet, and sharing sensitive information with competitors also depresses firms' incentive to collaborate horizontally. Related subjects will be investigated in later sections.

Cruijssen et al. (2007b) identify three different playing fields of logistics collaboration: maritime shipping, aviation logistics, and landside transport. Some horizontal collaboration forms such as maritime conferences and aviation alliances are heavily studied. However, according to more prevalent market power consideration, the capital-intensive nature, and longer average haul in maritime and aviation logistics, the conclusion drawn from horizontal collaborations in these two fields cannot be straightforwardly applied to that on landside. Our work focuses on HLC on landside, which is referred to as horizontal collaboration in following sectors. Readers who are interested can refer to Cruijssen et al. (2007b) for list of literatures on horizontal collaboration in maritime and aviation logistics.

2.3.2 Definition of horizontal collaboration

European Commission (2001) defines general horizontal cooperation in different areas (e.g. R&D, production, purchasing or commercialization) as "concerted practices between companies operating at the same level(s) in the market". This definition is suitable for both competitors, for example two LSPs who collaborate to better serve their clients, and unrelated firms, for example two companies active in the same product markets but in different geographical markets without being potential competitors. Cruijssen (2006) defines horizontal collaboration as "active collaboration between two or more firms that operate on the same level of the supply chain and perform a comparable logistics function on the landside". This definition is more or less the same as the previous one, and both of them does not mention the incentive for conducting such collaboration. Bahinipati et al. (2009) give their more explicit definition as "a business agreement between two or more companies at the same level in the supply chain or network in order to allow greater ease of work and cooperation towards achieving a common objective". The means of achieving such objective are presented as "proper manipulation, utilization and sharing of appropriate resources, such as machinery, technology and manpower". All of these definitions reveal more or less some key features of horizontal collaboration, however, possess a static perspective.

Lambert et al. (1999) investigate vertical logistics collaborations, in particular the logistics service outsourcing. They emphasize that the collaboration is rather an evolving process than static one. Their definition of vertical collaboration is "the process of working together among independent firms (two or more companies) along a supply chain in delivering products to end customers for the basic purpose of optimizing long-range profit for all chain members and creating a competitive advantage", which implies that the collaborative relationship progresses and develops. It is in this perspective the horizontal collaboration should be investigated.

There are many scholars who propose systematical framework and dynamic models that propose to examine collaborative relationships in a long-run and systematical perspective (Simatupang and Sridharan, 2008; Verstrepen et al., 2009). That means the collaborative relationship should not be considered as "business arrangement" or state of "being collaborative", but a development process with its own lifecycle and a complex of the interactions among the key elements in this process. Thus, we summarize the key features of horizontal collaboration, and give our definition of *horizontal collaboration* as follows:

- *Essence:* an evolving process with dynamic character
- *Collaborators:* firms that operate on the same level(s) of supply chain or logistics network
- *Manners:* working together to establish, revise and develop the collaborative relationship by sharing information, resources, opportunities and risks
- *Objectives:* maximizing long-range individual profit (monetary or intangible) by achieving shared performance goal

2.4 Drivers of Horizontal Collaboration

Asawasakulsorn (2009) identifies transportation complementarity and perceived cost reduction as two most important drivers of horizontal collaboration. We say firms have transportation complementarity if they have possibility to share either forward or backward vehicle capacity. Both of the geographical proximity of their logistics locations and their shipment planning affect the transportation complementarity. As collaboration reduces transportation cost, some costs of collaboration are unavoidably incurred, such as technology investment and training expenditure. Thus the perceived cost reduction is defined as the perceived cost of net transportation cost reduction, minus the cost increase from transportation collaboration. These two drivers represent an important aspect of collaboration incentive: the economical benefit. Hingley et al. (2011) conduct a qualitative investigation of the grocery retail supply chain in the UK. They identify a consensus of opinion from the participants that certain collaborative approaches would increase the asset utilization, thus promote the cost efficiency and at the same time reduce the environmental impact caused by logistics activities. There are some less tangible benefits, such as reputation benefits of being associated with such innovations, can be achieved by collaborations. According to this investigation, the potentials of improvements in efficiency and environmental sustainability, and the reputation benefit are the drivers of the implementation of horizontal collaboration. For a systematical overview of horizontal collaboration, we refer to Cruijssen et al. (2007b). They make an explicit survey on horizontal logistics cooperation, focusing on transportation on the landside. Cost and productivity, customer service and market position are identified as drivers of horizontal collaboration.

In our work, we identified following drivers of horizontal collaboration: cost reduction, service improvement, market position, skill and knowledge sharing, investment and risk sharing, emission reduction, and congestion reduction.

2.4.1 Cost reduction

Optimizing truck loading rate through collaboration routinely achieves cost savings and efficiency gains of between 6% and 10% according to Transport Intelligence (Graham, 2011), and up to 13% according to the computational case in Pan et al. (2012). As logistics operators working on the same level of supply chain coordinate their logistics planning and operational process to achieve higher synergy, the cost efficiency of the whole coalition improves. ECR France (2012) introduces a case of horizontal collaboration among three manufacturers: Bénédicta, Banania, and Lustucru. They have proximate manufacture locations that are in the north of France, and delivery to same regional distribution centers of Carrefour. As the cooperation synergy was identified, a 3PL company, FM logistic, was hired to consolidate their deliveries by shared external warehouse and joint distribution. The average fill rate was increased by 15% compared to the fill rate before cooperation. The storage cost also decreases: 16% reduction in average stockholdings in the regional distribution center is made.

Possible forms of such collaboration are backhaul capacity exchange (Asawasakulsorn, 2009; Institute of Grocery Distribution, 2007), joint delivery (Bahrami, 2002) and joint replenishment (Institute of Grocery Distribution, 2007). In these kinds of collaboration, potential lanes for capacity sharing or collaborative planning will be identified by exchange of specific delivery information such as geographic structure of logistics network, delivery frequency and volume, vehicle requirement, and delivery time window. Caputo and Mininno (1996) analyze in detail possible ways to improve global efficiency in horizontal collaboration (Figure 2.4). The practices in order management, inventory management, warehousing handling, packaging & utilization, and transport functions are introduced corresponding to branded product industry and large-scale trade businesses.

Table 2.4: Interventions of horizontal integration between branded industries and between large-scale trade businesses (Caputo and Mininno, 1996)

Functions	Intervention of horizontal logistic integration Branded product industry	Large-scale trade businesses
	Information flow	
Order management	Standardization of computerized document content Standardization of application system interface	Standardization of computerized document content Standardization of application system interface
Inventory management	Standard code choice for consumer units, cartons and pallets	Definition of economic order quantity and frequency Improvement of the automatic reordering system
	Physical flow	
Warehousing	Multi-supplier warehouse	Multi-distributor centre
Handling	Multi-supplier warehouse	Multi-distributor centre
Packaging and unitization	Pallet height standardization	Definition of the number of consumer units per carton Definition of pallet sub-multiples Standardization of carton arrangement on pallets
Transport	Co-ordinated multi-pick	Co-ordinated multi-drop
	Proposal regarding the aggregation of suppliers to a courier and the choice of a common courier	

2.4.2 Service improvement

In the case of Bénédicta, Banania, and Lustucru mentioned previously, the collaborative relationship improves not only the cost efficiency, but also the service quality. Average delivery frequency has been increased by 34%. The increase of delivery frequency allows more flexibility for logistics planning and reduces the inventory cost, which is highly appreciated by the retailers. And also, in a case where several suppliers sell identical products to the same customer, a higher delivery frequency, as the source of competitive advantage, lower the value of getting deliveries from the second supplier and therefore intensify price competition (Ha et al., 2003). Especially for enterprises of huge scale and intensive large-quantity deliveries, it is of great advantage if such horizontal collaboration was adopted to increase her delivery frequency.

Horizontal collaboration can also improve service level in another way. Cruijssen et al. (2010) present a project named the transport-arrangements in the Dutch Randstad metropolis. In this project, a Dutch LSP offers prominent shippers in the fashion sector to perform the distribution to their shops in the city centers. Since their distributions are consolidated, number of visits per shop decreases, and as a result, trucks interrupt store personnel less frequently, which increases the customer satisfaction.

2.4.3 Market position

Bahrami (2002) mentions that enterprises could attain a better position in fierce competition by horizontal collaboration. Take an example of small and medium sized LSPs, there are following advantages of horizontal collaboration, which helps them against large LSP in the logistics market. At first, by resource and skill sharing, they can work more efficiently than how they do individually. And also, with more resources such as available fleet and warehouses, and being more reliable as an alliance, it is more likely for them to have bigger contracts. Secondly, by collaborating with each other, they can achieve higher or fully geographic coverage, which increases the number of potential customers. In another aspect, horizontal collaboration can enhance the bargaining power of collaborative members in joint purchasing (Dyer and Singh, 1998).

2.4.4 Skill and knowledge sharing

During the implementation process of horizontal collaboration, collaborators make intensive communication and information exchanges. These intensive interactions provide them with access to the other partners' business process, practices and know-how, aiming at both individual competence development and global performance improvement. As mentioned by Bahinipati et al. (2009), collaborators improve the development process, such as sharing the development of new knowledge, products, and processes in the collaborative relationship.

2.4.5 Investment and risk sharing

It is obvious that through horizontal collaboration, the non-relationship-specific asset investment can be minimized since the investment duplication can be avoided by coordination and resource sharing among collaborators. On the other hand, horizontal collaboration can also allow collaborators to share other type of investment and the related risk. Hingley et al. (2011) mention that the significant investment required inhibits LSPs from establishing 4PL management. Similarly, as the market for LSPs being low-margins, strongly fragmented and fiercely competitive, LSPs cannot afford the investment for innovation. Therefore, logistics services remain a commodity and competition is still focused on the lowest price (Visser, 2007). Fischer (2003) recommends that collaboration could be an appropriate way of sharing the large investments needed for research and development (R&D) projects. In this way, collaborators share large quantity of investment and risk, and also the future returns. This is an approach suitable for both LSPs and other group of enterprises.

2.4.6 Emission reduction & congestion reduction

Carbon emission and road congestion are two environmental problems highly concerned by European Commission. EU leaders have committed to cutting emissions by at least 20 percent independently of what other countries decide to do. To underpin these commitments, they set three key targets to be met by 2020: a 20% reduction in energy consumption compared with projected trends (European Commission, 2009). The European Commission has also implemented a number of initiatives designed to lessen truck congestion on Europe's motorways. Its overriding objective is to reduce the 30% of truck trips involving empty loads – all of which cost an estimated 33.5 billion € per annum in fuel charges and emit between 20 - 30 million tons of CO_2 (Graham, 2011).

As for CO_2 emission, previous researches on certain horizontal collaboration forms have shown that they could lead to significantly economical and ecological improvement (Ballot and Fontane, 2010; Pan et al., 2013). A survey by Léonardi and Baumgartner (2004) establishes a very strong correlation between transportation efficiency and CO_2 emissions. Therefore, since horizontal collaboration could improve freight transportation efficiency, it would help reduce one of the major sources of CO_2 emissions. And it is obvious that as shipments being consolidated, smaller number of vehicle movement will be present in the city center. Thus horizontal collaboration can in this way enhance corporate responsibility.

2.5 Barriers to Horizontal Collaborations

From the previous section, we can see that the horizontal collaboration is fruitful, but there are still many barriers to the successful implementation of such relationship. From the literature, we identified following barriers: finding suitable partner with synergy, profit sharing mechanism, trust, information sharing, competitive issue, legal issue, enterprise culture, organizational structure, and entry/exit rules. These barriers will be investigated in detail in following sections.

2.5.1 Finding suitable partner with synergy

One of the main barriers to collaboration was finding the right partners (Palmer et al., 2013). Many companies relied on logistics service providers to suggest partners or ad hoc opportunities, and others attended various "speed dating" meetings, with varying levels of success. In logistics collaborations, the geographic proximity or flow balancedness, shipment complementarity, and coordinability are sources of synergies. The proximity of logistics locations is the source of collaboration possibility in cases of joint delivery and joint replenishment, and the flow balancedness enable the backhauling collaboration. And from a relationship point of view, if key players from both firms are located near each other this can enhance the relationship. The relationship between Target and 3M reflects the influence of proximity. According to a 3M representative, "the relationship developed over time since both companies are based in the Twin cities" (Lambert et al., 1996). The shipment complementarity is interpreted as the possibility of sharing vehicle spaces, and the coordinability between two enterprises can be measured by examining their shipment quantity and intensity. In our interaction with experts, it is noticed that there is no interest for firms to collaborate if a great disparity of dimension lies.

With the intention to implement horizontal collaboration, enterprises get into difficulty in finding the suitable partner in the first place. According to the investigation of Muir (2010), with the help of LSP (44%) and searching for partners by industry (37%) are the most adopted ways. Cruijssen et al. (2010) propose a horizontal collaboration between competitors initiated by LSP, which investigates the initiation and collaborative mechanism from the LSP's standpoint. The steps of the implementation of such collaboration are as follows: synergy evaluation $\rightarrow$ group selection $\rightarrow$ find the Rational Shapley Monotonic Path (RCMP) $\rightarrow$ price setting and sequential negotiation. The financial risk lies in organizing collaboration with a big number of potential players can be eliminated by the one-by-one negotiation procedure and the RCMP is defined to determine the negotiation plan, thus this approach allows LSPs to play a substantial role in horizontal collaboration initiation.

There are other possible facilitators of finding suitable partners. Zhang et al. (2008) propose Electronic Logistics Marketplaces (ELMs) as online logistics collaboration match-maker, for example bulletin service and private community. However, the result shows that the current ELMs are more likely to support the lower-level collaboration. At first, the inter-activities of lower-level collaboration are more standardized and the corresponding logistics service is less customized. Thus the communication among partners in cooperation and coordination can be codified into structured application more easily. Secondly, in the higher-level collaboration, the shared information is more confidential. Thus, participants in synergy have no willingness to set up mutual linkage on a public and open ELM. Other approaches with more social presence seem to work better. Organizations and workshops could act as a meeting place to make potential partners meet. For example, Institute of Grocery Distribution (2007, 2010) has listed many collaboration cases in both vertical and horizontal manners, which were brought about by the ECR workshop or conferences.

2.5.2 Profit sharing mechanism

The profit sharing mechanism is crucial for the establishment of collaborative relationship. It should be able to benefit all partners so as to provide them with incentive for collaborating. And also it should be fair and reasonable enough to guarantee the longevity of the collaboration. While Meyer (2011) identifies contribution quantification as one of the essential elements in collaboration, and proposes to allocate common gain (cost) according to contribution, it is sometimes difficult to implement in real cases.

According to the survey results in Palmer et al. (2013), current gain sharing mechanisms between partners are fairly simplistic relying on a basic percentage allocation of savings, or a logistics service provider setting rates. One example is the allocation rule proportional to number of pallets delivered, which roughly divide the gain according to volume. Cruijssen et al. (2010) gives some examples of the proportional rule:

- Proportional to the total load shipped
- Proportional to the number of customers served
- Proportional to the transportation costs before the collaboration
- Proportional to distance traveled for each shipper's orders
- Proportional to the number of orders

However, the proportional sharing mechanism cannot reveal truthfully the contribution of collaborators, and may induce instability of the collaboration.

The subject of profit allocation has been intensively investigated in cooperative game theory. Due to the complexity of the allocation models in game theory, logisticians propose to adopt hybrid mechanisms that combine simplest game-theoretic model and practical rule. In the case of Cruijssen et al. (2010), Shapley Value allocation is adopted to allocate the common gain among shippers, and differential synergy-claim factors are determined in business negotiation according to different bargaining power of shippers to determine the 3PL's share of the common gain. Ernst and Bleeke (1995) explain how the evolvement of the relative bargaining power of the partners is the key to understanding whether an alliance is likely to lead to a takeover. Hence the different bargaining power of collaborators should be considered in the sharing mechanism in order to propose a more satisfactory sharing scheme. When considering the coordination cost probably arising in the collaboration, the corresponding game becomes more complicated. Hence we need new sharing mechanism that is more stable and more generally applicable.

2.5.3 Trust

The survey conducted by Palmer et al. (2013) shows that all of the shippers, the LSPs, and the other organizations involved in supporting collaborations consider trust as the most important condition for a successful collaboration. A common understanding is that trust is the expectation that vulnerable action will be fulfilled. The trust in horizontal collaboration lies on the mutual belief that the global profitability is the common objective shared in the alliance. The positive effect of direct prior alliance experience on mutual trust has been mentioned in the literature. Lambert et al. (1996, 2004) state that firms with a prior history of positive interaction will have an advantage when building partnerships. Having worked closely and successfully with a partner in the past strengthens the chance of future successful interactions.

Riegelsberger et al. (2005) investigate the mechanics of trust. A framework that shifts the perspective towards factors that support trustworthy behavior is presented (Figure 2.5). Under this framework, trustee signals the influence of trust-warranting properties and aims to elicit positive affective reactions. Two examples, E-commerce and voice-enabled gaming environments, are investigated to illustrate how the framework functions to support trustworthiness.

It has also been noticed that the lack of cost-structure and cost-saving transparency is a source of mistrust in horizontal collaboration (Cruijssen et al., 2010; Graham, 2011). Interconnected information system could solve this problem. Riegelsberger et al. (2005) present design heuristics for an information system comprising (1) stable identity, (2) traceability and accountability, (3) group membership and group identity, (4) social presence, and (5) recording outcomes. Asawasakulsorn (2009) applies these design heuristics to the case of an Inter-

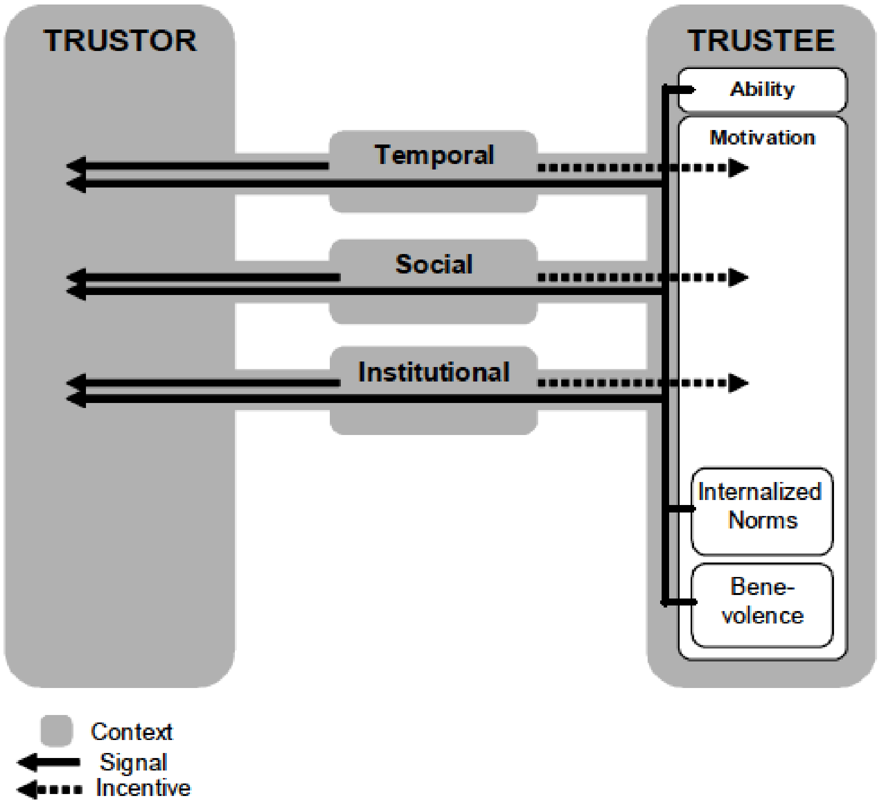

Figure 2.5: Framework of trust mechanics (Riegelsberger et al., 2005)

Organizational System (IOS). In their definition, the IOS is a specific form of information system serves as the facilitator of information sharing in horizontal collaboration. A paper-based IOS prototype was developed with a functional design aiming at raising trust among horizontal collaborators.

2.5.4 Information sharing

The high investment for constructing an inter-organizational information system may be an inhibitive factor. However, as stated in Verstrepen et al. (2009), their interviews and questionnaires indicate that the investment of information system is mainly a problem for horizontal collaborations of medium intensity. "Light forms of horizontal cooperation do not require specific information system investments, while high intensity initiatives have enough financial room to absorb the required information system investments."

With well-established information system, information sharing provides substantial benefits to participating members. Simatupang and Sridharan (2002) conclude the advantage of information sharing at strategic level, tactical level and in the behavior-control aspect. At the strategic level, information sharing of business objectives enables individual managers to achieve mutual understanding of competitive advantage and the system-wide supply chain as a starting point of collaboration. At the tactical level, the information integration helps the chain members to mitigate demand uncertainty and cope with decision-making complexity at different levels of planning horizon and in different organizations. Finally, information sharing is also useful when coping with the relational vulnerability of opportunistic behavior. Lambert et al. (2004) believe that effective communication, on both a day-to-day and a non-routine basis, is a key component of successful partnerships. Integrated E-mail systems, regularly scheduled meetings and phone calls, and the willingness to share good and bad news, as well as communication systems such as Electronic Data Interchange (EDI), all contribute to the success of a partnership.

Electronic Data Interchange (EDI) refers to the implementation of electronic data exchange that enables the transfer of standardized and structured data between the collaborators. It is widely adopted by firms with certain dimension to share information. The information, which are most often shared, include the availability of resources (e.g., capacity, inventory, and funds), the status of performance (e.g., time, quality, costs, and flexibility), the status of processes (e.g., forecasting, ordering, delivering, and servicing), and the status of contract. Xu and Dong (2004) emphasize that an important factor to facilitate the implementation and usage of the information system is to share processed data instead of non-processed, i.e. share data that is more specifically developed for the receiver's needs. Such data is often more valuable and will have a greater impact on planning efficiency and performance in the horizontal collaboration.

Another concern has been highlighted by Palmer et al. (2013). Even in a collaboration based on mutual trust with non-competitors, partners have no incentive to reveal sensitive information. Thus in centralized HLCs, where a trustee serving as the organizer/planning decision maker of the collaboration collects private information on partners' logistics profiles, the trustee should guarantee the secrecy of sensitive information submitted by partners. And in decentralized HLCs, where collaborators make their own decisions based on the collaboration mechanism predefined, the information exposure should be avoided by properly design the system protocols.

2.5.5 Competitive issue

As the horizontal collaboration implements in the same level of supply chain or supply network, the supply chain members who function similarly in the market place, maybe competitors, are involved into a collaborative relationship. Palmer et al. (2013) show that collaborators tend to avoid collaboration with competitors. As stated in the literature, many horizontal collaboration implementation fails, especially these between competitors. Graham (2011) considers trust, confidentiality and security as the primary obstacles limiting the collaboration among competitors. Brandenburger and Nalebuff (1998) define "co-opetition" as a new type of horizontal collaborative relationship, which is part competition and part collaboration. It describes the fact that in today's business environment, most companies can achieve more success in a dynamic industry than they ever could by working with a limited partner group. They also stated that the biggest commercial opportunities and greatest profits don't come simply from playing the game better than everyone else. They actually come from expanding the game from whatever it is at present to a new game that is bigger, better and more valuable for everyone involved. For example, in HLC among 3PLs, the co-opetition aiming at efficiency improvement and better customer service may create further logistics service demand, higher customer satisfaction, thus benefits both LSPs and customers. In a word, players cooperate to create the total value, while compete to get bigger share of the total value.

In another perspective, Meyer (2011) proposes that co-opetitors collaborate for part of their business where they have no competitive advantage. Bengtsson and Kock (2000) consider the visibility for customer as the most important characteristic to determine whether collaboration and competition should take place for a certain activity. Cruijssen et al. (2007b) mention that co-opetition can be beneficial if collaboration takes place for non-core activities, while competition stays unchanged for core activities. Thus the manufactures, whose logistics is a non-core activity and invisible for the customer, could possibly accept to collaborate even their competitors on logistics. Further, since the shipments of competitors are of the same or similar necessity fulfillment (similar product type and order dynamics), co-opetition on logistics is more implementable than the logistic collaboration between irrelevant enterprises. Bahrami (2002) explores the collaboration synergy that arises from the horizontal collaboration between two German consumer goods manufacturers (Henkel and Sckarzkopf). Three scenarios are compared, and the significant synergies achieved by joint distribution (based on the current logistics structure) and by global optimization of logistics structure demonstrate the viability of co-opetition.

There are already some successful implementations of co-opetition in Europe. Graham (2011) introduces that the Culina Group has crafted a successful collaborative solution that has been embraced by both competing and non-competing dairy goods manufacturers in the UK. Originally formed in 1994 to provide 0-5°C temperature controlled supply chain services, the Culina Group now markets its services to a broad range of dairy producers, including such brands as Muller, Danone and Kraft. Each customer fills a truck with its own dairy products, and Culina then picks up the truckload and delivers it to its own regional distribution center. There, the customers' dairy products are stored until they are combined with products from other manufacturers, and the combined truckloads are then delivered to a supermarket chain's regional distribution center. Institute of Grocery Distribution (2011) introduces the cooperation relationship between two competitors: Nestlé and United Biscuits. Obstacles such as cultural, brand protection, safeguarding product integrity are resolved by a series of meetings. Successful transport sharing realized by detailed planning of the internal stock movement, the customer delivery and the invoicing procedure. Cruijssen et al. (2007b) present the case of 8 Dutch producers of sweets and candy. They consolidate and delivery their goods by 3PL on a daily basis to improve the efficiency of their delivery processes. The primary objective is reducing the delivery cost, but at the same time, the customer service is also improved since that the reduced delivery number results in reduction of unloading and handling costs.

However, from the implementation cases we can see that only manufactures and 3PLs are involved in these horizontal collaborations. Hingley et al. (2011) state that retailers show the lack of willingness to participate in horizontal collaboration for increased efficiencies, customer service and reduced costs. Why retailers prefer to keeping out of the horizontal collaboration? Hingley et al. (2011) interpret this as follows: "the retailers have reached their current positions through significant horizontal mergers and acquisitions, thus physical distribution management (PDM) means far more to retailers than cost efficiency, as verified by the LSPs. Retailers place such a value on service levels and protecting sensitive sales information that it is difficult to envisage any situation where they would collaborate so much that they shared PDM. As such, retailers as gatekeepers and channel leaders are motivated more by safeguards against competition than by collaborative savings." In a recent interview with a manager of a fortune 500 super market, we are told that there is no attempt of horizontal collaboration in the enterprise yet, and he has never heard of horizontal collaboration between two retailers in competitive positions. This further confirms the credibility of the disappointing result found by Hingley et al. (2011).

2.5.6 Legal issue

To moderate the environmental impact caused by logistics activities such as carbon emission and road congestion, as an effective approach, horizontal collaborations are encouraged by both governments and international organizations. However, in the case of collaborations between competitors, the European Commission has erected roadblocks to discourage any collaboration that might lead to noncompetitive business practices. For now, the Commission appears to be more concerned about situations involving shared warehouse space where company books, product management and market strategies would be accessible among competitors than in cases where collaboration involves transport and truck space (European Commission, 2001).

Graham (2011) presents an implementation of the horizontal transport collaboration between two competitors (Bridgestone and Continental). In this case, special regional distribution center design and process re-engineering (separated inbound shipment and storage; joint outbound delivery management) are conducted of a 3PL. If the user plans to share space with a competitor, given the European Commission's concerns over potential noncompetitive collaborative practices, the separate warehouses design in this case can provide a safer solution.

2.5.7 Enterprise culture

The literature on different enterprise cultures and their compatibility is vast. In the context of horizontal collaboration, what we concerns the most is cooperative culture of enterprises, which affects the way enterprises in an alliance interact with each other. The success of collaborations also depends on the cooperative culture within a firm. Koppers et al. (2008) define cooperative culture as the specific set of ability, willingness and awareness of a firm and its employees to work in collaboration with other firms to offer customer-oriented solutions. It is influenced by the seven factors shown in Figure 2.6.

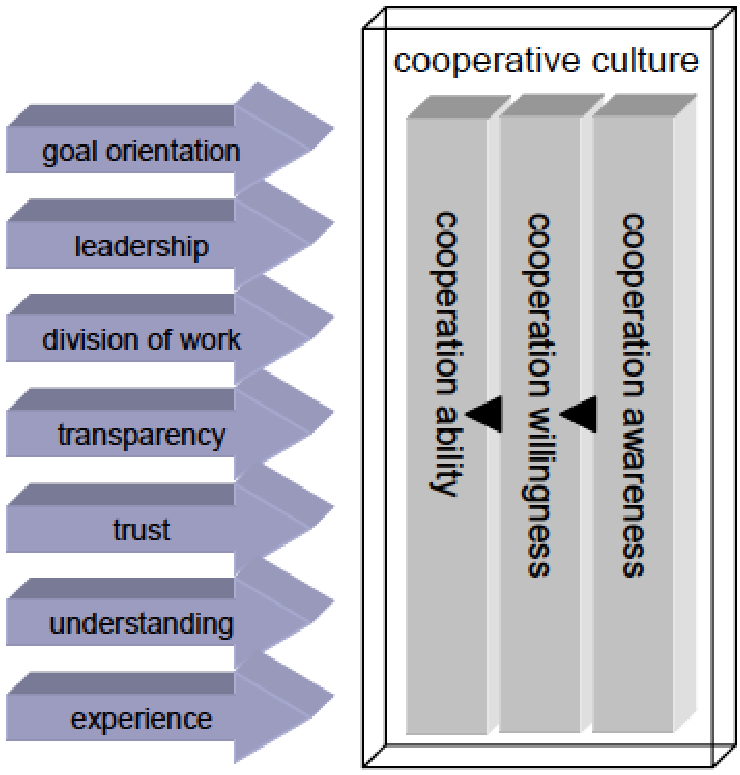

Figure 2.6: Influencing factors of cooperative culture in firms (Koppers et al., 2008)

The seven factors illustrated in Figure 2.6 are interpreted as follows:

- *Goal orientation:* collaboration partners strive and pursuit common goals;
- *Leadership:* appropriate leadership arrangements put the employees in the position to collaborate with the collaboration partners, e.g. encouragement of teamwork;

- *Division of work:* division of work resulting in workload reduction for each collaboration partner;
- *Transparency:* if partners have access to collaboration-related information without loss, delay or distortion, transparency exists;
- *Trust:* a corporate culture based on trust enables the employees to trust external collaboration partners;
- *Understanding:* a shared understanding for the business and current situation of the collaboration partner advances the success of collaboration. The knowledge of the collaboration partners' businesses allows the partner to analyze their strengths and weaknesses and coordinate them accordingly;
- *Experience:* experienced benefits and issues within collaboration can be taken into early consideration of collaboration planning.

This framework only analyzes how enterprise culture is influenced. The detailed profile of cooperative culture and the interaction of different types of cooperative culture need intensive investigation to guide collaborative practices.

In interview with 3PL, we are told that horizontal collaboration are often carried out between firms in the same industry. One reasons is the similarity of shipment content and shipment dynamic. Another reason may be that these firms with the same industry background may have similar behavior pattern and hold similar value. Palmer et al. (2013) conclude that companies in collaboration need a similar culture, similar business objectives and a desire to make collaboration work to increase the success possibility of the HLC.

2.5.8 Organizational structure

Horizontal collaboration results in inter-organizational relationships, which is under the multi-governance of collaborators. Appropriate organizational structure enables efficient management of such relationship. Bowersox et al. (2002) investigate the organizational issues in vertical collaboration. They highlight the inadequacy of command-and-control-based relationship and matrix organization in cross-enterprise collaboration. Cross-enterprise process organization structure is introduced as a facilitator of cross-enterprise collaboration. This kind of organization provides cross-organizational teams with a highly involved, self-directed environment that empowers them to generate maximum performance. In this organization, executives focus on managing processes (rather than functions) that lead to higher productivity, and integrate all facets of the organization by a rapid sharing of accurate information. This organizational structure is presented in Figure 2.7.

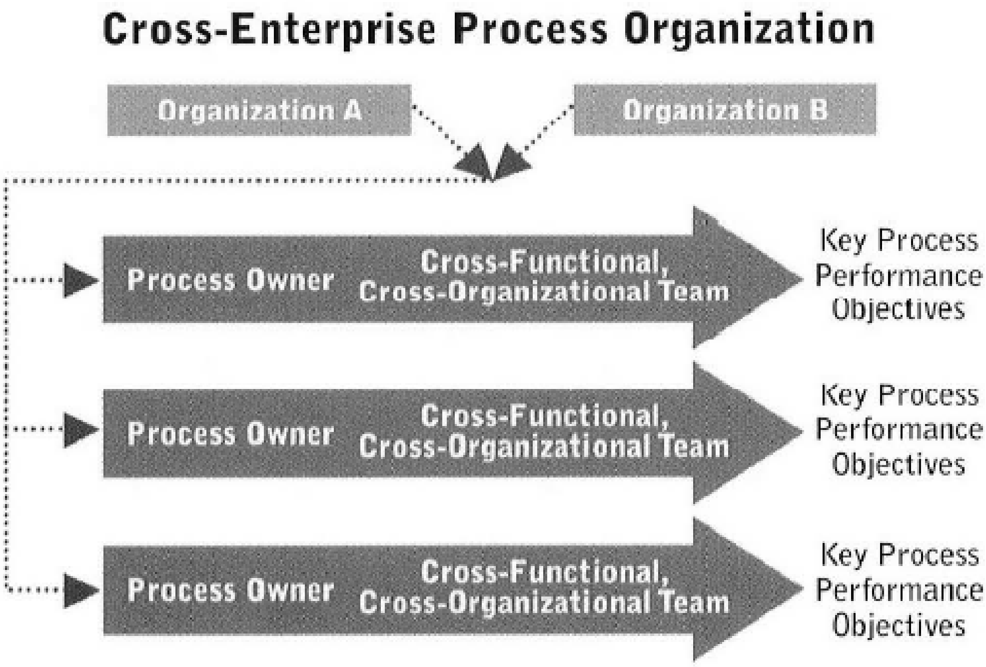

Figure 2.7: Cross-enterprise process organization (Bowersox et al., 2002)

They present also a framework as a guide to developing cross-enterprise collaboration in Figure 2.8. Audy et al. (2010) describe five generic coordination mechanisms of the logistics activities in a coalition, which can be take into consideration in designing collaborative organizational structure. These elements can be adapted and then applied to facilitate the implementation of horizontal collaborations.

Ramesh et al. (2010) stress the importance of top management commitment to achieve desired outcomes in supply chain collaboration. Similarly, Sandberg (2007) finds that there is a clear relationship between collaboration intensity and the positive effects experienced from the collaboration and the involvement of top management can greatly increase collaboration intensity, thus improve the outcome of collaborative relationship. A reason for this could be that

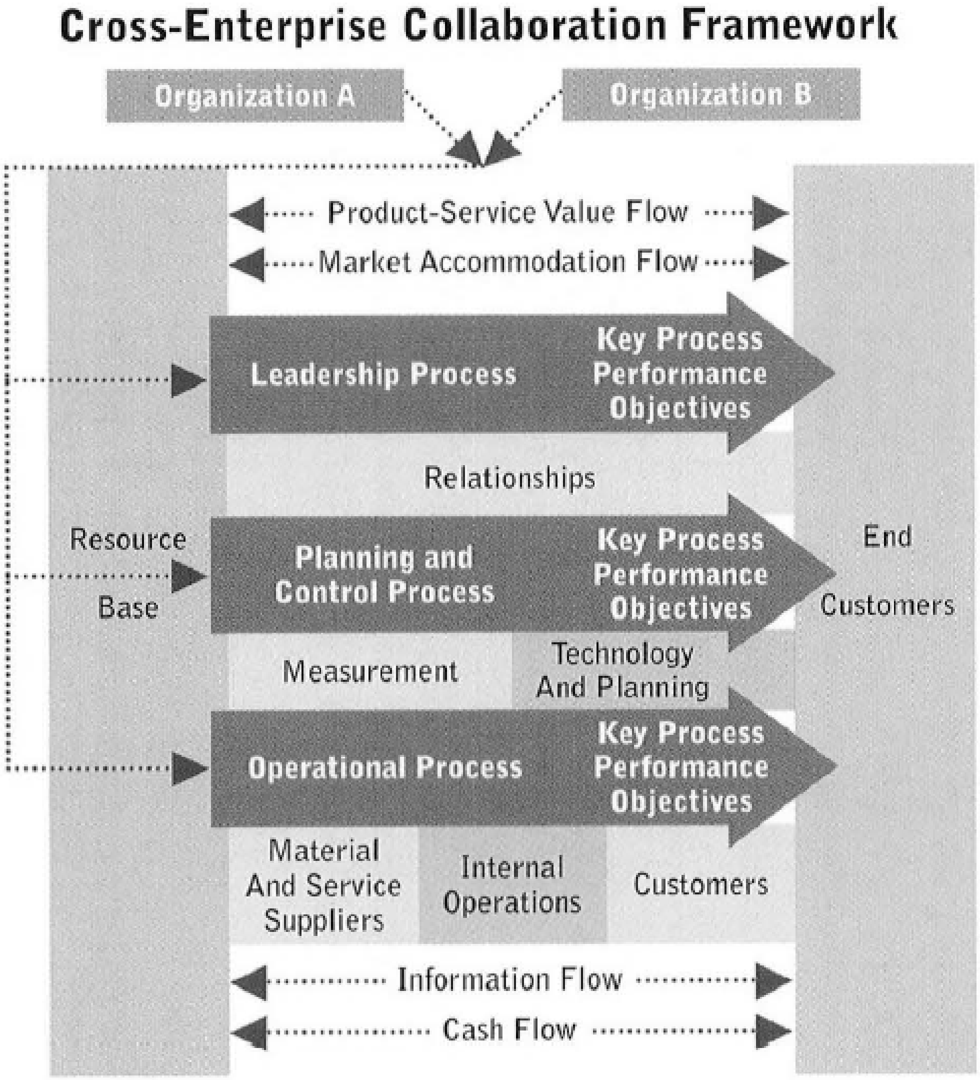

Figure 2.8: Cross-enterprise collaboration framework (Bowersox et al., 2002)

involvement by top management gives the logistics department the authority to carry out the collaboration and bring it to a more intensive level. So involving top management into the organizational structure could be an effective approach towards successful horizontal collaboration.

2.5.9 Entry/exit rules

In both centralized and decentralized HLCs, the entry and exit rules need to be well defined to support trust and the effectiveness of the collaboration relationship.

On one hand, in centralized HLCs, the requirement of information exposure makes the collaborators vulnerable to competitors. And the exit of some participants will certainly disturb the centralized orchestration of the logistics activities of the others. Thus a selective entry rule is used to guarantee the well evolvement of the collaboration. On the other, the centralized HLC induces firm bundling of participants. When participants feel unprofitable staying in the current collaboration relationship or find a more suitable one, a finely defined exit rule would provide them with evacuation option, while at the same time minimize the disturbance for the others.

In decentralized HLCs, even the participants are much less hooked than in a centralized HLC, an rule specifying the requirement for entering into the system is indispensable, in order to guarantee the participants are qualified enough to contribute to the collaboration. Once a participant has fulfilled the currently contracted obligations in the collaborative system, he can thus exit freely.

With the drivers and barriers of HLC introduced in previous sections, we provide a systematical framework of collaboration implementation in the following section.

2.6 Framework for Horizontal Collaboration Implementation

A systematical framework is needed during the whole collaboration process, from estimation, establishment, and performance evaluation, until long-term relationship evolving. And also, a systematic perspective serves as a guideline in investigating horizontal collaboration. This section investigates the LSPs who play a substantial role in horizontal collaboration, and reviews the literature on the framework of horizontal collaboration to provide a overview of this subject.

2.6.1 Logistics service providers

EyeForTransport (2006) provides the result of an investigation on the most outsourced logistics services in Figure 2.9. From this result, we can see that logistics services, especial transport activities, are mostly operated by LSPs.

Currently, there are three kinds of LSPs in the logistics market place: Carriers, 3PL and 4PL.

Carriers carry out the most straightforward service in a point-to-point network setup. They

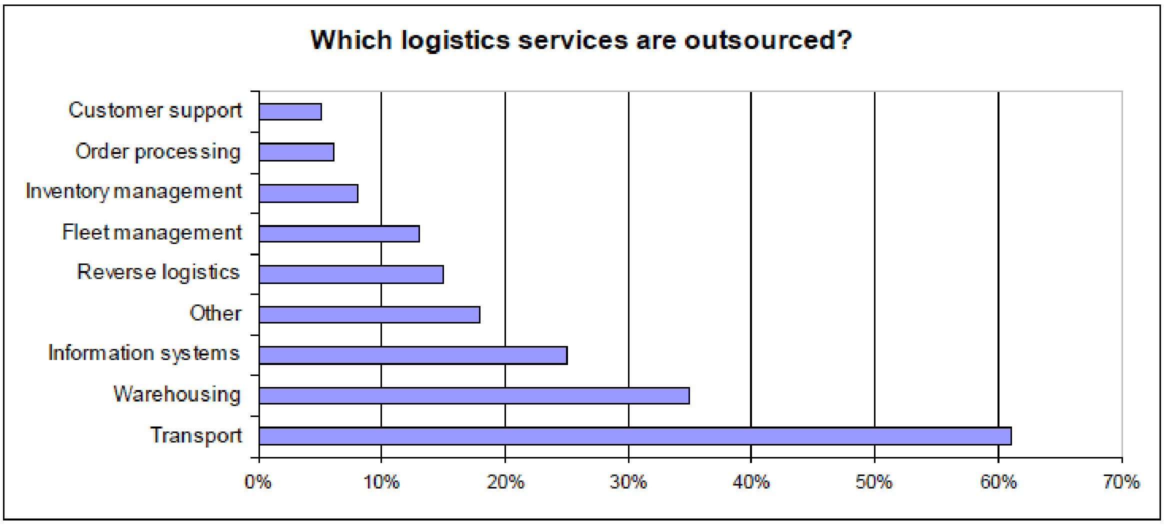

Figure 2.9: Which Logistics Services are Outsourced? (EyeForTransport, 2006)

carry out the haulage of products from one point to another, often with a full truckload. Similarly, in a multi-stop network setup, the transport operators haul full truckloads or LTL with many stops throughout a predetermined route.

Langley et al. (1999) give the following definition of a third-party service provider: A company that provides multiple logistics services for its customers, whereby the third-party logistics provider is external to the customer company and is compensated for its services. They typically specialize in integrated operation, warehousing and transportation services that can be scaled and customized. Often, these services go beyond logistics and included value-added services.

The concept of 4PL was introduced by Andersen Consulting (now: Accenture). These companies carry out the majority of the administrative activities but leave the physical activities to other contracted 3PLs. The definition given by Andersen Consulting is (Bumstead and Cannons, 2002): An integrator that assembles the resources, capabilities and technology of its own organization and other organizations to design, build and run comprehensive supply chain solutions. 4PL relies on an outsourcing provider to neutrally manage the entire logistics process.

