Collaborative logistics from the perspective of freight transport companies

Acknowledgements

More than six years ago, I decided to apply for a Ph.D. position at the research group Logistics. Although I was a little hesitant about it at first, I was eager and enthusiastic to start my journey as a researcher in October 2011. Going from UHasselt to FWO fellow, from IMOB to building D, from youngest to oldest Logistics Ph.D. student, from girlfriend to wife and from daughter to mother (even in the office), I must admit that my journey has turned into a real adventure. And as it goes in a lot of adventures, the most difficult roads lead to beautiful destinations. However, I would not have reached this destination if it had not been for the help and support of many people.

First, I would like to thank all the members of my jury who have been invaluable to my Ph.D.. Prof. dr. Wout Dullaert, thank you for your effort in reading my thesis and providing useful comments during the private and public defence. Dr. Patrick Beullens, thank you for becoming a member of my Ph.D. committee, for your useful remarks and numerous suggestions, for your perseverance when resubmitting our paper for the third time and for making me feel very welcome at the University of Southampton. Prof. dr. Kris Braekers, although you were not directly involved in my Ph.D., you were always there when I needed advice and provided me with useful ideas and insights whenever I popped by your office (again). Thank you for this. Prof. dr. Gerrit Janssens, thank you for giving me the opportunity to perform academic research, for always having confidence in my work, for the stories and souvenirs of foreign countries and for being the best host one could wish for when visiting Nazaré. And then there are two jury members who have been truly indispensable in creating and finalising this doctoral thesis. Prof. dr. An Caris, thank you for you everlasting support and enthusiasm throughout these six years. Your experience and knowledge have definitely raised this work to a higher level. Moreover, you were always there whenever I needed advice on the behaviour of little boys. Prof. dr. Katrien Ramaekers, working with you has been a true pleasure. Not only have you always been there for feedback, ideas or solutions related to my thesis, I felt like I could talk to you about anything. More than once, our '15 minute meetings' turned into conversations of more than an hour. An and Katrien, I have no idea how I would have done this without the both of you. Thank you for everything.

Next, besides their valuable input to my research, my colleagues have made the workplace feel like home to me. Even if the computers, printers, scanners and copiers broke down (which they often did), I had nothing to worry about, because they were always there to support me. I would like to thank all my colleagues of the research groups Logistics, Business Informatics and IMOB for the pleasant working environment and for all the fun activities, both in and out the office. A special thanks goes to the colleagues who I share an office with, my 'Ultimate B3'. Teun and Hilde, thank you for being my 'paranimfen', not only today but ever since we shared an office. I think I can honestly say we became true friends. Teun, you taught me how to make better presentations, how to perform a decent ANOVA and how to always stand up for your rights (even if you park your car where it is not allowed). Hilde, your enthusiasm and positive personality was as helpful as the caffeine I needed to kick-start the day every morning. Lien and Sarah, although you only joined our office in October, I truly consider you my youngest 'office children'. Our conversations about Temptation Island, fitness trainings and alpacas brightened my work days during these busy last months. Julie, although you are theoretically not a colleague any more, I still enjoy the time we spend together and you will always be the one who labelled me with the 'office mommy' title. Marijke, thank you for joining me in this adventure since day one and for your everlasting enthusiasm and support. Niels, thank you for setting the bar extremely high for all my future master thesis students and for being my ally these last few months. An, thank you for making me feel welcome at IMOB from the day I started my Ph.D.. I will forever associate game nights, picnics and Chinese lunches with you.

Finally, I would like to thank those who are most dear to me, my family. Their support has been invaluable. I would like to thank my family-in-law for always showing an interest in my work and for feeling genuinely sorry for me being a student with that little holidays. My uncles Geert and Denis and their families, thank you for always having my back and supporting me through thick and thin even though your tax money was used for my business trips. My sister Hanne, for reminding me how boring my research work is, for understanding me without words, for cheering me up when I needed it most and for being my best friend. My mom and dad, who have always been my biggest fans, thank you for your everlasting love, for setting a perfect example, for encouraging me in everything I do and for being proud of all my accomplishments. You mean the world to me. And finally, I would like to thank my husband Michiel and his mini-version Elias, you truly are the best part of me. Michiel, words cannot describe how thankful I am to have you in my life. You have always been my greatest believer, even at times I did not believe in myself. You were always there for me: having dinner ready when I came home from work, making me laugh with your (not always that) funny jokes, staying awake to listen to my stressed out stories, sacrificing yourself to play on the PlayStation when I was working again and giving me the best gift I could ever wish for, our son Elias. Elias, thank you for showing me the true meaning of love at first sight, for your endless curiosity and for adding joy to every single day (and night).