Stefansson (2004) defines 3PL as *"logistics service provider"*, while 4PL are defined as *"logistics service intermediary"*. A three-stage collaborative logistics management model (Stefansson, 2004) is presented in Figure 2.10.

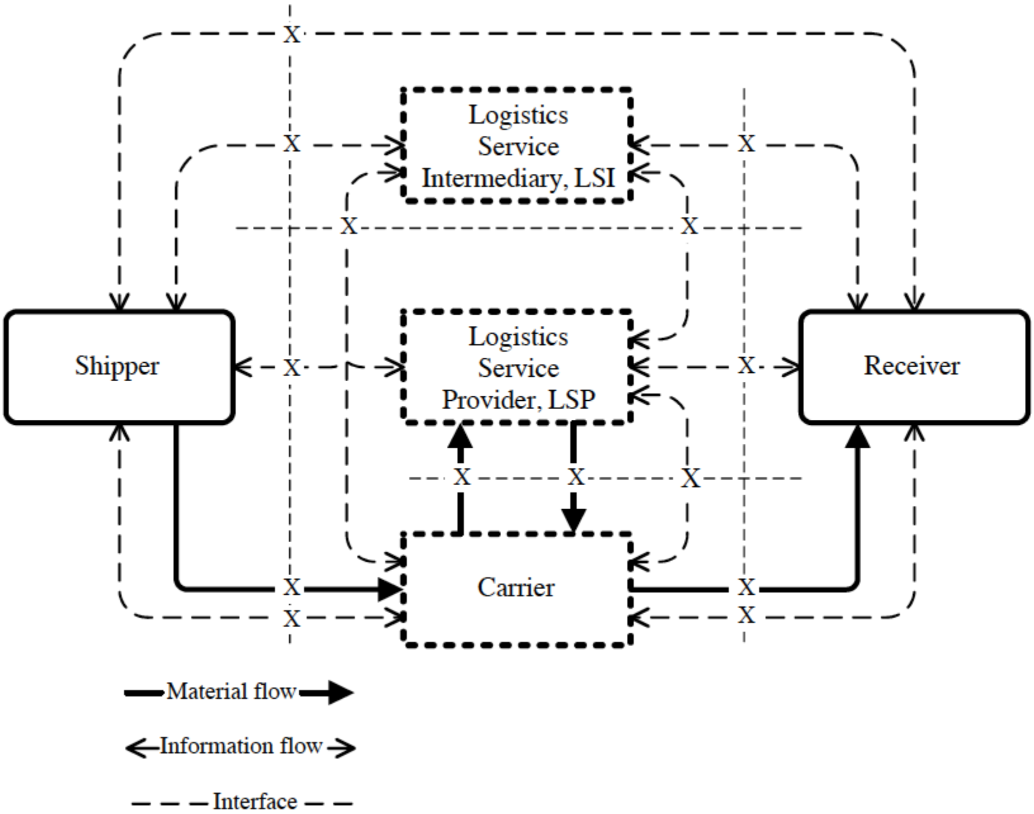

Figure 2.10: Collaborative logistics management model (Stefansson, 2004)

In this model, 3PL and 4PL are actual operators and planners of logistics activities, so they have substantive experience of logistics operation and planning, which enabling them to initiate or play an important role in horizontal collaboration. Take an example of 4PL, to reduce supply chain costs, General Motors (GM) formed a 4PL joint venture with Menlo Logistics called Vector SCM (Schwartz, 2000; Walsh et al., 2001). Each firm reportedly contributed $ 6 billion in start-up equity and all of GM's logistics staff transferred to the new firm. Vector SCM serves as a communications hub that integrates all technology systems used by GM's 12 3PL providers and provides a single point of contact through EDI. Estimations indicate order cycle times declined as much as 75 % from 60 to 15-20 days and customer lead times fell from 12 to 4-5 days. Vector SCM's revenue is linked directly to such order cycle time reductions. In this case, the Vector SCM venture is a 4PL link between only one firm and its 4PL. But considering the complexity and size of this supply chain, we can see that it provides a good working model of potential results if horizontal collaborators were to attempt such a venture.

2.6.2 Framework of horizontal collaboration

Collaboration has a life cycle from the time of engagement to disengagement / further development. Simatupang and Sridharan (2002) introduce the lifecycle of collaboration with four primary processes. First, the engagement process aims to identify the strategic needs, find the right partners, and set mutual agreements concerning performance. The second process involves forward-looking planning of resources, tasks, and capabilities for future requirements. Third, supply chain members perform daily operations to effectively meet the requirements of short and long-term goals. This is the implementation process in which the members execute the planning and to assess the overall performance. Fourth, the evaluation process is to evaluate and decide either to modify or to terminate the agreements.

At the initiative of horizontal collaboration, adequate feasibility test is needed to avoid unnecessary waste of monetary and time investment. Naesens et al. (2009) propose a strategic decision-support framework for the implementation of horizontal collaboration. The analytic hierarchy process (AHP) is utilized to develop this framework. This framework is illustrated in Figure 2.11.

Bahinipati et al. (2009) provide another approach, a generic quantitative model, to comprehensively assess the degree of collaboration and to evaluate whether such a project is really viable. The hybrid analytic hierarchy process-fuzzy logic model (AHP-FLM) approach is chosen to develop this model. Through this way, the complex and unstructured problem for 'compatibility test' is broken down into elements, and then a customized hierarchy structure is set up to demonstrate the relationship between different hierarchy levels and among these elements. The outcome of this paper provides an effective method combining subjective analysis with quantitative analysis for the semiconductor industry supply chain members to evaluate the success of such shared collaborative systems, and this method can be easily applied in horizontal collaborations.

Lambert et al. (1996) propose a partnership model to investigates how to build and maintain successful relationship, which is illustrated in Figure 2.12. Based on the facilitation of 20 partnership cases in a wide variety of contexts, Lambert et al. (2004) provide a systematic

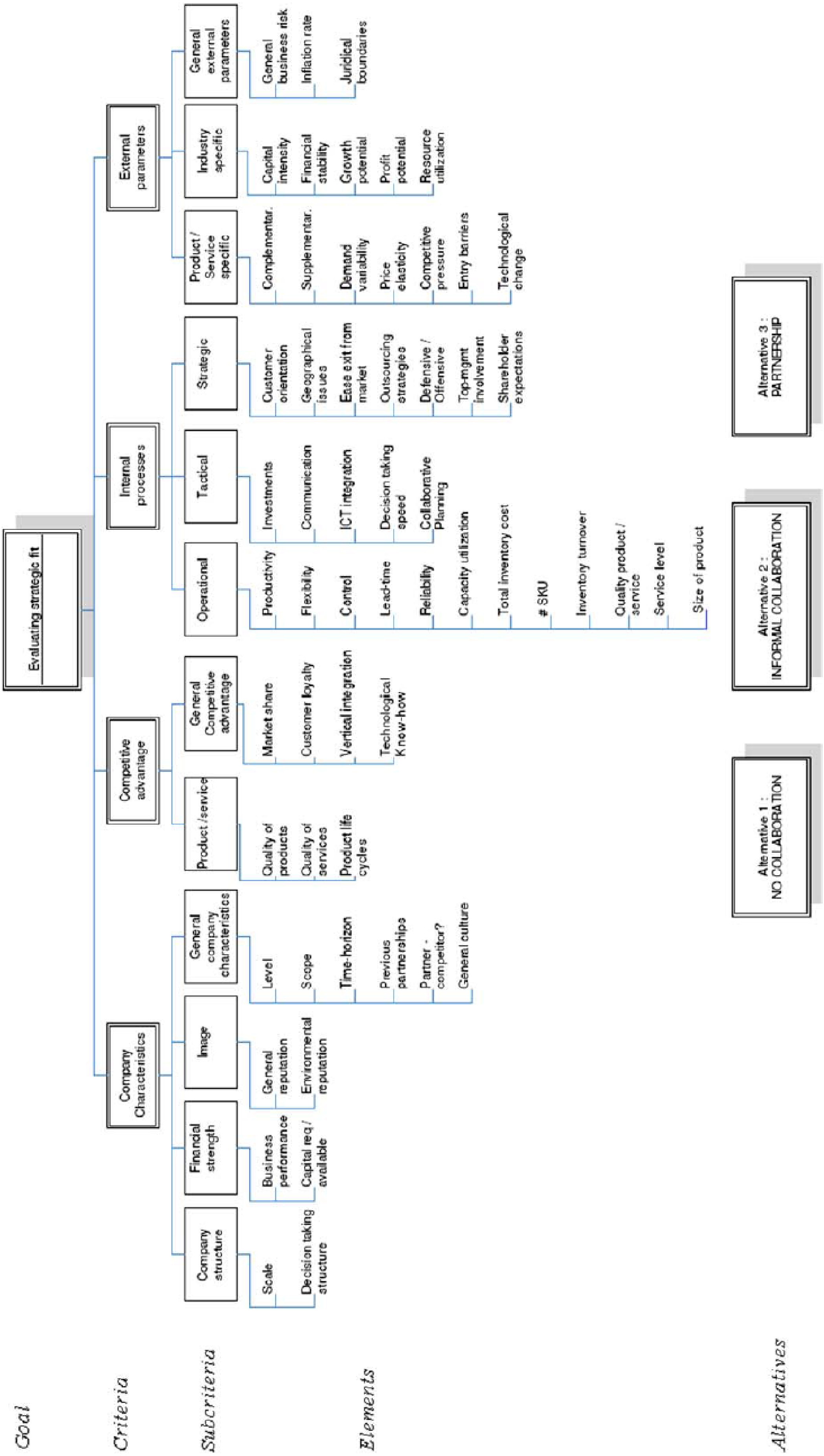

Figure 2.11: Hierarchical structure for evaluating strategic fit (Naesens et al., 2009)

validation of the partnership model and addresses a number of specific guidelines on how to implement the model. This research provides guide to applying the model to build and maintain successful relationships.

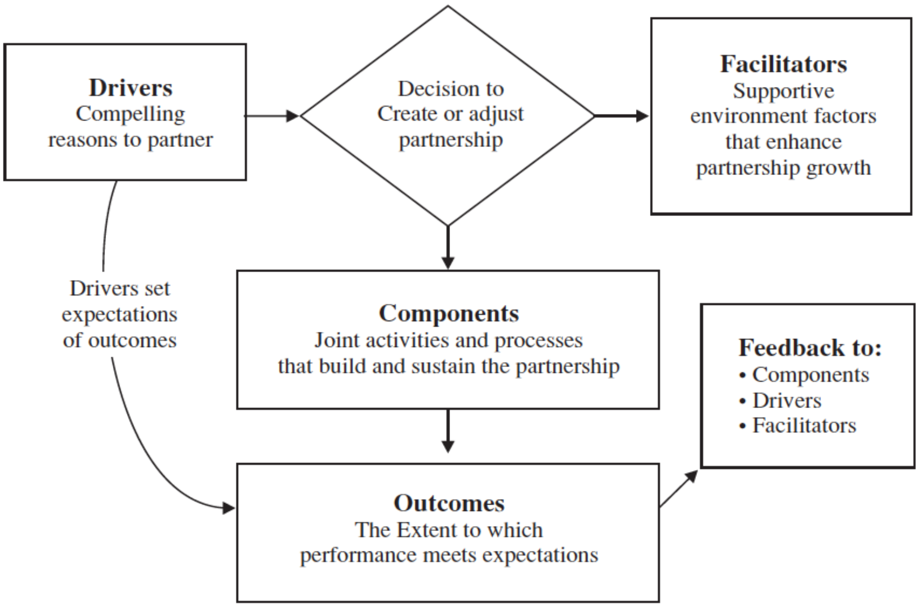

Figure 2.12: The partnership model (Lambert et al., 1996)

Hingley et al. (2011) investigate the role of LSPs in the logistics operation and planning, and then propose a collaboration model with suppliers, retailers and LSPs. This model is illustrated in Figure 2.13. In this model, a 4PL would organize horizontal collaboration for suppliers' benefit. But due to the lack of retailers' willingness to participate in horizontal collaboration, either it or traditional 3PL providers would need to offer the usual direct and unique deliveries to retailers with all the attendant inefficiencies in operations, costs and the environment associated within this final link in the supply chain network.

Institute of Grocery Distribution (2007) introduces a seven-step process that facilitates the collaboration on backward vehicle sharing, which is a detailed pilot plan with rich operational considerations. Initiated by a third party organization or a group of supply chain operators themselves, this cooperation process takes the first step by evaluating the transport compatibility. Then after a succession of operational consideration and coordination, cooperation relationship that reduces empty run could be established. It is relatively more accessible than many theoretical models.

Simatupang and Sridharan (2002) introduce a necessary element in the implementation of

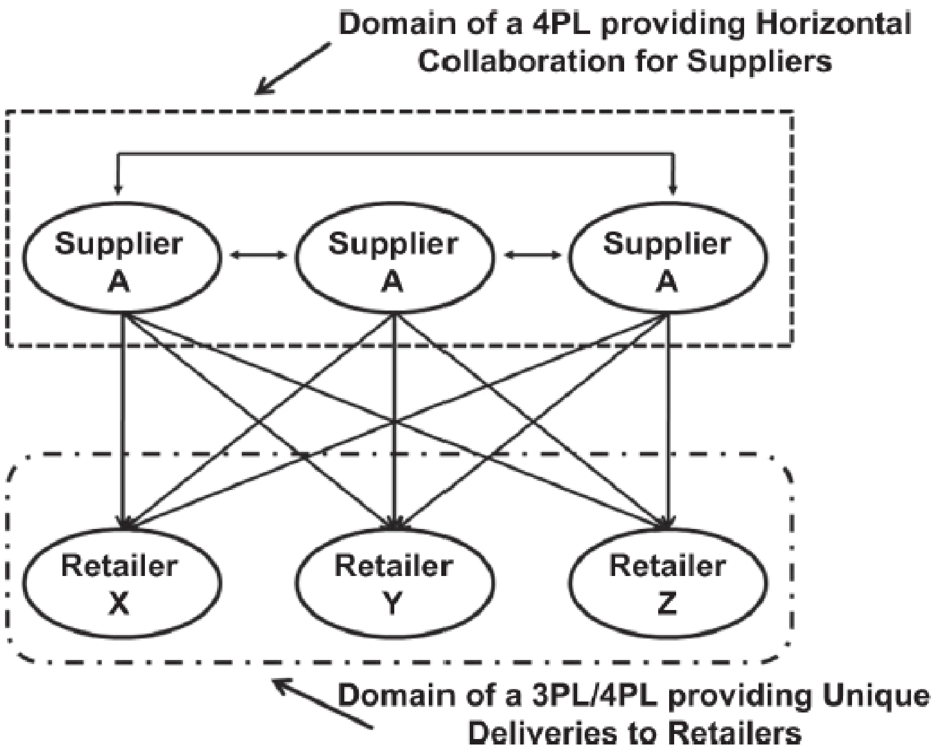

Figure 2.13: Future structure of 4PL involvement in horizontal collaboration (Hingley et al., 2011)

horizontal collaboration: incentive alignment. It aims at providing a mechanism for (re)alignment of the benefits and burdens so that responsibility for the attainment of overall profitability is internalized to the individual participants. Simatupang and Sridharan (2002) identify three types of strategies that can be used to motivate different members to align their behavior with the overall goal of the collaboration:

- *Rewarding productive behavior*: Reward observable actions that lead to a common goal, rather than reward the attainment of the goal itself;
- *Pay-for-performance*: Using performance metrics to evaluate the achievements of individual partners on important objectives of the cooperation;
- *Equitable compensation*: Joint goals are set and the gains that are created are allocated to the partners based on an ex-ante agreed gain-sharing mechanism.

Simatupang and Sridharan (2005) develop a collaboration index to measure the extent of collaboration that incorporates information sharing, decision synchronization, and incentive alignment. The study shows that there is a significant correlation between collaboration index and operational performance, and that enterprises should make collaborative efforts to improve overall performance.

Simatupang and Sridharan (2008) offer a concept for designing the five elements of the architecture of supply chain collaboration:

- *Collaborative performance system:* specify performance metrics and targets across the supply chain;
- *Information sharing:* share information about planning, process, control, and performance;
- *Decision synchronisation:* enable the members to make decisions that influence supply chain direction and performance;
- *Incentive alignment:* base on overall performance to induce productive behaviour and improvement;
- *Innovative supply chain processes:* enable them to smooth flows of goods, information, and money along the supply chain.

A framework with the five elements and their interrelations is presented in Figure 2.14. It is supposed that the collaboration members should collectively define and share the five elements of the architecture.

A practical method to develop and implement the design for collaboration in a systematic way is suggested as shown in Figure 2.15. The method consists of four cyclical steps: define strategic goals, design for collaboration, deploy the architecture, and diagnose any dysfunctions. The first step is to formulate the overall objectives and strategies of collaboration and to set specific metrics and targets and to specify action plans (defining how targets are to be achieved) in joint decision making, information sharing, incentive alignment, and innovative supply chain processes. The design for collaboration is then carried out to identify specifications for the five elements of the architecture and to seek and decide appropriate design solutions. The

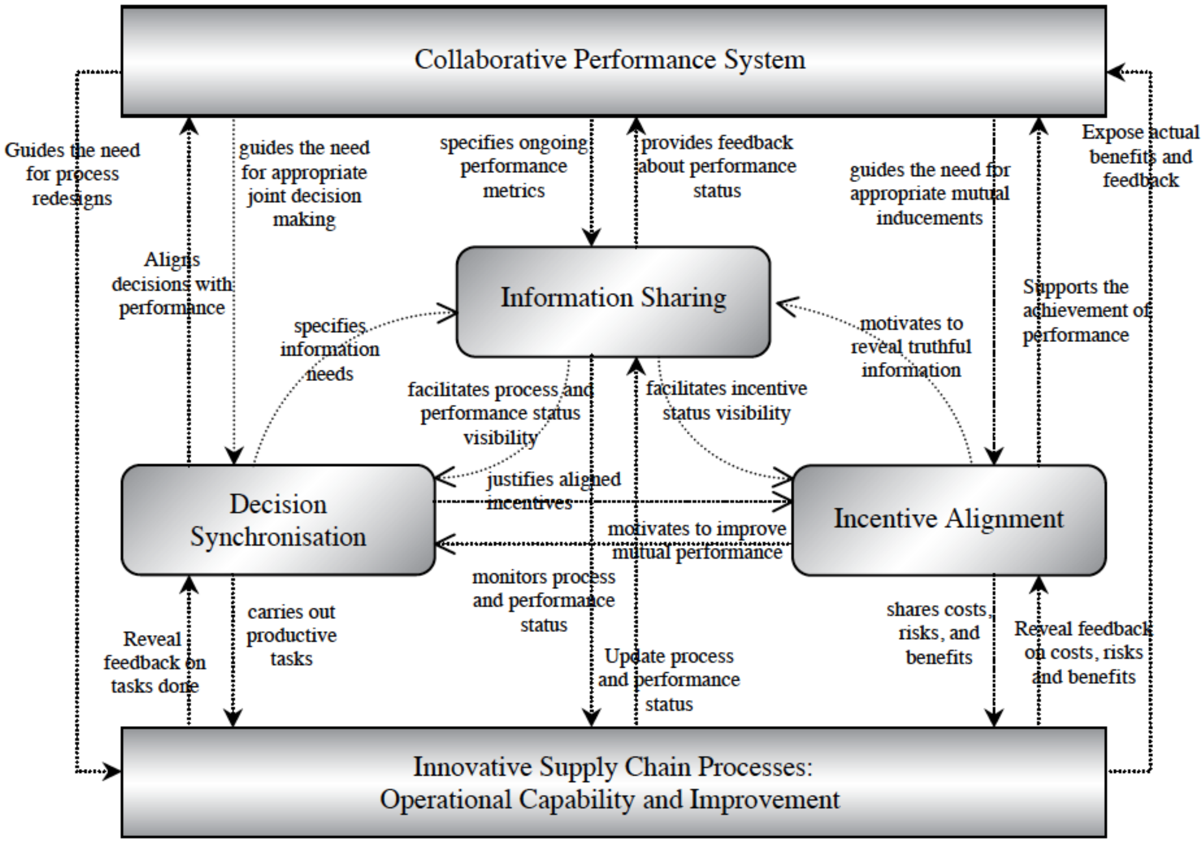

Figure 2.14: The architecture of supply chain collaboration the interplay between its five elements (Simatupang and Sridharan, 2008)

third step is to implement the actions plans, periodically review progress toward collaborative objectives, and provide feedback for further improvements. The final step is to identify sources of dysfunctions of key elements and acts as a starting point to redesign the elements of the architecture. An effective diagnosis can determine which issues have the most impact and which are cost effective to fix.

Palmer et al. (2013) develop a collaborative framework for HLCs, which highlights the processes necessary to achieve a successful collaboration. The outline is illustrated in Figure 2.16.

The outline framework has evolved into a business model canvas (BMC) based on an adapted version of Osterwalder's business model canvas, shown in Figure 2.17.

This includes the collaborative issues that need to be taken into account. The elements in this collaborative BMC include:

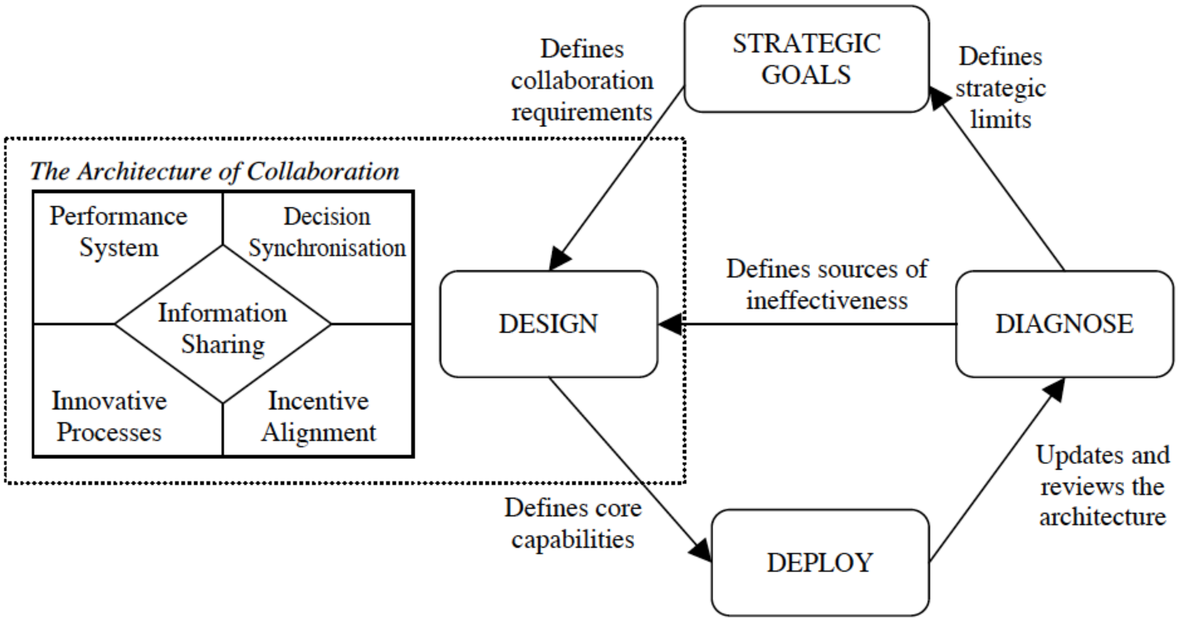

Figure 2.15: A broader view of the design for collaboration (Simatupang and Sridharan, 2008)

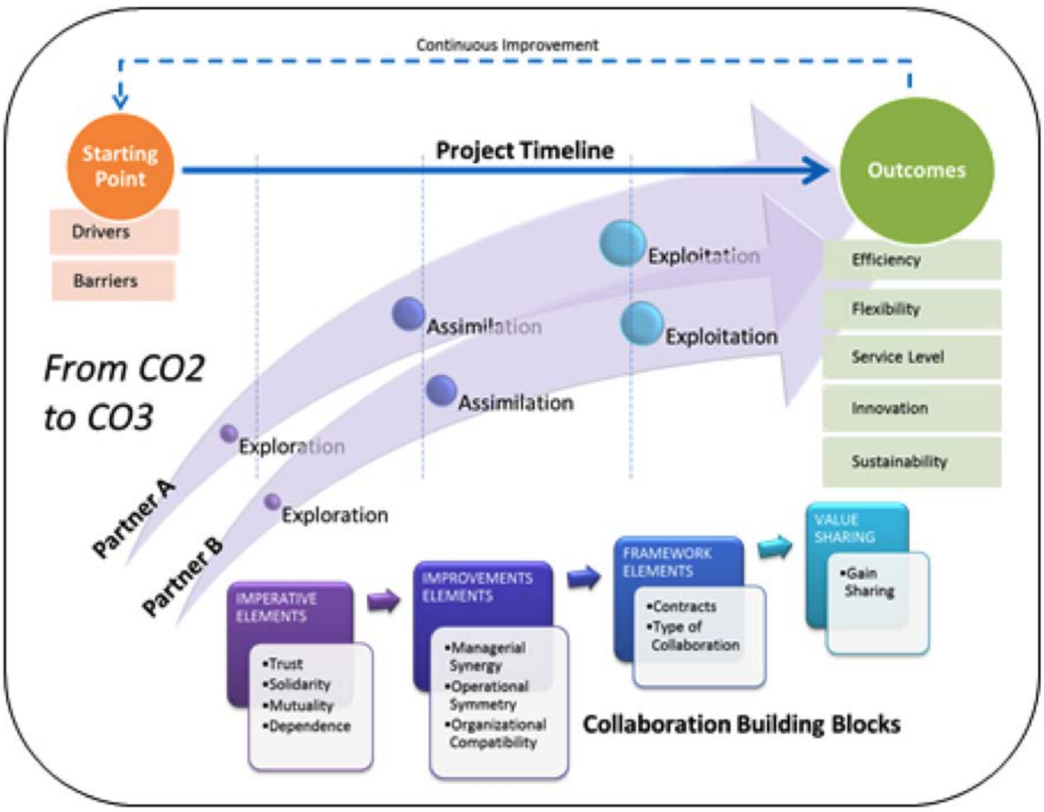

Figure 2.16: Outline collaborative framework (Palmer et al., 2013)

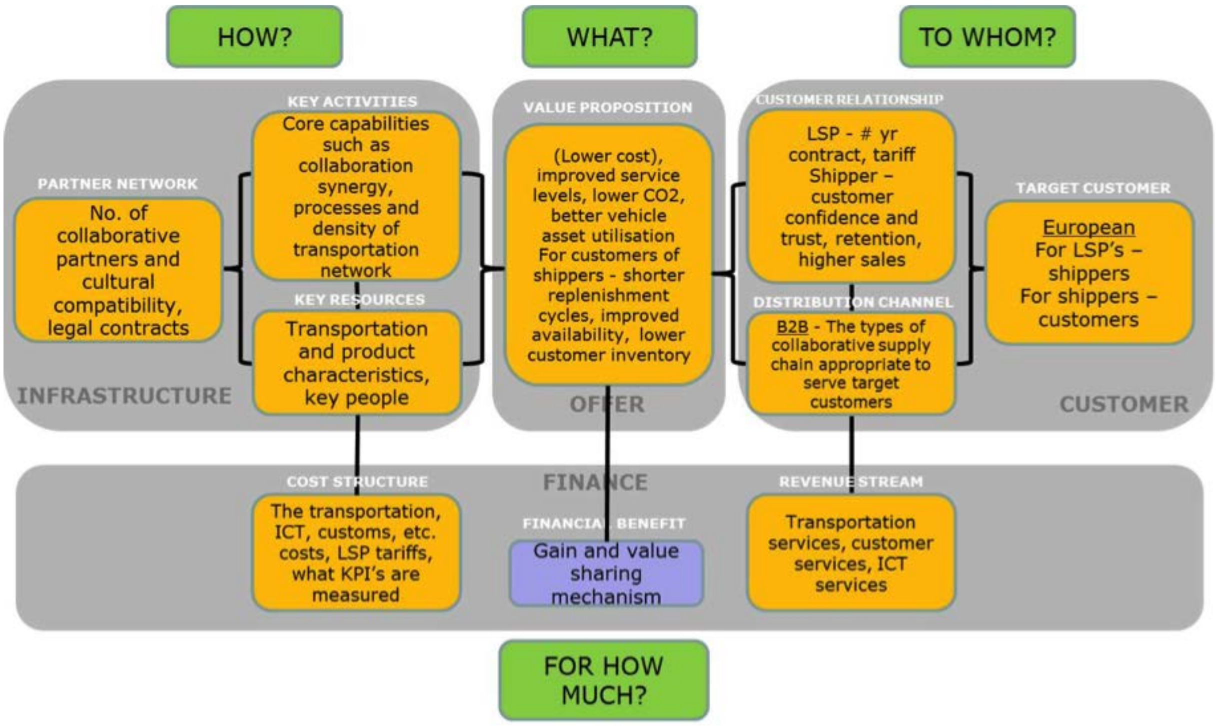

Figure 2.17: Adapted generic collaborative BMC (Palmer et al., 2013)

- The value proposition that represents the benefits of collaboration;
- The infrastructure used to support the collaboration representing the partnership characteristics, the key activities and resources required;
- The type of customers to be served, the relationship and method/distribution channels used to serve the customers;
- The financial elements covering the costs, services and gain sharing mechanisms.

The frameworks presented in this section focus on centralized HLCs, where a centralized organizer/planner is needed, and close integration of independent logistics networks is required. In the next section, we introduce both the centralized and decentralized organizational forms of the HLC in detail, and identify different approaches to construct the sharing mechanism in these kinds of HLCs respectively.

2.7 Two Organizational Forms of Horizontal Logistics Collaboration

In HLCs, strategic and operational decisions are made in order to attain performance objectives. Relative questions thus arise: where and by whom should these decisions be made? And how should the organization structure of the collaboration be adapted?

Thus there are two options for the organizational form: a centralized collaboration system, where a single centralized authority makes decisions on behalf of all the collaborators; or a decentralized collaboration system, which allows collaborators to make their own independent decisions (Chang and Harrington, 2000; Daft, 2009; Khare, 2006).

Current HLCs are mainly organized in a centralized manner, where a third-party organization collects the relative logistics information of all the collaborators, and make centralized decisions on operation execution and coordination among collaborators to improve the global efficiency. In such centralized collaboration systems, operational decisions can be made by applying optimization tools in the collaborative logistics network.

Besides the decision-maker and coordinator functions, the third-party organization also plays the role of gain allocator to distribute the common gain (cost reduction) among all collaborators. Since the gain sharing through side payment has been intensively investigated in cooperative game theory, we adopt the available game-theoretic tools to construct the sharing mechanism for the centralized HLC.

The advantage of the centralized collaboration system is that the logistics operations of all partners are highly coordinated and synchronized, which guarantees the high performance of the collaboration. However, the following drawbacks of the centralized collaboration system make this option infeasible for some cases.

- Ignoring the independence of the collaborators. Centralized decisions may be unacceptable for some members.

- Loss of agility in the dynamic environment. Once a coalition is formed, it is not easy to change the strategy, while the flows and market keep changing.
- Requiring private information revelation, which may be undesirable, especially in logistics collaborations among competitors.
- Both the centralized decision-making by applying optimization tools and the calculation of game-theoretic sharing scheme may induce high computational complexity, which inhibit its application in collaborations with large number of participants.

Thus another option, the decentralized organizational form for HLC, could overcome the obstacles to the implementation of large-scale collaborations. An example is the "*Physical Internet*", the concept of a worldwide-interconnected logistics system that is open to all LSPs and users (Montreuil, 2011). All LSPs and shippers can interconnect their logistics networks with this open logistics system in order to benefit from the synergies lying among the numerous requests delivered in this system, thus the regional and international logistics collaborations can be realized. This collaboration form provides collaboration candidates with a more flexible collaboration environment, where participants could freely enter and quit. And it seems more attractive than the collaboration among several companies since that it is able to exploit the synergies lying among a large number of participants. Thus the participants in the large open network can fully benefit from economies of scale.

The collaboration mechanisms in the centralized and decentralized HLCs will be investigated in the following chapters. In the following section, we present the research objectives of this dissertation.

2.8 Mechanisms for Horizontal Logistics Collaboration

Despite its important advantages, horizontal collaboration is not yet considerably employed in logistics. A survey made in Flanders (Cruijssen et al., 2007a) points out the difficulties for the implementation: find suitable partners and construct feasible collaboration mechanisms. We investigate these issues in both centralized and decentralized HLCs.

In centralized HLCs, the suitable partners are identified by synergy evaluation. In order to cover the partner-identification and the collaboration mechanism issues, we construct a collaboration model, which is a conducting process to facilitate the implementation of the HLC. This collaboration model serves as the guide for an organizer (a third party organization or a LSP) to conduct the HLC from the synergy-generation perspective. Following this model, the organizer identifies the potential collaboration partners with high synergy level, the stable collaboration groups, and the feasible gain sharing mechanism step by step.

Specially in the collaboration model, we focus on the game theoretic investigation of the coalition formation and stability problem and the gain sharing mechanism. There are already several sharing mechanisms actually applied in the collaboration practices, and more in the literature on the application of game theory in logistics. But some of the most important factors are not considered yet in both the practices and game-theoretic sharing models, and most of the papers focus on the collaboration games under restriction assumptions. This would make the current solutions in the literature unfeasible in the collaboration cases. For example, even the most famous sharing mechanism, the *Shapley Value*, may be unstable in some collaboration cases encountered in logistics. And many game-theoretic sharing mechanisms have either ignored the different bargaining power of players, or been too theoretic, too impractical to be applied in real-world cases. Furthermore, as coordination costs arises in the establishment of collaboration relationships, the cost savings in all coalitions decrease and the situation becomes trickier. In that case, many collaboration mechanisms assuming a more favorable game setting will be no longer applicable.

Thus a more comprehensive view of centralized logistics collaboration games is needed, and a generally applicable game-theoretic sharing mechanism, which takes into account some practical factors missing in current solutions will be indispensable for the conducting of HLCs. This dissertation models different collaboration schemes as cooperative games, identifies different collaboration game categories, and proposes a generally applicable sharing mechanism that takes into account coalition stability, players' contribution, and different bargaining power.

In order to implement the decentralized organizational form of HLCs, we choose the combinatorial auction theory as the theoretic basis, and use reverse combinatorial auction based logistics market as the collaboration mechanism in such open logistics systems. In the logistics market, the participants of the open logistics system submit bids on single logistics request or sets of requests according to their preferences, then the system determines a globally cost-efficient allocation of requests. In such system, the participants are free to make independent decisions about on which requests they would like to bid and at what price. The coordination activities among different actors are all realized by market mechanism.

In decentralized HLCs, especially in open logistics collaboration systems, the partner identification is not an issue since the large number of participants provides plenty of collaboration opportunities. We mainly focus on the system design and auction protocol issues in order to promote the feasibility and efficiency of the collaboration mechanism. More specifically, that is to specify how is the collaboration system configuration, and which auction protocols, such as biding rules, market clearing rules, and information revelation policy, are adopted. The aim of the research is to develop an open logistics collaboration system that is of well-specified protocol set to provide feasible collaboration scheme and market-based fair gain-sharing mechanism.

2.9 Conclusion

In this chapter, we illustrated the importance of road transport efficiency to both the national economic development and the cost efficiency for specific enterprises. However, the balance between transport efficiency and delivery frequency is difficult to achieve by current logistics system, since that the requirement imposed by fierce commercial competition of higher delivery frequency and atomized deliveries contradicts with LSPs' consolidation plan. Thus horizontal collaboration has become a major focus for its ability to improve transport efficiency and service quality at the same time.

Then we provided a comprehensive literature review on the HLC, which consists of four most important aspects: the definition of horizontal collaboration, what makes it so charming for enterprises, what inhibits the implementation, and frameworks to guide collaboration conducting. Horizontal collaboration provides competitive advantages for enterprises, but to achieve these advantages, suitable collaboration mechanisms need to be developed. This issue will be investigated in both centralized and decentralized collaborations.

In the first part of this dissertation (chapter 3-5), we investigate the collaboration mechanisms in centralized collaborations. Considering the complexity of multi-agent collaboration, we proposes a collaboration model in the following chapter as the guide to the collaboration conducting, which integrates important function modules such as coalition formation and gain sharing in a step-by-step collaboration process. Also, different collaboration schemes are identified in the following chapter for further game-theoretic investigations.

In the second part of this dissertation (chapter 6), we investigate the collaboration mechanism in decentralized collaborations, which is implemented by a set of collaboration system protocols. We propose the framework of an open logistics system where the transportation requests can be collaboratively delivered by different carriers. The request allocation and gain sharing in this collaborative system are carried out by combinatorial auction mechanism.

CHAPTER 3

Centralized Logistics Horizontal Collaboration Scheme

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3.1 Introduction

In order to overcome some implementation barriers to centralized HLC in an organized manner, we propose a general collaboration model and a tailored collaboration model for the *supply network pooling* (SNP), which is a specific horizontal collaboration modality adopted as the context where we validate our game-theoretic collaboration mechanisms.

This chapter is organized as follows:

Section 2 proposes a general collaboration model for different collaboration forms. It serves as a guide to collaboration conducting. This model is designed for centralized horizontal collaboration, where collaboration activities are arranged and coordinated by an organizer, since this kind of collaboration organization are the most usually adopted and effective according to current horizontal collaboration case studies.

Section 3 introduces the SNP that we consider as one of the possible application areas of our collaboration mechanisms. The simplified optimization model is presented.

Section 4 specifies some details in the general collaboration model to construct a specific collaboration model for the SNP, and indicates the game-theoretic investigations are integrated in which step of the model.

After the proposition of the collaboration model for the SNP, we identify some important factors that have not been widely considered in the literature on the logistics collaboration in order to construct a feasible collaboration mechanism in the model. Section 5 highlights the importance of these factors.

Section 6 concludes this chapter.

3.2 Need for a General Model of Collaboration Process

3.2.1 Centralized organization of horizontal collaboration

The collaboration model proposed in this section is of a centralized pattern, which means there is an orchestrator (a logistics service provider (LSP) or a third-party organization) in charge of the organization of the collaboration and the coordination among collaborators. In this subsection, we show the imperative need for such a centralized collaboration model.

Currently, the advantage of horizontal collaboration has become more and more noticed and appreciated, but the horizontal collaboration cases are still few. There are numerous examples of logistics collaboration in Europe but relatively few are horizontal freight based collaborations. Palmer et al. (2012) listed 25 horizontal collaboration cases in Europe, the country coverage is as illustrated in Figure 3.1.

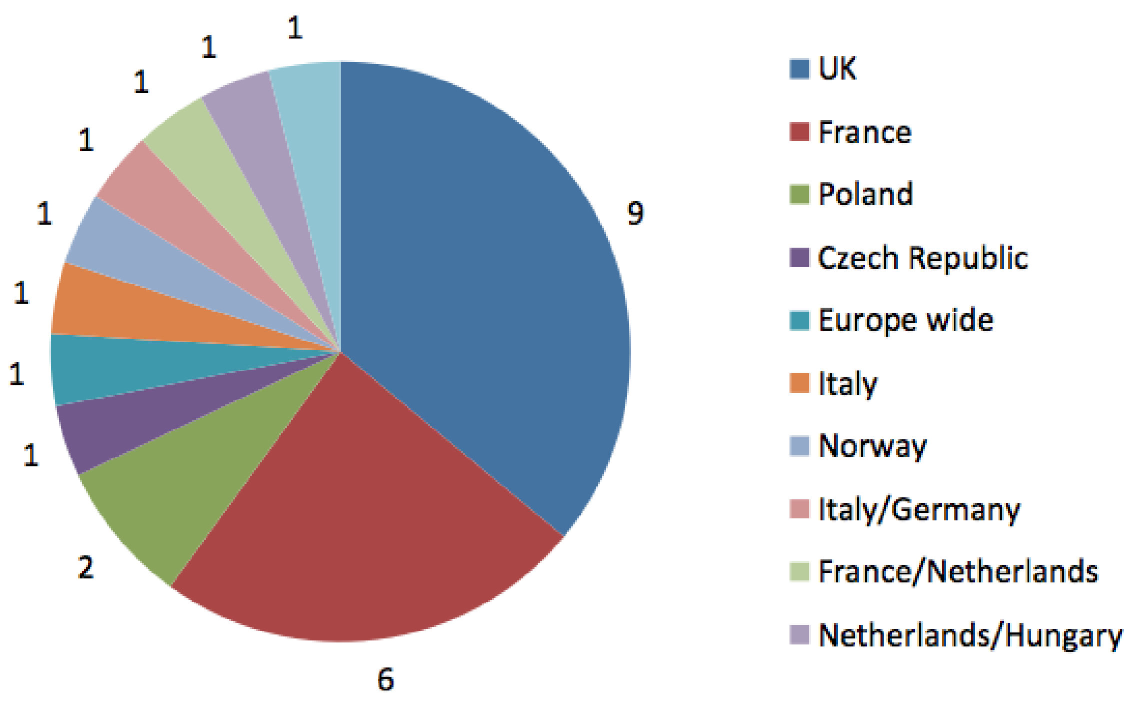

Figure 3.1: Country coverage of horizontal collaboration case studies (Palmer et al., 2012)

All the 25 case studies can be categorized as follows:

- Full-Truck-Load movements with backhauls/fronthauls to reduce empty running - 6 cases

- Consolidation of deliveries to customers using a common LSP - 13 cases

- Consolidation of deliveries to common customers organized by shippers themselves - 1 case

- Co-modal collaboration - 5 cases

We can see that more than half of the case studies (13 cases) were about freight consolidation and were carried out in collaboration with LSPs. Actually, some in the other 12 cases are also conducted with the help of or promoted by third-party organizations.

There are three main reasons for this kind of centralized collaboration. Firstly, most firms subcontract their transport demand to LSPs. With transportation orders from different firms, LSPs have the opportunity to see the complementarity and the synergy lying among the orders if any. In addition, LSPs have better understanding of operational issues and technical know-how for the freight consolidation. Secondly, a common trustee that serves as the organizer of collaboration could bridge the gap of lacking trust among potential collaborators, which removes the impediment to efficient collaboration. At last, as the number of collaborators increases, the centralized organization, where a organizer serves as a hub of communication, could reduce the complexity of coordination and simplify the process of multilateral negotiation. Thus the centralized organizational form can build collaboration out of chaos and fragmentation. Since centralized collaboration requires close integration of collaborators' logistics network and intensive coordination among logistic partners, in order to implement such collaborations, a collaboration model that serves as the guide tool for the organizer is needed.

In the long run, an open HLC platform with a decentralized configuration and a large number of participants may be more efficient and would provide more flexibility for potential collaborators, given that all collaboration-related specifications and rules are finely formulated and standardized. But currently, with all horizontal collaboration cases are still initiatives, a small tailored collaboration group with a centralized organization may be the most feasible organizational form of HLCs.

3.2.2 General model of collaboration process

For a successful implementation of centralized HLCs, a collaboration-conducting process that indicates the necessary steps is needed. A well-planned conducting process improves the effectiveness and the efficiency of the collaboration organization, and also, a gradually standardized and maturated process induces a higher possibility of the successful implementation of the centralized collaboration.

Our work takes into account the collaboration life cycle introduced in Simatupang and Sridharan (2002) in establishing the process, and focuses on the collaboration-relationship-establishing phase, which consists of four steps: the division of collaboration groups, the specification of collaboration mechanism based on synergy evaluation and compatibility assessment, the multilateral negotiation based on the organizer's collaboration-scheme proposition, and the contracting. Based on the similar idea, Cruijssen et al. (2010) propose an insinking procedure that guides LSP to initiate a logistics collaboration. This collaboration procedure tends to form the collaboration among several partners gradually, by adding one collaborator at a time. The collaboration procedure presented here aims at establishing a stable collaboration relationship among potential partners at a time by thoroughly investigating the coalition formation and gain sharing issues beforehand.

Besides the general identification of these four steps, also highly required are the decision-aiding tools such as the collaborative planning tool, which ensures the profitable collaboration outcome, and the collaboration mechanism, which guarantees a feasible organization structure and the incentive to collaborate to achieve the longevity of the collaborative relationship. Both of the two components play crucial roles in the second step of the process. We integrate these two functional modules in the process to propose a general collaboration-conducting model that can be applied to cases with different collaboration forms (pooling, lane matching, warehouse sharing, etc.) as illustrated in 4.3.

At the beginning of the process, we have got a set of candidates who have incentive to find suitable collaboration partners. Then we roughly evaluate the synergy and compatibility among the logistics networks of all candidates to separate them into several "collaboration groups", for

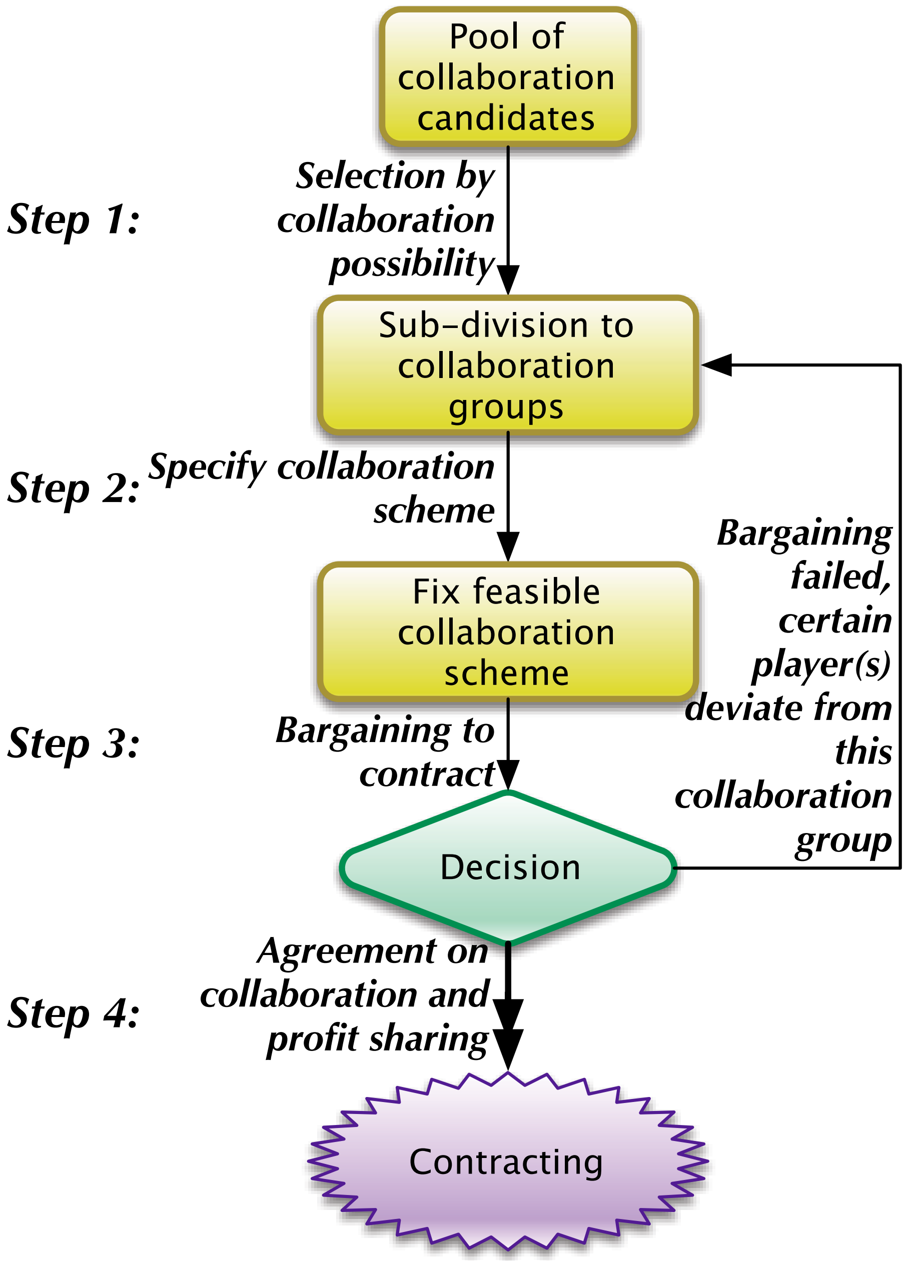

Figure 3.2: General model of collaboration process

example groups of companies operating in different regions. Depending on the collaboration form, a proposition by the organizer that specifies the related collaboration organization, the coordination details and the gain-sharing mechanism (the collaboration mechanism) should be put to the collaborators in the group in the step 2 as the basis of further negotiation. The step 2 is the most complicated one in this model, and the collaboration scheme specified in this step should consist of an optimization model or some other technical tools to find the efficient logistics scheme for collaborators, and a gain sharing mechanism to propose fair profit allocations. Based on the framework thus defined, there will still be some indefinite area left to bargaining. So in the step 3, collaborators try to establish an explicit contract by bargaining. In step 4, there are two possibilities: an agreement is achieved, and the collaboration relationship is finally established; or bargaining fails, someone in the collaboration group deviate, the others move back to step 2.

3.3 Supply Network Pooling: a Specific Modality of Horizontal Collaboration in Logistics

In this dissertation, we aim at developing a collaboration model that can be applied in different centralized horizontal collaboration cases, without specification of the exact collaboration mode. However, in order to verify the feasibility of the collaboration model developed, we need to investigate its application in a concrete logistics collaboration form. In this dissertation we choose the *supply network pooling* (SNP) collaboration (Pan, 2010) as the context of our research. In this section, we introduce the basic concept and the simplified optimization model of the SNP.

As defined and studied in Ballot and Fontane (2010) and Pan et al. (2012), the idea of pooling is the co-design of a communal logistics network for partners (suppliers, clients, carriers, etc.) with a common objective in order to share logistics resources and to improve the performance of logistics as a whole. The motivation is the consolidation of flows on shared facilities. Figure 3.3 illustrates an example of pooling. In this example, all partners (suppliers and retailers) plan their logistics network collaboratively by sharing facilities.

The optimization model used in the SNP is a Mixed Integer Linear Programming (MILP) based on the former works concerning the pooling network design problem. For more detail refer to Pan et al. (2013). Since the MILP model is not our main contribution, only a simplified model is presented here:

$$min: \quad \sum_{i\in O, j\in D} f(x_{ij})d_{ij} + \sum_{i,j\in D, i\neq j} f(x_{ij})d_{ij} + \sum_{i,j\in D, i\neq j} \alpha \cdot x_{ij} \tag{3.1}$$

$$s.t.: \quad x_{ij} = \sum_{k\in K} x_{ij}^{k}; i\in O\cup D, j\in D \tag{3.2}$$

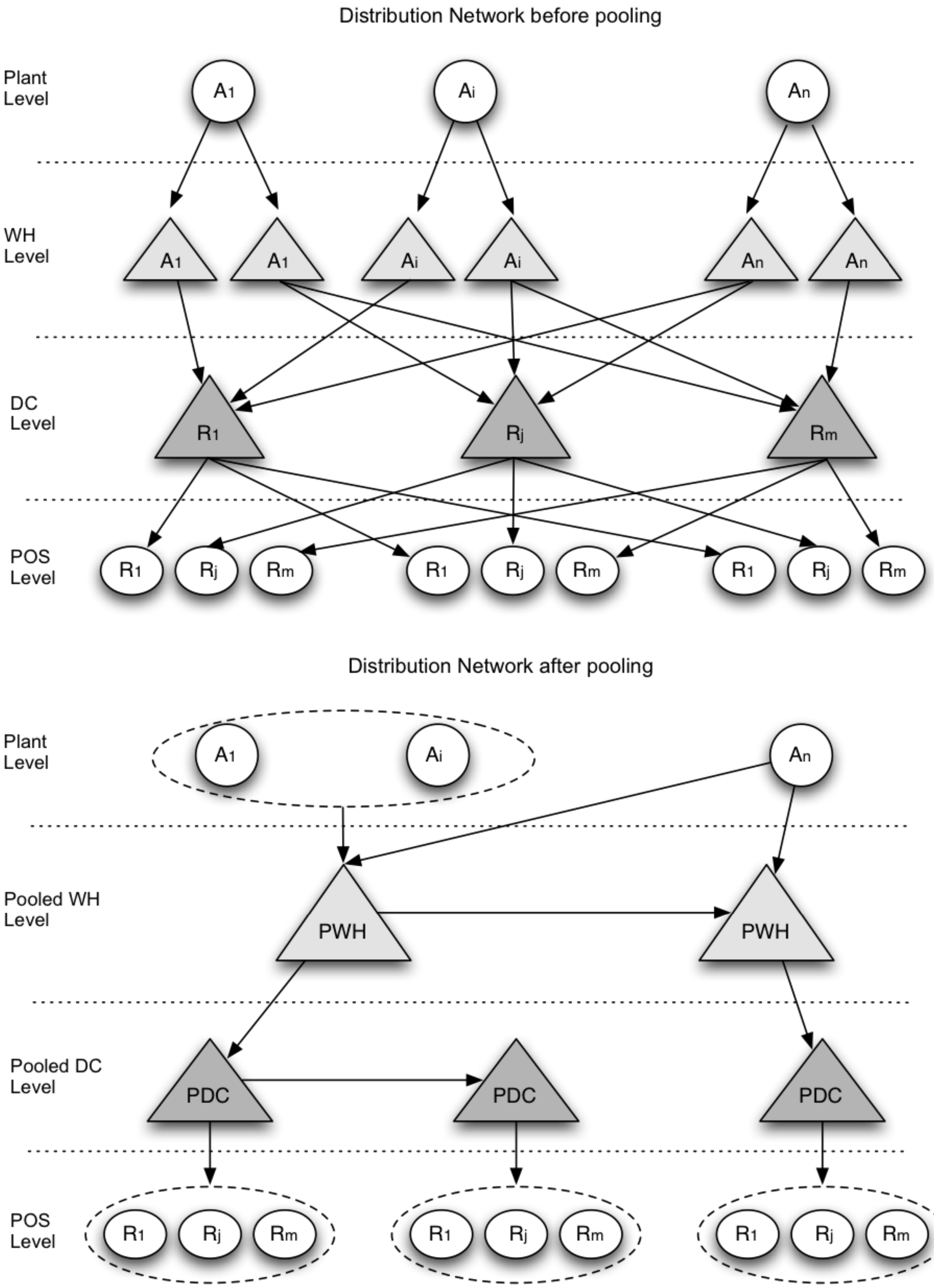

Figure 3.3: Illustration of the supply chains pooling (A_i: Supplier i; R_j: Retailer j;WH: Warehouse; DC: Distribution Center; POS: Point Of Sale)

$$\sum_{j\in D} x_{ij}^k = R_i^k; i \in O, k \in K \tag{3.3}$$

$$\sum_{i\in O} x_{ij}^k + \sum_{i\in D, i\neq j} x_{ij}^k = B_j^k + \sum_{i\in D, i\neq j} x_{ji}^k; j \in D, k \in K \tag{3.4}$$

O and D represent respectively the set of WH and DC. As presented in the example in Figure 3.3, pooling practice permits consolidating the flows to two nearby DC in one shipment. To do this, an added journey is necessary, for example from DC_i to DC_j and the DC_i is thus called a transit point to DC_j. Correspondingly an added transit cost is taken into account and it is calculated by α (€/ transited pallet) multiplied by x_{ij}, which is the number of transited pallet from DC_i to DC_j. K is the set of product; R_i^k and B_j^k are the supply of point $i \in O$ and the demand of point $j \in D$ of product k. x_a^k is the flow of product k on arc a. In particular the transportation cost is calculated as $f(x) \cdot d_{ij}$, where d_{ij} is the distance of arc ij and $f(x)$ in €/km is a piecewise linear function, in which the cost is composed by a fixed cost and a variable cost for each truck used for shipments on the arc.

Given the logistics infrastructure configuration and the orders in the logistics networks as input, this optimization model outputs the optimal collaboration scheme, which specifies how to consolidate and route orders in a pooled network.

3.4 Model of Collaboration Process for Supply Network Pooling

For the implementation of SNP, we define following model in Figure 3.4, which is of explicit details on each decision level.

In this collaboration model, a LSP or third-party organization, serving as the organizer and the communication hub, will play a crucial role. The organizer will be in charge of the organization of the collaboration process, the collection and assessment of collaborators' logistics profiles, the coordination among the collaborators, etc. Assuming that the side-payments among collaborators are used to ensure the final gain allocation, the organizer will also be the side payment implementer. The steps in this model are detailed as follows:

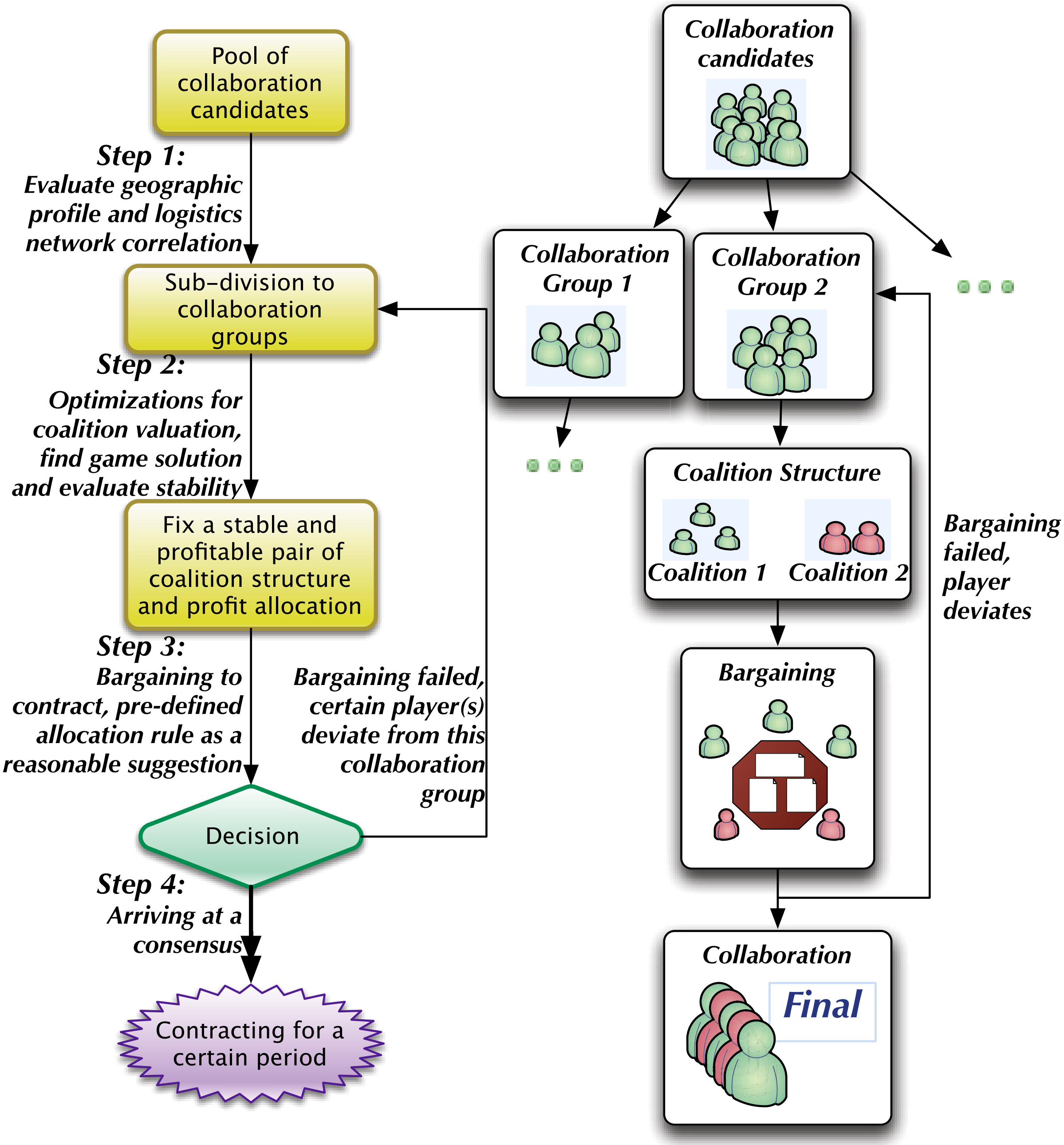

Figure 3.4: A specific collaboration model for the supply network pooling

- Step 1: evaluation of collaboration feasibility

Suppose that a collaboration organizer (a LSP or a collaboration-promoting organization) has a pool of candidates who have incentive to collaborate. To conduct the collaboration by following our model, the first process is to evaluate the feasibility and select collaboration groups from the pool. The criteria highlighted in the literatures are synergy, mutual learning, competition and culture issue.

In the position paper of CO^3 European project (Palmer et al., 2012), the synergy in logistics networks is identified as the most important partner-selection criterion according to the interviewees. In logistics collaborations, synergy mainly arises from geographic proximity, shipment complementarity and coordinability. The complementarity means that the shipments executed by different LSPs are of complement volumes/weights for consolidation, and the coordinability consists in the possibility to consolidate, for example overlapped pick-up and delivery time-windows, alike delivery frequency, etc. Thus these criteria should be examined at the very beginning.

The possibility for mutual learning is another important partner selection criterion. Companies prefer to cooperate with ones who have the know-how or good practices in the area they do not efficiently exploit, or high level of logistics operations to set the benchmark, as Palmer et al. (2012) shows.

Enterprises also try to find partners with similar background and culture, while avoiding collaborating with the competitors. According to Palmer et al. (2012), even though the similarity in background and culture is valuable, the enterprises interviewed have shown a preference for not working with competitors. So even if there are already collaboration cases between competitors (e.g. Institute of Grocery Distribution (2011)), the currently most-preferred partners should be the non-competitors in the same industry.

- Step 2: gain evaluation and establishment of collaboration mechanism

After qualitative selection, the collaboration groups containing compatible potential partners are formed. Then collaborative planning of logistics operations and quantitative investigation of synergy among individual logistics networks will be conducted, and the analysis will support the stable coalition formation decision. Then according to the stable coalition(s) identified, the collaboration model proposes feasible gain-sharing mechanism.

The optimization tool we introduced in the previous section will be applied in this step as a synergy evaluation tool to assess the potential transport cost reduction that can be generated. All possible subsets of all the members in a collaboration group are listed, and considered alternative coalitions. Supply network pooling schemes in all the alternative coalitions are identified by the optimization model. Then the difference between the total cost before pooling and that after pooling in each of the coalitions represents the synergy therein.

After the synergy evaluation, the collaboration mechanism, which consists of the coalition formation and gain sharing issues, is investigated using cooperative game theory as a guidance tool. A suitable coalition structure (CS, may be the grand coalition) is identified according to the results of synergy evaluation and the collaboration context, and the corresponding sharing mechanism is proposed. The detailed game-theoretic investigation will be introduced in the following two chapters.

- Step 3: bargaining on the collaboration details

In the step 2, stable CS and gain sharing mechanism are proposed. Then the collaborators will bargain on the details in the collaboration mechanism and other operational issues based on the previous proposition.

- Step 4: collaboration decision

If a consensus is achieved by collaborators, they contract to move into the execution phase; if not, some in the group deviate and the others turn back to step 2.

Following this collaboration process and specifying the technical details in each step (e.g., the collaboration mechanism in step 2), an organizer will be able to carry out the collaboration project in a well-organized manner.

In the next section, we consider the factors that should be considered in constructing the collaboration mechanism in step 2 of the model.

3.5 Important Factors in Centralized Horizontal Logistics Collaborations

In the collaboration model proposed, what should we take into account in constructing the collaboration? We identify the following three important factors: the bargaining power, the coordination cost (CCs), and the global/individual-optimum collaboration preference. These factors impact either the potential collaborators' decision of participation, or the feasibility of a specific sharing mechanism, and thus should be considered during the game modeling and solving process.

3.5.1 Bargaining power

In current logistics collaborations, most sharing rules are based on the contribution of players (e.g., proportional rules, Shapley value). To some extent this principle is fair. However, in some pooling cases where players have different negotiation positions in practice, the bargaining power of players that is missed in those sharing mechanisms could be important to the stability of game.

In a negotiation, the bargaining power is the ability of a person, group, or organization to exert influence over another party in order to influence the outcome of the negotiation and to achieve a deal which is favorable to themselves. Hamel (1991) describe the bargaining power as the following:

> *"Bargaining power at any point in time within an alliance is a function of who needs whom the most. This, in turn, is a function of the perceived strategic importance of the alliance to each partner and the attractiveness to each partner of alternatives to collaboration."*

In a logistics collaboration, such bargaining power may come from the size, the know-how, the market position, and the small number of alternatives. Such a situation is quite common in logistics activities and between buyers and suppliers. We specify a partner's bargaining power as "the ability to achieve a more favorable gain-sharing allocation for himself" in the context of the centralized HLC.

We give an simple example to show how the bargaining power impacts the gain-sharing outcome, and why we need to model this factor in the sharing mechanism.

Suppose that two carriers *a* and *b* can consolidate their flow, and achieve a transportation cost reduction of 1000 € by contributing equally in this collaboration. If in this pooling case we don't consider the bargaining power difference between them, each of them will get 500 € according to the famous Shapley value. But if we consider that carrier *a* has higher bargaining power over carrier *b* (e.g. *a* has other alternative collaborators while *b* has not), *a* would claims higher share of the cost reduction, and it is quite possible that *b* would accept a reasonable sharing scheme for establishing the collaboration. Thus the bargaining power should also be taken into account in determining the sharing scheme. In addition, we claim that the bargaining power could be very important when there are more than 2 participants in the collaboration, and especially when the coalition consists of collaborators from different sides (supplier, 3PL, or retailer).

3.5.2 Coordination cost

Mittermayer and Monroy (2008) divide the CCs arising in the logistics collaboration into structural and activity-dependent costs, such as IT and logistics facility investment, system integration cost, organization cost for all supporting departments, additional personnel costs, etc. In the SNP context, we define the *coordination costs* (CCs) as the extra costs arising in the pooling collaboration that enables the well proceeding and evolvement of the collaboration. These costs are corresponding to all collaborators and the structure of the collaboration.

In short terms collaboration, for example to decide one collaborative shipment, the impact of CCs is easy to be taken into account. Decider could easily set up the optimum transport plan if it is profitable, or stop the collaboration if not profitable due to the high CCs. most of works in the literature are based on this situation (in most cases the CCs are directly considered in the transport optimization process). However, for collaboration in long terms, i.e. logistics pooling, the current research outcomes could have limits if we consider the possible variation of CCs in the future. Also, since the CCs change in different coalitions, one should take these costs into account to decide with whom he will collaborate, and up to which point the collaboration should be extended. This impacts the collaboration structure. Furthermore, when constructing the sharing mechanism, the CCs should also be considered so as to make the potential collaborators with high CCs have incentive to participate, provided that the collaboration can bring substantial global logistics cost reduction.

3.5.3 Global/individual-optimum preferences

Another factor could be important in logistics pooling is the participants' preference in collaboration relationship. We identify two collaboration preferences, the global/individual optimum ones, which impact the feasibility of a pooling collaboration.

With global-optimum preference, a collaboration will be carried out following a globally optimal planning scheme if it is globally profit-maximizing, even if some collaborators may have better options. Many studies in logistics pooling use this preference type as prerequisite to collaboration. Because, firstly they claimed that the global optimum solution is the best one to the whole party (usually supported by optimization process), and secondly in most case it is possible to arrive at a fair sharing scheme for all participants. The assumptions are true in those cases where the pooling is organized by a very powerful participant. A good example is the consolidation collaboration among subsidiaries. However, in some pooling cases, the assumptions could be invalidated. For example in the case shown in chapter V where no fair or stable sharing scheme can be found (the Core is empty in the language of game theory).

With individual-optimum preference, a collaboration will be put into practice if and only if the collaboration structure and sharing mechanism guarantee that there is no participant has another option that makes him better off. Most spontaneous logistics collaborations fall into this category, especially those with competitors. In particular, individual-optimum preference or global-optimum preference could let collaborators make the same decision in some cases. For example participants with individual-optimum preference will prefer to stay in the global-optimum collaboration if it is also individually profitable.

These two preferences result in different requirements for both the coalition formation and gain sharing schemes. The global-optimum preference expects a collaboration structure that yielding the highest global cost reduction, while collaborators with individual-optimum preference have incentive to collaborate in a way maximizing their own profit. Thus different collaboration mechanisms considering these two preferences respectively should be developed.

3.6 Conclusion

In this chapter, we firstly propose a general collaboration model for different forms of logistics collaboration. Then we introduce the context of our game-theoretic investigation, the supply-network-pooling collaboration, and tailor the general collaboration model for the supply-network-pooling collaboration. In the end of this chapter, we highlight three important factors that need to be considered in constructing the collaboration mechanism in this model.

With the supply-network-pooling optimization tool already developed, we are able to identify the most profitable pooling scheme and the contribution of each collaborator. The remaining work consists of the examination of the coalition formation and the gain sharing issues in the collaboration. That is to find out how to form collaboration coalitions and what kind of gain-sharing mechanism should be constructed to facilitate the implementation of the collaboration.

In the business reality, the coalition formation is mostly intuition or experience based. And widely applied are the gain-sharing mechanisms based on truckload/less-than-truckload tariff or proportional sharing rules (Cruijssen et al., 2007b). However, the examination of the coalition stability and the considerations of the collaborators' real contribution, the CCs, and their bargaining powers are missing in these practical sharing mechanisms, which is not fair and may result in the instability of the coalition thus formed. To identify the existing game-theoretic tools in the literature that could be applied in the supply-network-pooling collaboration, we investigate the cooperative game theory in the following chapter.

CHAPTER 4

Cooperative Game Theory: Tool-box to Construct Feasible Collaboration Mechanisms

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4.1 Introduction

Game theory is being increasingly considered as a decision-aiding tool for collaboration issues. Here, the game is a description of the possible strategic interaction that participants, that is to say players, can undertake by submission to certain constraints and the interest of the actual player (Osborne and Rubinstein, 1994). Consequently, the result of a game therefore depends on the decision taken by each player. To satisfy the decision-making issue, the games theory suggests rational solutions.

Myerson (1997) gives the following formal definition of game theory:

> *"Game theory can be defined as the study of mathematical models of conflict and cooperation between intelligent rational decision-makers".*

Coincidently, Harsanyi (1966) gives definitions of two main approaches of game theory: the non-cooperative and the cooperative. A game is cooperative if commitments (agreements, promises) are fully binding and enforceable. A game is non-cooperative if the commitments are not enforceable. Though the enforceability of commitments in the game may not be the fundamental distinction between cooperative and non-cooperative approaches. As to Aumann (1994), the non-cooperative game theory is applied in cases where players have contradiction on individual objectives, such as in the *zero-sum game* or some other strategic form game. The *zero-sum game* is also called *strictly competitive game*, where the gain (or loss) of a participant is exactly balanced by the losses (or gains) of the other participant(s). The non-cooperative game theory intimately concerned with the processes and rules defining a game, and the player strategic choices that interact and induce different game outcomes.

The cooperative game theory is applied in cases where potential collaborators can achieve more benefit by collaborating than staying alone. In that case players have incentive to achieve binding commitments for a win-win outcome. Such collaboration among game players is often organized in terms of binding commitments. The cooperative game theory abstracts away from game rules, and focuses on the coalition formation and gain sharing issues.

In this chapter, basic cooperative game theory concepts will be introduced, and corresponding denotations will be given. All the investigations of cooperative logistics games will be based on these concepts and denotations.

This chapter is structured as follows:

Section 2 is devoted to a literature review on cooperative game theory, where basic concepts, two different approaches to game solutions, and farsighted stability investigations are introduced.

In Section 3, we introduce a terminology framework of cooperative game theory. The most important game-theoretic concepts are illustrated in detail based on this terminology system. We focus on two most fundamental problems: coalition formation and gain allocation.

Section 4 highlights some implementation issues of the logistics horizontal collaboration that have not been fully addressed in cooperative game theory. This kind of ineffectiveness of the current game-theoretic solutions imposes the requirement for new collaboration mechanisms.

Section 5 concludes this chapter. At first, we briefly summarized the useful theoretical tools that we identified in the literature. Then according to the unfeasibility of current solutions and the specific requirement of logistics-horizontal-collaboration implementation, we identify the necessary properties that a feasible gain sharing mechanism should have.

4.2 Literature Review on Cooperative Game Theory

Gain sharing and *coalition formation* are two fundamental components of horizontal logistics collaboration mechanisms, where "gain" represents the utility generated in collaboration, and "coalition" represents a group of players (potential collaborators). These two problems are intensively addressed in cooperative game theory. The coalition formation focuses on which coalitions should form to maximize the total utility generated by collaboration under stability constraint, while the gain sharing emphasize the fairness of utility allocation, which provoke incentive to stable long-term collaboration.

The "utility" concept is one of the most important concept in games theory, since it is the focus of both gain sharing and coalition formation problems. This term, mainly used in economics, can be defined as the satisfaction obtained from an object or service (Neumann and Morgenstern, 1944). In a concrete logistics collaboration case, it could be a compound amount of benefits achieved in the collaboration. In addition, the utility is transferable or not transferable between players in a given game. Kannai (1992) defines *transferable-utility games* (TU-game) as games in which the sum of all player payoffs equals the total utility generated by the collaboration. Our investigation is based on this TU-game setting.

Nagarajan and Sosic (2008) divide cooperative game theoretic approaches into multivalued-mapping and single-valued-mapping approaches, which are also called Core-like and value-like approaches. Multivalued-mapping approaches, such as *Core* and *coalition structure Core* (CS Core), give a set of possible utility allocations for coalition members. These allocations conform to some general properties of feasible solution, thus can be considered as "the set of more feasible propositions". Since that Core-like approaches only propose a set of solutions, without identifying a specific proposition, they usually serve as stability criterions; and value-like approaches, such as *Shapley value* (SV), try to identify a specific allocation by a set of axioms, usually serve as allocation rules.

4.2.1 Core-like approaches

Among all multivalued-mapping approaches, the *Core* and the *coalition-structure Core* (CS Core) may be the best-known stability concepts. Here, the coalition structure (CS) consists of separately formed independent coalitions, with each of all the players in a game staying in exactly one coalition. Such kind of collaboration structure is formed because sometimes it is not desirable or not the most profitable that all players collaborate in one big coalition. The Core and the CS Core address the stability of the grand coalition (the coalition containing all players in the game) and an arbitrary CS respectively. The *Core*, firstly introduced by Gillies (1959), contains all stable allocations, which guarantee that there is no coalition can benefit by jointly deviating from the grand coalition. Its main drawback is that the Core may be an empty set in some games. Bondareva (1962) and Shapley (1967) independently describe a necessary and sufficient condition for the non-emptiness of the Core of a cooperative game. Specifically, the Core of a game is non-empty if and only if the game is balanced (Shapley, 1967). But it is not sure that some kind of logistics collaboration games will always be balanced (due to different level of synergy lying in partial and global collaborations). And in addition, to verify the balancedness of a game is also difficult, especially for games with a large number of players. Aumann and Dreze (1974) generalize the Core solution concept to games with CS, i.e. the *CS Core*. Similarly, given a CS, the CS Core contains all allocations that can guarantee that there will be no incentive to deviate from this CS for any of the players. Aumann and Dreze (1974) prove that a necessary condition for the non-emptiness of the CS Core of a game is that the CS formed is the optimal one. "Optimal" means this CS can generate highest global profit. Thus in terms of Core stability criterion, the optimal CS is the most stable one among all possible collaboration structures.

The emptiness of the Core in some specific games is one of its main disadvantages. Shapley and Shubik (1966) introduce the *ε-Core*, which uses a constrain-relaxing (or tightening) factor ε to obtain a adjusted Core. When the Core of a game is empty, one can use large enough positive ε to relax the Core constraints and to find a non-empty ε-Core, which contains the relatively stable allocation solutions for the game. In that case, the ε value can be interpreted as the level of opposition against the grand-coalition stability. Similarly, a non-empty *ε-CS-Core* can always be found by using a large enough ε to relax the CS Core constraints. Maschler et al. (1979) formally defines the *least Core* as being the ε-Core with smallest possible ε value so that the ε-Core is not empty. For games with empty Core, this solution can be interpreted as the allocation set that contradicts the least with Core stability.

The *bargaining set* is another well-known Core-like solution concept, which was introduced by Aumann and Maschler (1961); Davis and Maschler (1963); Shubik (1967). Especially, Aumann and Maschler (1961) originally discovered the *objection* and the *counter-objection* concepts, which are two fundamental theoretic elements in the development of bargaining set. The *objection* represents the argument illustrated by a player during the bargaining process in order to refuse current allocation and try to get a higher share of total utility in the current coalition; while the *counter-objection* represent the argument that the other players in the coalition have to refute the objection. Maschler (1992) describes these two concepts in the following concrete bargaining procedure:

> *"...when a player expresses a justified objection, it should be interpreted as if he is saying to the other player: "I like you, and want to be with you in the coalition, but you are getting too much. In fact, not that I really want to leave you, but I can take my business elsewhere and earn more. If you try to find other partners you will find yourself losing. So why shouldn't you give me some of your share and we will both be happy?" Expressing an unjustified objection is not convincing. By expressing a counter-objection, the other player is in fact saying: "I like you too in our coalition, but I do not feel that I should compensate you. Even if you move away, I can still protect my share without you."*

Clearly, the bargaining set contains the Core (or CS Core) for each specific CS, since there is no objection for Core (or CS Core) allocation. In fact, many solution concepts (such as kernel (Solymosi, 1999), nucleolus (Schmeidler, 1969)) have intersection or some kind of correlations with the *Core* concept, which makes the *Core* one of the most approvable and acceptable solution concepts in cooperative game theory.

4.2.2 Farsighted stability

These solution concepts introduced in the previous subsection are criticized to be myopic, since they take into account only one-step deviation. In fact, all coalition members who want to deviate from current CS, when making the final strategical deviation choices, should take into account the other players' strategical response to their deviation. Suppose a CS denoted by $P = \{S_1, S_2, ...S_k\}$, and there is a coalition $S_i \notin P$ who can be better off by deviating from P. For a myopic view of stability, since the coalition S_i has incentive to deviate, CS P is not stable. However, we should consider further deviations. Any deviation would trigger a sequence of deviations, which may end with an outcome where the initial deviators, members of S_i, receive lower payoffs than in initial CS P. In such case, if members of S_i were farsighted enough, they would prefer to not deviate in the first place. Thus CS P, non-stable in the myopic view, may prove to be stable in farsighted sense. Thus we come to a conclusion that the stability of the grand coalition or some specific CSs that are not Core-stable (or CS-Core-stable) may be supported by farsighted coalition stability investigation.

A solution concept that examine the coalition stability by farsighted is *largest consistent set* (LCS), introduced by Chwe (1994). The main idea of this solution concept is the introduction of indirect domination relationships as the criteria in stability investigations. He defines the LCS as follow:

> *"I define the largest consistent set, a solution concept which applies to situations in which coalitions freely form but cannot make binding contracts, act publicly, and are fully farsighted in that a coalition considers the possibility that once it acts, another coalition might react, a third coalition might in turn react, and so on, without limit".*

It is criticized to be too "inclusive", so Xue (1998) and Mauleon and Vannetelbosch (2004) proposed refinement of LCS in their works. Konishi and Ray (2003) proposed a dynamic approach to CS stability, the *equilibrium process of coalition formation* (EPCF). By allowing all moves to take place in real time, as it were, the definition of the EPCF, where farsighted discount factor is introduced, allows to bridge the gap between myopic notions of stability (such as those implicit in the Core or the bargaining set) and the more recent definitions based on farsightedness (such as those in Aumann and Myerson (2003), Bloch (1996), Chwe (1994), Mariotti (1997), Ray and Vohra (1997), Ray and Vohra (1999) and Xue (1998)) by simply changing the discount factor of players. Extreme myopia would correspond to a discount factor of zero, while extreme farsightedness would be approximated as the discount factor converges to unity. This approach can verify the stability of CS Core elements by farsighted arguments, while in the other hand, can support some farsighted stable grand coalition (or some farsighted stable CS), which is not in the Core (or CS Core), as stable outcome. But to find this EPCF, specific algorithm for computing fixed point in this model should be developed. In spite of the persuasive reasoning of EPCF model, its applicability in collaborative games with large number of players remains unclear.

4.2.3 Value-like approaches

Shapley (1952) introduced his famous *Shapley value* (SV), which is a representative allocation rule. It is the player's average contribution to all possible coalitions, and the sum of all players SVs equals the utility generated in the grand coalition. This makes it can be applied as a gain sharing mechanism in TU games. It can be generalized in the collaboration with CS. The CS SV is the aggregation of the SV allocation vectors in all sub-coalitions in CS. SV conforms five axioms: *individual fairness, efficiency, symmetry, additivity*, and *null player*. *Symmetry* axiom means that all players in the game are treated equally. But in business reality, companies possess different bargaining power, which comes from company size, market share or some other aspects, so it will be more realistic, weighted allocation rules that take this into account.

Monderer and Samet (2002) construct an explicit theoretical framework for variations on SV, and the *weighted Shapley value* (WSV) introduced by Shapley (1952, 1953) alongside the standard SV is re-examined in this framework. In WSV, the *symmetry* axiom is relaxed by considering players' different weights, which firstly assumed to be regarded as bargaining power in cooperative games. Kalai and Samet (1987) axiomatize this allocation rule. Monderer et al. (1992) prove the *monotonicity* of the WSV in convex game, but this does not hold for general cooperative games. The monotonicity mentioned here means that when a player's weight is increased, while keeping the other players' weights unchanged, the player's payoff in the given game increases. As Owen (1968) has shown, the weights in the construction of WSV cannot be interpreted as a measure of power, but players' delay to reach the grand coalition, which induces that in some games, when one player's weight increases while keeping other players' weights unchanged, the payoff of this player may decrease. Haeringer (2006) propose another way to introduce players' weights in the SV, which is named *modified weighted Shapley value* (MWSV) and is monotonic with respect to player weights. The main drawback of this work is that it may allocate negative payoffs, thus non-stable in logistics collaboration cases.

In this section, we overviewed the different approaches in cooperative game theory to collaboration issues. In order to understand these approaches in detail, we introduce the terminology and the mathematical formulations of important concepts in the next section.

4.3 Terminology and Important Concepts of Cooperative Game Theory

4.3.1 Definition of cooperative game and game properties

A cooperative game can be denoted by $G = (N, v)$, where N, the grand coalition, is the set of all potential collaborators called "*players*" in cooperative games, and v is the value function which is the utility difference between the singleton status where no collaboration among members of a coalition and the collaborative scheme in the coalition. In this dissertation, we consider the *saving game*, where the value function v represents the cost savings in collaboration. Coalition S is a subset of N. The collection of all coalitions S that $S \subset N$ is denoted by Ω_N, and the number of coalitions in Ω_N is 2^n ($|\Omega_N| = 2^n$). The number of the members in S is denoted by $|S|$ that $|S| \leq n$. For each $S \subseteq N$, we have $v(S)$ that gives the common gain created by S, thus $v(S)$ represents the synergy lies in the coalition S. We use $v(P)$ to denote the sum of savings achieved in the CS $P = \{S_1, S_2, ...S_k\}$, such that $v(P) = \sum_{l=1}^{k} v(S_l)$.

Definition 4.1. The game $G = (N, v)$ is **super-additive** if the value function v satisfies equation (4.1)(Shapley, 1971).

$$v(S) + v(T) \leq v(S \cup T),\ \forall S, T \subseteq N \textit{ and } S \cap T = \emptyset \tag{4.1}$$

It signifies that the two separate coalitions can create at least as much value if they form one large coalition.

Definition 4.2. The game $G = (N, v)$ is **convex** if the value function v is **supermodular** (4.2)(Shapley, 1971).

$$v(S) + v(T) \leq v(S \cup T) + v(S \cap T),\ \forall S, T \subseteq N \tag{4.2}$$

Driessen (1988) shows that the **supermodularity** of v is equivalent to (4.3):

$$v(S\cup\{i\})-v(S)\leq v(T\cup\{i\})-v(T),\forall S\subseteq T\subseteq N\{i\},\forall i\in N \tag{4.3}$$

That means the incentives for joining a coalition increase as the coalition grows. The *superadditive* games and *convex* games have some good properties that make them easier to solve. We will detail this in the following two sections.

A cooperative game with an arbitrary coalitional structure P can be denoted by $G=(N,v,P)$, where CS P is a partition of N into coalitions, *i.e.*, $P=\{S_1,S_2,...,S_k\}$ where for all $l\in\{1,2,...,k\}$ we have $S_l\subseteq N$, $\bigcup_{l=1}^{k}S_l=N$, and $(i\neq j)\rightarrow S_i\cap S_j=\emptyset$. Noting that we also take $\{N\}$ as a special CS, the set of all possible CSs $\mathscr{P}=\{P_1,P_2,...\{N\}\}$. Thus specially, we have game $G=(N,v,\{N\})$, abbreviated by $G=(N,v)$, as the cooperative game in the grand coalition. A cooperative game with a CS other than the grand coalition means that the collaboration will be organized separately in different coalitions. All players collaborate only with the members in the same coalition and share the cost savings generated in the coalition.

4.3.2 Stability of coalition formation

Before introducing the most important Core-like solutions, we present some basic concepts.

Definition 4.3.