Lotte Verdonck
May 22, 2017

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List of Abbreviations

ACAM = alternative cost avoided method
ADA = aggregate-disaggregate-aggregate
ALNS = adaptive large neighbourhood search
ANOVA = analysis of variance
ARP = arc routing problem
BB = budget balanced
BF = bundling frequency
BILP = binary integer linear program
CARP = capacitated arc routing problem
CCFLP = cooperative carrier facility location problem
CCLCP = cardinality constrained lane covering problem
CGM = cost gap method
CM = collaborative mechanism
CND = compensation for non-delivery
CP = coalition performance
CPFR = collaborative planning, forecasting and replenishment
CPU = central processing unit
CPWV = contribution-and-power weighted value
CUARP = collaboration uncapacitated arc routing problem
CVRP = capacitated vehicle routing problem
DA = deterministic annealing
DC = distribution centre

DDSCCP = deterministic dynamic single carrier collaboration problem
ECM = equal charge method
EPM = equal profit method
FTL = full truckload
GRASP = greedy randomised adaptive search procedure
IC = incentive compatible
ICT = information and communication technology
IP = integer program
IR = individually rational
KPI = key performance indicator
KS = Kalai Smorodinsky
LC = clustered customers, by Li and Lim (2003)
LCP = lane covering problem
LNS = large neighbourhood search
LR = randomly distributed customers, by Li and Lim (2003)
LSP = logistics service provider
LTL = less than truckload
MARS = modelling autonomous cooperating shipping companies system
MCLCP = multi-carrier lane covering problem
MDCARPFTL = multi-depot capacitated arc routing problem with full truckloads
MDCVRP = multi-depot capacitated vehicle routing problem
MDPDP = multi-depot pickup and delivery problem
MDPDPTW = multi-depot pickup and delivery problem with time windows
MILP = mixed integer linear program
MIP = mixed integer program
MNT = minimum number of trucks
NP = non-deterministic polynomial time
NSTR = nomenclature uniforme des marchandises pour le statistiques de transport revisée

OD = origin-destination
OROD = one-dimensional relative outlier detection
PC = production-consumption
PDP = pickup and delivery problem
PDPTW = pickup and delivery problem with time windows
RAM = random access memory
RHP = rolling horizon planning
SAF = stand-alone frequency
SME = small and medium-sized enterprises
SPDCM = second-price-based dynamic collaborative mechanism
SPSS = statistical package for the social sciences
SR-GCWS-CS = simuroute generalised Clarke and Wright's savings algorithm with cache and splitting
TCLCP = time constrained lane covering problem
TEU = twenty foot equivalent unit
TLC = total logistics cost
TT = total transport time
U.K. = United Kingdom
VMI = vendor managed inventory
VRP = vehicle routing problem
VRPTW = vehicle routing problem with time windows
WRSM = weighted relative savings model

List of Symbols used in Chapters 3 to 6

Chapter 3: Cost and profit allocation

N = grand coalition, cooperation of all partners
$i, j \in N$ = individual coalition partner
$S \subseteq N$ = subcoalition, subset of partners of the grand coalition
$c(N), c(S)$ = cost of a (sub)coalition
$c(\{i\})$ = stand-alone cost of partner i
$v(S)$ = characteristic function, cost savings amount of subcoalition S
y_i = cost (or savings) allocated to partner i
w_i = weight used to allocate (non-separable) costs or savings to partner i
m_i = separable cost associated with partner i