- An **allocation** x is a vector $\{x_1,x_2,...x_n\}$ with elements $x_i(i\in\{1,2,...n\})$ that indicate the corresponding payoffs for players i in a game $G=\{N,v,P\}$;
- An allocation $\{x_1,...x_n\}$ is **individual rational** if $x_i\geq v(i)\forall i\in N$;
- An allocation $\{x_1,...x_n\}$ is **efficient** if:
  - for $G=(N,v,\{N\})$: $\sum_{i=1}^{n}x(i)=v(N)$;
  - for $G=(N,v,\{S_1,S_2,...S_k\})$: $\sum_{i=1}^{|S_l|}x(i)=v(S_l)\,\forall j\in\{1,2,...k\}$

Definition 4.4. An **imputation** is an efficient and individually rational allocation.

An allocation is a concrete proposition about how to share the gain in collaboration relationship. Specially for a coalition S, we have $x(S)=\sum_{i\in S}x_i$. The imputation set is a refinement of the allocation set, which eliminates the obviously unreasonable allocations. All imputations guarantee that each player will achieve more cost savings than what he can achieve by himself (zero in formalized games), and the savings in a coalition are shared out by the members in the coalition. The set of all imputations of a game $G = (N, v, P)$ is denoted by $I(N, v, P)$, and we abbreviate the imputation set of a game $G = (N, v, \{N\})$ by $I(N, v)$.

The common idea of Core-like solutions is that they try to identify a set of imputations that can make a predetermined CS stable. Thus the Core-like approaches can also be used to verify the stability of an arbitrary CS: given an CS, if the Core-like approach can find an non-empty set of imputation, that means this CS satisfies the corresponding stability criteria.

Definition 4.5. The **Core** of game $G = (N, v)$ is defined by equation 4.4.

$$Core(N, v) = \{x | \sum_{x_i \in x} x_i = v(N) \text{ and } x(S) \geq v(S) \; \forall S \subseteq N\} \tag{4.4}$$

The Core is the set of all allocations that share out the cost savings in the grand coalition and make every coalition and individual get more than they can achieve by deviating from the grand coalition. As Kannai (1992) illustrated, It is the set of all feasible payoff vectors that no player or coalition can improve upon by acting alone. Thus receiving a Core allocation, no one in the grand coalition will have incentive to deviate.

Aumann and Dreze (1974) introduce the Core for games with arbitrary CS, named *CS Core*. Given a CS, the CS Core is the set of allocations that makes no one in the CS have incentive to deviate.

Definition 4.6. The **CS Core** of $G = (N, v, P)$ where $P = \{S_1, S_2, ...S_k\}$ is defined by equation 4.5.

$$CS\,Core(N, v, P) = \{x | \sum_{i \in S_l} x_i = v(S_l) \; \forall \; S_l \in P, \text{ and } x(S) \geq v(S) \; \forall \; S \subseteq N\} \tag{4.5}$$

The CS Core stability guarantees the players' preferences to the current CS in comparing with all other possible CSs in the game.

The common constraint set in the definitions of Core and CS Core is defined as *collective rationality*:

Definition 4.7. An allocation $x = \{x_1, x_2, ...x_n\}$ is **collectively rational** if $x(S) \geq v(S)\ \forall S \subseteq N$.

Then combining with the *imputation* definition previously presented, we come to a general Core definition for games with an arbitrary CS $G = (N, v, P)$ where $P \in \mathscr{P} = \{P_1, P_2, ...\{N\}\}$.

Definition 4.8. The *general Core* of $G = (N, v, P)$ is defined by equation 4.6.

$$G - Core(N, v, P) = \{x | x \textit{ is } \textbf{collective rational} \textit{ and } x \in I(N, v, P))\} \tag{4.6}$$

The general Core allocations satisfy the *collective rationality* and the *efficiency*. Intuitively, the Core allocations guarantee that the payoff for each coalition (or individual) is greater than what the coalition (or individual) can obtain by itself, thus no coalition (or individual) will have incentive to deviate from the CS to form another coalition that $S \notin P$.

Definition 4.9. The grand coalition (or a CS) is said to be **stable** or **Core stable** if the corresponding G-Core is non-empty.

The Core of some games may be an empty set. Shapley (1971) proves the following theorem about the non-emptiness of the Core:

Theorem 4.1. *A game $G = (N, v)$ is convex is a sufficient condition for the non-emptiness of $Core(N, v)$.*

But the convexity is too exigent for logistics collaboration games. In the context of logistics collaboration, the savings resulting from the participation of a new player may decrease as the collaboration group grows, since the synergy among logistics flows are gradually reaped. And even in super-additive games, the Core may be empty. In many games, the stability of the grand coalition cannot be guaranteed. Thus we need to investigate the stability of collaboration structure in a more general setting, and try to identify the stable CSs. Aumann and Dreze (1974) proves a necessary condition for the non-emptiness of the CS Core in a game.

Theorem 4.2. *A necessary condition for the non-emptiness of the CS Core of a game $G = (N, v, P^*)$ is that $v(P^*) \geq v(P_l)\ \forall P_l \in \mathscr{P}$.*

The CS Core of a game is non-empty only if the CS formed is the optimal one. "Optimal" means this CS can generate highest global cost savings. In the sense of CS Core stability, the optimal CS is the most stable. Even if the CS Core is empty, in considering that the optimal CS can achieve the highest global cost saving, which leaves more leeway for the side payment aiming at a global acceptable solution, it is more stable than other CSs. Rahwan and Jennings (2008) developed an improved dynamic programming algorithm to find an optimal CS. This algorithm is efficient enough for our case scale.

4.3.3 Farsighted stability of Core allocations

In this section, we prove that the *G-Core* is credible stability guarantee that is also valid in farsighted points of view.

Konishi and Ray (2003) introduce a dynamic approach to the stability of CS, named *equilibrium process of coalition formation* (EPCF). Denoting the set of all possible CS P by $\mathscr{P}$ that $\mathscr{P} = \{P_1, P_2, ...\{N\}\}$, the *process of coalition formation* (PCF) is a transition probability $p : \mathscr{P} \times \mathscr{P} \to [0,1]$ (so that $\sum_{P_k \in \mathscr{P}} p(P_i, P_k) = 1, \forall P_i \in \mathscr{P}$). Based on a fixed allocation rule, a PCF p induces a value function $v_i(P_k, p)$, which is used to evaluate farsighted players' CS preference. A PCF is *equilibrium* if transition probability and players' preference are consistent in this PCF. EPCF can be interpreted in the following way. A PCF induces value function $v_i(P_k, p)$ based on the given allocation rule, while the value function, interpreted as players' farsighted estimation of total payoff throughout the PCF, make players have incentives to move to profitable CS according to their preference, no matter whether such moves are consistent or not with the PCF. An EPCF is such equilibrium: EPCF p^* can induce a value function that can in turn ensure this EPCF.

Denoting the set of all PCFs by $\mathscr{F}$, they construct a set mapping $\phi : \mathscr{F} \to \mathscr{F}$. It is proved by Kakutani fixed point theorem that a fixed point $p^* \in \phi(p^*)$ exists and is an EPCF. In such an EPCF, if there exists absorbing state (or CS) P_i that $p(P_i, P_i) = 1$, which means that no farsighted players have incentive to deviate, we can confirm that P_i is a stable CS.

We can confirm the farsighted stability of G-Core elements by such EPCF approaches. A

PCF is *deterministic* if $p(P_i, P_j) \in \{0, 1\}, \forall P_i, P_j \in \mathscr{P}$. Let x_i^P denote i's payoff in P, we have following definition of *strong Core state*:

Definition 4.10. A **strong Core state** is a CS P such that there is no coalition S with $x_i^S \geq x_i^P \ \forall\, i \in S$ and for at least one player, $x_i^S > x_i^P$.

Konishi and Ray (2003) proves the following theorem:

Theorem 4.3. *If P is a* ***strong Core state*** *of a value function, then there is a threshold value of the discounter factor. With the discount factors bigger than this threshold value (the players are farsighted enough), there exist a deterministic EPCF with P as its* ***unique absorbing state****.*

This theorem means that if a CS P is a strong Core state and the players are farsighted enough, P will be the only stable CS in the farsighted point of view. We give the proof of the following lemma:

Lemma 4.4. The non-emptiness of the corresponding G-Core is the **sufficient and necessary condition** for a CS P to be a strong Core state.

Proof.

- At first, we prove the **sufficiency**. Let x^P be a G-Core allocation, and x^S be an allocation in coalition S. The non-emptiness of the G-Core induces that $\sum_{i \in S} x_i^P \geq v(S)$, so that there is no such coalition S with $x_i^S \geq x_i^P \ \forall\, i \in S$ and for at least one player, $x_i^S > x_i^P$. Thus the CS P is a strong Core state and the sufficiency is proved.

- Then we prove the **necessity**. If the G-Core is empty, there exist coalition(s) S that $v(S) \geq x(S)$, and allocation(s) x^S that $x_i^S \geq x_i^P \ \forall\, i \in S$ and for at least one player, $x_i^S > x_i^P$. Thus the CS P is not a strong Core state. The necessity is proved.

□

We have the following theorem:

Theorem 4.5. *Given that the players are farsighted enough, the non-emptiness of the G-Core is the* ***sufficient and necessary condition*** *for the existence of a deterministic EPCF with the optimal CS P^* as its* ***unique absorbing state****.*

That means if the G-Core of a game is non-empty, the optimal CS P^* will be the final preference for all players in the game from the farsighted point of view.

4.3.4 Game-theoretic allocation rules

Due to the emptiness possibility and the non-uniqueness of Core-like solutions, the value-like solutions, especially the SV, are more intensively addressed for analyzing practical collaboration schemes.

At first, we introduce the *marginal contribution* concept:

Definition 4.11. The **marginal contribution** of a player i to a coalition S that $i \in S$ is $v(S) - v(S \backslash \{i\})$.

The SV is a solution concept evaluating the deserved payoff of player i according to its marginal contributions to all the subsets of $N \backslash \{i\}$. This concept is originally proposed in Shapley (1952). In a TU-cooperative game $G = (N, v)$, the SV is a payoff vector $\phi(v) = (\phi_1(v), \phi_2(v), \ldots \phi_n(v))$ satisfying four axioms: *efficiency*, *dummy players*, *symmetry* and *linearity*, which are axiomatized by Hart et al. (1997).

Axiom 4.1.

- **Efficiency**: $v(N) = \sum_{i \in N} \phi_i(v)$;
- **Dummy players**: If $v(S \cup \{i\}) = v(S) \, \forall S \subseteq N$, $i \in N$ but $i \notin S$, then $\phi_i(v) = 0$;
- **Symmetry**: If $v(S \cup \{i\}) = v(S \cup \{j\}) \, \forall S \subseteq N$, *and* $i, j \in N$ but $i, j \notin S$, then $\phi_i(v) = \phi_j(v)$;
- **Linearity**: if $(v+w)(S) = v(S) + w(S)$, then $\phi(v+w) = \phi(v) + \phi(w)$;

It has been proven that there is always a unique solution that satisfies all four axioms, i.e. the SV $\phi(v)$. For a game $G = (N, v, \{N\})$, it can be calculated by formula (4.7):

$$\phi_i(v) = \sum_{S \subseteq N; i \in S} \frac{(|N| - |S|)! \cdot (|S| - 1)!}{|N|!} \cdot [v(S) - v(S \backslash \{i\})], \quad \forall i \in N. \tag{4.7}$$

As shown in the formula above, it is easier to calculate than Core-like solutions, and the SV of some special game have favorable properties.

Theorem 4.6. *For any super-additive game, the SV is a stable imputation whether in the Core or in the farsighted stable set (Béal et al., 2008).*

The SV concept can also be generalized in games with CS. The CS SV is the aggregation of the SV allocation vectors in all sub-coalitions $S_i \in P$. Denote player i's SV in game $G = (N, v, \{N\})$ by ϕ_i^G, the player i's CS SV in game $G = (N, v, P)$ is his SV $\phi_i^{G_l}$ in the decomposed game $G_l = (S_l, v, \{S_l\}), S_l \in P$ and $S_l \ni i$.

The CS SV ϕ^G in a game $G = (N, v, P)$ where $P = \{S_1, S_2, ...S_k\}$ can be calculated by formula (4.8)

$$\phi_i^G(v) = \sum_{S \subseteq S_l \in P; S \ni i} \frac{(|S_l| - |S|)! \cdot (|S| - 1)!}{|S_l|!} \cdot [v(S) - v(S \backslash \{i\})], \qquad (4.8)$$
$$\forall \{i, S_l\} \; that \; i \in S_l \in P.$$

The *Symmetry* axiom that CV satisfies means that all players in the game are treated equally. But in business reality, companies possess different bargaining power, which comes from company size, market share or some other aspects, so it will be more realistic that weighted allocation rules are adopted in collaborations to take different bargaining power into account.

The WSV is introduced by Shapley (1952, 1953) alongside the standard SV. In WSV, the *symmetry* axiom is relaxed by considering players' different weights, which can be regarded as bargaining power in real world collaboration context. Then we introduce the technical details of the WSV.

Definition 4.12. An **unanimity game** is a game $G = (N, u_S)$ where $u_S(T) = 1 \; if \; T \supseteq S$, and $u_S(T) = 0$ otherwise (Monderer and Samet, 2002).

All games can be decomposed as a linear combination of unanimity games: $v = \sum_{S \subseteq N} \alpha_S u_S$, where α_S is the coefficient of unanimity game u_S. The SV is an equal allocation of unanimity games' value to players, *i.e.*, $s_i = \sum_{S \ni i} \frac{\alpha_S}{|S|}$; while the WSV is a weighted allocation according to the weights w assigned to players, *i.e.*, $WSV_i = \sum_{S \ni i} \frac{\alpha_S w_i}{\sum_{j \in S} w_j}$. This allocation rule is axiomatized by Kalai and Samet (1987).

Monderer et al. (1992) proves the monotonicity of the WSV in convex game, but this does not hold for the general cooperative game that we investigated in this dissertation. The monotonicity mentioned here means that when a player's weight increases, while keeping the other players' weights unchanged, the player's payoff in the given game also increases. As Owen (1968) has showed, the weights in the construction of WSV cannot be interpreted as a measure of power, but the players' delay to reach the grand coalition, which means it is not sure that as one player's weight increases while keeping other players weights unchanged, if his payoff will increase. Haeringer (2006) proposes the MWSV that is monotonic with respect to player weights. This solution concept generates different sets of bargaining weights to divide the worth of unanimity games, depending on whether the unanimity game coefficient α_S is positive or negative. However, it may allocate negative payoffs, thus may be non-stable in some collaboration games.

4.4 What is Missing in the Literature?

The proposed solution concepts in the literature provide coalition formation suggestions and gain sharing mechanisms for the implementation of logistics horizontal collaborations; nevertheless we perceive some kind of ineffectiveness of current game theoretic approaches to feasible collaboration mechanisms. It is partly due to these ineffectivenesses that their applications in centralized logistics collaborations are still rare. This ineffectiveness mainly consists in the lack of general applicability, and in the lack of bargaining power consideration despite the influence of this factor in supply chain management.

As current logistics horizontal collaborations are still in the initial phase, almost all collaboration cases are organized in small groups of collaborators with high synergies among them. In this kind of collaborations, the entry of any new collaborator in the group brings substantial marginal cost savings. Furthermore, these cases are always organized by a common LSP, which minimizes the coordination costs (CCs) arising both in the establishment of collaboration relationship and in the collaboration execution, such as the electronic data interchange (EDI) cost, the investment on relative information system and network infrastructure, and the coordination effort. All these induce a non-empty Core, and make the grand coalition the most preferable one to form. In this case, it is reasonable to neglect the CCs, and to model the horizontal collaborations as super-additive games with non-empty Core.

To meet the requirement of collaboration mechanisms for the current collaboration cases, the research works on the logistics application of cooperative game theory focus either on special collaboration modalities that can be modeled as super-additive games with non-empty Core, or on logistics games with restricting assumptions of negligible CC and non-empty Core. Perea et al. (2009) study models of collaboration between the nodes of a network that represents a distribution problem. They examine the sharing mechanisms in the specific super-additive distribution games that always have non-empty cores. Krajewska et al. (2007) investigate horizontal collaborations among freight carriers in order to balance their order portfolios, thus reducing the empty running and achieving substantial cost savings. Without general stability verification, they use empirical computational results to investigate the application of CC sharing mechanism. Similarly, Lozano et al. (2013) study the horizontal collaboration among shippers in order to reduce empty backhaul cost. The CCs is neglected and the collaboration is modeled as a super-additive game. A specific case study was conducted and the non-empty Core together with some other allocation mechanisms are computed and compared. There are other papers investigating the combination of several game-theoretic solutions in constructing sharing mechanisms. Özener and Ergun (2008) study the cost allocation problem in a collaborative transportation procurement network. Without CC consideration, the lane covering problem is modeled as a game with non-empty Core.

A collaboration among several logistics actors may be of an empty Core, which means some sub-coalitions can get better payoff (share of total cost reduction) by collaborating in the sub-coalition than in the grand coalition. Hence there are two options for them. Either they may prefer to stay in the grand coalition to benefit the increase of delivery frequency due to large scale, or they can deviate from the grand coalition, thus to form a CC. In the former case, a sharing model that considering the presence of an empty core is needed. There are some works proposing models for logistics games with empty Core. Frisk et al. (2010) propose an allocation mechanism in collaborative forest transportation, which is the combination of proportional allocation rule and Core stability validation. They propose to use ε-Core when the Core is empty. Dai and Chen (2011b) investigated a carrier collaboration problem. They propose several profit allocation mechanism that combine Core solution concept with SV, proportional allocation and contribution-based allocation. They propose an approximated non-empty Core to replace the Core formulations in their models for cases with empty Core. In the latter, the collaboration need to be modeled as a game with CS. This issue is rarely investigated in the literature on game-theoretic approaches to logistics horizontal collaboration.

We list the previous papers in Table 4.1, and indicate the type of logistics games they deal with.

Table 4.1: Literature on the application of cooperative game theory to logistics collaborations

	Super additive game	Consider only cases with non-empty Core	Shapley value based	Proportional rule based
Özener and Ergun (2008)	✖	✖		
Perea et al. (2009)	✖	✖		✖
Lozano et al. (2013)	✖	✖	✖	✖
Krajewska et al. (2007)	✖	✖	✖	
Frisk et al. (2010)	✖			✖
Dai and Chen (2011)	✖		✖	✖

We can see that the literature mainly focus on super-additive collaborations with non-empty Core. And the proposed gain sharing mechanisms are either Shapley-value-based or proportional-rule-based.

The bargaining power is another important factor that has apparent impact on the gain sharing in the collaboration. A company's bargaining power depends on its scale, prestige, market share, and some other factors. Cruijssen et al. (2010) is one of the scarce works that has considered collaborators' different bargaining power. In Cruijssen et al. (2010), SV allocation is adopted to allocate the common gain among shippers, and differential synergy-claim factors are determined in business negotiation according to different bargaining powers of shippers to determine the 3PL's share of the common gain. Since in the business practice, the bargaining power plays a significant role in the determination of sharing mechanism, we consider it an indispensable factor in a feasible sharing mechanism.

As the horizontal collaboration evolves, it will become more and more compelling to both major companies and SMEs. More horizontal collaboration cases with more complicated configuration and organization structures will emerge, thus requiring more robust collaboration mechanisms that are generally applicable. And the involvement of competitors in a collaboration relationship, as introduced in Institute of Grocery Distribution (2011), will raise higher requirement for the fairness of sharing mechanism, which includes these two criteria: sharing according to contribution, and using bargaining power to maintain competitive edge. These goals have not been achieved yet in the literature.

4.5 Conclusion

In this chapter, we identify the following concepts in cooperative game theory that possess interesting properties in constructing feasible collaboration mechanisms.

As to Core-like concepts used to examine coalition stability, the *general Core* concept that merges the Core and the CS Core concept is quite interesting. The general Core is applicable for both super-additive games, where the optimal CS is the grand coalition, and the non-super-additive games. Only if it is non-empty, the optimal CS of the game is stable and all the imputations in the general Core can guarantee the stability, in both myopic and farsighted point of view. When a game with the optimal CS is of an empty general Core, the ε-*Core* and the ε-*CS-Core*, as the set of the most stable imputations for the grand coalition and the optimal CS, could be a reasonable proposition for the collaboration.

As for the value-like concepts used to propose a specific fair allocation, the SV and its generalization in games with CS that takes all collaborators contributions to all possible coalitions are quite persuasive, except for collaborations between two or a very small number of agents. But none of the weighted values is quite feasible in modeling collaborators' different bargaining power.

It seems that both the coalition formation solutions in the logistics collaboration literature and the value-like approaches developed in the game-theoretic literature are still not fully feasible for a direct application in collaboration implementations, thus we propose our game-theoretic collaboration mechanisms including stable coalition examination and gain sharing models in the following chapter to overcome this obstacle.

CHAPTER 5

Game-Theoretic Investigation in Supply-Network-Pooling Collaborations

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5.1 Introduction

In this chapter, we identify four collaboration categories, and investigate the collaboration mechanisms in these categories of the *supply-network-pooling* (SNP) collaboration respectively. The collaboration mechanisms consisting of the *coalition formation* and *gain-sharing* solutions are investigated by the cooperative-game-theoretic approach. We propose stable *coalition structures* (CSs) and different sharing mechanisms for the pooling collaboration cases in different categories, and then construct a general gain-sharing mechanism for all feasible pooling collaborations. At the end of this chapter, a SNP case study in the French retail chain and a simple computational case are presented to show the effectiveness of the collaboration mechanisms proposed.

This chapter is organized as follows:

In Section 2, we use the game-theoretic investigation to show why the proportional sharing mechanism, which is widely applied in logistics collaborations, would harm the efficiency of the HLC. Thus we need to construct new sharing mechanisms to promote the efficiency and the stability of the HLCs in the long-run.

In Section 3, we conduct game-theoretic investigations to show the importance of the coordination costs (CCs) and the bargaining power considerations in the SNP games.

Section 4 identifies four categories of the SNP game according to different level of CCs and global/individual-optimum preferences in the game.

In Section 5, we propose a set of *Contribution-and-Power-Weighted-Value* (CPWV) sharing mechanisms for each of the four SNP-collaboration categories. We investigate the coalition-formation issue, and develop game-theoretic sharing mechanisms for these categories respectively. These sharing mechanisms take into account the contribution of collaborators, the CCs, and the different collaborators' bargaining power.

Section 6 summarizes the coalition formation scheme for the SNP collaborations, and proposes a general gain-sharing model that is applicable for all feasible SNP collaborations.

Section 7 introduces a SNP case study in the French retail chain to show the effectiveness of the coalition formation scheme and the general gain-sharing model proposed. This case study is based on the real world data provided by the Club Déméter (the association of major logistics players in France, www.club-demeter.fr). Also, a simple computational case is presented to compare the performance of the model proposed and that of Shapley value when the Core of the game is empty.

Section 8 concludes this chapter.

5.2 Game-Theoretic Investigation into the Proportional Sharing Mechanism

The most common HLC modality is that conducted by a common LSP of several clients, the gain sharing of which is carried out by means of an identical tariff table proposed for all clients in the same pool. That means, all participants in such collaboration will get his share of the common gain proportional to some predetermined factors (e.g. total load shipped, distance traveled). This rule is chosen in practice due to being easy to understand and convenient. In logistics collaboration conducted by a LSP, this rule can be easily applied in the form of a logistics service tariff table, while at the same time avoid the side payments among collaborators. The proportional rule guarantees the existence of a stable CS in both super-additive and non-super-additive collaborations. But this sharing scheme presents many disadvantages. The first is the inefficiency. Under proportional sharing rule, the stable CS finally formed is not the most efficient one that maximize the global cost saving. Secondly, this sharing rule does not take the contribution of collaborators as a criterion to determine the gain sharing. Thus two collaborators who have equal shipment volumes (provided that the volume-proportional rule is adopted) but offer different opportunity of consolidation will get identical payoffs. This is obviously unfair, and may reduce the incentive to collaborate, especially when collaborating with competitors.

Suppose the gain achieved in each coalition is shared among its members based on proportional rule according to a given list of shares $(a_i)_{i \in N}$ (e.g. individual transportation costs before collaboration, different quantities of volume·distance shipped, etc.). Therefore when a coalition S forms, its member i will get a share of $x_i = \frac{a_i}{\sum_{j \in S} a_j} \times v(S)$. Banerjee et al. (2001) shows that there will be common ranking for all possible coalitions in such a coalition formation game, and thus the coalitions with the highest *profit ratios* will be successively formed. The *profit ratio* $r(S)$ is the ratio of the gain achieved in coalition S to the sum of the shares of members i in S, $r(S) = \frac{v(S)}{\sum_{j \in S} a_j}$. In a proportional-sharing collaboration, given the list of shares, it is the *profit ratio* exclusively determine the collaborators' preferences to coalitions. At first, in the grand coalition N, the sub-coalition with the highest profit ratio will be formed. Then among the remaining collaborators, the coalition with the highest profit ratio will be formed, and so forth, until the stable CS is constructed. There will always be a stable CS for such kind of collaboration, but it is highly probable that the stable CS formed in proportional-sharing collaboration is not the optimal CS in terms of the global efficiency. The following example illustrates this.

Example 5.1. Suppose there are firms $1, 2, 3$ in current collaboration pool with shipment quantity vector $a = \{3, 3, 4\}$, and cost saving

- $v(1) = v(2) = v(3) = 0$;
- $v(\{1,2\}) = 60$, $v(\{1,3\}) = 60$, $v(\{2,3\}) = 60$;
- $v(\{1,2,3\}) = 90$.

The cost saving is shared by the members of coalition proportionally to their shipment quantities, therefore the coalition $\{1,2\}$, whose profit ratio $r(\{1,2\}) = \frac{60}{3+3} = 10$ is the highest among all coalitions, will be formed. Even though the coalition $\{1,2,3\}$ can create much more social welfare than $\{1,2\}$, it is less preferred by firms 1 and 2 due to its lower profit ratio $r(\{1,2,3\}) = \frac{90}{3+3+4} = 9$. Thus for promoting the global efficiency, other allocation rule is needed. Since this is a super-additive game with a non-empty Core, the SV $\{30, 30, 30\}$ coincides with the CPWV proposition when collaborators have identical bargaining power, and both are in the Core.

Hence the application of proportional sharing mechanisms harms the efficiency of the HLCs, and we need new sharing mechanisms for the implementations of HLCs. What are the factors that need to be considered in a feasible sharing mechanism? In the next section we investigate this issue.

5.3 Coordination Cost and Bargaining Power: Two Important Factors in Centralized Horizontal Logistics Collaborations

In the literature on the game-theoretic approaches to the HLCs, the CCs and bargaining power have not been taken into account in constructing sharing mechanisms. Here we use demonstrative examples to show how these two factors impact the SNP games.

Example 5.2. There are three pooling partners in the grand coalition N, thus $N = \{1,2,3\}$. When the CCs are not considered in the game modeling, the value function of the pooling game $G_p = (N, v, P^*)$, which represents the cost savings can be achieved in each coalition, is defined as the following:

- $v(1) = v(2) = v(3) = 0;$
- $v(\{1,2\}) = 17;\ v(\{1,3\}) = 19;\ v(\{2,3\}) = 18;$
- $v(\{1,2,3\}) = 30.$

The game is super-additive and the Core of this game is non-empty, as showed in Figure 5.1.

Taking into account the CCs in the game modeling, we define the value function of the pooling game $G_p = (N, v, P^*)$ as the following:

- $v(1) = v(2) = v(3) = 0;$
- $v(\{1,2\}) = TCR(\{1,2\}) - CC(\{1,2\}) = 17 - cc;$
- $v(\{1,3\}) = TCR(\{1,2\}) - CC(\{1,2\}) = 19 - cc;$
- $v(\{2,3\}) = TCR(\{2,3\}) - CC(\{2,3\}) = 18 - cc;$

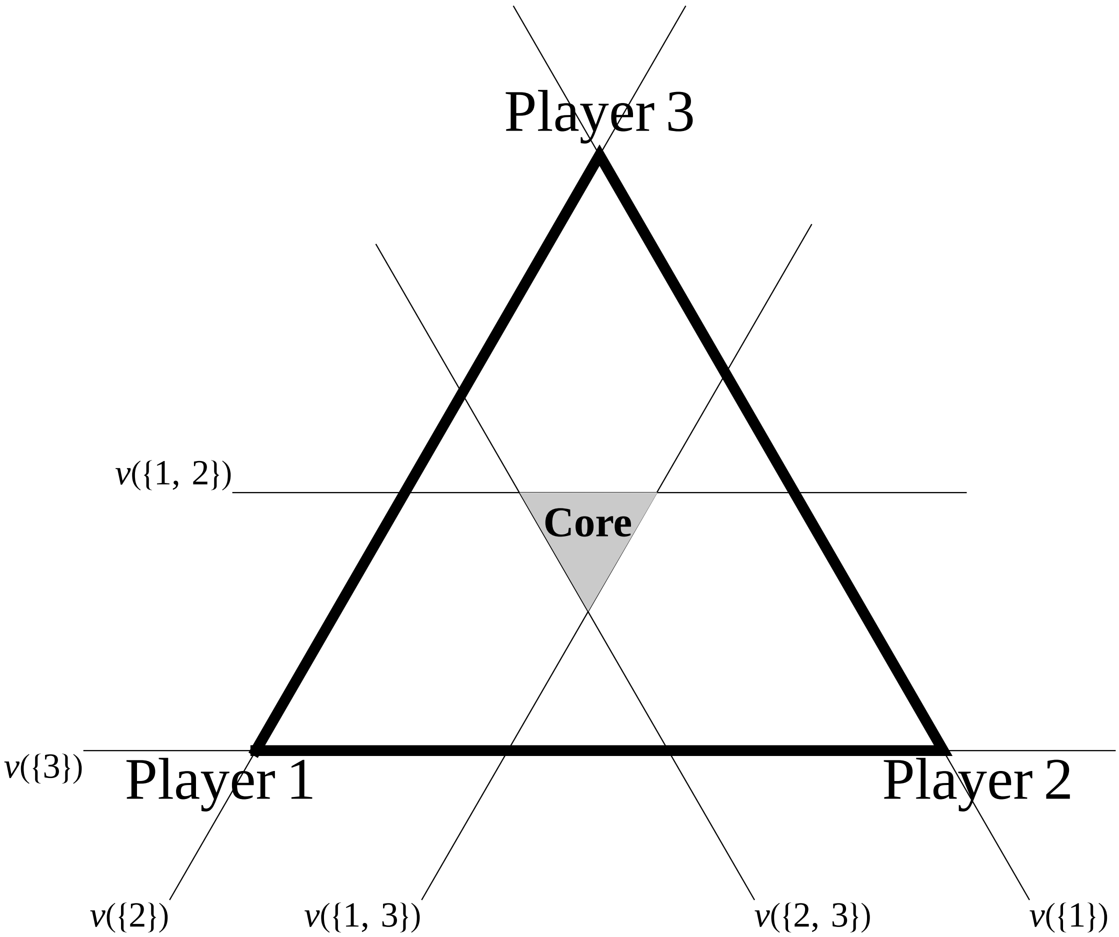

Figure 5.1: Core of the pooling game with CCs equal to 0

- $v(\{1,2,3\}) = TCR(\{1,2,3\}) - CC(\{1,2,3\}) = 30 - 2cc.$

we define the coordination cost function $CC(S)$ as linear function of coalition scale (number of players in the coalition), thus $CC(S) = cc \cdot (|S| - 1)$, where cc is the CC rate.

When $cc > 6$, the pooling game $G_p = (N, v, P^*)$ is non-super-additive and it is of an empty Core. In this case, the players may collaborate either in the grand coalition or in a CS form. Thus we can see that the presence of the CCs impacts the game property and the players' collaboration decisions.

Now let us investigate how bargaining power factor impact the sharing scheme. In Example 5.2, when there is no CC, all allocations in the Core are feasible sharing proposals. When we consider all players as symmetry, the Shapley value (as showed in Figure 5.2) is a credible proposal since it considers all players' contribution to different coalitions. However, when players' bargaining power differs, there should be a sharing model that uses the relative bargaining power to favor the players with higher negotiation positions in order to propose more acceptable sharing scheme. For example, when player 3 has higher bargaining power than 1 and 2, the sharing model should draw the Shapley value point toward player 3 according to the relative bargaining power to find a allocation point more favorable for player 3. However, this point should be kept within the core to guarantee the stability of the collaboration (this will be further discussed later in this chapter). Therefore taking into account the bargaining power is really of interest and allows to check stability when an agreement is reached.

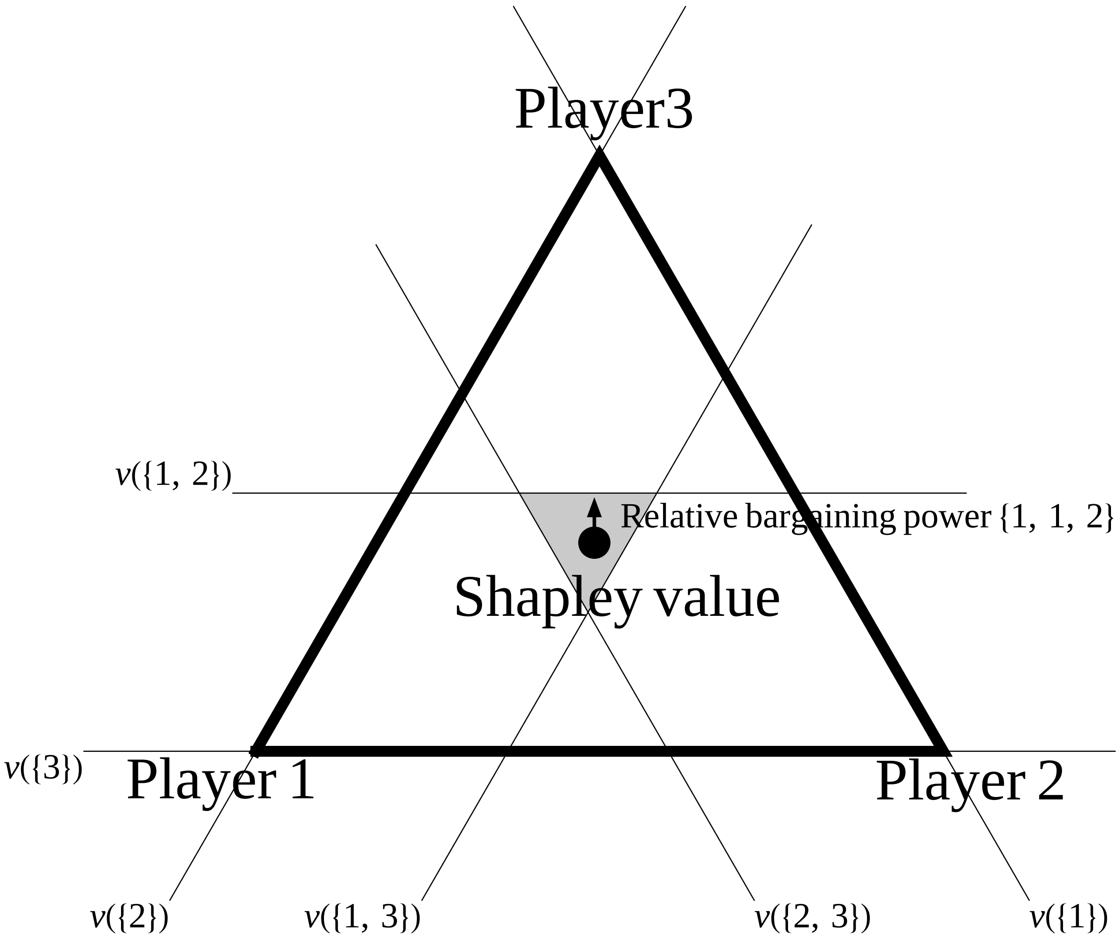

Figure 5.2: Shapley value of the pooling game with nil CCs

Before constructing the sharing mechanism by taking into account both the CCs and the bargaining power, we identify different pooling categories in the following section.

5.4 Identification of Different Supply Network Pooling Categories

In game theoretic investigation, we broadly divide pooling collaborations into 4 categories with respect to the combination of two criteria that have not been taken into account in the literature: negligible or significant CCs, and different collaboration preferences due to the characters of the collaborators, as shown in Table 5.1.

Table 5.1: Different categories of pooling cases

Preference Coordination cost	Global optimum	Individual optimum
Negligible	C1: super-additive collaboration with global optimum preference	C2: super-additive collaboration with individual optimum preference
Significant	C3: non-super-additive collaboration with global optimum preference	C4: non-super-additive collaboration with individual optimum preference

One of the most important criteria used to distinguish pooling categories is the existence of *coordination costs* (CCs). These are the extra costs committed to the collaboration, i.e. communication costs, investments in IT or in facilities, etc. In the literature on the game-theoretic investigation of logistics collaboration, the costs of the coordination among players for forming and maintaining a coalition were always considered negligible (Audy et al., 2012; Hennet and Mahjoub, 2010). We notice that this remains true in some cases, for example when logistics collaboration occurs among the customers of a common LSP. Since the LSP already holds the prerequisite elements (information, facility, etc.) for collaboration among its customers, the CCs are negligible. Otherwise, CCs may become significant. For example the logistics collaboration among different LSPs.

When CCs are considered negligible, new participants can join the group without paying any extra cost, the corresponding cooperative game is super-additive (the merge of flows is either beneficial or indifferent) and the coalition containing all participants (i.e., the grand coalition) will generate the highest common gain (C1 and C2 in Table 5.1). As CCs increase to a significant level, the game becomes non-super-additive. The gain resulting from the synergy arising out of the collaboration between certain participants may be less than the CCs needed to form the corresponding collaboration relationship, and the merger of coalitions is not always profitable. In this case, a collaboration scheme based on a partitioning of the grand coalition (collaboration occurs only within sub-groups of participants, namely, the sub-coalitions) may be preferable (C3 and C4 in Table 5.1). The partition generating the highest global profit is called the *optimal coalition structure* (optimal CS) (Aumann and Dreze, 1974). It should be noted that the grand coalition in some non-super-additive games could also be the optimal CS.

The organization of pooling collaboration resulting in different preferences of players is another essential factor. The *global optimum* preference often comes from centralized governance. For example in the collaboration among the suppliers of Carrefour through consolidation and collaboration center, the pooling scheme was established to maximize the global cost efficiency. Another example could be the logistics collaboration among the subsidiaries of a group corporation. In these cases, all players have incentive to maximize the global cost reduction, so the CS that yields the highest global gain will be stable. Contrarily, when independent (or self-interested) suppliers or carriers organize pooling collaborations among them, they will try to maximize their individual profits by forming the most individually beneficial coalition(s).

Most of the existing research on logistics collaboration focuses mainly on the C1 and C2 categories, where CCs are negligible, and on the corresponding super-additive collaboration game with non-empty Core, where the grand coalition will always be the optimal CS (Dai and Chen, 2011b; Houghtalen, 2007; Krajewska et al., 2007); but there are very few researches on non-super-additive collaborations (El Omri et al., 2007). In the following section, we will propose the collaboration mechanisms for each of the four pooling categories.

5.5 Collaboration Mechanisms

5.5.1 C1: super-additive collaboration with global optimum preference

5.5.1.1 Example of C1 collaboration

The consolidation and collaboration center (CCC) of Carrefour (Rognon, 2009) illustrated in Figure 5.3 is an example of C1 collaborations.

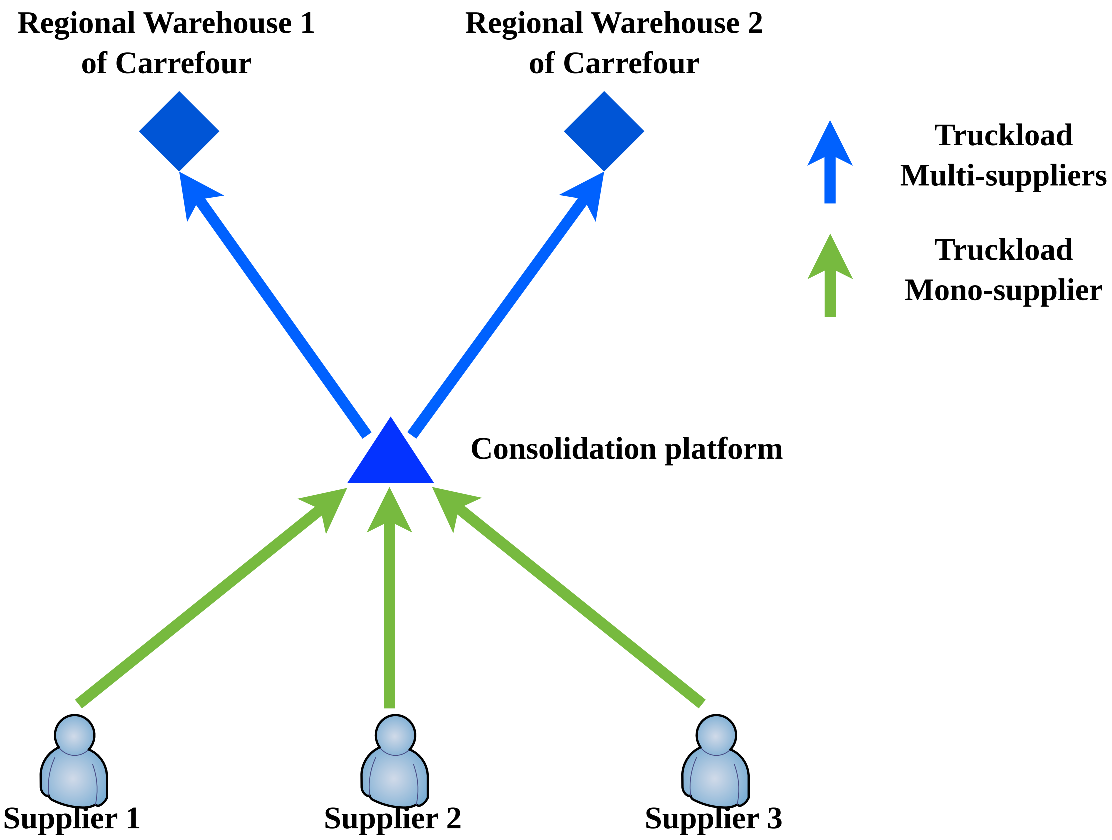

Figure 5.3: Example in C1 category: consolidation and collaboration center of Carrefour

The suppliers of Carrefour directly deliver merchandises to the consolidation center by full truckload. Then in the consolidation center, the consolidated multi-client freight are expedited to the regional warehouse using truckload shipping. In this collaboration relationship, Carrefour is the centralized organizer to implement a global optimum collaboration scheme that maximizes the global cost reduction. Since the collaboration between Carrefour and the suppliers is based on the existing dealing relationship, there is no significant CCs.

5.5.1.2 Coalition formation in C1 collaborations

In a super-additive SNP collaboration, the grand coalition can achieve the highest global profit among all possible CSs. Thus the grand coalition will be stable for the collaborators with the global-optimum preference. Even if whether the Core is non-empty is still uncertain, the possibility to increase freight frequency arising from the collaboration among a large quantity of collaborators can support the collaboration in the grand coalition. In SNP optimization model, we evaluate only the transportation cost reduction based on periodical flow of goods. The collaborators will realize that besides the transportation cost reduction, an increased freight frequency is also an obvious competitive advantage of the SNP, which may reduce the inventory cost and the lead time of deliveries. So it may be more preferable to stay in a collaboration relationship among as many collaborators as possible, rather than to deviate.

5.5.1.3 Gain-sharing mechanism in C1 collaborations

At first, we give a formal definition of the pooling game. We define the SNP game as $G_p = (N, v, P^*)$. In this pooling game, N is the set of all potential collaborators. v is the value function of all possible coalitions or CSs in the game, which represents the cost savings could be achieved by collaborating in the coalition or CS. Hence $v(S)$ and $v(P)$ represent the cost savings can be achieved in coalition S and in CS P respectively. Considering the coordination cost function denoted by $CC(S)$, the value function defined as $v(S) = TCR(S) - CC(S)$ is the difference between the transportation cost savings $TCR(S)$ and $CC(S)$. As previously presented, the optimal CS P^* that $v(P^*) \geq v(P)$, $\forall\, P \in \mathscr{P}$ is the most stable one in a game, we always investigate the sharing mechanism in a game with the optimal CS.

Definition 5.1. The *supply network pooling game* is defined as $G_p = (N, v, P^*)$, where $v(S) = TCR(S) - CC(S)$ and P^* is the optimal CS that $v(P^*) \geq v(P)$, $\forall\, P \in \mathscr{P}$.

We start investigating the sharing mechanism in the SNP collaboration with negligible CCs and global-optimum preference (C1). Since in this case the grand coalition N is always the optimal CS, we study the SNP game $G_p = (N, v, \{N\})$ where $v(S) = TCR(S)$.

Frisk et al. (2010) propose an *equal profit method* (EPM) approach that tries to get an allocation that provides an as equal relative profit as possible among the participants. The sharing mechanism in this dissertation is based on the same idea to minimize the difference between the participants' relative payoffs. However, we think it is more reasonable to start from the Shapley value allocation, since it is a credible contribution measurement, and take into account some important factors in the sharing mechanism.

We suggest that a fair sharing model in the pooling games should take the following factors into consideration: contribution to the common profit, bargaining power that impacts the negotiation result, and stability consideration for the long-term collaborative relationship. Since the *Shapley value* (SV) is based on the average marginal contribution of players, it can thus be considered as the measure of players' contribution to the common profit. Bargaining power should be modeled into the construction of such a fair sharing model by weight, so that if a player's weight increases while that of the others remains unchanged, the first player's payoff increases. Furthermore, the allocation rule should incorporate the stability consideration as it is constructed. Taking all these criteria into account, we propose the following linear programming (LP) as a sharing model to compute a fair allocation, named *contribution-and-power weighted value* (CPWV).

$$
\begin{aligned}
MIN: \quad & \theta \\
s.t.: \quad & \frac{x_i}{s_i w_i} - \frac{x_j}{s_j w_j} \leq \theta, \forall i, j \in N; && (5.1) \\
& \sum_{i \in S} x_i \geq v(S), \forall S \subset N; && (5.2) \\
& \sum_{i \in N} x_i = v(N); && (5.3) \\
& x_i \geq 0, \forall i \in N. && (5.4)
\end{aligned}
$$

x_i in this LP is the CPWV payoff to player i; s_i is the SV payoff of player i; w_i is the factor denoting the bargaining power of player i, which is usually a composite factor whose determination is achieved by negotiation. This adjustment factor plays an important role in the allocation solution according to the outcome of negotiation. Since the SV in a super-additive game with no dummy player will always be positive (a dummy player having no contribution is not considered in the game), and the bargaining power factors are positive, thus it is guaranteed that $s_i > 0$

and $w_i > 0$. This LP can identify a payoff vector x that minimizes the maximum difference between any two players' payoff rates defined as $x_i/(s_i \cdot w_i)$. The other constraints guarantee that the solution is in the Core.

From the LP of CPWV, we can easily prove that the CPWV of a game with non-empty Core satisfies following axioms:

Axiom 5.1. Proportionality: if for $i, j \in N$, $v(S \cup \{i\}) = v(S \cup \{j\}) \forall S \subseteq N$ and $i, j \notin S$, then $x_i/w_i = x_j/w_j$ when $x_i/(s_i \cdot w_i) - x_j/(s_j \cdot w_j) = 0$;

Axiom 5.2. Efficiency: $\sum_{i \in N} x_i = v(N)$;

Axiom 5.3. Individual rationality: $x_i \geq v(i), \forall i \in N$;

Axiom 5.4. Collective rationality: $\sum_{i \in S} x_i \geq v(S), \forall S \subset N$;

Axiom 5.5. Weak monotonicity: if $w'_i > w_i$, and $w'_j = w_j \forall j \in N$ and $j \neq i$, then $x'_i \geq x_i$;

The proportionality axiom means that if two players i and j can be replaced by each other in any coalition without changing the value of the coalition, they will get payoffs proportional to their weights provided that the two payoff allocations x_i and x_j do not cause the increase of θ value. The efficiency axiom means that the common gain achieved by collaboration will be shared out among all collaborators. The individual and collective rationality axioms mean that the CPWV allocation is immune to unilateral or multilateral deviation. The weak monotonicity axiom holds if as player i's weight increases while that of the others remains unchanged, player i's payoff will increase or stay the same, depending on if Core-stability can be satisfied. Using this sharing mechanism, the payoff vector calculated satisfies the previous axioms, and takes players' contribution and bargaining power into account, thereby being fair and reasonable for players, and can be applied to model the complicated multilateral bargaining process. Once all players arrive at a consensus on the appropriate set of bargaining-power factors, the CPWV model can propose a reasonable allocation.

The CPWV model only studies super-additive logistics games with non-empty Core. But this kind of game may have an empty Core, even in HLC cases, the game with empty Core is rarely seen. Here we propose an extended model for those unusual cases.

Example 5.3. For example in a game with 3 players, with the following value function:

- $v(1) = v(2) = v(3) = 0$,
- $v(\{1,2\}) = v(\{1,3\}) = v(\{2,3\}) = 7$;
- $v(\{1,2,3\}) = 10$.

There is no allocation that can satisfy all the Core constraints at the same time. Thus the Core is empty even if the grand coalition is still the optimal CS.

When the collaboration organizer or the participants have the incentive to achieve the global optimum solution, we look for an alternative to the Core solution to build a feasible sharing mechanism for the C1 collaboration with an empty Core. Shapley and Shubik (1966) introduce the ε-Core and the weak ε-Core.

Definition 5.2. **ε-Core** is defined as follows:

$$\begin{aligned} \varepsilon - core(N,v) = \{x | x(S) \geq v(S) - \varepsilon \ \forall (S \subseteq N \ and \ S \neq \emptyset), \\ and \ x \in I(N,v)\} \end{aligned} \tag{5.5}$$

Definition 5.3. **Weak ε-Core** is defined as follows:

$$\begin{aligned} Weak \ \varepsilon - Core(N,v) = \{x | x(S) \geq v(S) - |S|\varepsilon \ \forall (S \subseteq N \ and \ S \neq \emptyset), \\ and\, x \in I(N,v)\}. \end{aligned} \tag{5.6}$$

When the Core of the game is empty, with sufficiently large ε value, a non-empty ε-Core or weak ε-Core can always be found. Compared with the ε-Core, the ε value in the non-empty weak ε-Core can be directly interpreted as the highest individual sacrifice/give-up that players would like to afford for achieving the collaboration in the grand coalition. Hence we adopt the latter to construct the sharing model. Maschler et al. (1979) formally define the *weak least Core* (WLC) as follows:

Definition 5.4. **Weak least Core** (WLC) is the non-empty weak ε-Core with smallest possible ε value, noted by ε^*.

For games with empty Core, the WLC can be interpreted as the allocation set that contradicts Core stability the least. Based on the CPWV model above, we propose an alternative solution by replacing the Core-stability constraint with the WLC constraint. This solution denoted by CPWV in WLC can be computed via the following LP.

$$
\begin{aligned}
MIN: \quad & \theta \\
s.t.: \quad & \frac{x_i}{s_i w_i} - \frac{x_j}{s_j w_j} \leq \theta, \forall i, j \in N && (5.7) \\
& \sum_{i \in S} x_i \geq v(S) - |S|\varepsilon^*, \forall S \subset N && (5.8) \\
& \sum_{i \in N} x_i = v(N). && (5.9) \\
& x_i \geq 0, \forall i \in N && (5.10)
\end{aligned}
$$

This solution is suitable for C1 pooling case with an empty Core. By using this solution, we can always find an appropriate compromise for the players with full-collaboration preference, and this allocation satisfies *proportionality*, *efficiency*, *individual rationality*, *weak monotonicity* and the following axiom:

Axiom 5.6. Weak collective rationality: $\sum_{i \in S} x_i \geq v(S) - |S|\varepsilon^*$, $\forall S \subset N$.

5.5.2 C2: super-additive collaboration with individual optimum preference

5.5.2.1 Example of C2 collaboration

We illustrate an example of C2 collaboration in Figure 5.4.

In the collaboration among the clients of a common third party logistics, the CCs are negligible since the 3PL has already the information of the clients' logistics service requirements. The 3PL will work as the centralized collaboration organizer. However, the clients are independent agents. They have incentive to collaborate in the most preferable coalition with suitable gain-sharing mechanism, thus to maximize their own profit.

The difference between C1 and C2 is that, in the example of C1 category, Carrefour who plays a very powerful role has the incentive to fully explore the synergy among the supplier

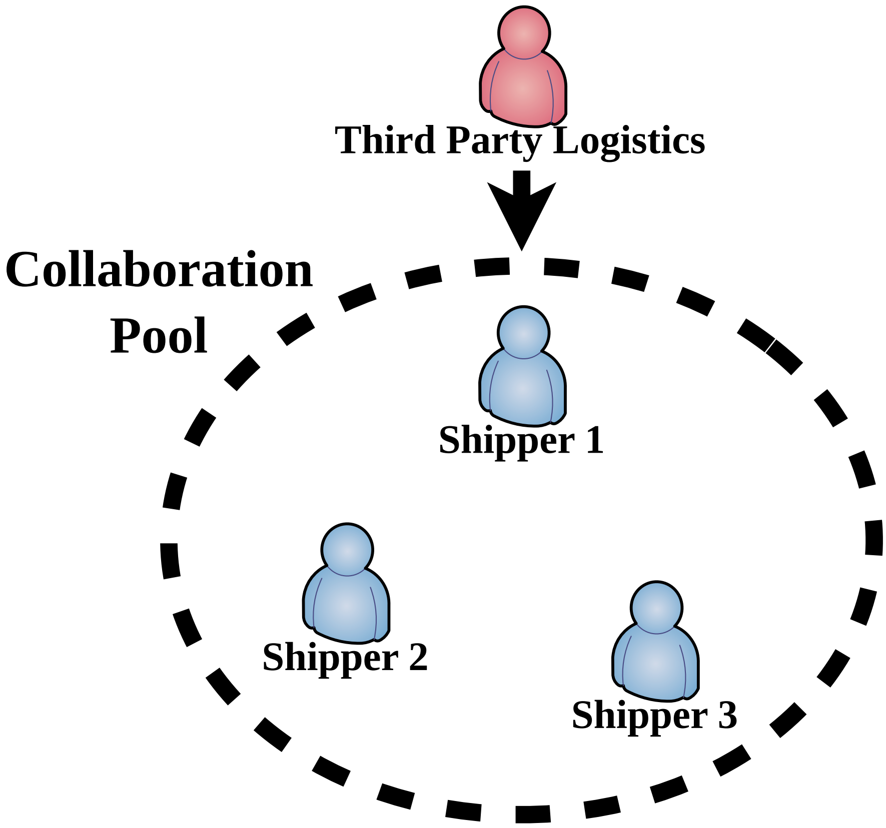

Figure 5.4: Example in C2 category: collaboration among the clients of a common third party logistics

deliveries, hence there is a global-optimum preference; whereas in the example of C2, shippers can select the best collaboration scheme for themselves (via a common 3PL), so that they have individual-optimum preferences.

5.5.2.2 Coalition formation and gain sharing in C2 collaborations

In C2 collaborations, the grand coalition will still be the optimal CS. According to real-world case study experiences, when the CCs are negligible, collaborators can get much higher payoffs by collaborating in the grand coalition than in any sub-coalition. When the Core is non-empty, in such super-additive SNP games, regardless of players' global optimum or individual profit preferences, they will prefer the collaboration in the grand coalition. Hence when the Core is non-empty, we can use the CPWV sharing mechanism to allocate the common gain in the SNP game.

When the Core is empty, since the optimal CS (the grand coalition) is unstable, there will be no CS that is stable in terms of Core stability. For such games with self-interested players, the grand coalition would not be formed. Arnold and Schwalbe (2002) and Konishi and Ray (2003) show that when the Core is empty, even a dynamic coalition formation process may not converge. In this case, the collaboration scheme is infeasible in the sense that it is inherently unstable. Therefore this question is beyond the scope of this dissertation whose focus is to study the collaboration mechanism for profitable and feasible logistics collaborations.

5.5.3 C3: non-super-additive collaboration with global optimum preference

5.5.3.1 Example of C3 collaboration

We illustrate an example of C3 collaboration in Figure 5.5.

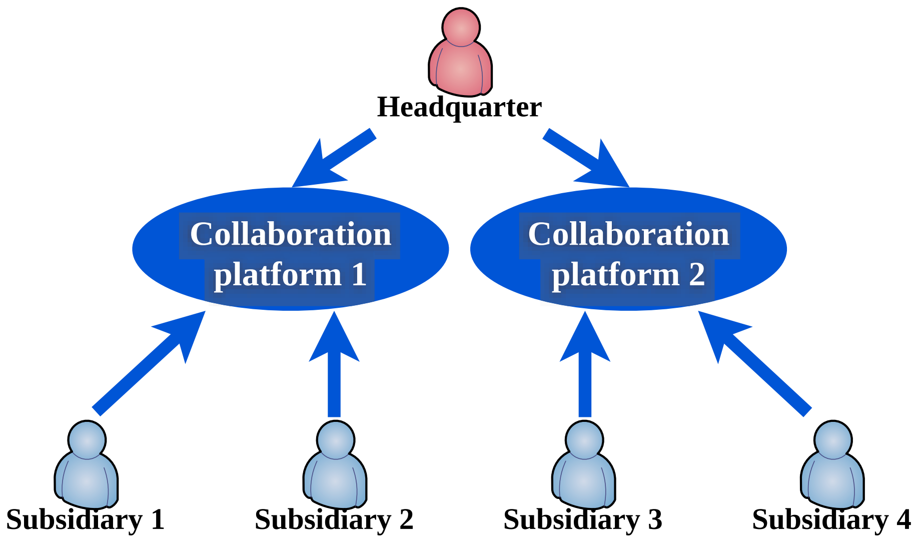

Figure 5.5: Example in C3 category: collaboration among the subsidiaries of a group company

An example of C3 category could be the collaboration among the subsidiaries of a group company. This kind of collaboration is of a global-optimum preference. Since it requires considerable investment for the construction of IT based collaboration platform, the collaborations are only conducted within the most profitable coalitions. Therefore we need to model the CCs in the SNP game and to consider the CSs other than the grand coalition.

5.5.3.2 Coalition formation in C3 collaborations

In a non-super-additive collaboration, the collaborators with global-optimum preference have no incentive to deviate from a CS that optimizes the global cost reduction of the whole pooling group (the optimal CS). Under global-optimum preference assumption, the optimal CS will be implemented.

As a credible stability criterion, CS Core is the set of all imputations that no collaborator can benefit by deviating. The individual Core stability for all coalitions $S_i \in P$ only guarantees that collaborators prefer S_i to the sub-coalitions T of S_i ($T \subset S_i$), while the CS Core stability guarantees the collaborators' preferences to the optimal CS in comparison with all other possible CSs. Thus the CS Core is the most reliable stability judgement for non-super-additive collaborations. From another point of view, even when the CS Core is empty, the optimal CS is still the most stable one among all CSs. Aumann and Dreze (1974) showed that a necessary condition for non-emptiness of the CS Core is that the CS formed is the optimal one. In the sense of CS Core stability, the optimal CS is the most stable one. Even if the CS Core is empty, in considering that the optimal CS can achieve the highest global cost saving, which leaves more leeway for the side payment aiming at a global acceptable solution, it is more stable than other CSs.

5.5.3.3 Gain-sharing mechanism in C3 collaborations

As CCs rise to a high level, the SNP game is no longer super-additive and the optimal CS may not be the grand coalition. In this case, a sharing mechanism in a game with CS will be needed. Before investigating the sharing mechanism, it is important to highlight two peculiarities of non-super-additive pooling games: the occurrence of negative (or unreasonable) SVs and the determination of the optimal CS. These peculiarities should be taken into account in constructing the CPWV model.

When the pooling game is non-super-additive, for some coalitions whose synergy is lower than the CC to pay ($v(S) = TCR(S) - CC(S) < 0$), the value function v in game $G_p = (N, v, P^*)$ may be negative. And due to a negative marginal contribution to some coalitions, some players may have negative SVs, even when the grand coalition is still globally optimal and stable (a real-life example will be shown in section 5.7.1.3). In this case, the SVs computed with v defined in the original game cannot truthfully represent the real contribution of players, and the CPWV model cannot calculate reasonable payoffs. Here we give a simple example to illustrate this problem.

Example 5.4. There are three pooling partners in the grand coalition N, thus $N = \{1,2,3\}$. We define the coordination cost function $CC(S) = 300 \cdot (|S| - 1)$. The value function of the pooling game $G_p = (N, v, P^*)$ is defined as follows:

- $v(1) = v(2) = v(3) = 0$;
- $v(\{1,2\}) = TCR(\{1,2\}) - CC(\{1,2\}) = 600 - 300 = 300$;
- $v(\{1,3\}) = TCR(\{1,2\}) - CC(\{1,2\}) = 600 - 300 = 300$;
- $v(\{2,3\}) = TCR(\{2,3\}) - CC(\{2,3\}) = 0 - 300 = -300$;
- $v(\{1,2,3\}) = TCR(\{1,2,3\}) - CC(\{1,2,3\}) = 1200 - 600 = 600$.

We can see that the logistics network of player 1 have intersections with that of both 2 and 3, but the logistics networks of 2 and 3 are independent and there is no possibility to consolidate. The players are surely to collaborate in the grand coalition since that it is the most profitable CS. An intuitive way to assess players' contribution to the grand coalition may be as follows: since each of 1 and 2 contributes equally in the coalition $\{1,2\}$, they should share the saving 300 equally; so does the coalition $\{1,3\}$. Thus the stable and fair allocation should be $\{300,150,150\}$ for $\{1,2,3\}$. However, the SV computed is {400,100,100}, since it takes into account the negative contribution of 2 and 3 in the coalition {2,3}, even if such negative-utility coalition won't really form.

To always generate reasonable non-negative SVs, we propose the use of the value function in the *super-additive cover* of the original game as the input of SV computation (Aumann and Dreze, 1974). The super-additive cover of a pooling game $G_p = (N, v, P^*)$ is denoted by $\hat{G}_p = (N, \hat{v}, \{N\})$. The value $\hat{v}(S)$, is defined by: $\hat{v}(S) = \max\{\sum_{S \in P_S} v(S) | P_S \text{ is a partition of } S\}$. The intuitive meaning of super-additive cover is that when new members join a coalition, only the most beneficial collaboration will actually occur, and the coalition thus formed will collaborate in an optimal partition of this coalition. The SV computed with $\hat{v}$ in the super-additive cover will always be positive, provided that there is no dummy player in the pooling game, and reasonable for all cases. Further, Pérez-Castrillo and Wettstein (2001) find that his dynamic non-cooperative approach implements the SV of the super-additive cover as an equilibrium outcome for games with CS, which supports the application of super-additive cover SV. Note that the super-additive cover of a super-additive game is the game itself, so it is a generally feasible way to compute the SV.

And in the stability assessment, the unreasonable negative values of the value function may relax the Core constraints, thus we adopt super-additive cover value function $\hat{v}$ in the CS CPWV sharing mechanisms.

To construct the sharing mechanism for non-super-additive games, another issue is the determination of the optimal CS P^*, in which the pooling collaboration should be carried out. In this dissertation we adopt the model developed in Rahwan and Jennings (2008) to compute the optimal CS. Once the latter is determined, we have to integrate into the CPWV model the corresponding generalizations of the SV and the Core, i.e. the CS SV and the CS Core computed with $\hat{v}$, which are based on the work of Aumann and Dreze (1974).

We adapt the CPWV to non-super-additive pooling games by integrating the CS SV and the CS Core (computed with super-additive cover $\hat{v}$ and corresponding to the optimal CS). This solution named CS CPWV is helpful to support pooling cases in C3 category in table 5.1 when the CS Core is non-empty. The following LP computes the CS CPWV allocation.

$$
\begin{aligned}
MIN: \quad & \theta \\
s.t.: \quad & \frac{x_i}{s'_i w_i} - \frac{x_j}{s'_j w_j} \leq \theta, \forall i, j \in S_k, \forall (S_k \in P^* \ and \ \hat{v}(S_k) > 0) && (5.11) \\
& \sum_{i \in S} x_i \geq \hat{v}(S), \forall S \subset N && (5.12) \\
& \sum_{i \in S_k} x_i = \hat{v}(S_k). \forall S_k \in P^* && (5.13) \\
& x_i \geq 0, \forall i \in N && (5.14)
\end{aligned}
$$

In this CS, s'_i is the CS SV of player i computed by the value function of the super-additive cover $\hat{v}$ with respect to the optimal CS P^*. To implement this allocation rule, the coalitions $S_k \in P^*$ that $\hat{v}(S_k) = 0$ should be excluded from this collaboration group to make sure that $s'_i > 0$. Note that in the pooling cases in C3 and C4 categories, the optimal CS may or may not be the grand coalition. When the optimal CS is the grand coalition, the CS CPWV model is of the optimal CS $P^* = \{N\}$ and $S_1 = N$ being the only sub-coalition in P^*.

Similarly, from the formulation of the CS CPWV, we can see that CS CPWV of a game in coalitional form with non-empty CS Core satisfies the *efficiency, individual rationality, collective rationality*, and *weak monotone axioms*.

When the CS Core is empty in a pooling collaboration of type C3, a compromise can be achieved by replacing constraints (5.18) in previous model with the following constraint set:

$$\sum_{i \in S} x_i \geq \hat{v}(S) - |S|\varepsilon^{**}, \forall S \subset N, \tag{5.15}$$

where ε^{**} is the corresponding ε value in the *Weak Least CS Core* (WLCSC).

5.5.4 C4: non-super-additive collaboration with individual optimum preference

5.5.4.1 Example of C4 collaboration

We illustrate an example of C4 collaboration in Figure 5.6.

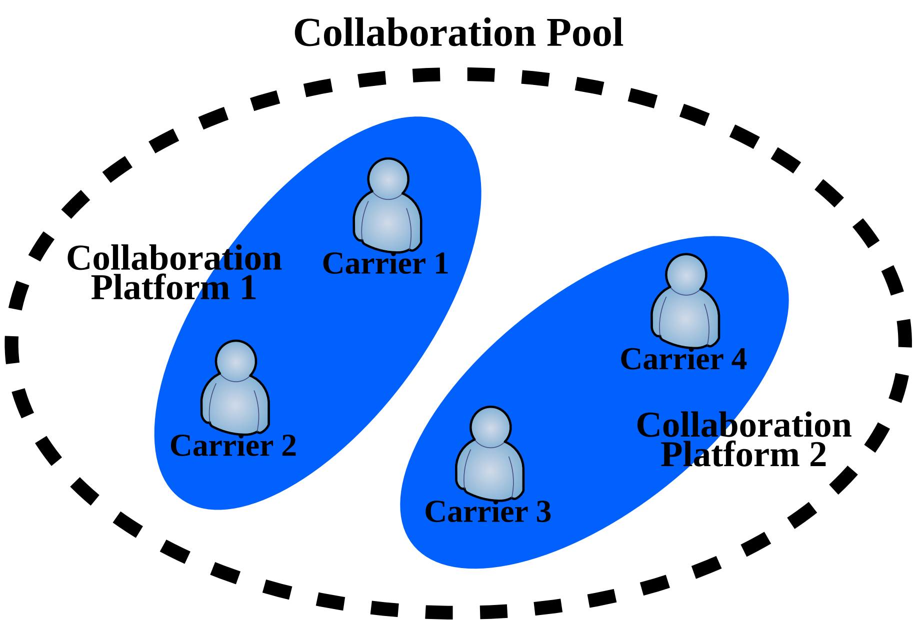

Figure 5.6: Example in C4 category: collaboration among different carriers

In a collaboration among different carriers, the implementation of collaboration platforms yields significant CCs, and the independent carriers will have individual-optimum preference.

5.5.4.2 Coalition formation and gain sharing in C4 collaborations

In reality, usually the global-optimum preference assumption cannot be fulfilled. Potential collaborators try to maximize their own profit, rather than global performance. When the CS Core is non-empty, we can use the same coalition formation and gain sharing mechanisms presented in section 5.5.3. When the CS Core is empty, the C4 SNP collaboration is also infeasible due to inherent instability.

5.5.5 Coalition Formation and Gain Sharing Schemes

We investigate the stable coalition formation and gain sharing issues in this section. The scheme of stable coalition formation in the SNP collaboration is illustrated in Figure 5.7.

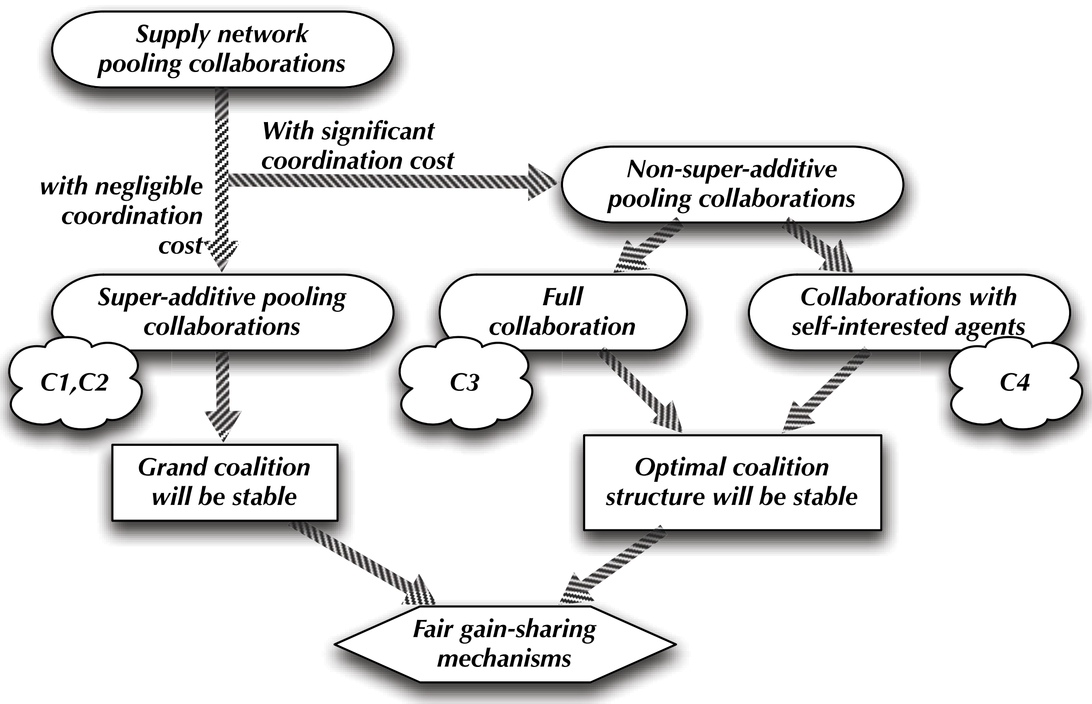

Figure 5.7: Scheme of stable coalition formation in the supply-network-pooling collaboration

We also propose a set of CPWV solutions that is applicable for all feasible pooling collaboration categories, listed in table 5.2.

Table 5.2: Gain-sharing solutions for different supply network pooling categories

	CCs	Preference	(CS) Core	Solution
Pooling categories	Negligible	C1: Global optimum	Non-empty	CPWV
			Empty	CPWV in WLC
		C2: Individual optimum	Non-empty	CPWV
			Empty	Infeasible
	Significant	C3: Global optimum	Non-empty	CS CPWV
			Empty	CS CPWV in WLCSC
		C4: Individual optimum	Non-empty	CS CPWV
			Empty	Infeasible

For collaborators with individual-optimum preference, especially for co-opetitors (competitive collaborators), the gain-sharing mechanism should be well defined to conform to the fairness and stability criteria. And in the cases with global-optimum preference, even if the fair gain sharing is a less importunate demand, it may affect the client satisfaction (in collaborations initialized by a LSP among its customers) and the motivation of subsidiaries to collaborate (in intra-group collaborations).

The gain sharing mechanisms proposed in Frisk et al. (2010) and Dai and Chen (2011b) are of similar formulation forms to the CPWV sharing mechanism set. The sharing mechanism in Frisk et al. (2010) proposes to minimize the highest difference between any two players' ratio of the allocated cost to the cost before collaboration, thus to achieve the fairness of the sharing scheme. It can be interpreted as a Core-guaranteed proportional sharing. Dai and Chen (2011b) proposes the combinations of Shapley value, Core, and other solutions to identify a feasible allocation. It can be interpreted as Core-guaranteed-sharing-mechanism set. Both of these two sharing mechanisms consider only the collaborations with negligible CCs (thus super-additive) in a symmetrical-players setting. The difference of the CPWV sharing mechanism set is that it considers the CCs and proposes feasible sharing mechanisms for super-additive/non-super-additive collaboration games with non-empty/empty Core (CS Core); it proposes to look for a feasible sharing scheme in the most stable allocation sets (Core/WLC/CS Core/WLCSC) by departing from the Shapley value point and taking into account the players' bargaining power.

When players share the global profit, whenever the Core (CS Core) is empty/non-empty, the CPWV solutions constructed for identified feasible pooling collaboration categories provide fair and reasonable gain-sharing solutions with general applicability. The coalition stability in different games, the players' contributions and the players' bargaining powers are considered in the model. In particular, when players are willing to maximize their individual profit (self-interested) and the game has a non-empty Core (or CS Core), stable and reasonable solutions are still available. On the contrary, if the Core is empty, it can be said that the pooling game is infeasible because there is no stable solution for optimal CS.

5.6 Generally Applicable CPWV Sharing Model

In this section, we provide an identical sharing model for all feasible SNP collaborations by integrating all the previously presented sharing mechanisms. At first, we provide following lemmas, propositions and corresponding proofs to support the integration of different sharing mechanisms.

Since the super-additive cover of a super-additive game is the game itself (Aumann and Dreze, 1974), so it is easy to prove the following corollary.

Corollary 5.1. The Core and the WLC of a super-additive pooling game $G_p = (N, v, \{N\})$ respectively coincide with the Core and the WLC of its super-additive cover $\hat{G}_p = (N, \hat{v}, \{N\})$.

In order to prove the coincidence between other Core-like concepts in non-super-additive games and that of the corresponding super-additive cover, we prove the following lemma.

Lemma 5.2. If $P_S^* = (S_1, ...S_i, ...S_k)$ is an optimal CS of S,then for all S_i that $S_i \in P_S^*$,we have $v(S_i) = \hat{v}(S_i)$.

Proof. Assume that $v(S_i) \neq \hat{v}(S_i)$, since $\hat{v}$ is the super-additive cover of v, hence $v(S_i) < \hat{v}(S_i)$, and there is such a $P_{S_i}^*$ that $v(P_{S_i}^*) = \hat{v}(S_i) > v(S_i)$, which makes $P = (S_1, ...P_{S_i}^*, ...S_k)$ more profitable than P_S^*. This contradicts the optimality of P_S^*, hence proves the claim. □

Proposition 5.3. If allocation $x = \{x_1, ...x_n\}$ is in the CS Core of $G_p = (N, v, P_N^*)$, ($P_N^* = (S_1, ...S_k) \in \mathscr{P}$ is the optimal CS), then x is in the Core of $\hat{G}_p = (N, \hat{v}, \{N\})$.

Proof. Since x is in the CS Core of $G_p = (N, v, P_N^*)$, we have

$$x(S_i) = v(S_i),\ \forall S_i \in P_N^*$$
$$x(S) \geq v(S),\ \forall\, S \subset N.$$

According to lemma 5.2,we have $x(S_i) = v(S_i) = \hat{v}(S_i)$, $\forall\, S_i \in P_N^*$. Hence $\sum_{S_i \in P_N^*} x(S_i) = \sum_{S_i \in P_N^*} \hat{v}(S_i)$ and $x(N) = \hat{v}(N)$.

$\forall\, S \subset N$, we have $P_S^* = (S_1, ... S_k)$ as the optimal CS of S. Since x is in the CS Core, we have $x(S_j) \geq v(S_j)$, $\forall\, S_j \in P_S^*$. According to lemma 5.2, we get $x(S_j) \geq \hat{v}(S_j)$, $\forall\, S_j \in P_S^*$. Sum the two sides up respectively we get $\sum_{S_j \in P_S^*} x(S_j) \geq \sum_{S_j \in P_S^*} \hat{v}(S_j)$, hence $x(S) \geq \hat{v}(S)$, $\forall\, S \subset N$. Thus we have

$$x(N) = \hat{v}(N),$$
$$x(S) \geq \hat{v}(S),\ \forall\, S \subset N,$$

and x is in the Core of the super-additive cover $\hat{G}_p$. □

Proposition 5.4. If x is in the Core of $\hat{G}_p = (N, \hat{v}, \{N\})$, then x is in the CS Core of $G_p = (N, v, P_N^*)$ (P_N^* is the optimal CS).

Proof. Since x is in the Core of $\hat{G}_p = (N, \hat{v}, \{N\})$, we have

$$x(N) = \hat{v}(N),$$
$$x(S) \geq \hat{v}(S),\ \forall\, S \subset N.$$

Assume that there is some $S_i \in P_N^*$ for which $x(S_i) \neq \hat{v}(S_i)$, since $x(N) = \hat{v}(N)$, so there will be at least one coalition $S_+ \in P_N^*$ that $x(S_+) > \hat{v}(S_+)$ and another coalition $S_- \in P_N^*$ that $x(S_-) < \hat{v}(S_-)$, which contradicts the assumption. So

$$x(S_i) = \hat{v}(S_i),\ \forall\, S_i \in P_N^*.$$

Similar to the proof in proposition 5.3, we can prove the claim. □

Combining the propositions 5.3 and 5.4, we obtain the following theorem:

Theorem 5.5. *The CS Core of the original pooling game $G_p = (N, v, P^*)$ coincides with the Core of the corresponding super-additive cover $\hat{G}_p = (N, \hat{v}, \{N\})$.*

Now we prove the coincidence between the weak least CS Core of a non-super-additive game and the WLC of its super-additive cover.

Theorem 5.6. *The weak least CS Core of the original pooling game $G_p = (N, v, P^*)$ coincides with the WLC of the corresponding super-additive cover $\hat{G}_p = (N, \hat{v}, \{N\})$.*

Proof. At first, we prove that if x is in the weak least CS Core of $G_p(N, v, P_N^*)$ (P_N^* is the optimal CS), then x is in the WLC of $\hat{G}(N, \hat{v}, \{N\})$.

Since x is in the weak least CS Core of $G_p(N, v, P_N^*)$, we have

$$x(S) \geq v(S) - |S|\varepsilon^*, \; \forall\, S \subset N$$
$$x(S_i) = v(S_i), \; \forall\, S_i \in P_N^*$$

where ε^* is the minimal ε value to make the weak ε CS Core non-empty. And it will also make the corresponding weak ε Core of the super-additive cover to be the WLC, since the original CS Core and the super-additive cover Core coincide.

According to lemma 5.2, we have $x(S_i) = v(S_i) = \hat{v}(S_i), \; \forall\, S_i \in P_N^*$, hence $x(N) = \hat{v}(N)$.

$\forall S \subset N$, we have $P_S^* = (S_1, ...S_k)$ as the optimal CS of S. Since x is in the weak least CS Core, we have $x(S_j) \geq v(S_j) - |S_j|\varepsilon^*, \; \forall\, S_j \in P_S^*$. According to Lemma 5.2, we get $x(S_j) \geq \hat{v}(S_j) - |S_j|\varepsilon^*, \; \forall\, S_j \in P_S^*$. Sum the two sides up respectively we get $\sum_{S_j \in P_S^*} x(S_j) \geq \sum_{S_j \in P_S^*} \hat{v}(S_j) - |S|\varepsilon^*$, hence $x(S) \geq \hat{v}(S) - |S|\varepsilon^*, \; \forall\, S \subset N$.Thus we have

$$x(N) = \hat{v}(N),$$
$$x(S) \geq \hat{v}(S) - |S|\varepsilon^*, \; \forall\, S \subset N,$$

and x is in the WLC of the super-additive cover game.

Similarly, we can prove the reverse. Hence the claim is proved. □

We define a *generalized Shapley value* as follows:

Definition 5.5. The **generalized Shapley value** for a general pooling game $G_p = (N, v, P^*)$ where $P^* \in \mathscr{P} = \{P_1, ...\{N\}\}$ is a contribution-assessing tool that is valid for both super-additive and non-super-additive games. It can be computed by the following formulation:

$$\phi_i^{G_p}(\hat{v}) = \sum_{S \subseteq S_l \in P^*; S \ni i} \frac{(|S_l| - |S|)! \cdot (|S| - 1)!}{|S_l|!} \cdot [\hat{v}(S) - \hat{v}(S \backslash \{i\})], \qquad (5.16)$$
$$\forall \{i, S_l\} \ that \ i \in S_l \in P^*.$$

When the pooling game $G_p = (N, v, P^*)$ is super-additive, the generalized SV equals the SV.

Thus we can use the generalized SV and the Core (and the CS in case the Core is empty) of the super-additive cover of the original game to construct a general applicable CWPV model, instead of a set of different sharing mechanisms. Given a general pooling game $G_p = (N, v, P^*)$, where $P^* \in \mathscr{P}$ and $v(P^*) \geq v(P) \ \forall \ P \in \mathscr{P}$, we have the following definition.

Definition 5.6. The **general CPWV** model is as follows:

Input: $G_p = (N, v)$

Output: P^*, $x = \{x_1, ...x_n\}$

Compute $\hat{v}$ in $\hat{G}_p = (N, \hat{v}, \{N\})$;

Identify P^*;

Compute generalized SV $\phi_i^{G_p}(\hat{v})$ with respect to P^*;

Compute ε^* in CS of $\hat{G}_p$;

If:$\varepsilon^* < 0$;

then: $\varepsilon \longleftarrow 0$;

else: $\varepsilon \longleftarrow \varepsilon^*$;

Solve this LP to compute x:

$$MIN: \quad \theta$$

$$s.t.: \quad \frac{x_i}{\phi_i^{G_p}(\hat{v}) \cdot w_i} - \frac{x_j}{\phi_j^{G_p}(\hat{v}) \cdot w_j} \leq \theta, \forall i, j \in S_k, \ \forall (S_k \in P^* \ and \ \hat{v}(S_k) > 0); \qquad (5.17)$$

$$\sum_{i \in S} x_i \geq \hat{v}(S) - |S|\varepsilon, \forall S \subset N; \qquad (5.18)$$

$$\sum_{i \in N} x_i = \hat{v}(N); \qquad (5.19)$$

$$x_i \geq 0, \forall i \in N. \qquad (5.20)$$

Thus, we construct a CPWV gain-sharing model that is generally applicable for all feasible pooling collaborations. In the following section, we use a real-world-data-based case study and a simple computational case to compare the performance of the general CPWV model and that of SV.

5.7 Illustration of the Application of CPWV Model

In this chapter, we show how supply chain agents use the general CPWV model to collaborate, form coalitions, and share the gain achieved through collaborative supply-network planning. The case study in this chapter are conducted with real flow data of French retail supply network provided by Club Déméter (the association of major logistics players in France, www.club-demeter.fr). This support enables us to conduct studies on a more reliable basis to validate the feasibility of the game-theoretic investigation and the general CPWV model.

In order to show the effectiveness of the general CPWV model for the SNP collaborations with empty Core, we conduct a computational case. The Shapley value and the solution computed by the CPWV model are compared.

5.7.1 Supply chain pooling collaboration in French retail supply network: sharing by general CPWV model

5.7.1.1 Presentation of the case

The aim of this case study is to validate the practicability of the developed general CPWV model. To this end, a pooling collaboration based on real data from FMCG supply chains in France has been investigated. Our partners in this research provide us with an original database, which contains the weeklong flows of one retailer and its four suppliers in the food sector, from the suppliers' Warehouse (WH) to the retailer's eight national Distribution Centers (DC) with the locations of all WHs and DCs. Since the WHs are not far from each other (within 10km), we assume that their flows were from a single point to simplify the problem. The characteristics of the flows are described in table 5.3. One can notice that the suppliers have very different flow sizes and a different number of shipment points (DC). This case with generality can help us understand the impact of the player's power on the gain-sharing model.

Table 5.3: Characteristics of flows of the pooling case during the week studied (NS:Num of sites; SF:Sum of flows in pallet; NL:Num of links; AF:Average flows/link; SDF: Standard deviation of flows/link; AK:Average KM/link; SDK:Standard deviation of KM/link)

	NS	SF	NL	AFL	SD	AK	SDK
Supplier 1	1	77	1	77	-	511	-
Supplier 2	1	714	8	89,25	32,63	519	148
Supplier 3	1	55	4	13,75	20,63	491	187
Supplier 4	1	63	2	31,5	37,48	476	71

We consider the suppliers as players in the game. Thus there are four players in the game (N, v, P^*), where $N = \{1,2,3,4\}$ represents the set of four suppliers. In this pooling case, we mainly focus on the impact of different CCs on the collaboration schemes: super-additive collaborations where the $CC(S) = 0\ \forall S \subseteq N$ and non-super-additive collaborations where the CC becomes significant.

5.7.1.2 Definition and computation of value function

In cooperative game theory, the value function $v(S)$ is the value created by the coalition S, and this value will be shared by the members (denoted by i, $i \in S$) of the coalition. Given that this dissertation focuses on logistics pooling, and that the corresponding optimization problem aims at minimization of the sum of transportation cost, the value created by pooling should be the reduction of the total transportation costs minus the CCs. So the value function of coalition S is defined as $v(S) = B(S) - M(S) - CC(S), \forall S \subseteq N$, where $B(S)$ is the transportation cost of coalition S before pooling, $M(S)$ is the optimized transportation cost after pooling, and $CC(S)$ is the coordination cost of coalition S. Assuming that without collaboration the suppliers will independently ship their flows to the retailer, the non-pooling transportation cost $B(S)$ can be calculated by summing all singleton sub-coalitions of S, for example $B(\{1,2,3\}) = B(1) + B(2) + B(3)$. The transportation cost of coalition S after pooling $M(S)$ is obtained by applying the optimization model of Mixed Integer Linear Programming (MILP) for the SNP presented previously (Pan et al., 2013).