Chapter 4: Joint route planning

$\mathcal{N}$ = set of nodes, coinciding with $\{\mathcal{I}, \mathcal{Z}\}$
A = set of arcs
$\mathcal{I} \subseteq \mathcal{N}$ = set of customer nodes, coinciding with $\{P,D\}$
$\mathcal{Z} \subseteq \mathcal{N}$ = set of depot nodes, coinciding with $\{\tau,\tau'\}$
$P \subseteq \mathcal{I}$ = set of pickup locations (indices g, h)
$D \subseteq \mathcal{I}$ = set of delivery locations (indices g, h)
$2n$ = total number of pickup and delivery locations

$\tau \subseteq \mathcal{Z}$ = set of vehicle start locations

$\tau' \subseteq \mathcal{Z}$ = set of vehicle end locations

K = set of vehicles (index k)

m = particular number of vehicles available

C = capacity of vehicles

q_g = amount of demand or supply at node g

$[e_g, l_g]$ = time window of node g

s_g = service time of node g

c_{gh} = distance-dependent cost associated with arc (g, h)

t_{gh} = travel time associated with arc (g, h)

x^k_{gh} = decision variable equal to 1 if arc (g, h) is traversed by vehicle k, 0 otherwise

Q^k_g = load of vehicle k when leaving node g

B^k_g = time at which vehicle k begins service at node g

M, W = constants used for linearisation of constraints

x = feasible solution

x' = current best solution

x^* = best solution

w^d, w^r = weights of destroy (d) and repair (r) neighbourhoods

Ω^d, Ω^r = collection of destroy (d) and repair (r) neighbourhoods

T = deterministic threshold value

T_{max} = maximal value for threshold value T

ΔT = reduction parameter for threshold value T

r = random number between zero and one

U = uniform distribution

ω^2 = value indicating effect size of experimental factors

t = Student t distribution statistic

α = statistical significance level

SS = sum of squares

df = degrees of freedom

MS = mean square

F = F statistic

p = significance level

ϵ = penalty term

All other symbols have the same meaning as those used in Chapter 3.

Chapter 5: Cooperative facility location

I = set of carriers (index i)

$\mathcal{A}$ = set of distribution centres (index a)

$\mathcal{B}$ = set of customers (index b)

$\mathfrak{c}_{iab}$ = cost of transporting a single product unit from carrier i to distribution centre (DC) a and on to customer b

F_a = fixed cost of operating DC a

D_{ib} = demand for products of carrier i in customer zone b

T_a = capacity or throughput limit of DC a

g_{ia} = indicator that equals 1 if DC a belongs to carrier i, 0 otherwise

w_i = indicator that equals 1 if carrier i takes part in the cooperation, 0 otherwise

z_{iab} = total number of product units transported from carrier i to customer zone b via DC a

o_a = decision variable that equals 1 if DC a is operational, 0 otherwise

All other symbols have the same meaning as those used in Chapters 3 and 4.

Chapter 6: Intermodal barge networks

$v(N)$ = total cost savings amount of the grand coalition

z_i = number of shipments of partner i per year

oc = order cost

Q = yearly demand

q = shipment size

D_{ph} = distance pre-haulage

D_{mh} = distance main-haulage
D_{eh} = distance end-haulage
TC_r = transport cost road
TC_{iww} = transport cost inland waterways
TT = total transport time
Cap_r = capacity truck
MNT = minimum number of trucks
Cap_{iww} = capacity vessel
$UsedCap_{iww}$ = vessel fill rate
L_r = cost to (un)load truck
L_{iww} = cost to (un)load vessel
d = interest rate
vg = value of goods
wc = warehouse cost

All other symbols have the same meaning as those used in Chapters 3 and 4.

Chapter 1

Introduction and problem statement

1.1 Introduction

Severe competition in global markets, the introduction of products with shorter life cycles, rising fuel and labour prices, a growing body of transport legislation and the heightened expectations of customers have caused profit margins of shippers and carriers to shrink (Cruijssen et al., 2007b). Traditionally, logistics service providers (LSPs)[1] relied on their internal potential to reduce costs and increase profitability. Most companies, however, have exhausted the opportunity to improve efficiency through process optimisation and the application of new technologies. Moreover, the results of these initiatives were often not as positive as expected, since each measure focuses on the efficiency of a single functional entity in the supply chain (Ireland and Bruce, 2000). In order to survive under the ever increasing pressure to operate in a more efficient way, shippers and carriers are obliged to adopt a collaborative focus which opens up cost saving opportunities that are impossible to achieve with an internal company focus. LSPs realise that they have to invest in developing stronger and mutually beneficial relationships with each other (Ergun et al., 2007a; Wang and Kopfer, 2011). Global Commerce Initiative and Capgemini (2008) state that the future supply chain needs to be a collaborative supply chain. This statement is supported by recent initiatives, like the establishment of the Pan-European collab-

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[1] An overview of the abbreviations used in Chapters 1 to 6 can be found at the beginning of the thesis.

oration platform CargoStream (CargoStream, 2017) and the set-up of supply chain orchestrator TRI-VIZOR (TRI-VIZOR, 2017).

Various types of cooperative supply chain relationships in the field of transport and logistics have been discussed in both professional and academic literature. Both vertical cooperation in supply chains and lateral cooperation in supply networks have been the focus of a multitude of research efforts over the last decades. The goal of vertical cooperation is to establish mutually beneficial cooperations between parties operating at different levels of the supply chain offering complementary services to avoid unnecessary logistics costs. In most cases, vertical collaborations are established between customers and suppliers. Practical examples of vertical cooperation are Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting and Replenishment (CPFR) (Verduijn and Iding, 2004; Cruijssen, 2006). Simatupang and Sridharan (2002) define lateral cooperation as cooperation aimed at gaining more flexibility by actively combining and sharing capabilities in both vertical and horizontal ways. Through cooperating laterally and integrating operations with companies operating at the same and different levels of the supply chain LSPs are able to create an effective and efficient logistics network (Cruijssen, 2006). Coyle et al. (2009) refer to this type of cooperation as full collaboration.

In comparison to research on vertical and lateral cooperation, the literature on horizontal cooperation in logistics remains scarce and scattered across various research domains. Horizontal logistics cooperation may be defined as cooperation between two or more firms that are active at the same level of the supply chain and perform a comparable logistics function (Cruijssen et al., 2007c). Existing studies on horizontal logistics cooperation mainly emphasise the illustration of potential cost savings or provide a theoretical overview of drivers, impediments and structure of horizontal alliances between LSPs (Leitner et al., 2011). While the amount of literature concerning horizontal cooperation on the land-side is rather limited, a great deal of research investigates horizontal collaboration in the maritime shipping and aviation industry. In maritime shipping, attention is focused on conferences. These conferences are alliances of several ocean carriers that offer their services on a specific transport line against collective tariffs and identical service levels (Van Eekhout, 2002). Also in aviation horizontal cooperation constitutes a focal element, some well-known examples of major alliances are SkyTeam (20 members; SkyTeam (2017)), Star Alliance (28 members; Star Alliance (2017)) and OneWorld (14 members; OneWorld (2017)).

In this research context, the goal of the thesis is to investigate horizontal cooperation between logistics service providers in depth on a strategic and operational level. More specifically, the impact of various horizontal collaboration strategies, partner characteristics and allocation mechanisms on collaborative performance and stability is analysed.

1.2 Opportunities and challenges of horizontal logistics cooperation

The overall motive for LSPs to engage in a cooperation project is each participant's expectation of a positive net present value (Parkhe, 1993). The goal is to jointly generate a profit in the exchange relationship that cannot be generated when the firms operate in isolation. Cruijssen et al. (2007c), referring to Bartlett and Ghoshal (2004), mention three ways in which cooperating firms can create these mutual benefits: (1) through pooling their resources and concentrating on (core) activities, (2) through sharing and leveraging the specific strengths and capabilities of participating firms and (3) through exchanging different or complementary resources to achieve joint gains. However, numerous surveys also report that 50 to 70 percent of all started strategic partnerships fail for one reason or another (Schmoltzi and Wallenburg, 2011). Because every partner remains independent, the risk of opportunism remains real. Besides that, the planning of the required activities or the measurement of the realised output of the partnership turn out to be complicated tasks (Cruijssen et al., 2007c). As such, this section provides a literature overview of factors that may induce or impede LSPs to form and maintain a horizontal cooperation with fellow companies. The opportunities and challenges defined here serve as a general guideline throughout the entire thesis. By numerically analysing strategic and operational collaboration decisions, recommendations can be made to LSPs on how to leverage opportunities and overcome challenges in a collaborative context.