The coordination cost $CC(S)$ is defined as:

$$CC(S) = \begin{cases} 0 & \text{if}|S| < 2 \\ cc \cdot (|S|-1) & \text{if}|S| \geq 2. \end{cases} \tag{5.21}$$

We can further change the coefficient cc (the extra cost for adding a new player to the game) to study the impact of CC on the optimal CS of the game.

Thus we have demonstrated the method to calculate the value of $B(S)$, $M(S)$ and $CC(S)$, thus the value of $v(S)$ for a given coalition S. All results are presented in table 5.4 for the coalitions in our case.

Table 5.4: Value function of coalitions with cc: coordination cost coefficient

Coalition S	B(S)	M(S)	CC(S)	v(S)
{1}	3263	3263	0	0
{2}	27698	27698	0	0
{3}	5792	5792	0	0
{4}	2933	2933	0	0
{1,2}	30961	30432	cc	530-cc
{1,3}	9055	9055	cc	-cc
{1,4}	6196	6196	cc	-cc
{2,3}	33490	29561	cc	3929-cc
{2,4}	30631	28777	cc	1854-cc
{3,4}	8725	7730	cc	994-cc
{1,2,3}	36753	32294	2cc	4459-2cc
{1,2,4}	33894	31510	2cc	2384-2cc
{1,3,4}	11988	10993	2cc	994-2cc
{2,3,4}	36423	30639	2cc	5783-2cc
{1,2,3,4}	39686	33373	3cc	6313-3cc

5.7.1.3 Sharing schemes in the pooling game

This pooling case with real-world data will be investigated under two assumptions: with coefficient $cc = 0$ (C1 or C2 in Table 1) or $cc > 0$ (C3 or C4). At first, we investigate the pooling games with $cc = 0$.

- **Super-additive pooling scenarios**

When $cc = 0$, this game is super-additive, and has a non-empty Core, thus the grand coalition will be stable. By collaborating in the grand coalition, 15.9% logistics cost savings (6,313 € for one week) can be achieved. Then we consider how to divide the common gain. To compute a CPWV allocation, we need to determine the players' bargaining power. In a real application of the CPWV solution, this bargaining power vector would be determined by business negotiation or a bargaining power function with multiple factors agreed upon by all collaborators. Nagarajan and Sosic (2008) introduce bargaining games in supply chain collaboration with bargaining power consideration, while Crook and Combs (2007) review the related literature on bargaining power in a supply chain management context. Since this is beyond the scope of this dissertation, in our illustrative case study, we simply adopt an arbitrary bargaining power vector $\{1, 2, 1, 3\}$ as the input for our model to show the impact of bargaining power on the allocation. Higher weights are intentionally distributed to supplier 2 and especially to supplier 4 to demonstrate the impact of bargaining power on the allocation.

We compute the CPWV allocation in this game, and compare it with the SV allocation. These two allocations are illustrated in figure 5.8. We can see that our sharing mechanism further adjusts the gain allocation according to different bargaining powers, for example the payoff of supplier 3 with power weighted at 1 clearly decreases, in contrast to that of supplier 4 with power weighted at 3. While the modification the bargaining power vector changes payoffs, the Core stability of the allocation is always guaranteed.

- **Non-super-additive pooling scenarios**

As cc increases, the coalition profits decrease, and the player whose logistics network has the least potential for synergy will leave the grand coalition first. Only coalitions with high synergy will survive. In the end, when cc increases to a level where none of the players feels it is profitable to collaborate, the optimal CS will be singletons. In our pooling game, when $cc \geq 530$, the grand coalition is no longer stable, and when $cc > 3929$, players tend to form singletons. Figure 5.9 shows how the optimal CS changes as the coefficient cc increases. The vertical axis denotes the scale of the largest coalition in the optimal CS. We can see that $cc = 530$, 1854 and 3929 are the boundary points of evolution of optimal CS in this case.

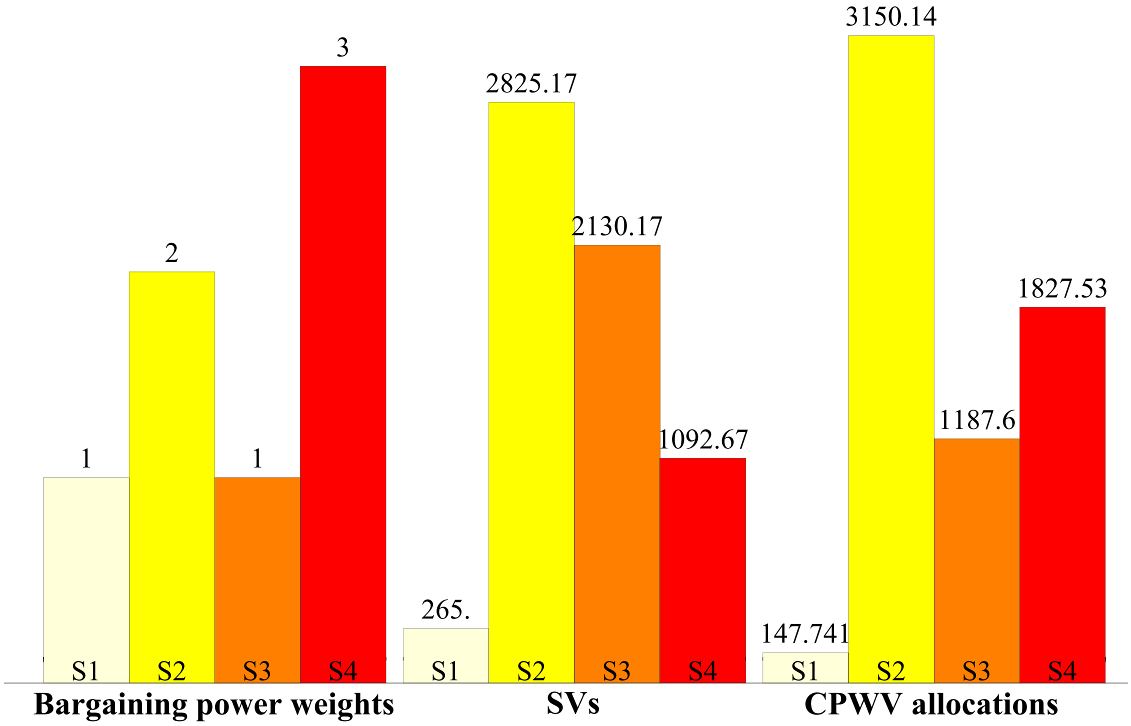

Figure 5.8: Comparison of allocations in the pooling case with nil CC

And as we discussed previously, we demonstrate in this non-super-additive scenario of pooling the occurrence of negative SVs, presented in figure 5.10. We illustrate the (CS) SV allocations when cc increases in steps of 100 from 0 to 4200. We can see that in the game where $cc = 500$, in which the grand coalition is the optimal CS and the Core is non-empty, supplier 1's SV is negative (the SV allocation is {-110, 2450, 1755, 718}). This is also the case for the game with $cc = 1800$ where Player 4 has a negative CS SV (the CS SV allocation is {0}, {1360, 930, -107}). In these cases, another allocation rule is necessary to achieve a globally optimum solution. Hence the general CPWV model in section 5.6 based on super-additive cover concept is employed.

We compute different SV allocations of the super-additive cover when cc increases and the corresponding CPWV allocations with bargaining power weight vector $w = \{1,2,1,3\}$. The two sharing schemes are illustrated in figure 5.11 and figure 5.12 respectively. There is an apparent difference between the two sharing schemes. With the integration of players' bargaining power and game-theoretic solutions, the CPWV sharing model can propose theoretical feasible solutions and at the same time captures more factors that are important for real-world collaboration implementation.

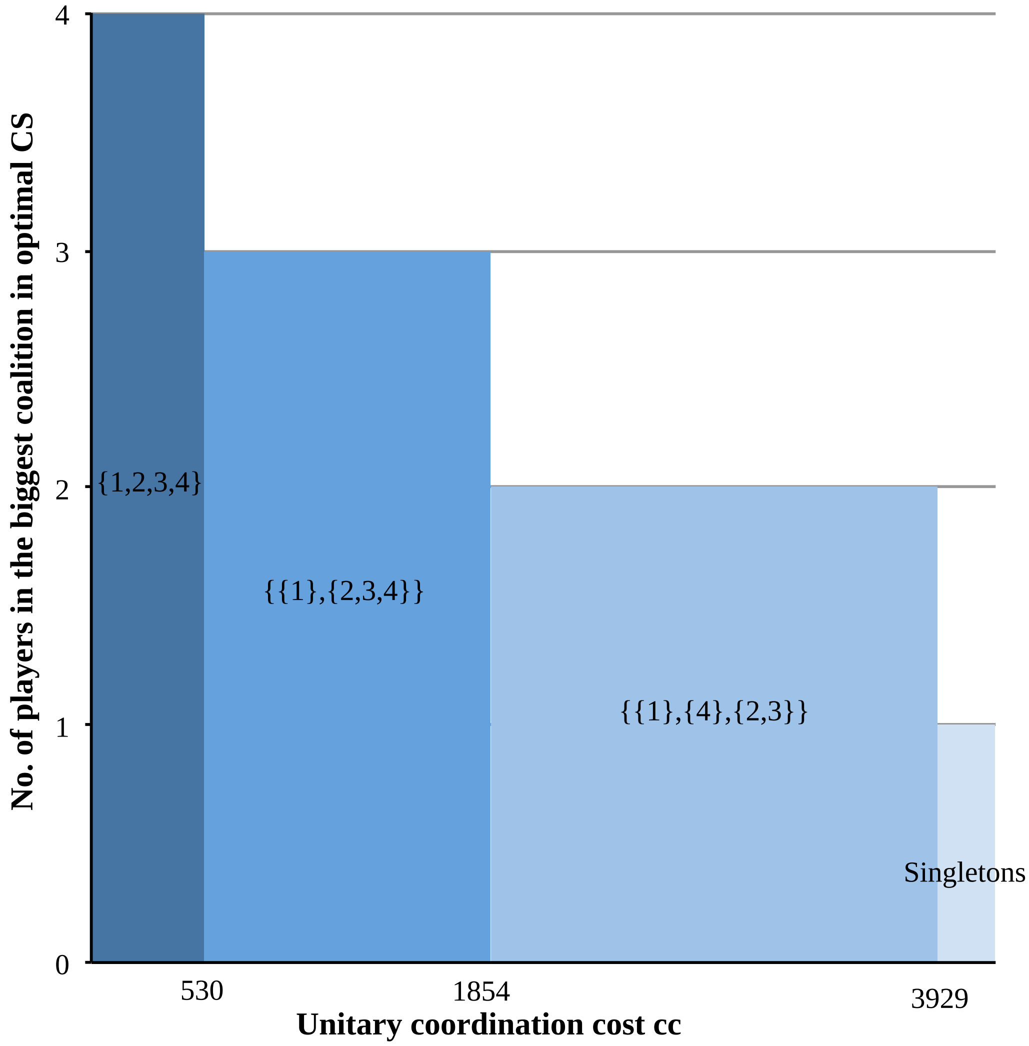

Figure 5.9: Optimal coalition structure submitted to different coordination costs

There are three remarks for figure 5.11 and figure 5.12. First, there is no longer a negative SV in any of the scenarios due to super-additive cover. Second, overall, the SVs before or after super-additive cover have not been significantly changed, compared with figure 5.7. However, the payoff to player 3 is very different for SV or CPWV, but less obvious for the other players. Third, in a coalition having only two players, for instance in the sub coalition {2,3} when $cc = 1854$, the CPWV model allocates payoffs to Players 2 and 3 according to their power, while in the SV allocation they share the gain equally. Overall, the allocation solution computed using the general CPWV model is more appropriate for non-super-additive pooling cases.

As an example, we investigate the case with $cc = 1500$, which represents the C3 pooling case in Table 1. In this case, the game has an optimal CS $P^* = \{\{1\},\{2,3,4\}\}$ and a non-empty

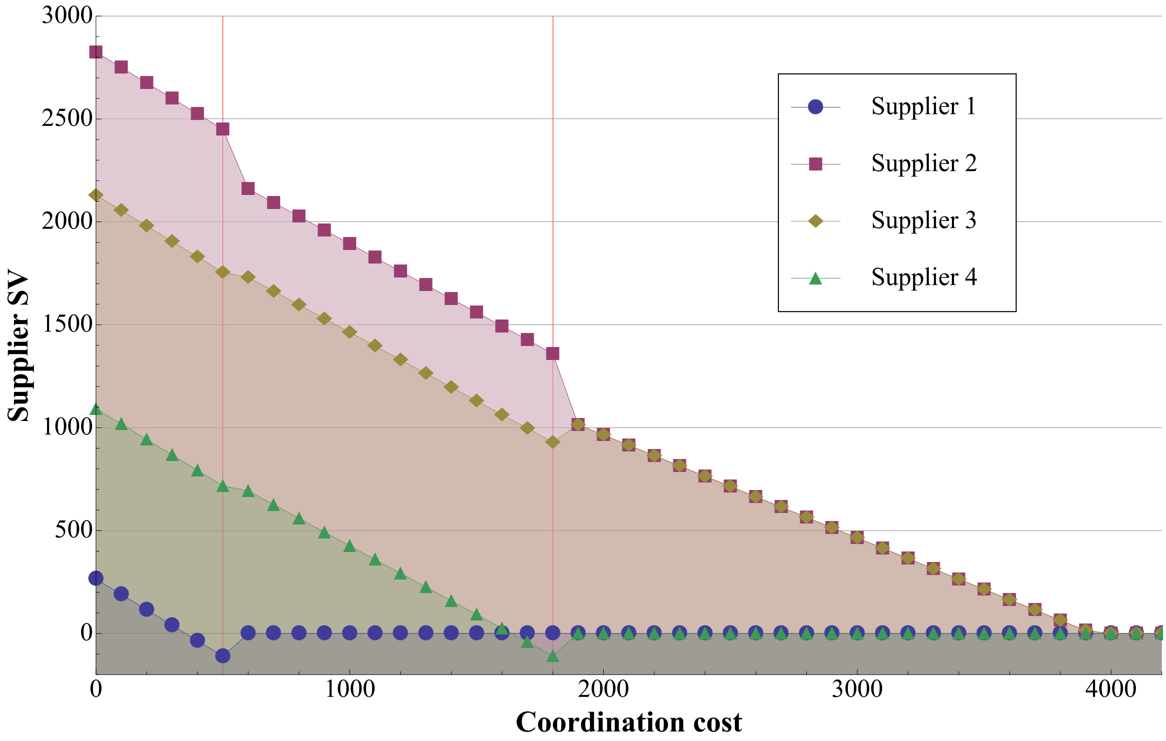

Figure 5.10: Player SVs/CS SVs as coordination cost increases

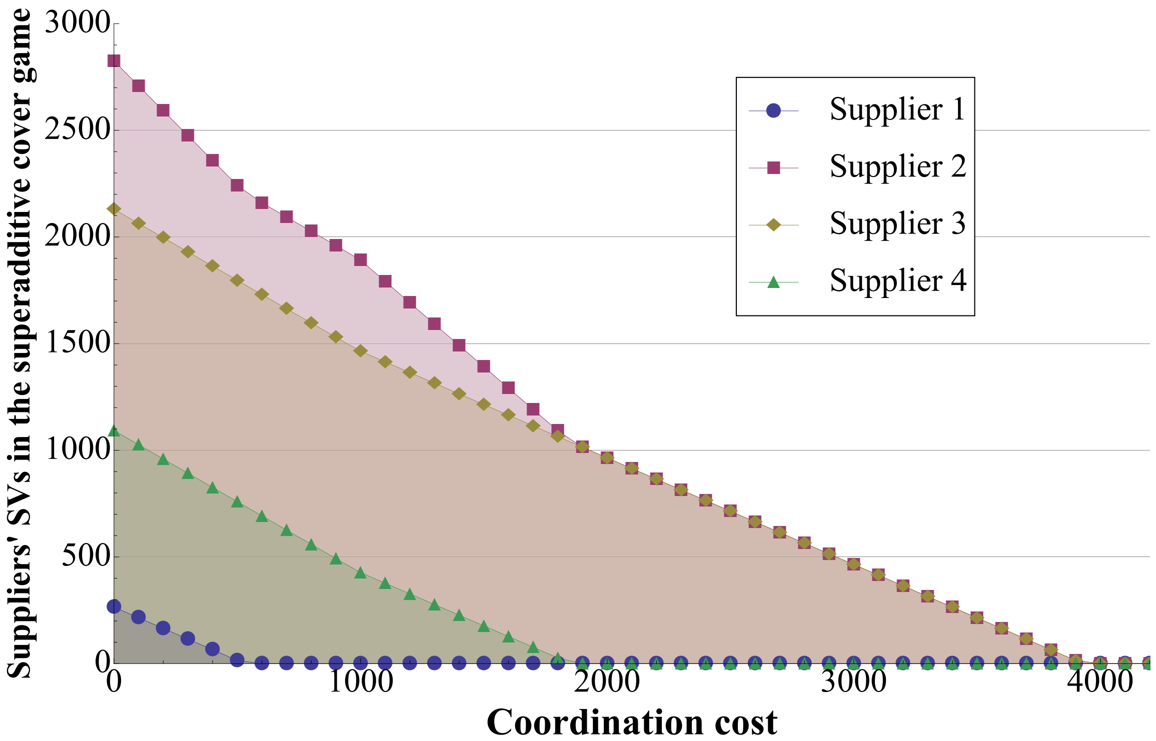

Figure 5.11: Player SV/CS SV of pooling games computed by super-additive cover value function $\hat{v}$

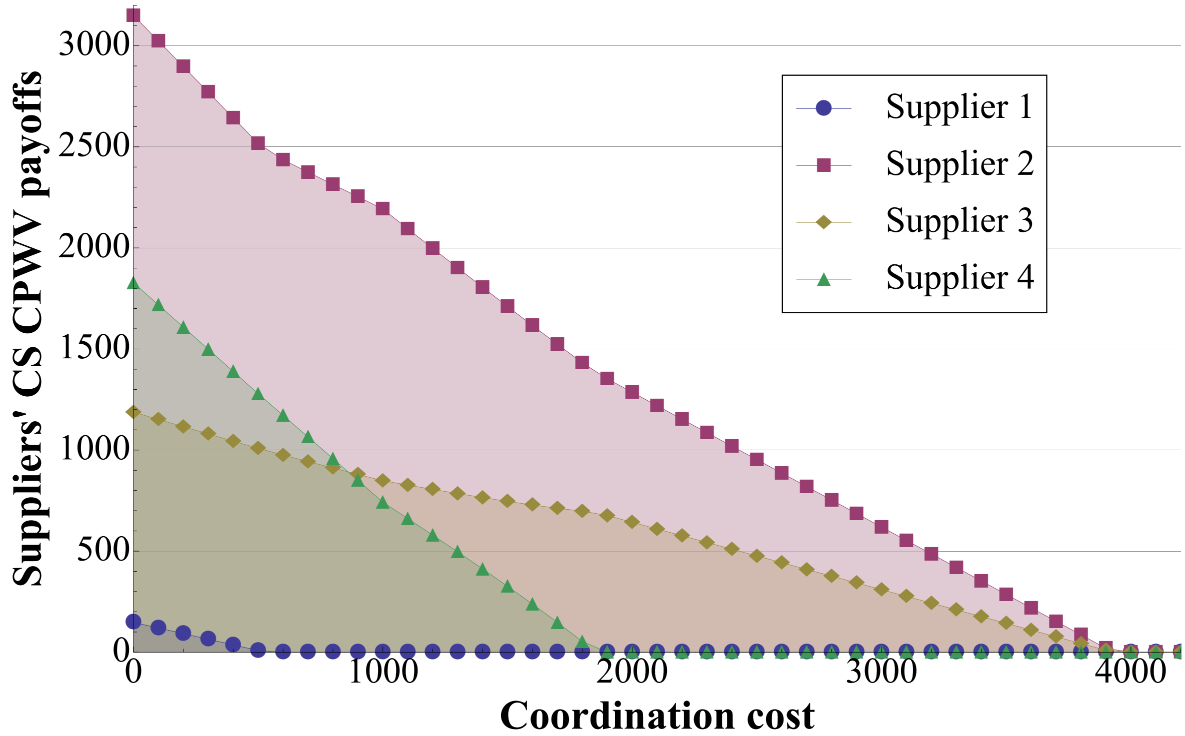

Figure 5.12: Player CPWV/CS CPWV (with weight vector w=1,2,1,3) of pooling games computed by super-additive cover value function $\hat{v}$

CS Core. Supplier 1 in this game remains a singleton due to low synergy, and suppliers 2, 3, 4 collaborate. Figure 5.13 shows the comparison between the SV allocation of the super-additive cover and the CS CPWV allocation.

In this case, the SV allocates payoffs of nearly the same value to suppliers 2, 3, while the CS CPWV allocation makes a distinction between payoffs according to both contribution and bargaining power. In addition, in a game with non-empty (CS) Core, the general CPWV model will always propose Core-stable allocations.

The results show that the general CPWV model is able to provide fair and stable sharing schemes for both super-additive and non-super-additive pooling games. Furthermore, the integration of bargaining power in the CPWV model makes this sharing mechanism more "flexible", which means that the solution proposed are adapted for concrete pooling cases with different bargaining positions under the fair and stable constraints. Compared with the proportional sharing mechanism and the SV, the advantage of the CPWV model is obvious.

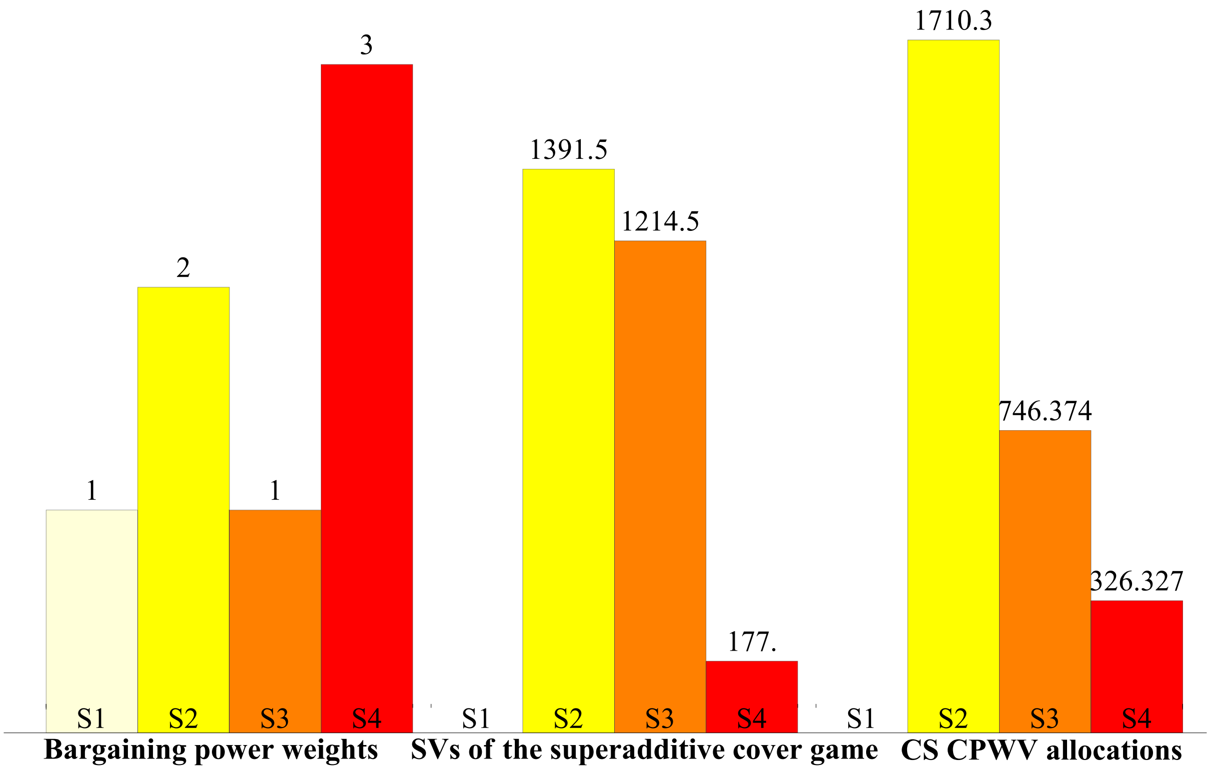

Figure 5.13: Comparison of allocations in the pooling case with $cc = 1500$

5.7.2 Performance of different sharing mechanisms when the Core is empty

The collaboration with empty Core is rare in practice. However, its presence is possible as the logistics flows of collaborators change over the time. That is the reason why we investigate and propose sharing mechanisms for collaborations with empty Core (CS Core). In this section, we compare the performance of the Shapley value and the general CPWV model when the Core is empty.

SV is extensively discussed in the literature, and is adopted to propose gain-sharing schemes in different circumstances. Practitioners have already paid attention to this theoretic tool and try to apply it in logistics collaborations. This allocation rule takes all collaborators' marginal contribution to different coalitions into account, then propose contribution-based gain-sharing scheme. It is more fair and acceptable than the proportional rule. For example, if SV is used to share the gain in example 5.1, the SV allocation $\{30, 30, 30\}$ will satisfy all the 3 firms and makes the grand coalition $\{1,2,3\}$ stable. In addition, SV has good stability property in super-additive collaborations. Béal et al. (2008) prove that, for any super-additive game, its SV is a stable imputation either in the Core or in the farsighted stable sets. But in non-super-additive collaborations, SV cannot guarantee the stability of the collaborative relationship. And due to the absence of bargaining power consideration, it is infeasible for modeling the business reality. For example, in two-agents collaboration, the SV will always allocate the common gain equally, which is not a must in real cases.

Here we show the advantage of the CPWV sharing mechanism by using another example.

Example 5.5. Imagine collaboration among 3 players $\{1,2,3\}$, with the following value function:

- $v(1) = v(2) = v(3) = 0$;
- $v(\{1,2\}) = 6$, $v(\{1,3\}) = 7$, $v(\{2,3\}) = 5$;
- $v(\{1,2,3\}) = 8$.

The Core of this game is empty. In case players have a global-optimum preference, the generally applicable CPWV model will find a proposition in the CS. The SV allocation is $x_{SV} = \{19/6, 13/6, 8/3\}$ and the CPWV allocation is $x_{CPWV} = \{11/3, 5/3, 8/3\}$ when the bargaining power vector is $\{1,1,1\}$.

We assess the stability of the two allocations by their highest *excess* among all coalitions: $\max_{S \subseteq N} e(S, x_{SV})$ and $\max_{S \subseteq N} e(S, x_{CPWV})$. The *excess* of a coalition S is defined as the difference between its value and payoff.

Definition 5.7. *Excess* is defined as $e(S,x) = v(S) - x(S)$.

Excess represents the sacrifices of players in S made to form the grand coalition. The highest excess of the SV allocation is $7/6$ and that of CPWV allocation is $2/3$, which means that the highest sacrifice of some players in the CPWV solution is much lower than that of the SV solution. Since the ε^* used in CPWV model is obtained by computing the CS, the CPWV allocation will minimize the players' highest sacrifice for the formation of the grand coalition, as the example shows. In this sense, it will be the most acceptable solution that can support players' decision-making in implementing the full-collaboration relationship.

As the proportional rule results in loss of global efficiency, without any contribution and bargaining power consideration, and the SV achieves partially stability in certain collaboration categories, and takes into account contribution but not different bargaining power, we need some allocation rule that performs better than the state of the art. The *generally applicable CPWV model* designed for both super-additive and non-super-additive games, whenever the Core (CS Core) is empty/non-empty, provide stable solution propositions with good flexibility. The coalition stability in different games, the players' contributions and the players' bargaining powers are considered in the model. This sharing-mechanism can serve as convenient and powerful tool in the third step in the collaboration-conducting model, to help collaborative partners' decision-making process.

5.8 Conclusion

In this chapter, we identified the following four pooling collaboration categories:

- Collaborations with negligible CCs and global-optimum preference;
- Collaborations with negligible CCs and individual-optimum preference;
- Collaborations with significant CCs and global-optimum preference;
- Collaborations with significant CCs and individual-optimum preference.

Each of these categories with empty or non-empty Core are separately examined. Different coalition formation schemes and variations of CPWV gain-sharing mechanism are proposed for the feasible collaboration cases. After proving the coincidences between the Core-like concepts in different pooling games and the Core-like concepts in their super-additive-cover games, we propose a generally applicable gain-sharing model. To implement this sharing model, we need to assess the synergies lying in different coalitions, and establish a bargaining-power-factor-determination model by the multilateral negotiation of all collaborators. Once the previous steps are taken, we can apply the general gain-sharing model to provide an allocation suggestion as a solid basis for further bargaining.

With the general CPWV model that is robust and guarantees the incentive to collaborate, SNP collaborations become easier to be implemented. It is the same case for the other forms of logistics horizontal collaborations (collaborative vehicle routing, warehouse sharing, etc.). After the evaluation of the synergies lying in all possible coalitions executed by other optimization or simulation tools, we can use the same game-theoretic approach and the general CPWV model to propose a feasible collaboration mechanism, thus to facilitate the implementation of the centralized specific collaborations. In this chapter we focus on coalition formation sensibility to CCs, but in real implementations this would mix also with volume and price fluctuations to determine the coalition formation and gain sharing in the pooled system.

In the case study presented, we consider only the transportation cost reduction as the common gain to share. With the sharing mechanism, we can also share other gain achieved in the HLCs, such as the carbon emission (or carbon tax). Readers who are interested can refer to another French retail chain case study that we carried out (Xu et al., 2012a).

CHAPTER 6

Framework of Decentralized Collaboration Mechanisms in Interconnected Logistics Network

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6.1 Introduction

In the chapters 3-5, we presented the game-theoretic model that we developed as the collaboration mechanism for the implementation of centralized horizontal logistics collaborations. This kind of collaborations occurring among a limited number of collaborators is planned and coordinated by a centralized decision maker, a neutral third-party organization, after the detailed private information concerning the collaborators' logistics profiles being reported to the decision maker. This kind of collaboration is obviously cost efficient, but it is only suitable for the collaborations among a limited number of partners. The computational complexity and the information revelation issues prohibit the implementation of centralized collaboration among many partners. For example, within a highly open logistics networks such that one can easily join or leave the group, stable coalitions are hardly findable. Also in such networks the collaborative relationship is very unstable therefore players will not have incentive to reveal their information, likewise common agreement and global optimum solution are difficult to be reached. Thus in this case with a medium/large number of players, a decentralized collaboration system is more suitable. We consider the decentralized HLC system as an alternative to the centralized one.

In this chapter we propose a framework of the decentralized collaboration mechanisms in a concrete context: the interconnected logistics network (ILN) (Sarraj et al., 2012). This chapter is organized as follows:

Section 2 justifies why we need to investigate the decentralized collaboration mechanism, and why use the mechanism design approach.

In section 3, we give an introduction to mechanism design theory, a theoretic tool to construct the collaboration mechanisms in decentralized HLC systems. We identify two mechanism design approaches: the inverse optimization and the combinatorial logistics auction.

In section 4, we present the context of the decentralized HLC mechanism investigation: the interconnected logistics network. The framework of the collaboration mechanism based on the combinatorial auction (CA) is presented.

In section 5, we develop the bidding intelligence of the automated proxy agents, which is used to support the carriers' bidding-decision-making process.

Section 6 presents an integer linear programming model used to aggregate the bids submitted by carriers, and determine the request allocation and the payment.

In Section 7, we present an illustrative case to show how the previously define system protocols works in a CA of a specific hub.

Section 8 concludes this chapter.

6.2 Why We Need Decentralized Collaboration Mechanism?

Khare and Taylor (2004) make the following definition of a decentralized system: "a decentralized system is one which requires multiple parties to make their own independent decisions." Thus a decentralized collaboration system is a platform with specific rules, based on which all collaborators in the system make their autonomous decisions. According to the rules, collaborators decide independently their own strategies (or actions to take) aiming at maximizing their individual profit. Then the strategies independently taken are aggregated to determine an outcome, which specifies the collaboration details and determines the payoffs for all participants. This kind of collaboration system is entirely different from the centralized ones.

The collaboration among carriers through auction-based logistics marketplace (Dai and Chen, 2011a) is an example of the decentralized collaboration system. The carriers in this collaboration system make their own outsourcing and bidding decisions, and the system protocols aggregate these decisions to specify the request allocation and transaction among the carriers. The concept of *Physical Internet* (Montreuil, 2011; Sarraj, 2013; Sarraj et al., 2012) is another example of the decentralized collaboration system. In these works, a conceptual collaborative logistics network aiming at a fundamental transformation of the current logistics system is proposed. This approach claims to universally interconnect the currently independent logistics networks as the Internet in logistics. The collaboration mechanism is not yet established, but considering the scale of this system, it will probably be decentralized (Ballot et al., 2012, 2011; Montreuil, 2011; Sarraj, 2013; Sarraj et al., 2012).

In this kind of decentralized collaboration systems, there is no centralized planner to implement a globally optimal collaboration scheme, hence the centralized collaboration mechanism does not work. All the agents in the system are independent decision makers and will try to maximize the individual profit. Thus the most important property of the decentralized collaboration mechanism is being able to stimulate the collaborators to make decisions that coincide with the global efficiency. This mechanism should guarantee that by making such decisions, the agent can also maximize his own profit. A feasible and efficient decentralized collaboration mechanism should possess the following properties:

- **Flexible participation:** No long-term commitments are needed to participate the decentralized system. Logistics actors with collaboration incentive could enter and exit the system freely or under flexible conditions.

- **Secrecy:** During the collaboration process, the strategies (or actions) adopted by individual collaborators are the only information revealed to all participants. No further private information revelation is required in the collaboration.

- **Distributed decision-making:** Each collaborator independently makes his strategy decisions. The independent decision-makings of collaborators are based on their own private information and their estimations of that of the others. The distributed decision-makings enable the guarding of private information, and moderate the high computational complexity induced by large number of participants.

- **Incentive compatibility:** Since private information is not required to be fully or truthfully reported in decentralized systems, collaborators will prefer to report the information that could maximize their individual profit. That may harms the benefit of the others and the efficiency of the collaboration system. Thus the mechanism adopted in such systems should make the self-interested decisions made by collaborators and the decisions inducing optimal global efficiency as coincident as possible.

We identify mechanism design theory as a suitable tool to construct such collaboration mechanisms in decentralized systems. Mechanism design theory is the tool to model, analyze, and solve decentralized design problems in engineering involving multiple autonomous agents that interact strategically in a rational and intelligent way (Narahari et al., 2009). The incentive compatibility and information revelation issues are intensively investigated in mechanism design theory in a distributed-decision-making setting. We present mechanism design theory and two mechanism-design-theoretic approaches in the following section.

6.3 Mechanism Design: Approaches to Decentralized Horizontal Logistics Collaboration Mechanisms

6.3.1 Preliminaries to mechanism design theory

Narahari et al. (2009) give the following specification of mechanism design theory:

> *"The theory of mechanism design is concerned with settings where a policy maker (or social planner) faces the problem of aggregating the announced preferences of multiple agents into a collective (or social) decision when the actual preferences are not publicly known. ... The theory also clarifies the extent to which the preference elicitation problem constrains the way in which social decisions can respond to individual preferences. In fact, mechanism design can be viewed as the art of designing the rules of a game to achieve a specific desired outcome. The main focus of mechanism design is to design institutions or protocols that satisfy certain desired objectives, assuming that the individual agents, interacting through the institution, will act strategically and may hold private information that is relevant to the decision at hand."*

According to the citation, we can summarize the objective of mechanism design theory as follows: design institutions or protocols to truthfully elicit the actual preferences of rational agents in order to make collective decision correspond with individual preferences. To achieve this goal, the Bayesian games (Harsanyi, 1967, 1968a,b) are investigated as a crucial foundation of mechanism design theory.

First of all, in Bayesian games, the initial private information of the player i is conventionally called the "type", noted as θ_i; and relatively the information released by the player is called the "reported type", noted as $\hat{\theta}_i$. For example, in a classical auction game, the type of a player is his evaluation for the object in auction; and the reported type is his bid (public or sealed). As assumptions of game, each player i, should perfectly know his own type θ_i, but those of the other players is unknown for player i. In a typical Bayesian game, it is however possible to have a probabilistic to guess the type of a player, noted as p_i for player i. Each player has a set of actions or pure strategies S_i from which he can choose his strategy combination according to his type. And each player i has his own utility function u_i that specifies the payoff that player i would get for any profile of actions and any profile of types (θ, s). Hence we have the following definition of the Bayesian game.

Definition 6.1. A **Bayesian game** Γ is defined as a tuple

$$\begin{aligned} \Gamma = \quad & (N, (\Theta_i), (S_i), (p_i), (u_i)), \\ where: \quad & N: \ the\ set\ of\ all\ players; \\ & \Theta_i: \ the\ set\ of\ player\ i's\ types; \\ & S_i: \ the\ pure\ strategy\ set\ of\ player\ i; \\ & p_i: \ the\ type\ probability\ distribution\ of\ player\ i; \\ & u_i: \ the\ utility\ function\ of\ player\ i. \end{aligned} \tag{6.1}$$

The Bayesian game is defined in a mechanism design environment, this environment uses *social choice function* (systematical choice function in logistics collaboration systems) to achieve the incentive compatibility goal. This function maps the aggregation of reported player types to an outcome set, and different outcomes induce different payoffs for the players. In real applications of mechanism design theory, the concretization of social choice function is a set of outcome determination institutions or protocols. The mechanism design environment is illustrated in figure 6.1.

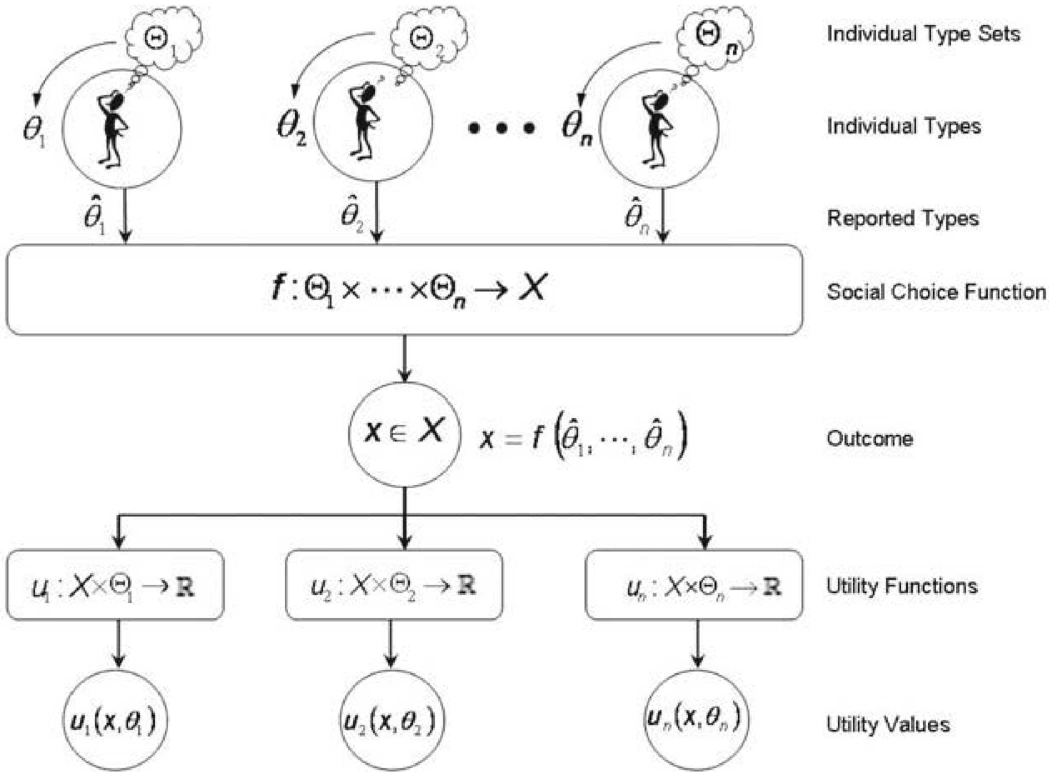

Figure 6.1: Mechanism design environment (Narahari et al., 2009)

The process to play a Bayesian game is showed in Figure 6.1.

- Players know their own type, but in order to maximize their individual profit, they communicate their reported types to the system planner.

- The social choice function, which is a common knowledge for all players, aggregates the reported types, and determines an outcome.

- The players get their own payoffs according to their own utility functions and their types.

The mechanism design thus focuses on how to define the social choice function to make players' self-interested actions as coincident as possible with the systematical efficiency.

We identify two major mechanism design approaches to decentralized logistics collaboration systems: the inverse optimization and the logistics auction approaches. In the following section, we introduce these two approaches, focusing on the logistics auction approach.

6.3.2 Two mechanism design approaches to decentralized horizontal logistics collaborations

There are two mechanism design approaches to implement the HLCs. The first approach is based on inverse optimization, and the other is based on logistics auction mechanism. We introduce these two approaches in the following two sections.

6.3.2.1 Inverse optimization approach to decentralized horizontal logistics collaborations

Agarwal and Ergun (2008) investigate a multi-commodity flow game in carrier alliance. In such game, players (carriers) can pool their assets together to form collaborative service network, thus improve asset utilization and increase revenue. Different from previous researches on multi-commodity flow game, Agarwal and Ergun (2008) consider a decentralized approach to promote the efficiency of the alliance. They allow players to have their own capacities for transportation service in the edges of the service network, and can ask for a capacity exchange price when sharing capacity with others. In this case, each player has an individual-revenue-maximizing strategy represented by a linear programming (LP), and the mechanism introduced in this paper will identify the capacity exchange prices that drive individual beneficial strategies to coincide with the global optimal cooperation scheme represented by a centralized optimization LP. Once the capacity exchange prices are identified and adopted by carriers, the individual strategies selfishly made by them will result in the global optimal solution.

Houghtalen et al. (2011) further develop this approach by integrating the core stability constraints, and implementing this mechanism in a simulated alliance setting in which capacity exchange prices obtained using the mechanism will be in place for a length of time (for example, a quarter), while the volume and location of cargo demand realized by the alliance may change on a daily basis. The result shows that at least 80% of the alliance profit can be recovered, regardless of the variability of distribution of demand.