1.2.1 Opportunities

Opportunities may be organised into six groups, namely costs and productivity, customer service, market position, product related drivers, external motives and expected cooperation outcomes. Table 1.1 provides an overview of relevant references related to these groups. As this table demonstrates, most recent literature on horizontal cooperation opportunities dates back to 2011. Since then, research mainly focuses on the illustration of potential cost savings through various collaboration strategies (cf. Chapter 2).

A first group consists of costs and productivity related opportunities. A horizon-

Table 1.1: Opportunities of horizontal logistics cooperation

Opportunities	Relevant references
Costs and productivity	Bleeke and Ernst (1995)
	Song and Panayides (2002)
	Cruijssen et al. (2006)
	Cruijssen et al. (2007b)
	Cruijssen et al. (2007c)
	Zigmas and Benas (2007)
	Bloos and Kopfer (2011)
	Kopfer et al. (2011)
	Leitner et al. (2011)
	Wang and Kopfer (2011)
Customer service	Closs and Cook (1987)
	Cruijssen et al. (2007b)
	Cruijssen et al. (2007c)
Market position	Bleeke and Ernst (1995)
	Cruijssen et al. (2007b)
	Cruijssen et al. (2007c)
	Bloos and Kopfer (2011)
Product related drivers	Zigmas and Benas (2007)
	Bloos and Kopfer (2011)
External motives	Cruijssen and Salomon (2004)
	Verstrepen et al. (2009)
Expected cooperation outcomes	Song and Panayides (2002)
	Cruijssen et al. (2006)
	Cruijssen et al. (2007c)
	Krajewska et al. (2008)

tal cooperation provides companies the opportunity to gain access to and learn from the competencies and capabilities of their partners. In this way, they can improve their own operation processes by enhancing their cost control capacities, for example

(Bleeke and Ernst, 1995; Cruijssen et al., 2007c; Bloos and Kopfer, 2011). Next to the access to partner skills, LSPs, who collaborate with companies that they were competing with in the past, could benefit from overlapping transport networks. As such, they can build more reasonable and cost efficient transport plans that better utilise their vehicle fleet, reduce their travel time and decrease their level of empty haulage (Leitner et al., 2011). Other cost related cooperation opportunities are the possibility to share capital investments or to involve in joint purchasing which may lead to reduced procurement costs (Song and Panayides, 2002; Cruijssen et al., 2007b,c; Zigmas and Benas, 2007). Horizontal cooperation enables participating LSPs to take advantage of cost reductions through both economies of scale, achieved by integrating an increased number of available customer orders, and economies of scope, reached by the combination of customer tours which might lower asset repositioning (Kopfer et al., 2011; Wang and Kopfer, 2011). According to a study of Cruijssen et al. (2006), the most convincing opportunity to engage in a horizontal logistics cooperation is the potential increase in a company's productivity of its core activities with better usage of storage facilities, increased load factors and decreased empty mileage as most common examples.

Horizontal cooperation not only offers cost and productivity improving effects, but also enables companies to generate more customer value and respond to heightened customer expectations. Through pooling their resources and concentrating on core activities, cooperating companies can specialise while at the same time broaden their service portfolio (Cruijssen et al., 2007c). Sharing and learning from the skills and competencies of partner firms and exchanging resources can also lead to an increased level of service quality in terms of frequency of deliveries, delivery speed, geographical coverage, order cycle consistency, delivery reliability and flexibility (Closs and Cook, 1987; Cruijssen et al., 2007b).

Next, market or market position related opportunities are considered. Specifically for carriers, the required volume involved in serving large shipper companies can exclude these companies from entering the tendering process on an individual basis. Collaboration can be useful in expanding the available fleet, service range and geographical coverage of these companies in order to increase their customer reach (Bleeke and Ernst, 1995). Furthermore, a horizontal cooperation can enhance the participating companies' competitive position or market power which helps to protect their market share and safeguards them against uncertain market conditions (Cruijssen et al., 2007b,c). Cooperating with partner companies may also create chances to enter new markets and get in touch with new, profitable customers (Bloos and Kopfer, 2011).

LSPs may also be induced to form a horizontal partnership by product related drivers. Working closely together with other LSPs and combining resources and skills can create an opportunity to fill in gaps or broaden current product lines. Through cooperation LSPs can offer a more complete range of logistics services. They are able to respond better to rising customer expectations by complementing their own services with those of partnering companies (Zigmas and Benas, 2007; Bloos and Kopfer, 2011).

Horizontal logistics partnerships may also be driven by external motives. According to Verstrepen et al. (2009), these may be divided into three categories, namely customer related, economy related and industry related motives. External customer motives concern the increasing demand of the customer base with regards to flexibility, quality and reliability of the provided service. Customers making use of the transport services of collaborating organisations may enjoy lower prices due to reductions in transport companies' cost levels and improvements in quality of service and delivery reliability as a consequence of more efficient route planning. Evolutions within the economic environment constitute a second category of external motives. Rising fuel prices and stringent rules and regulations may be examples stated in this context. A third category of external motives is related to the characteristics of the logistics industry. Increased market concentration and competitive pricing, leading to reduced profit margins, create an environment in which it may be difficult to operate as an autonomous LSP. Through cooperation organisations seek to improve their efficiency and profit levels, in this way maintaining their continuity in the long run. An external motive not discussed by Verstrepen et al. (2009), but equally relevant in today's logistics environment relates to the ecological reasoning to cooperate. The growing global awareness that human activities have a devastating impact on our living environment drives LSPs to take their responsibility. In this perspective, horizontal cooperation may create an opportunity to reduce the negative impact road transport has on the environment. The resulting reduction in kilometres driven and number of used trucks leads to a decline in external costs of transport, consisting of congestion, costs linked to traffic accidents and to pollution (Cruijssen and Salomon, 2004; Van Lier et al., 2016).

Besides the previous five opportunities, organisations often base their decision to collaborate on the expected positive outcomes they will experience as a result of engaging in a partnership. According to Song and Panayides (2002), cooperation effects on participating companies can be divided into five categories. A first category relates to the financial consequences of horizontal logistics cooperation. LSPs can increase their profit level and shareholder wealth and reduce their financial risk by means of sharing capital investments with partnering companies. Second, general transport efficiency could be improved due to a better utilisation of vehicles, decreased travel times and distances and reduced empty mileage (Cruijssen et al., 2006). Besides a reduction in transport costs, purchasing costs can also be lowered when partnering companies involve in joint purchasing and put additional pressure on suppliers to cut prices (Cruijssen et al., 2007c). Third, collaborating with fellow LSPs provides positive strategic effects, referring to entry in new customer markets and expansion of geographical coverage. Engaging in a horizontal relationship can also enable a participating company to satisfy heightened customer expectations by means of higher delivery frequency, increased reliability and possibility to offer a broader range of logistics services. Finally, horizontal cooperation among LSPs can be a powerful approach to improve operational planning. By cooperating they can develop more efficient transport plans and increase their asset repositioning capabilities (Krajewska et al., 2008).

1.2.2 Challenges

According to Cruijssen et al. (2007b,c), challenges related to sustainable partnerships can be divided into four groups, namely partner selection and reliability, identification and division of joint benefits, balance of negotiation power and information and communication technology (ICT). Based on their relevance in practice, two groups, labelled determination of operational scope and competition legislation, have been added. Table 1.2 presents an outline of relevant references related to these groups. Similar to the research performed on collaborative opportunities, the most recent paper on horizontal cooperation challenges dates back to 2011. Since then, collaborative research mainly focuses on the illustration of potential cost savings through various collaboration strategies (cf. Chapter 2).