In this approach, the system need to collect the private logistics information of all members (in assuming that all members report their information truthfully) to compute the appropriate capacity exchange prices that make all the members have incentive to cooperate in a global optimal way. In addition, the capacity exchange prices are implemented as regulations. But the members in an alliance may refuse to exchange capacities at such prices that may be against their best interests, especially provided that such mechanism would result in non-stable allocation of the common gain. Thus using price regulation as the incentive compatibility solution is somehow unreasonable and difficult to implement.

6.3.2.2 Logistics auction approach to decentralized horizontal logistics collaborations

In this section, we firstly introduce the preliminaries to the logistics auction. Then we give a literature review on its applications in HLCs.

- **Preliminaries to logistics auction**

McAfee and McMillan (1987) define auctions as market institutions with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants. In an auction, the auctioneer (may be the owner of what is auctioned or a third-party) collects the bids submitted by bidders (propositions of price on the items), and make allocation decisions. Here the submitted bids are reported types $\hat{\Theta}$ of bidders, and the allocation rules or protocols play the role of social choice function $f(\hat{\theta}_1, ..., \hat{\theta}_n)$. The logistics auctions are always carried out in a reverse manner: The shippers post transportation requests in the auction market, and LSPs propose the prices at which they would like to delivery the services. Thus the requests are allocated in a way to minimize the logistics service procurement cost.

In order to induce win-win outcomes in logistics collaborations based on the auction mechanism, the design of auction protocols is a crucial issue. The auction protocols consist of bidding rules, information revelation policy, and market-clearing rules.

As for bidding rules, auctions can be categorized into single-item and combinatorial ones, and single-round and iterative ones. In single-item auctions, bidders can only bid for each item separately; while in combinatorial auctions (CA), bidders are allowed to bid on single item or bundle of items (the combination of multiple items). The advantage of CA is that bidders can fully express their bidding preference (e.g. a bundle of transportation requests that can be consolidated in one vehicle), thus can reap the synergies among single items. In single-round auctions, bids are submitted in the form of sealed bids, and the outcome is determined immediately after the submission; while in iterative auctions, bidders get feedbacks such as the actual winners of each round, the currently highest bids in this round etc., and can adapt their strategies according to these feedbacks.

As for information revelation policy, auctions can be categorized into open and closed ones, depending on whether other bidders know the bids and bidder identities in the auction process. The most famous types of open auctions are English auction and Dutch auction, where bids are submitted publicly. The best-known closed auctions are the first-price auction, the second-price auction, and the CA, where bids are submitted in the form of sealed bid.

The market-clearing rules is the most important parts in the protocol, as they specify request allocation and prices based on bids of auction participants. For example, in second-price logistics auctions, the auctioned transportation request will be allocated to the LSP whose bid (proposed price) is the lowest among all bidders. In order to motivate the LSPs to reveal their true valuations of the request, the payments for the winner of the auction will not necessarily be the bid that he submitted, but equal to the second lowest bid for delivering the request.

Since that the determination of the efficient allocation in single item auctions is less complicated than that in CAs, the single item auction literature mainly focuses on the payment determination aspect while investigating market-clearing issues. The Vickrey mechanism (also called the sealed-bid second-price auction) is a single item auction mechanism that is used to avoid manipulative biddings. The insight of Vickrey is that even all LSPs have incentive to lie about their cost for higher payment from this network, making the LSPs payment depend only on the declarations of other LSPs eliminate this manipulative element. Mas-Collel et al. (1995) prove the truthfulness of this mechanism, which means by applying this mechanism, the optimal bid strategy for rational LSPs is to report truthfully their costs. Hershberger and Suri (2001) investigate a slightly generalized version of the Vickery mechanism in logistics network formation context. In their work, they suppose an auction with multiple requests on the edges of the network available, but bidders (LSPs) are restricted to submit bids independently for each edge.

With the costs reported by all LSPs in the network with n nodes and m edges, their mechanism computes the cost of the shortest path with edge e and that without edge e, then the payment that will be allocated to the winning LSP on edge e is the difference between these two costs, i.e., the worth of edge e.

In the single-item logistics auctions, bidders are assumed to submit their bids for each edge independently, which results in the uncertainty of winning in segment auctions. Hence the reasonable strategy for bidders is to bid an request without considering the potential synergy among bidden requests, so that they can benefit from serving the request even in the worst situation. On one hand, this increases the logistics service cost; on the other hand, this prevent LSPs from reaping the synergy lying in customer requests to the extreme extent.

CA is an efficient approach to the systematical efficiency. In CA, each bidder is allowed to bid for each possible combination of requests (both single request and a bundle of requests as a whole), so they can take into account the compatibility of requests to bid more competitively. In this way, both the customer satisfaction and the systematical efficiency are improved.

In the supply network formation context with CA mechanism, the winners of the auction will be chosen to maximize the systematical cost efficiency of the requests awarded. In such auction, the well-known Vickrey-Clarke-Groves (VCG) mechanism, which is a generalization of the Vickrey mechanism in CA, may yield non-core payments. Roughly stated, the payments computed by the VCG mechanism can be so high that there may be a coalition of dissatisfied LSPs who can propose another auction outcome (request allocation and payment set) that is preferred by all LSPs in the coalition and the bid inviters. Day and Raghavan (2007) investigate the construction of a mechanism that encourage the truth revealing by paying bidders more than what they bids, while not suffering from the extremely high costs of the bid inviters. They provide a computing procedure that can be applied in any sealed-bid CA for arriving at bidder-Parato-optimal core outcomes, which is incentive compatible and socially acceptable for both the bid inviters and the bidders. By applying this mechanism, all bidders' best strategy is to bid their true cost for carrying out the request/ bundle of requests.

However, as Rothkopf et al. (1990) state, even if Vickery auction mechanisms (for single-item or combinatorial auction) are theoretically proved being incentive compatible, they are rarely applied and seems impractical due to the lack of robustness in the face of cheating and of fear of cheating, and due to the reluctant to follow the truth-revealing strategies. Also, the payment-determination mechanism presented in Day and Raghavan (2007) may be suitable for the auctions of high-value items (such as Federal Communications Commission's spectrum auctions), but is not feasible to be applied in the logistics service sector, due to the transparent cost structure and tariff, and the huge number of requests sealed with on a daily basis. Thus the first-price payment determination in CA seems to be highly perceivable and practical, and we can easily imagine that over-high bidding price won't happen in the logistics sector with low barriers to entry, a large number of actors, and fierce competition.

The request allocation issue receives much attention in CA literature. It is modeled as a winner determination problem (WDP) in CA theory. The WDP in the reverse logistics auction is that: Given a set of bids (propositions of acceptable prices), find an allocation of requests to bidders (the auctioneer can keep some of the requests) that minimizes the total logistics service procurement costs. Since that the WDPs in most CAs are computationally complex (NP-complete), any optimal algorithm for the problem will be slow on some problem instances. Thus basically all real-world WDPs are being solved by search algorithms Sandholm (2006). Sandholm (2002) is such a search algorithm that allows CAs to scale up to significantly larger numbers of items and bids.

- **Application of logistics auction in horizontal logistics collaborations**

In the literature on the application of mechanism design approaches in the HLC, the logistics auction receives much more attention than the inverse optimization. There are two categories of auction-based logistics collaborations: logistics auction marketplaces that match requests and logistics services, and logistics collaboration systems that enable request exchanges among LSPs.

We give the following examples to illustrate these two categories.

Example 6.1. Logistics network formation: Multiple LSPs are currently active in the market, each of them possessing some capacity to deliver the transport service on certain segments of the global supply network. In such context, the LSPs bid for customers' requests on different segments, while the customers try to form the most cost-efficient logistics network by making the most efficient LSPs (those with the lowest bids) on different segments collaborate to delivery the goods. In such a logistics system with auction mechanism, on each edge respectively, the LSPs with the highest efficiency (lowest reported cost) will win the request, and thus the systematical efficiency will increase.

Example 6.2. Carrier request exchange: Multiple carriers have each their own transportation requests, though some of the requests cannot be efficiently delivered (small quantity in those lanes). Through auction market, carriers subcontract their low-efficiency requests to the others, in order to increase their profit, and promote the systematical efficiency.

The first one is to use the auction mechanism as the logistics service procurement tool, while in the second example, the auction mechanism is used as a request exchange mechanism.

With regard to the single-item auction based logistics marketplace, Figliozzi et al. (2003) perform a simulation of the single-item freight auction based marketplace with demands occurring with a Poisson distribution and under a Vickery second-price auction method.

Ledyard et al. (2002) introduces the development and the implementation of the first freight exchange system using CA. In 1992, the largest procurer of trucking services in the world, Sears Logistics Services (SLS), engaged the consulting firm of Joseph Swanson and Company (JSCO) to help consolidating its trucking services. Based on the combined-value trading technology being developed within the California Institute of Technology (Caltech) by the founders of Net Exchange (NEX), a project was executed, aiming at implementing a combinatorial-auction-based procurement system.

In this procurement system, 3-years contracts to supply lanes are auctioned. Considering the probable resistance of carriers to participate in the auction due to the anxiety of diminishing their profit margin, a small number of qualified carriers are selected to have the exclusive rights to bid in the auction. The design team from SLS, JSCO, and NEX chose an iterative version of the sealed-bid procurement auction, in which bidding proceeded in rounds. In each round, bidders are required to submit their bids for both single lanes and bundles of lanes, based on their cost to supply these lanes and the complementarity among the SLS lanes and their current contracts committed by other clients. The SLS auctioneer determines the winners as their bids minimize the total procurement cost when it allows only one carrier per lane. At the end of each round, the auctioneer announces the provisional winner, and holds these provisional winning bids. Going to the next round, the carriers submit new bids against that set. The auction proceeds like this until the total procurement cost did not decline by a predetermined percentage from the previous round, then the just-completed round is declared to have been the final round, and SLS pay the winning bidders their asking prices.

This auction is a first-price iterative CA. Theoretically, each bidder could submit a huge number of bids, which makes the combinatorial WDP insolvable. However, practical factors limited the number of bids. During the implementation of the SLS procurement system, the number of bids submitted per carrier was limited to 4595, and no carrier complained that he could not submit enough bids. Thus the computational complexity problem of the CA could be solved from practical viewpoint.

The carriers' overall reaction to this auction mechanism is favorable. To acquire the transport services for 536 lanes using this auction-based procurement system, SLS achieves $ 3.3 million (13 percent) of total cost savings, comparing with the previous rates. Over a three-year period, SLS saved more than $ 84.75 million by running six combined-value auctions.

We can see that the CA-based logistics marketplace can achieve significant service procurement cost reduction by exploiting the synergies among requests. Despite the advantages of online freight marketplaces, some shippers hesitate to join online marketplaces (especially public ones) as they do not assume responsibility for the execution and performance of the business entities in this system. And some shippers believe that trust, vital for good relationship, cannot be built without person-to-person negotiation. The use of private marketplaces with several contracted shippers and carriers may be a solution to increase the reliability of the online matchmaking system, and so does a public online marketplaces where agents (shippers and carriers) may be certified based on their service records and business credentials. Some carriers look down on online freight marketplaces because they think that the fierce competition may further cut into their already low margins. Limited number of carriers in the private marketplace can help to moderate the price competition.

Another approach is to use CA-based request-outsourcing market to help LSPs improve their cost efficiency. Regan and Song (2003) introduce an application of the simplest single-item first-price sealed-bid auction in small and medium carrier collaboration. In such kind of collaboration, carriers firstly form a collaborative group and make mutual agreement on performance and price. When a carrier obtains an order, it will evaluate the compatibility between this order and his scheduled operations by optimization tools, to decide whether to auction this order to the other carriers. When this order is auctioned, the other carriers evaluate this order, and the carriers having compatible operations will bid for it. Analysis shows that such collaborative system the system is a Pareto efficient one in which no participants are harmed and many are better off. Jin and Wu (2006) investigate a supplier strategy to gain more profit without declining the systematical efficiency in on-line reverse auctions by forming coalitions. This supplier collaboration case can be directly translated to a carrier collaboration case. Considering the different cost structure of the suppliers, they may have different competitive advantage when the attributes of orders vary. Thus in auctions for various orders using second-price auction mechanism, suppliers have incentive to form coalitions to avoid intra-coalition competitive bidding and to share the profit. By applying the auction mechanism with supplier coalition and the corresponding profit distribution scheme, the order will always be assigned to the supplier with the lowest cost, and the winning supplier will get the highest payoff in its coalition. The profit increment (compared with no-coalition scenario) achieved in supplier coalition is at buyers' charge. Schwind et al. (2009) introduce their ComEX intra-enterprise request exchange system used to reduce the total cost of its profit centers. Delivery time windows and some other practical constraints are considered in this system. The simulation result shows that up to 14% of the total cost can be reduced by applying this request exchange system.

The combinatorial-auction-based freight exchange collaboration, which focuses on using well defined market mechanism to promote the request allocation efficiency, is feasible in developing decentralized HLC mechanisms. It is able to achieve systematical efficiency in a decentralized HLC system. Thus we adopt the CA mechanism to develop the decentralized collaboration mechanism in HLC systems.

6.4 Interconnected Logistics Network: Study Background

6.4.1 Interconnected logistics network

The idea of the *interconnected logistics network* (ILN) is to interconnect the fragmented and independently operated logistics networks in order to improve the global logistics efficiency. The supply network pooling (SNP) and PI network are two such examples. In this dissertation, we adopt the latter as the background to investigate the application of MD in logistics collaborations, and consider the design of collaboration mechanism in such collaboration systems.

Concerning the performance of PI, previous works are mainly focussed on the assessment of transportation efficiency. A first estimate of the performance of the PI vs. the actual organization was carried out by continuous approximation method. This work based on a very stylized approach shows very encouraging results with reduction in cost between 33% and 50% (with stock) and t.km by 22% (Ballot et al., 2011). And as introduced in Ballot et al. (2012), the logistics efficiency increases as the network dedication and fragmentation being reduced by the PI approach.

Sarraj et al. (2012) give the first demonstration of the potential of logistics efficiency improvement of the PI based on actual logistics operations. They develop the routing protocols in the PI and conduct a simulation with real-world order data from fast-moving-consumer-goods (FMCG) sector in France. It is based on an interconnected logistics network (ILN), which is compared with overlapping logistics networks in Figure 6.2. The result is quite encouraging. The load is increased by nearly 20%, the time lost in night rests nearly disappears, the shift to trains is major and leads to a 60% reduction of CO_2 emissions in France, without sacrificing lead-times or jeopardizing the operational costs that are even lower.

Sarraj et al. (2012) use a simulation model to investigate the efficiency of the ILN collaboration system. In this system, the transportation requests in different supply networks are

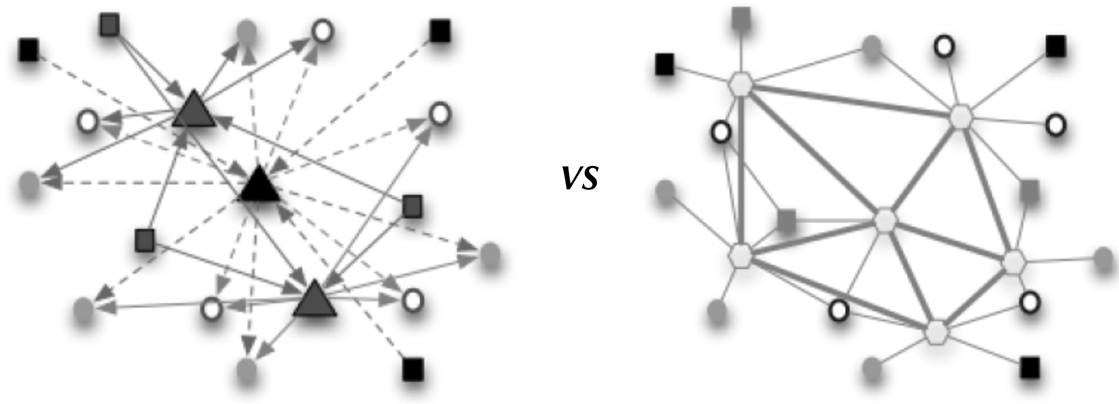

Figure 6.2: Mechanism design environment (Sarraj et al., 2012)

consolidated in the universal PI network and delivered by collaborative carriers. The simulation shows that the truck fill rate and lead time has been significantly improved by the ILN collaboration. In this simulation framework, the decision of the request routes are predetermined by the A* shortest path optimization (Dechter and Pearl, 1985). When a request arrives at an hub, it will be loaded to the most filled truck among all the trucks in the hub that will take the same route as the request, so as to estimate briefly the potential synergy in the ILN system. However, such request-allocation rule represents centralized decision-making at least at the level of the hub, and a suitable decentralized collaboration mechanism consisting of the request-allocation and gain-sharing protocols is needed for the realization of such ILNs.

In order to improve the implementability of such ILN collaborations, we propose the following decentralized HLC system: transportation requests are submitted to the system by shippers, and the routes of the requests are predetermined by shortest path optimization, just as in Sarraj et al. (2012). All carriers can participate in this open logistics system, to collaboratively deliver the shipper requests. The participation of carriers and their own networks form the infrastructure of the system.

In such an open logistics network setting, the allocation of transport requests and the gain sharing issue are the key factors to implement such innovation. Thus we investigate the application of CA in the ILN cases as the request-allocation and gain-sharing mechanisms. Considering the impact of prices proposed by carriers on different segments of the supply network on the request-allocation-and-reallocation decisions made independently by shippers, we propose a CA-based collaboration mechanism that enables the use of collaborative request delivery to increase the systematical logistics efficiency.

We aim at developing a CA-based collaboration mechanism, whose main procedure is as follows: CAs are conducted in each hub in every predetermined time interval to allocate or reallocate requests arrived in the hub. Each local carrier is a bidder in the CA, who evaluates its cost and expected profit margin to fulfill request bundles and then propose bids. With combinatorial bids submitted, the organizer of the CA solves a WDP to find how to allocate requests. The framework of system protocols, the bidding intelligence of the automated proxy agents, and the WDP formulation are developed. The design details are presented in the following sections.

6.4.2 Framework of the combinatorial-auction based interconnected-logistics-network system

In order to guarantee the high efficiency in this open logistics system, while making all participants in this system can benefit from the synergies therein, following protocols are established.

Transportation requests and the corresponding asking prices are submitted by shippers to this system founded on the interconnection of carriers' networks. Once a transport request is received, the route to delivery this request is determined by the A* shortest path optimization (Dechter and Pearl, 1985), as a sequence of hubs, which begins with the original hub and ends with the destination.

In each hub, arrived requests (both the requests whose origin is the hub and those passing through the hub) are put in a pool, and in each predetermined time interval intra-hub single-round sealed-bid CA are carried out to allocate (or reallocate) the requests in the pool to carriers. The CA details are as follows: When a CA begins in an hub, the requests information and their routes are communicated to all local carriers. The carriers evaluate the requests and submit sealed bids for request bundles via automated proxy agent. The bidding intelligence of the automated proxy agents is developed to help carriers generate profitable and competitive bids basing on cost evaluation, expected profit margin, etc. All these bids will be collected by the auctioneer. The collected bids will be preprocessed, and then evaluated to make request allocation/reallocation decisions.

The reason why we allow the reallocation of requests (the carrier shifting behavior) is due to the consideration of system efficiency. The reallocation of requests in the intermediate hubs enables the co-delivery of the requests by different carriers through different segments of the ILN. The most cost-efficient carriers in each segment will be in charge of the segmental request delivery tasks, and thus the systematical transportation efficiency is increased.

In each intermediate hub, requests (or carriers) have possibility to shift their carriers (or requests). However, the arbitrary carrier-shifting or request-shifting behaviors are undesirable for the sake of both the carriers and the shippers in the system. From shippers' perspective, it is not acceptable to be dropped halfway, or be forced to accept a higher rate due to the deviations of some requests in the same truck. And for carriers, the arbitrary carrier-shifting behaviors of shippers result in high uncertainty of efficiency and profitability.

Thus in order to promote efficiency by allowing request reallocation, while restricting arbitrary carrier-shifting or request-shifting to avoid disorder, we need corresponding regulations in terms of system protocols. In the CA-based ILN system, the requests are relocated through market mechanism. When no other carrier can propose more attractive price for a request bundle, the carrier who has brought the bundle to this hub engages to delivery the request to its destination, thus to avoid carrier's unilateral request-shifting behavior. When request allocation decision implies request reallocation, the corresponding shipper should pay a compensation equaling half of the difference between previous and current prices to the previous carrier for its carrier-shifting behavior. Specially, if a request bundle was previously allocated to a carrier, this bundle will be delivered as a whole from then on (thus indivisible), unless there is a division-and-reallocation decision making all the shippers of this bundle better off. It can also be interpreted as that: the division and reallocation of a already-formed request bundle should make all shippers of the bundle better off. This protocol is used to avoid shipper's unilateral carrier-shifting behavior that may harm the interests of the other shippers in the same bundle. These carrier-shifting/request-shifting protocols are guaranteed by the coaction of bidding regulation and WDP formulation, which will be detailed in section 6.6.2.

6.5 Autonomous Proxy Agents

The autonomous proxy agent is wildly discussed in the literature on auction theory, Cramton and Ausubel (2006); Parkes and Ungar (2000) are two examples. The proxy agent is a bidding representative that proposes bids, or bids directly on behalf of its bidder. It is used either to aid bundle-bid-generation or to constraint the set of possible bidding strategies.

In logistics CAs, the carriers would encounter difficulties when making bidding decisions, due to the exponential number of possible bundles in the number of requests. 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 not only for the bidders, but also the auctioneer, who needs to solve the NP-complete WDP.

Plummer (2003) observes that, in spite of the advantage of bundle bids for carriers, most carriers do not submit bundle bids in many applications of logistics CA, which is mainly due to the novelty of large CA and the complexity of identifying profitable bidding strategies. Thus the carriers need an efficient and effective bidding strategy to benefit from logistics CAs. Moreover, An et al. (2005) find that, the profit of shippers increases in the number of strategical carriers who submit profitable bundle bids, and cleverer the carriers are, more synergies lying among single requests can be reaped and distributed among carriers and shippers. Thus from the perspective of the decentralized-HLC-system implementer, a bidding-assistant tool is needed to improve the systematical efficiency. We propose the use of automated proxy agents to facilitate and assist the bidding-decision-making process of carriers.

At each hub and in every predetermined time interval, one CA is carried out to allocate the requests already arrived at the hub to local carriers. Then the request information is communicated to the local carriers' proxy agents, and the agents analyze the requests and submit bids according to carriers' personalized configuration (cost function, profit margin, etc.). The proxy agents need to make decisions on which request bundles to bid on and how much to bid for each of these bundles in order to maximize carriers' profit. Thus we develop the profitable bundle identification and cost evaluation intelligence of the proxy agents in this section.

At first, we propose a process to identify feasible and profitable request bundles, where an algorithm to identify compatible request groups is developed. Then we propose the cost evaluation of different request bundles and specify what information the proxy agents need in order to submit appropriate bids on behalf of the carriers.

6.5.1 Identification of feasible and profitable request bundles

In a CA carried out in one hub, the local carriers are in face of a network consisting of all the segments that the requests currently in the hub will pass through, which we call the *request network*, illustrated in Figure 6.3.

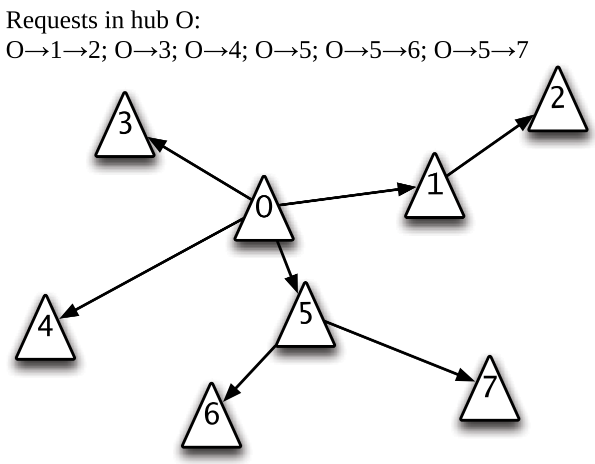

Figure 6.3: The request network faced by carriers in a CA in hub *O*

To note that the request network is not the logistics network consisting of all the carriers networks, but only part of it corresponding to the requests currently in the hub. In investigating the bid generation problem, we find that there is no need to consider all subsets of requests in one hub as potential bundle bids. The reason is that only the requests whose destinations are distributed along the same route are compatible with one another, and thus can be jointly delivered by one truck. We put all compatible requests that can be consolidated along a common route in the same *compatible group*. After identifying all such compatible groups (may be overlapping), we consider the subsets of each of the groups as feasible request bundles.

For one specific hub, its request network exhibits a tree topology, as illustrated in Figure

6.4.

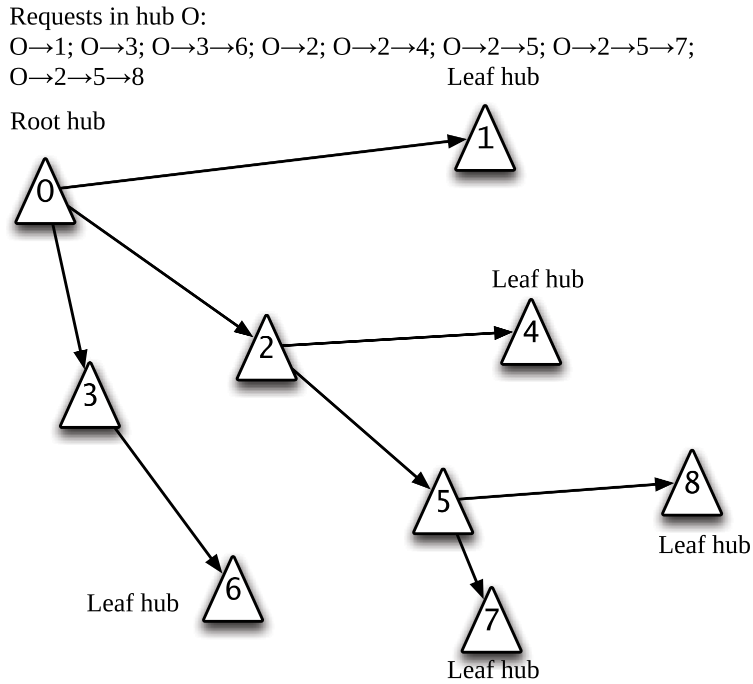

Figure 6.4: Illustration of the tree topology of the request routes from hub O

There are *leaf hubs*, where no outgoing delivery, and a *root hub*, where no incoming delivery, in this network. All other hubs are called *intermediate hubs*. All requests are from the root hub to the other hubs. Once a request enters into the decentralized HLC system, its route from the origin to the destination is made and will not change. Carriers that have been allocated request bundles have to respect the predetermined routes of the requests in the bundle. We define *leaf requests* or *intermediate requests* as the requests whose destination is a leaf hub or an intermediate hub respectively. It is important to note that there is no loop in the tree topology since we assume that there will be one and only one shortest path for each request. We define the *length* of a request by the number of segments it passes. For example, in Figure 6.4, a request from root hub O to hub 8 is of length 3.

Use $\leftarrow$ and $\rightarrow$ to represent "in" and "out" operations. G_m denotes the mth compatible group. The algorithm identifying compatible groups in a specific hub is as follows. Thus we identify all the sets G_1, ..., G_m as compatible groups.

Initialization: Put intermediate requests into set *IR*, and put leaf requests into set *LR*. Order requests in *LR* according to the index of their destination hubs.
Set group index $p = 0$;
Set request variable $q = NULL$;
Loop;
  If *LR* is empty, **then return**;
  If the first request in $LR = q$, **then** $LR \to q, G_p \leftarrow q$;
  Else set $q =$ the first request in *LR*;
    $p++$;
    $LR \to q,\ G_p \leftarrow q$;
    Find the set CS_q of requests compatible with q in *IR* (requests whose segments all belong to q);
    $G_p \leftarrow CS_q$;
Go to Loop;

After the identification of the compatible groups G_1, ..., G_m, we examine the generation of request bundles. The volume of request r is denoted by v_r. It is a one-dimensional variable representing the length of the standardized containers, and each carrier t is of an available capacity va_t representing the total length of the containers it can be charged with. Since in *fast moving consumer goods* (FMCG) sector the weight of requests is not an issue, we do not take this into account. Note that in order to simplify the bid generation problem, we consider the vehicles in this system as different carriers (or bidders) to propose its bundle bids so as to limit the scale of the bundle bids submitted (only the bundle bids with a volume less than single vehicle's capacity are feasible). Thus one carrier t_i can bid on the request bundles being the subsets $RB_1, ..., RB_k$ of compatible groups $\{G_1, ..., G_j, ..., G_m\}$ that $RB_1, ..., RB_k \subseteq G_j,\ j \in \{1, ..., m\}$, $RB_1, ..., RB_k \neq \emptyset$, and $\sum_{r \in RB} v_r \leq va_t, \forall RB \in \{RB_1, ..., RB_k\}$, where va_t is the single-vehicle capacity.

6.5.2 Cost evaluation of request bundles

With all feasible request bundles generated, we investigate the cost evaluation of the valid bundles. The segment between two directly connected hubs h_a and h_b is denoted by s_{h_a,h_b}. The distance of segment s is denoted by d_s and the total distance of request r is denoted by d_r. The volume of request r is denoted by v_r. If we denote the fixed cost rate (€$/truck$) of carrier t_i by c^i_f, the distance-related variable cost rate (€$/km$) of carrier t_i by $c_v d^i$, and the distance-and-volume-related variable cost rate (€$/km \cdot load$) of carrier t_i by $c_v dv^i$, then the carrier t_i's transportation cost CT^i_{RB} for a request bundle RB (with a volume less or equal than truckload) is calculated by Equation 6.2.

$$CT^i_{RB} = c^i_f + c^i_{vd} \cdot \max\{d_r | r \in RB\} + c^i_{vdv} \cdot \sum_{r \in RB} d_r \cdot v_r. \tag{6.2}$$

The carrier t_i's bidding price for a bundle RB is computed by $P^i_{RB} = CT^i_{RB} \cdot (1 + mr^i)$, where mr^i is the bidding margin rate of carrier t_i representing its extra-cost rate (e.g. administrative costs) plus its expected profit margin rate.

In the CA-based ILN system, we adopt the practical first-price payment determination scheme, as stated in the previous chapter. Once a bid is accepted, the payment by shipper to carrier t_i for carrying a specific request r^* in bundle RB is computed by sharing the price among all requests delivered according to the product of the request's distance and volume. So the shipper payment to carrier t_i for request r^* is computed by Equation 6.3.

$$PS^i_{r^*} = \frac{P^i_{RB} \cdot d_{r^*} \cdot v_{r^*}}{\sum_{r \in RB} d_r \cdot v_r} \tag{6.3}$$

And the shipper payment rate for delivering request r^* is computed by Equation 6.4.

$$RS^i_{r^*} = \frac{PS^i_{r^*}}{d_{r^*} \cdot v_{r^*}} = \frac{P^i_{RB}}{\sum_{r \in RB} d_r \cdot v_r} \tag{6.4}$$

This payment rate can also be interpreted as the individual logistics efficiency. A low payment rate for request r^* implies high logistics efficiency for the shipper of r^*.

After the development of bid bundle generation and cost evaluation strategies, the carriers are able to identify feasible and profitable bundle bids. In the following section, we propose the suitable bidding language for the bid submission, and a CA formulation that integrates the submitted bids, and identifies an auction outcome specifying request allocation and corresponding payments.

6.6 Combinatorial Auction in the Interconnected-Logistics-Network System

6.6.1 Choice of bidding language

Bidding language is used to express bidders' preference to different request bundles. The most basic bid, called *atomic bid*, is the pair (RB, P_{RB}), where RB is a request bundle and P_{RB} is the price the bidder would like to accept for delivering the bundle RB. Bidders can also submit OR bids, denoted by $(RB_1, P_{RB_1})OR...OR(RB_k, P_{RB_k})$, to represent that the bidder want to deliver any combination of $RB_1, ..., RB_k$ and accept corresponding prices. The OR bidding language is suitable when there is no substitutability among $RB_1, ..., RB_k$. XOR bids are submitted to express bidder preference to at most one among all bundles, e.g., XOR bid $(RB_1, P_{RB_1})XOR...XOR(RB_k, P_{RB_k})$ means that the bidder want to deliver only one of the bundles $RB_1, ..., RB_k$. Considering that the bidders in each hub are carriers with limited capacities, the XOR bidding language is suitable for our case.

6.6.2 Winner determination problem formulation

We formulate the WDP in this section. The set of all bidders (carriers) in a root hub h_O is denoted by $\mathscr{T}_{h_O} = \{t_1, ..., t_n\}$, and the set of all transport service requests (containers) in h_O is denoted by $\mathscr{R}_{h_O} = \{r_1, ..., r_l\}$. Requests are put in CA pool when arriving at the hub. A bundle RB is a set of requests: $RB \subseteq \mathscr{R}_{h_O}$. Carrier t_i in this hub evaluates its bidding prices $\{P^i_{RB_1}, ..., P^i_{RB_k}\}$ to delivery different bundles $RB_1, ..., RB_k \subseteq \mathscr{R}_{h_O}$, and submit bids $\{b^i_{RB_1}\ XOR...XOR\ b^i_{RB_k}\}$ where $b^i_{RB} = \{RB, P^i_{RB}\}$ for bundles $RB_1, ..., RB_k \subseteq \mathscr{R}_h$, i.e., the bundle preferences and the minimal prices that the carrier t_i will accept for carrying the request bundles. Using binary decision variables $x^i_{RB} \in \{0, 1\}$ to describe if allocate bundle RB to carrier t_i , carrier t_i gets the bundle RB if $x^i_{RB} = 1$. $\{x^i_{RB} | t_i \in \mathscr{T}_{h_O}, RB \subseteq \mathscr{R}_{h_O}\}$, an aggregation of all x^i_{RB}, is an allocation of requests to carriers. We use $\mathscr{I}_{h_O}$ to denote the set of incoming carrier index and request bundle pairs $\{i, RB\}$. $\{i, RB\} \in \mathscr{I}_{h_O}$ means that carrier t_i have carried bundle RB to the hub h_O, and h_O is an intermediate hub of the request bundle RB. We use RS'^{i}_{r} to denote the previous payment rate of request r, and use RS^{i}_{r} to denote the current payment rate. If carrier t_i carried RB to hub h_O ($\{i, RB\} \in \mathscr{I}_{h_O}$), in order to guarantee that no request will be dropped halfway, the submission of a bid $b^{i}_{RB} = \{RB, P^{i}_{RB}\}$ by carrier t_i is imposed, where the current payment rate RS^{i}_{r} of RB equals to or less than the previous rate RS'^{i}_{r}.

Given a set of bids submitted in the XOR bidding language in hub h_O, the WDP_{XOR} in ILNCA can be formulated as the following integer linear programming:

$$
\begin{aligned}
min: \quad & \sum_{t_i \in \mathscr{T}_{h_O}} \sum_{RB \subseteq \mathscr{R}_{h_O}} P^{i}_{RB} \cdot x^{i}_{RB} && (6.5)\\
s.t.: \quad & \sum_{t_i \in \mathscr{T}_{h_O}} \sum_{RB \subseteq \mathscr{R}_{h_O}, RB \ni r} x^{i}_{RB} = 1; \ \forall r \in \mathscr{R}_{h_O} && (6.6)\\
& \sum_{RB \subseteq \mathscr{R}_{h_O}} x^{i}_{RB} \leq 1; \ \forall t_i \in \mathscr{T}_{h_O} && (6.7)\\
& RS'^{i}_{r} - \sum_{t_j \in \mathscr{T}_{h_O}} \sum_{RB_u \subseteq \mathscr{R}_{h_O}, RB_u \ni r} x^{j}_{RB_u} \frac{P^{j}_{RB_u}}{\sum_{r' \in RB_u} d_{r'} \cdot v_{r'}} \geq 0;\\
& \forall r \in RB_w | \{i, RB_w\} \in \mathscr{I}_{h_O} && (6.8)
\end{aligned}
$$

Where x^{i}_{RB} is a binary decision variable that $x^{i}_{RB} \in \{0, 1\}$. The objective function (6.5) is to minimize the sum of the service procurement costs P^{i}_{RB} according to the allocation vector $\{x^{i}_{RB} | t_i \in \mathscr{N}_{h_O}, RB \subseteq \mathscr{R}_{h_O}\}$. Denote the optimal solution by $\{x^{*i}_{RB} | t_i \in \mathscr{N}_{h_O}, RB \subseteq \mathscr{R}_{h_O}\}$, the objective function value $\sum_{t_i \in \mathscr{N}_{h_O}} \sum_{RB \subseteq \mathscr{R}_{h_O}} P^{i}_{RB} \cdot x^{*i}_{RB}$ determined by the optimal allocation is the total logistics service procurement cost for delivering all the requests in this CA in the hub h_O. Constraint sets 6.6 and 6.7 guarantee the feasibility of solution (Lehmann et al., 2006). The constraint set 6.6 guarantees that all requests are allocated exactly once. The constraint set 6.7 guarantees that each bidder can be allocated at most one bundle.

There are interests on both the shipper side and the carrier side to restrict each other's partner-shifting behavior. The constraint set 6.6 and the previously presented bidding requisition for carriers guarantee that no halfway-dropping of requests. Furthermore, we add the constraint sets 6.8 to place the restrictions for shippers' arbitrary carrier-shifting behaviors. The constraint sets 6.8 specify that if one bundle RB was carried to the hub by a carrier, its whole reallocation or division-and-reallocation will be allowed, given that all the shippers of the requests in bundle *RB* will be given lower payment rate.

Using this WDP formulation, all carriers will be stimulated to compete by bidding for the most efficient request bundles as possible, while collaborate with other carriers who are more cost efficient on certain segments to improve the systematical efficiency.

6.7 Illustrative Case: Combinatorial Auction in One Hub

We use a illustrative case to show how this CA-based collaboration mechanism works in one hub. The requests in the request network of hub O are listed in Table 6.1.

Table 6.1: Requests in hub O

Request	Destination	Load units	Current carrier
r_1	h_1	5	
r_2	h_3	5	
r_3	h_2	5	t_1
r_4	h_5	4	t_1
r_5	h_4	5	
r_6	h_5	3	
r_7	h_5	3	

Thus the set of incoming request bundle and carrier pairs $\mathscr{I}_{h_O}$ contains only one element $\mathscr{I}_{h_O} = \{\{t_1, \{r_3, r_4\}\}\}$. The request network of hub O is illustrated in Figure 6.5, where the distances are indicated on the segments.

There are carriers t_1, t_2, t_3 and t_4 currently in the hub O and each of them have a loading capacity of 10 units. There are three compatible groups G_1, G_2, G_3 that $G_1 = \{r_1, r_2\}$, $G_2 = \{r_3, r_5\}$, $G_3 = \{r_3, r_4, r_6, r_7\}$. And the volumes of the following request bundles are less than single-carrier capacity 10:

$$\{r_1\}, \{r_2\}, \{r_3\}, \{r_4\}, \{r_5\}, \{r_6\}, \{r_7\};$$
$$\{r_1, r_2\};$$
$$\{r_3, r_4\}, \{r_3, r_5\}, \{r_3, r_6\}, \{r_3, r_7\};$$
$$\{r_4, r_6\}, \{r_4, r_7\};$$

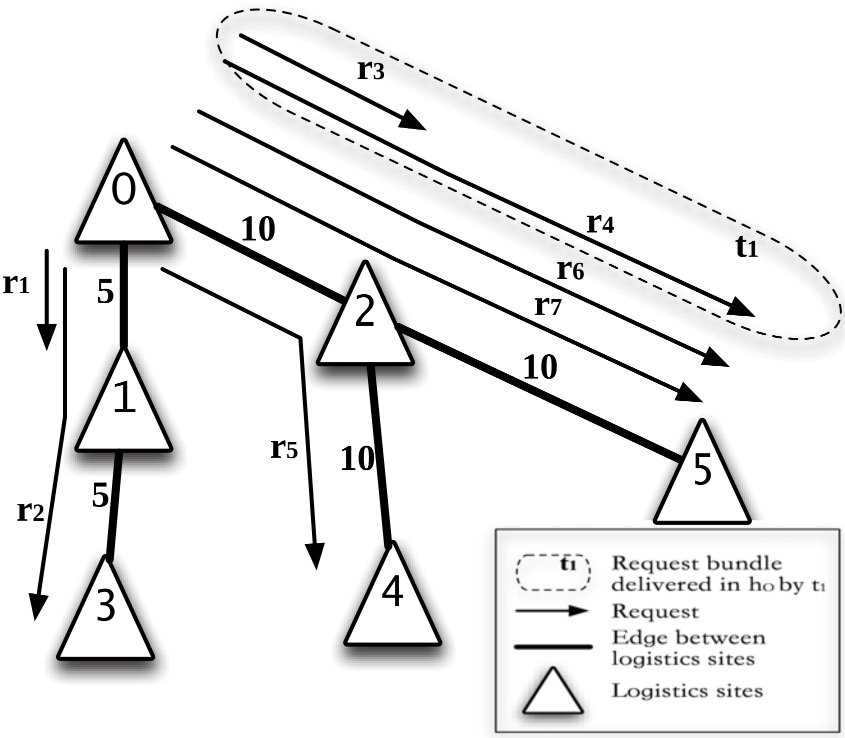

Figure 6.5: Request network of hub O

$$\{r_6, r_7\};$$

$$\{r_4, r_6, r_7\};$$

We conduct this illustrative case by assuming that: the carriers have identical fixed and variable cost rate, but different margin rates $\{mr^1, mr^2, mr^3, mr^4\}$, and $mr^1 < mr^2 < mr^3 < mr^4$. We assume that the carriers only submit bids for the following request bundles with high loading rates: $RB_1 = \{r_1, r_2\}$, $RB_3 = \{r_3, r_5\}$, $RB_4 = \{r_4, r_6, r_7\}$, which does not impact the logistics efficiency in this case. In order to avoid half way dropping in case that some of the requests in RB_2 receive no bid, the carrier t_1 is obligated to submit a bid $(RB_2, P^1_{RB_2})$ that induces the same or lower payment rate $RS^1_{r_3}$ and $RS^1_{r_4}$ for r_3 and r_4 in RB_2, since t_1 has brought the bundle to hub O. Here, we assume that the carrier t_1 propose bidding prices that guarantee the same payment rate as previously, thus $(RB_2, P^1_{RB_2})$ induces $RS^1_r = RS'^1_r,\ \forall r \in \{r_3, r_4\}$. The bids submitted by the carriers are listed in Table 6.2.

All carriers bid on the most efficient request bundles in order to be one of the winners in the CA. Since the profit margin $mr^1 < mr^2 < mr^3 < mr^4$ and the carriers have identical cost rate, thus we have: $P^1_{RB} < P^2_{RB} < P^3_{RB} < P^4_{RB},\ \forall\ RB \in \{RB_1, RB_2, RB_3, RB_4\}$. We assume that the variation of profit margins mr^i is a minor factor compared with the average loading rate,

Table 6.2: Bids submitted by four carriers

Carriers	Bundle bids	Obligation
t_1	$(RB_1, P^1_{RB_1})$ $(RB_4, P^1_{RB_4})$ $(RB_3, P^1_{RB_3})$	$(RB_2, P^1_{RB_2})$
t_2	$(RB_1, P^2_{RB_1})$ $(RB_3, P^2_{RB_3})$ $(RB_4, P^2_{RB_4})$	
t_3	$(RB_1, P^3_{RB_1})$ $(RB_3, P^3_{RB_3})$ $(RB_4, P^2_{RB_4})$	
t_4	$(RB_1, P^4_{RB_1})$ $(RB_3, P^4_{RB_3})$ $(RB_4, P^2_{RB_4})$	

so that the shipper of request r_3 can benefit lower payment rate when r_3 is delivered in bundle $RB_3 = \{r_3, r_5\}$. Thus in order to achieve the global efficiency, the following request allocation decision is made:

$$RB_1 = \{r_1, r_2\} \to t_3;$$

$$RB_3 = \{r_3, r_5\} \to t_2;$$

$$RB_4 = \{r_4, r_6, r_7\} \to t_1.$$

The carrier t_4 will get no request bundle due to low cost efficiency.

In this request allocation decision, the carrier t_1 who proposes the lowest cost rate obtains the request bundle RB_4 with the highest volume·distance value. And other two profitable request bundles are allocated to carriers t_2 and t_3. The request bundle $RB_2 = \{r_3, r_4\}$ are divided and reallocated to different carriers since both the two shippers of requests r_3 and r_4 can be better off after the reallocation.

Then we list the payments made after the request allocation in Table 6.3. Note that, the bidding price P^i_{RB} is the payment requirement for delivery to the destination. In each hub, only the payments for the delivery to the next hub actually occur.

Table 6.3: Payments after the request allocation

	r_1	r_2	r_3	r_4	r_5	r_6	r_7	Sum
t_1				$\frac{P^1_{RB_4}}{4}$		$\frac{3 \cdot P^1_{RB_4}}{16}$	$\frac{3 \cdot P^1_{RB_4}}{16}$	$\frac{5 \cdot P^1_{RB_4}}{8}$
t_2			$\frac{P^2_{RB_3}}{3}$		$\frac{P^2_{RB_3}}{3}$			$\frac{2 \cdot P^2_{RB_3}}{3}$
t_3	$\frac{P^3_{RB_1}}{3}$	$\frac{P^3_{RB_1}}{3}$						$\frac{2 \cdot P^3_{RB_1}}{3}$

The shippers of requests r_3 and r_4 will respectively pay the carrier t_1 the compensations equal to half of the differences: $\frac{5\times10}{5\times10+4\times20}\cdot {P'}^1_{RB_2} - \frac{5\times10}{5\times10+5\times20}\cdot P^2_{RB_3} = \frac{5}{13}\cdot {P'}^1_{RB_2} - \frac{1}{3}\cdot P^2_{RB_3}$ and $\frac{4\times20}{5\times10+4\times20}\cdot {P'}^1_{RB_2} - \frac{4\times20}{4\times20+3\times20+3\times20}\cdot P^1_{RB_4} = \frac{8}{13}\cdot {P'}^1_{RB_2} - \frac{2}{5}\cdot P^1_{RB_4}$, where ${P'}^1_{RB_2}$ is the bidding price of t_1 in the previous hub minus the payments occurred for the delivery on the previous segment.

6.8 Conclusion

In this chapter, we briefly introduce mechanism design theory and its two approaches. We focus on CA theory and its applications in the logistics sector. In the literature on logistics auction, the CA has been proved an effective mechanism to foster logistics collaborations on decentralized multi-agent platforms. However, these solutions are still based on the current logistics norm.

In this chapter, we investigate an innovative HLC form, the CA-based ILN collaboration system. In this decentralized HLC system, shipper requests are collaboratively delivered by different carriers in order to improve systematical efficiency. In order to implement such kind of decentralized HLC system, the collaboration mechanism needs to be developed. We adopt CA mechanism to specify the request allocation and gain sharing issues in this context.

First, we develop the framework of system protocols to define how this system functions. The logistics network formation, request route determination, request allocation, and gain sharing issues are discussed. In addition, we propose protocols to regulate arbitrary partner-shifting behaviors of both the shippers and the carriers in the system.

Secondly, since the carriers may encounter high complexity of request evaluation problem, we propose to use automated proxy agent to facilitate the bidding process. The bidding intelligence of the automated proxy agent is developed, consisting of the automatic profitable request bundle proposition and the bidding price evaluation. Thus it becomes much more convenient for carriers to participate in the logistics reverse CA.

Then in order to construct a feasible collaboration mechanism under the system framework setting, we propose a WDP formulation to allocate the requests and share the gain among system agents. This formulation, combined with regulatory protocols, enables the collaborative request delivery along the request routes while guaranteeing the good operation of the ILN system.

At last, we use a illustrative case to show the CA mechanism in a specific hub.

The objective of this chapter is to give a framework of the application of mechanism design theory in the decentralized interconnected logistics networks. Some important issues and validation works are still missing at this very early stage. This framework helps us to outline the avenue to in-depth research works in the future. One possible direction is to build up a simulation model to validate the proposed CA-based collaboration mechanism, as well as to assess its performance. We can also study other auction mechanisms to compare with the one proposed here.

CHAPTER 7

Conclusion

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7.1 Summary of the Dissertation

In this dissertation, we first present the rationale for our research. As horizontal logistics collaboration (HLC) attracts much attention from both academics and practitioners, research works and real world case studies have been carried out to address this subject. Both theoretic investigations, mainly focusing on different modalities or optimization tools to conduct HLCs, and case studies on HLC implementation in real business contexts show its effectiveness in cutting transportation costs, improving service level, and reducing carbon emissions. However, HLC implementation is still relatively rare due to some major barriers, including lack of feasible collaboration mechanisms to cover practitioners' needs.

To provide an overview of HLC, especially implementation issues, we review the literature on drivers, barriers, and implementation frameworks. Two HLC categories are identified: centralized and decentralized. We identify the cooperative-game-theoretic approach as a feasible approach to collaboration mechanisms that could facilitate the implementation of centralized HLCs limited to few participants for practical reasons. Mechanism design approach is used to construct collaboration mechanisms in decentralized HLCs.

In the first and major part of this dissertation (Chapter 3-5), we investigate the collaboration mechanism in centralized HLCs. As HLC is still in its infancy, all current centralized HLC cases are carried out among a few leading businesses in a centralized manner. In order to provide a guide for the collaboration organizer, we propose a general collaboration model as a process that integrates different function modules. This model can be adopted for conducting all kinds of centralized HLCs. In particular, we choose supply network pooling as the context of our game-theoretic investigation. We provide the details of this general collaboration model and propose a specific collaboration model.

Next, we investigate the collaboration mechanism in implementation of supply network pooling. A feasible collaboration mechanism consists of two parts: determining the coalition(s) to be formed and deciding how to allocate the gain achieved among the collaborators.

We then examine cooperative game theory as a toolbox to determine suitable coalition formation guides and gain-sharing mechanisms. The current literature on cooperative game theory is a rich source of solutions that could serve as components of feasible collaboration mechanisms, but no single game-theoretic solution can truly fit every logistics pooling case. Moreover, collaboration mechanisms presented in the literature on game-theoretic approaches to HLC are mostly constructed for super-additive HLC games, and the coordination costs (CCs) arising in the collaborations are beyond the scope. The literature tends to overlook how some non-super-additive collaborations could also generate substantial synergies (when the CCs remain relatively minor), or that game properties could change over time with variation in cost or volume. Also neglected in the literature is the issue of bargaining-power in sharing mechanisms. All collaborators are considered equally whereas this is not the case in the actual business world, especially when we consider the diversity of firms involved in supply chains.

In order to construct feasible collaboration mechanisms, we first identify all possible centralized HLC categories. Observing a gap between the current literature and actual HLC implementation, we examine the coalition-formation issue in all of these categories and propose a set of *contribution-and-power-weighted value* (CPWV) variations as reliable and reasonable gain-sharing mechanisms. We then integrate the super-additive cover concept and propose a general gain-sharing model for all feasible HLC cases. This model considers collaborator contribution, bargaining power, and coalition stability at the same time. Since the details in this model are examined in each of the HLC categories, the model is generally applicable to all four categories. We also conduct one case study based on real-world data from a French retail network and a computational case to show how the general gain-sharing model works when the HLC game is of an empty/non-empty Core.

In the real-world case study, a supply-network-pooling game among four suppliers is modeled and solved in two scenarios: the super-additive scenario with negligible CCs and the non-super-additive scenario with significant CCs. In both scenarios, the sharing schemes proposed by the general CPWV model are in the general core and are perceived as acceptable for all collaborators. The results show that the general CPWV model is a reliable and generally applicable tool in conducting centralized HLCs with coalition stability and an environment where costs and volumes tend to change.

In the second part of this dissertation (Chapter 7), we present a framework for the collaboration mechanism in decentralized HLC systems. The decentralized HLC has some interesting properties such as unlimited participants, enter-and-exit flexibility (lack of which is a main barrier for pooling), etc. In decentralized HLC systems, there is no central decision-maker who makes decisions for all participants except to decide the collaboration rules. Participants make their own decisions, complying with the system protocols. Logistics activities will be orchestrated by the collaboration mechanism and the participants' profit motives. We investigate the collaboration mechanism issue in the interconnected logistics network (ILN) system, which is a decentralized HLC system presented by Sarraj et al. (2012). We adopt the mechanism design approach to construct the collaboration mechanism therein. Through the co-action of the protocols, proxy agents, and the WDP formulation developed in this chapter, the ILN system motivates the agents' collaborative request delivery to improve system efficiency. We also present an illustrative case to show how this collaboration mechanism works.

7.2 Limits of the Centralized Game-Theoretic Collaboration Mechanism in the Dissertation

Four main limits of the centralized game-theoretic collaboration mechanism are proposed in this dissertation.

7.2.1 Operational complexity

In order to implement HLCs by applying game theoretic tools at the operational level, a huge information collection will be needed to compute the gain sharing for each pooled operation.

The information collection that requires private information revelation may induce resistance to participation. From organizer's point of view, it increase the organizational complexity, since both the information collection and the computation of the sharing scheme could be time-consuming.

7.2.2 Complexity for large-scale collaborations

The advantage of the general CPWV model proposed is the general applicability for different small- and medium-scale collaboration cases. The model can be applied in HLCs with different collaboration modalities. However, due to the heavy computational burden induced by core-constraint computation, SV calculation, and sub-coalition optimizations, the game-theoretic approach and the CPWV model are feasible only for current multilateral collaborations among a small number of partners, when the synergies within the collaboration are non-linear, but player-dependent. When the grand coalition contains n players, the number of all sub-coalitions ($\{N\}$ and non-singleton sub-coalitions) where the optimizations should be carried out equals $2^n - n - 1$. As the number of players n increases, it increases exponentially. For example, when there are only 6 players in a pooling game, we should do $2^6 - 6 - 1 = 57$ optimizations, whereas when there are 10 players in the pooling game, we need to do $2^{12} - 12 - 1 = 4083$ optimizations in order to evaluate the contribution of players. Moreover, the complexity of the CPWV allocation calculation increases exponentially.

In order to avoid both the operational and the computational complexity in HLCs with a large number of players, the convergence with a tarif to be determined must be studied to overcome the complexity barriers.

7.2.3 Flexibility

The cooperative-game-theoretic approach introduced in this dissertation is based on a centralized collaboration organization. The advantage of this kind of collaboration organization is that it increases the chances of success.

Centralized optimization and planning guarantees that collaborators' synergy is fully exploited. The disadvantage, however, is that the business will be engaged in the collaboration scheme in the mid-to-long-term, and so might lose some strategy-altering flexibility.

7.2.4 High fluctuation of collaboration environment

In supply chain and logistics, volumes and costs change with time. These changes require recalculating gain-sharing and checking stability again and again in order to propose periodic collaboration schemes. This could cause instability and reduce flexibility. Updating the collaboration scheme according to periodic predictions can mitigate this problem. However, this may make sensitive cost and volume data collection more complex over time.

7.3 Limits of the Decentralized CA-based Collaboration Mechanism in the Dissertation

In this dissertation, we propose a CA-based collaboration mechanism framework for an ILN collaboration system. We observe the following limits of the proposed framework.

7.3.1 Novelty and complexity of combinatorial auction

Due to the newness of CA, there are not many logistics agents who know how to bid "wisely" in CAs. Hence, the ability to achieve the complementary synergies of the CA mechanism has not been fully exploited. The complexity of bid evaluation in CAs also hinders strategic carrier bidding, which reduces system efficiency. The complexity of the winner determination problem (WDP) in CAs is another issue that limits the collaboration scale (even though, the problem scale is much higher than in centralized HLCs), but can be overcome by striking a balance between the optimality of allocation decision and real-time problem solving capability.

In addition, the novelty of the approach could lead to trust issues for participants. Some research work is necessary to prove the interest and the robustness of the approach for the unequal stakeholders.

7.3.2 Lack of model verification by simulation

Due to the complexity of running a comprehensive simulation experiment that would mirror reality, this dissertation proposes only a theoretical framework. There may be some aspects that have not been considered in the model. For example, how the different bidding strategies affect the system performance. A simulation model with specific operational details is needed to verify and perfect the collaboration mechanism.

The difficulty of the proof is also lying in the simulation approach as the research must take into account the bidders' behaviors.

7.4 Perspectives

We propose following directions for further research on the collaboration mechanisms of centralized/decentralized collaborations.

7.4.1 Operation-based collaboration mechanisms

The game-theoretic collaboration mechanism that we have developed reflects a macro-perspective. That means the coalition formation and gain-sharing investigation is conducted by using statistics (e.g. the sum of the previous year's cost savings). This induces a need for side payments after a certain period of the collaboration, in order to implement the gain allocation scheme. Gain allocation mechanisms can also be based on individual operations. Each co-action of two collaborators induces transactions between the collaborators, the rate of which is predetermined by the rules established at the beginning of the collaboration. In this way, no side payment is needed for carrying out the gain-sharing scheme, since the gain is allocated every time it is generated, but with an increase in workload. A tradeoff between accuracy and efficiency must be studied in order to facilitate the dissemination of the approach.

7.4.2 Simulation model with practical details

A simulation model with practical details, well-developed bidding intelligence, and carriers with different bidding strategies would be needed to verify the feasibility of the CA-based ILN collaboration system. By conducting this simulation, we could verify if the system functions well, and how different system configurations could affect its performance. We could also use real-world data sets in the simulation to evaluate the efficiency difference between the current logistics system (status quo) and the collaboration system. Comparison of the key performance indicators of the two different logistics systems is vital to check the efficiency of the CA-based ILN collaboration system, and thus merits future research.

7.4.3 Other request allocation and gain sharing mechanisms

In order to allocate requests and determine the payments in CA, we need to solve a WDP which is NP-complete. The WDP formulation that we have proposed in this dissertation also considers system protocol constraints, thus the WDP that we need to solve is further complicated by system protocol constraints (e.g. no arbitrary partner-shifting behaviors). In order to implement decentralized HLC systems, either new heuristic algorithms must be developed to obtain a solution with high quality in acceptable time interval, or we must use other concise collaboration mechanisms closely tied to operational issues, in order to specify the request allocation and gain-sharing rules, such as the highest-fill-rate loading protocol proposed by Sarraj et al. (2012). Another approach could be local implementations of CA in large scale systems to study its efficiency and feasibility.

Bibliography

Agarwal, R., Ergun, Ö., 2008. Mechanism design for a multicommodity flow game in service network alliances. Operations Research Letters 36, 520–524.

Albino, V., Carbonara, N., Giannoccaro, I., 2007. Supply chain cooperation in industrial districts: A simulation analysis. European Journal of Operational Research 177, 261–280.

An, N., Elmaghraby, W., Keskinocak, P., 2005. Bidding strategies and their impact on revenues in combinatorial auctions. Journal of Revenue and Pricing Management 3, 337–357.

Arnold, T., Schwalbe, U., 2002. Dynamic coalition formation and the core. Journal of Economic Behavior & Organization 49, 363–380.

Asawasakulsorn, A., 2009. Transportation collaboration: Partner selection criteria and interorganizational system design issues for supporting trust. International Journal of Business and Information 4.

Audy, J., D'Amours, S., Rönnqvist, M., 2012. An empirical study on coalition formation and cost/savings allocation. International Journal of Production Economics 136, 13–27.

Audy, J.F., D'Amours, S., Lehoux, N., Rönnqvist, M., 2010. Coordination in collaborative logistics, in: International workshop on supply chain models for shared resource management, Brussels.

Aumann, R., Dreze, J., 1974. Cooperative games with coalition structures. International Journal of Game Theory 3, 217–237.

Aumann, R.J., 1994. Handbook of game theory with economic applications. North-Holland.

Aumann, R.J., Maschler, M., 1961. The bargaining set for cooperative games. Princeton University.

Aumann, R.J., Myerson, R.B., 2003. Endogenous formation of links between players and of coalitions: An application of the Shapley value. Springer.

Bahinipati, B., Kanda, A., Deshmukh, S., 2009. Horizontal collaboration in semiconductor manufacturing industry supply chain: An evaluation of collaboration intensity index. Computers & Industrial Engineering 57, 880–895.

Bahrami, K., 2002. Improving supply chain productivity through horizontal cooperation: The case of consumer goods manufacturers. Cost Management in Supply Chains. Physica: Heidelberg, New York , 213–233.

Ballot, E., Fontane, F., 2010. Reducing transportation co2 emissions through pooling of supply networks: perspectives from a case study in french retail chains. Production Planning & Control 21, 640–650.

Ballot, E., Gobet, O., Montreuil, B., 2012. Physical internet enabled open hub network design for distributed networked operations, in: Service Orientation in Holonic and Multi-Agent Manufacturing Control. Springer, pp. 279–292.

Ballot, E., Montreuil, B., Fontane, F., 2011. Topology of logistic networks and the potential of a physical internet., in: International Conference on Industrial Engineering and System Management, Metz - France.

Banerjee, S., Konishi, H., Sönmez, T., 2001. Core in a simple coalition formation game. Social Choice and Welfare 18, 135–153.

Béal, S., Durieu, J., Solal, P., 2008. Farsighted coalitional stability in tu-games. Mathematical Social Sciences 56, 303–313.

Bengtsson, M., Kock, S., 2000. "Coopetition" in business networks—to cooperate and compete simultaneously. Industrial marketing management 29, 411–426.

Bloch, F., 1996. Sequential formation of coalitions in games with externalities and fixed payoff division. Games and Economic Behavior 14, 90–123.

Bondareva, O., 1962. The theory of the core in an n-person game. Vestnik Leningrad. Univ 13, 141–142.

Bowersox, D., Closs, D., Stank, T., 2002. How to master cross-enterprise collaboration. Supply Chain Management 7, 18–29.

Brandenburger, A., Nalebuff, B., 1998. Co-opetition. Doubleday, New York.

Bumstead, J., Cannons, K., 2002. From 4PL to managed supply-chain operations. Technical Report. The Chartered Institute of Logistics and Transportation.

Caputo, M., Mininno, V., 1996. Internal, vertical and horizontal logistics integration in italian grocery distribution. International Journal of Physical Distribution & Logistics Management 26, 64–90.

Chang, M.H., Harrington, J.E., 2000. Centralization vs. decentralization in a multi-unit organization: A computational model of a retail chain as a multi-agent adaptive system. Management Science 46, 1427–1440.

Chang, Y., 1998. Logistical Management. Hwa-Tai Bookstore Ltd., Taiwan.

Chwe, M., 1994. Farsighted coalitional stability. Journal of Economic Theory 63, 299–325.

Council of Logistics Management, 2004. Definition of logistics.

Cramton, P., Ausubel, L.M., 2006. The clock-proxy auction: A practical combinatorial auction design, in: Combinatorial Auctions. MIT Press. chapter 5.

Crook, T., Combs, J., 2007. Sources and consequences of bargaining power in supply chains. Journal of Operations Management 25, 546–555.

Cruijssen, F., 2006. Horizontal cooperation in transport and logistics. Ph.D. thesis. Tilburg University.

Cruijssen, F., 2012. Horizontal collaboration: A co3 position paper.

Cruijssen, F., Borm, P., Fleuren, H., Hamers, H., 2010. Supplier-initiated outsourcing: A methodology to exploit synergy in transportation. European Journal of Operational Research 207, 763–774.

Cruijssen, F., Cools, M., Dullaert, W., 2007a. Horizontal cooperation in logistics: opportunities and impediments. Transportation Research Part E: Logistics and Transportation Review 43, 129–142.

Cruijssen, F., Dullaert, W., Fleuren, H., 2007b. Horizontal cooperation in transport and logistics: a literature review. Transportation journal 46, 22–39.

Daft, R.L., 2009. Organization theory and design. Cengage learning.

Dai, B., Chen, H., 2011a. A multi-agent and auction-based framework and approach for carrier collaboration. Logistics Research 3, 101–120.

Dai, B., Chen, H., 2011b. Profit allocation mechanisms for carrier collaboration in pickup and delivery service. Computers & Industrial Engineering .

Davis, M.D., Maschler, M., 1963. Existence of stable payoff configurations for cooperative games. Princeton University, Econometric Research Program.

Day, R., Raghavan, S., 2007. Fair payments for efficient allocations in public sector combinatorial auctions. Management Science 53, 1389–1406.

Dechter, R., Pearl, J., 1985. Generalized best-first search strategies and the optimality of a*. Journal of the ACM (JACM) 32, 505–536.

Directorate-General for Mobility and Transport, 2011. Road Freight Transport Vademecum 2010 Report. Technical Report. European Commission.

Dornier, P., 1997. Recomposition de l'approche logistique dans le secteur des produits de grande diffusion: intégration fonctionnelle, intégration sectorielle, intégration géographique. Ph.D. thesis. MINES ParisTech. Paris.

Driessen, T., 1988. Cooperative games, solutions and applications. Kluwer Academic Publishers.

Dyer, J., Singh, H., 1998. The relational view: Cooperative strategy and sources of interorganizational competitive advantage. Academy of management review , 660–679.

ECR France, 2012. Information et échanges sur les concepts de la mutualisation logistique.

El Omri, A., Ghaffari, A., Jemai, Z., 2007. Multipal retailer cooperation for joint transpotation and inventory decisions, in: 19th International Conference on Production Research.

Ernst, D., Bleeke, J., 1995. Is your strategic alliance really a sale? Harvard Business Review 73, 97–105.

European Commission, 2001. Guidelines on the applicability of article 81 of the ec treaty to horizontal cooperation agreements. Official Journal, C 3, 1.

European Commission, 2009. EU climate change and energy package.

European Environment Agency, 2010. Load factors for freight transport (TERM 030) – Assessment report. Technical Report. European Environment Agency.

Eurostat, 2012.

EyeForTransport, 2006. Outsourcing Logistics Europe 2006. Technical Report. EyeForTransport. London, United Kingdom.

Figliozzi, M., Mahmassani, H., Jaillet, P., 2003. Framework for study of carrier strategies in auction-based transportation marketplace. Transportation Research Record .

Fischer, K., Chaib-Draa, B., Muller, J.P., Pischel, M., Gerber, C., 1999. A simulation approach based on negotiation and cooperation between agents: a case study. Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on 29, 531–545.

Fischer, M., 2003. The new economy and networking. New Economy Handbook , 343–367.

Frisk, M., Göthe-Lundgren, M., Jörnsten, K., Rönnqvist, M., 2010. Cost allocation in collaborative forest transportation. European Journal of Operational Research 205, 448–458.

FTA, PwC, 2012. The logistics report 2012. Technical Report. FreightTransport Association & PricewaterhouseCoopers.

Gillies, D., 1959. Solutions to general non-zero-sum games. Contributions to the Theory of Games 4.

Graham, L., 2011. Transport Collaboration in Europe. Technical Report. ProLogis Corporate.

Ha, A., Li, L., Ng, S., 2003. Price and delivery logistics competition in a supply chain. Management Science , 1139–1153.

Haeringer, G., 2006. A new weight scheme for the shapley value. Mathematical Social Sciences 52, 88–98.

Hamel, G., 1991. Competition for competence and interpartner learning within international strategic alliances. Strategic management journal 12, 83–103.

Harsanyi, J.C., 1966. A general theory of rational behavior in game situations. Econometrica: Journal of the Econometric Society , 613–634.

Harsanyi, J.C., 1967. Games with incomplete information played by “bayesian” players part i. Management Science 14, 159–183.

Harsanyi, J.C., 1968a. Games with incomplete information played by “bayesian” players part ii. Management Science 14, 320–334.

Harsanyi, J.C., 1968b. Games with incomplete information played by ‘bayesian’players, part iii. Management Science 14, 486–502.

Hart, S., Mas-Colell, A., Division, N.A.T.O.S.A., 1997. Cooperation: game-theoretic approaches. Springer.

Hennet, J., Mahjoub, S., 2010. Toward the fair sharing of profit in a supply network formation. International Journal of Production Economics 127, 112–120.

Hershberger, J., Suri, S., 2001. Vickrey prices and shortest paths: What is an edge worth?, in: Foundations of Computer Science, 2001. Proceedings. 42nd IEEE Symposium on, IEEE. pp. 252–259.

Hingley, M., Lindgreen, A., Grant, D., Kane, C., 2011. Using fourth-party logistics management to improve horizontal collaboration among grocery retailers. Supply Chain Management: An International Journal 16, 316–327.

Houghtalen, L., 2007. Designing allocation mechanisms for carrier alliances. Ph.D. thesis. Citeseer.

Houghtalen, L., Ergun, Ö., Sokol, J., 2011. Designing mechanisms for the management of carrier alliances. Transportation Science 45, 465.

Institute of Grocery Distribution, 2007. ECR UK Collaborative Green Distribution. Technical Report. Institute of Grocery Distribution.

Institute of Grocery Distribution, 2010. ECR Sustainable Transport Project. Technical Report. Institute of Grocery Distribution.

Institute of Grocery Distribution, 2011. Guide to transport technology case study nestlé/ub – transport collaboration.

Jin, M., Wu, S., 2006. Supplier coalitions in on-line reverse auctions: Validity requirements and profit distribution scheme. International Journal of Production Economics 100, 183–194.

Kalai, E., Samet, D., 1987. On weighted shapley values. International Journal of Game Theory 16, 205–222.

Kannai, Y., 1992. The core and balancedness, in: Handbook of game theory with economic applications. Elsevier. volume 1. chapter 12, pp. 355–395.

Khare, R., 2006. What is decentralization?

Khare, R., Taylor, R.N., 2004. Extending the representational state transfer (rest) architectural style for decentralized systems, in: Software Engineering, 2004. ICSE 2004. Proceedings. 26th International Conference on, IEEE. pp. 428–437.

Klaus, P., Kille, C., 2007. Top 100 in european transport and logistics services. Hamburg: Deutscher Verkehrs-Verlag 20.

Konishi, H., Ray, D., 2003. Coalition formation as a dynamic process. Journal of Economic Theory 110, 1–41.

Koppers, L., Zelewski, S., Klumpp, M., 2008. Social production factors in supply chain cooperations, in: Proceedings of the 15th International Working Seminar on Production Economics. Igls, Innsbruck, pp. 363–374.

Krajewska, M., Kopfer, H., Laporte, G., Ropke, S., Zaccour, G., 2007. Horizontal cooperation among freight carriers: request allocation and profit sharing. Journal of the Operational Research Society 59, 1483–1491.

Lambert, D., Emmelhainz, M., Gardner, J., 1996. Developing and implementing supply chain partnerships. International Journal of Logistics Management, The 7, 1–18.

Lambert, D., Emmelhainz, M., Gardner, J., 1999. Building successful logistics partnerships. Journal of Business Logistics 20, 165–182.

Lambert, D., Knemeyer, A., Gardner, J., 2004. Supply chain partnerships: model validation and implementation. Journal of business Logistics 25, 21–42.

Langley, C., Newton, B., Tyndall, G., 1999. Has the future of third-party logistics already arrived. Supply Chain Management Review 33, 85–94.

Ledyard, J., Olson, M., Porter, D., Swanson, J., Torma, D., 2002. The first use of a combined-value auction for transportation services. Interfaces 32, 4–12.

Lehmann, D., Müller, R., Sandholm, T., 2006. The winner determination problem. Combinatorial auctions , 297–317.

Léonardi, J., Baumgartner, M., 2004. CO_2 efficiency in road freight transportation: Status quo, measures and potential. Transportation Research Part D: Transport and Environment 9, 451–464.

Lozano, S., Moreno, P., Adenso-Díaz, B., Algaba, E., 2013. Cooperative game theory approach to allocating benefits of horizontal cooperation. European Journal of Operational Research .

Mariotti, M., 1997. A model of agreements in strategic form games. Journal of economic theory 74, 196–217.

Mas-Collel, A., Whinston, M.D., Green, J., 1995. Microeconomic theory. Oxford university press Oxford.

Maschler, M., 1992. The bargaining set, kernel, and nucleolus. Handbook of game theory with economic applications 1, 591–667.

Maschler, M., Peleg, B., Shapley, L., 1979. Geometric properties of the kernel, nucleolus, and related solution concepts. Mathematics of Operations Research 4, 303–338.

Mauleon, A., Vannetelbosch, V., 2004. Farsightedness and cautiousness in coalition formation games with positive spillovers. Theory and Decision 56, 291–324.

McAfee, R., McMillan, J., 1987. Auctions and bidding. Journal of economic literature 25, 699–738.

Mejias-Sacaluga, A., Prado-Prado, J., 2002. Integrated logistics management in the grocery supply chain. International Journal of Logistics Management, The 13, 67–78.

Meyer, D., 2011. Collaborative competition + sustainability = the 21st century supply chain solution.

Meyer-Rühle, O., Bozuwa, J., Kille, C., Burg, R., 2008. Statistical coverage and economic analysis of the logistics sector in the EU. Technical Report. ProgTrans AG.

Mittermayer, H., Monroy, C.R., 2008. Adaptation of coordination mechanisms to network structures. Journal of Industrial Engineering and Management 1, 169–185.

Monderer, D., Samet, D., 2002. Variations on the Shapley value. volume 3. Elsevier.

Monderer, D., Samet, D., Shapley, L., 1992. Weighted values and the core. International Journal of Game Theory 21, 27–39.

Montreuil, B., 2011. Toward a physical internet: meeting the global logistics sustainability grand challenge. Logistics Research 3, 71–87.

Muir, M., 2010. European Supply Chain Horizontal Collaboration – A Brief Analysis of Eyefortransport's Recent Survey. Technical Report. Eyefortransport.

Myerson, R.B., 1997. Game theory: analysis of conflict. Harvard University Press.

Naesens, K., Gelders, L., Pintelon, L., 2009. A swift response framework for measuring the strategic fit for a horizontal collaborative initiative. International Journal of Production Economics 121, 550–561.

Nagarajan, M., Sosic, G., 2008. Game-theoretic analysis of cooperation among supply chain agents: Review and extensions. European Journal of Operational Research 187, 719–745.

Narahari, Y., Garg, D., Narayanam, R., Prakash, H., 2009. Game theoretic problems in network economics and mechanism design solutions. Springer-Verlag New York Inc.

Neumann, J.v., Morgenstern, O., 1944. Theory of gamesand economic behavior.

Nof, S., Morel, G., Monostori, L., Molina, A., Filip, F., 2006. From plant and logistics control to multi-enterprise collaboration. Annual Reviews in Control 30, 55–68.

Osborne, M.J., Rubinstein, A., 1994. A course in game theory. The MIT press.

Owen, G., 1968. Communications to the editor—a note on the shapley value. Management Science 14, 731–731.

Özener, O.Ö., Ergun, Ö., 2008. Allocating costs in a collaborative transportation procurement network. Transportation Science 42, 146–165.

Palmer, A., Saenz, M.J., van Woensel, T., Ballot, E., 2012. CO^3 position paper: Characteristics of collaborative business models. Technical Report. CO^3 european project commission.

Palmer, A., Slikker, M., De Kok, T., Ballot, E., Pan, S., Herrero, D., Gonzalez, E., Saenz, M.J., Lu, m., 2013. Development of collaborative business models. Technical Report. CO^3 european project commission.

Pan, S., 2010. Contribution à la définition et à l'évaluation de la mutualisation de chaînes logistiques pour réduire les émissions de CO_2 du transport: application au cas de la grande distribution. Ph.D. thesis. MINES ParisTech.

Pan, S., Ballot, E., Fontane, F., 2013. The reduction of greenhouse gas emissions from freight transport by pooling supply chains. International Journal of Production Economics 143, 86–94.

Pan, S., Ballot, E., Fontane, F., Hakimi, D., 2012. Environmental and economic issues arising from the pooling of smes' supply chains: case study of the food industry in western france. Flexible Services and Manufacturing Journal , 1–27.

Parkes, D.C., Ungar, L.H., 2000. Preventing strategic manipulation in iterative auctions: Proxy agents and price-adjustment, in: AAAI/IAAI, pp. 82–89.

Perea, F., Puerto, J., Fernández, F., 2009. Modeling cooperation on a class of distribution problems. European Journal of Operational Research 198, 726–733.

Pérez-Castrillo, D., Wettstein, D., 2001. Bidding for the surplus: a non-cooperative approach to the shapley value. Journal of Economic Theory 100, 274–294.

Plummer, C.L., 2003. Bidder response to combinatorial auctions in truckload procurement. Master's thesis, Massachusetts Institute of Technology .

Prakash, A., Deshmukh, S., 2010. Horizontal collaboration in flexible supply chains: a simulation study. Journal of Studies on Manufacturing 1, 54–58.

Rahwan, T., Jennings, N., 2008. An improved dynamic programming algorithm for coalition structure generation, in: Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems-Volume 3, International Foundation for Autonomous Agents and Multiagent Systems. pp. 1417–1420.

Ramesh, A., Banwet, D., Shankar, R., 2010. Modeling the barriers of supply chain collaboration. Journal of Modelling in Management 5, 176–193.

Ray, D., Vohra, R., 1997. Equilibrium binding agreements. Journal of Economic Theory 73, 30–78.

Ray, D., Vohra, R., 1999. A theory of endogenous coalition structures. Games and Economic Behavior 26, 286–336.

Regan, A., Song, J., 2003. An auction based collaborative carrier network. Transportation Research Part E: Logistics and Transportation Review 2.

Riegelsberger, J., Sasse, M., McCarthy, J., 2005. The mechanics of trust: A framework for research and design. International Journal of Human-Computer Studies 62, 381–422.

Ring, P., Van de Ven, A., 1992. Structuring cooperative relationships between organizations. Strategic management journal 13, 483–498.

Rognon, J., 2009. Retour d'expérience CARREFOUR : Des CCC pour tendre les flux de produits secs. Supply Chain Magazine 40, 22–24.

Rothkopf, M., Teisberg, T., Kahn, E., 1990. Why are vickrey auctions rare? Journal of Political Economy , 94–109.

Sandberg, E., 2007. Logistics collaboration in supply chains: practice vs. theory. International Journal of Logistics Management, The 18, 274–293.

Sandholm, T., 2002. Algorithm for optimal winner determination in combinatorial auctions. Artificial Intelligence 135, 1–54.

Sandholm, T., 2006. Optimal winner determination algorithms. Combinatorial auctions , 337–368.

Sarraj, R., 2013. Interconnexion des réseaux logistiques: éléments de définition et potentiel. Ph.D. thesis. Ecole Nationale Supérieure des Mines de Paris.

Sarraj, R., Ballot, E., Pan, S., et al., 2012. Potential of routing protocols for freight in open logistics networks: the case of fmcg in france, in: 4th International Conference on Information Systems, Logistics and Supply Chain.

Schmeidler, D., 1969. The nucleolus of a characteristic function game. SIAM Journal on applied mathematics 17, 1163–1170.

Schwartz, E., 2000. Gm eyes cost-savings by outsourcing logistics. InfoWorld .

Schwind, M., Gujo, O., Vykoukal, J., 2009. A combinatorial intra-enterprise exchange for logistics services. Information systems and e-business management 7, 447–471.

Shapley, L., 1952. A value for n-person games, in: Contributions to the Theory of Games, Volume II.. Princeton University Press.

Shapley, L., 1953. Additive and non-additive set functions. Ph.D. thesis. Princeton University.

Shapley, L., 1971. Cores of convex games. International Journal of Game Theory 1, 11–26.

Shapley, L., Shubik, M., 1966. Quasi-cores in a monetary economy with nonconvex preferences. Econometrica: Journal of the Econometric Society , 805–827.

Shapley, L.S., 1967. On balanced sets and cores. Naval research logistics quarterly 14, 453–460.

Shubik, M., 1967. Essays in mathematical economics in honor of Oskar Morgenstern. Princeton University Press Princeton.

Simatupang, T., Sridharan, R., 2002. The collaborative supply chain. International Journal of Logistics Management, The 13, 15–30.

Simatupang, T., Sridharan, R., 2005. The collaboration index: a measure for supply chain collaboration. International Journal of Physical Distribution & Logistics Management 35, 44–62.

Simatupang, T., Sridharan, R., 2008. Design for supply chain collaboration. Business Process Management Journal 14, 401–418.

Simchi-Levi, D., Simchi-Levi, E., Kaminsky, P., 1999. Designing and managing the supply chain: Concepts, strategies, and cases. McGraw-Hill United-States.

Solymosi, T., 1999. On the bargaining set, kernel and core of superadditive games. International Journal of Game Theory 28, 229–240.

Spekman, R., Kamauff Jr, J., Myhr, N., 1998. An empirical investigation into supply chain management: a perspective on partnerships. Supply Chain Management: An International Journal 3, 53–67.

Stefansson, G., 2004. Collaborative logistics management–the role of third-party service providers and the enabling information systems infrastructure. Chalmers University of Technology, Göteborg .

Verstrepen, S., Cools, M., Cruijssen, F., Dullaert, W., 2009. A dynamic framework for managing horizontal cooperation in logistics. International Journal of Logistics Systems and Management 5, 228–248.

Visser, L., 2007. Logistics Collaboration between Shippers and Logistics Service Providers. Technical Report. Fontys University of Applied Sciences.

Walsh, E., Bradley, P., Gooley, T., Cooke, J., 2001. GM shifts global logistics strategy. Logistics Management and Distribution Report 40.

Xu, K., Dong, Y., 2004. Information gaming in demand collaboration and supply chain performance. Journal of Business Logistics 25, 121–144.

Xu, X., Pan, S., Ballot, E., 2012a. Allocation of transportation cost & co2 emission in pooled supply chains using cooperative game theory, in: 14th IFAC Symposium on Information Control Problems in Manufacturing, Bucharest, Romania.

Xu, X., Pan, S., Ballot, E., 2012b. Game theoretic contribution to horizontal cooperation in logistics, in: 4th International Conference on Information Systems, Logistics and Supply Chain, Quebec, Canada.

Xu, X., Pan, S., Ballot, E., 2013. A sharing mechanism for superadditive and non-superadditive logistics cooperation, in: International Conference on Industrial Engineering and System Management, Rabat, Morocco.

Xue, L., 1998. Coalitional stability under perfect foresight. Economic Theory 11, 603–627.

Zhang, C., Yu, H., Liu, Z., 2008. Logistics collaboration supported by electronic logistics marketplaces, in: Advanced Management of Information for Globalized Enterprises, IEEE. pp. 1–5.

Collaboration Mechanism in the Horizontal Logistics Collaboration

Abstract: As the result of the more and more ambitious production and marketing strategies, such as Just-In-Time and increasing customization of products, the current vertical logistics collaboration approaches based on single supply chain seems insufficient to achieve further improvements in transportation efficiency. The horizontal logistics collaboration (HLC), which has been proved an effective approach to efficiency improvement, has attracted both academics and practitioners. One of the main barriers to the implementation of HLCs is the lack of feasible collaboration mechanism, in particular the gain sharing mechanism. We identify two organizational forms of HLCs: the centralized and decentralized ones. For centralized HLCs, we propose a collaboration model that is a collaboration conducting process integrating decision-aiding tools to guide the implementation of the collaboration. We also develop a generally applicable game-theoretic sharing mechanism for different categories of centralized HLCs modeled as super-additive and non-super-additive cooperative games. This sharing mechanism takes into account the collaborators' contribution, the coalition stability, and the bargaining power to propose a credible sharing scheme for collaborators. The approach is illustrated by numerical example taken from logistics cases. For the implementation of the decentralized HLCs, we propose an open collaborative logistics framework, and design the system protocols as the collaboration mechanism that specifies the combinatorial-auction-based request allocation and payment determination to foster the collaborations.

Keywords: Horizontal logistics collaboration, Collaboration mechanism, Centralized/decentralized collaboration, Supply network pooling, Cooperative game theory, Combinatorial auction

Mécanismes de Collaboration dans la Collaboration Logistique Horizontale

Résumé: En raison des stratégies de production et de marketing de plus en plus ambitieuses telles que le Juste-à-Temps et la personnalisation au client, les approches de collaboration logistique verticale qui sont courantes atteignent une limite d'efficacité notamment en transport. La collaboration logistique horizontale (CLH) et plus particulièrement la mutualisation, dont l'efficacité a été prouvée dans la littérature et dans les cas réels, a attiré l'attention des chercheurs ainsi que des praticiens. Cependant, un des obstacles principaux à la mise en œuvre des CLHs est l'absence d'un mécanisme de collaboration raisonné, en particulier un mécanisme de partage des gains. Nous identifions deux formes d'organisation centralisée et décentralisée. La forme centralisée est limitée à de petites coalitions, celle décentralisée pouvant comprendre de nombreux participants. Pour des CLHs centralisées, nous proposons un modèle de collaboration qui est un processus de conduite qui intègre les outils d'aide à la décision. Nous développons également un mécanisme de partage par la théorie des jeux. Ce mécanisme est applicable aux différentes catégories des CLHs centralisées, qui peuvent être modélisées par des jeux coopératifs super-additif ou non. Afin de proposer un plan de partage crédible aux collaborateurs, ce mécanisme de partage prend en compte la contribution de chacun des collaborateurs, la stabilité de la coalition et leur pouvoir de négociation. Ce cadre est illustré par des exemples numériques issus de cas logistiques. Pour la mise en œuvre des CLHs décentralisées, nous proposons un cadre de travail de logistique collaborative qui est ouvert aux participants potentiels, et avons conçu des protocoles fondés sur le mécanisme d'enchère combinatoire, qui spécifient l'allocation de demande de livraison et la détermination de paiement pour faciliter les collaborations. Cette dernière partie s'appuie sur la théorie dite de Mechanism Design.

Mots clés: Collaboration Logistique horizontale, Mécanisme de collaboration, Collaborations centralizée et decentralizée, Mutualisation des réseaux d'approvisionnement, Théorie des jeux coopératifs, Enchère combinatoire

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