A first challenge in the establishment of a sustainable horizontal collaboration refers to the selection of suitable partners. The analysis of the strategic and organisational capabilities of a potential partner requires knowledge about its physical and intangible assets, its competencies and skills and its main weaknesses. This type of information is often held private in the respective organisation. Partner selection thus turns out to be a difficult and often expensive task. Moreover, the amount of attainable collaborative savings is influenced by the degree of fit between the collaboration participants. According to Brouthers et al. (1995) cooperating with an unsuitable partner can be more damaging to an organisation than not cooperating at all. As such, the aim is to find partnering firms with similar or complementary strategic ori-

Table 1.2: Challenges of horizontal logistics cooperation

Challenges	Relevant references
Partner selection and reliability	Parkhe (1993)
	Brouthers et al. (1995)
	Lambert et al. (1999)
	Cruijssen et al. (2006)
	Cruijssen et al. (2007b)
	Cruijssen et al. (2007c)
	Wang and Kopfer (2011)
Identification and division of joint benefits	Cruijssen et al. (2007b)
	Cruijssen et al. (2007c)
	Peeta and Hernandez (2011)
	Wang and Kopfer (2011)
Determination of operational scope	Verstrepen et al. (2009)
	Wang and Kopfer (2011)
Balance of negotiation power	Bleeke and Ernst (1995)
	Cruijssen et al. (2007b)
	Cruijssen et al. (2007c)
Information and communication technology	Cruijssen et al. (2007b)
	Cruijssen et al. (2007c)
Competition legislation	Cruijssen et al. (2007c)
	Cruijssen (2006)

entations, managerial practices, organisational cultures and partnership goals in order to realise a smooth cooperation and a significant level of collaborative profits (Parkhe, 1993; Lambert et al., 1999; Cruijssen et al., 2007b,c). Furthermore, when partners have been selected and the partnership has been established, uncertainty about partner reliability and their commitment to promises contribute significantly to the complexity of the cooperation. Although developing a central plan for the partnership will lead to the achievement of maximal collaborative profits, some participants may still enlarge their gains by leaving from the central plan and, by this, reducing their partners' benefits. As a consequence, it is necessary to offer participating companies incentives for not behaving in an opportunistic way. This problem can be solved through the appointment of a reliable party that can coordinate the cooperation or the implementation of alignment mechanisms (Cruijssen et al., 2006, 2007c; Wang and Kopfer, 2011). Cooperative game theory may provide a mathematical framework that can be used to tackle these partner selection and reliability challenges. Nagarajan and Sošić (2008) discuss the application of the coalition formation game and the Nash equilibrium within a collaborative logistics context. While coalition formation games aid in defining stable coalition structures (Kahan and Rapoport, 1984), the Nash equilibrium could serve as an allocation solution that each of the participants agrees upon (Nash, 1951).

Next, it appears that partnering companies find it difficult to determine beforehand the benefits or operational savings of cooperating horizontally. The narrow scope of most collaborations prevents full understanding of the nature, extent and distribution of risks or rewards that might accumulate during the lifetime of the cooperation. It is essential, however, to obtain a fair distribution of expected and unexpected costs and benefits. Distrust and doubts about the fairness of the cost or profit allocation have caused many horizontal logistics collaborations to break up. It is of capital importance to ensure a fair allocation mechanism in which the contributions of each LSP are quantified and accounted for, since this should induce partners to behave according to the collaborative goal and may improve cooperation stability (Cruijssen et al., 2007b,c; Peeta and Hernandez, 2011; Wang and Kopfer, 2011).

Besides selecting a mechanism to share collaborative benefits and costs, deciding on the operational and practical organisation of a cooperation might turn out to be a challenging task (Verstrepen et al., 2009). Partnering companies need to agree on the collaboration strategy (cf. Chapter 2), the allocation of resources and the applicable key performance indicators (KPIs), among others (Martin et al., 2016). Considering the autonomy of each of the participants, they may have different company strategies and in turn different operational objectives. Developing a central operational plan integrating both individual preferences and collaborative considerations thus requires a substantial amount of negotiations (Wang and Kopfer, 2011).

Another threat to the sustainability of a horizontal cooperation is the evolution of the relative bargaining power of the participating companies over the lifetime of the collaboration. Relative bargaining power depends on three factors: the initial strengths and weaknesses of the partners, how these strengths and weaknesses change over time and the potential for a competitive conflict. When partnering LSPs are more or less equal, it can become harder for them to distinguish themselves in the eyes of the customer. Otherwise, when there are significant power differences between the participating organisations, it is possible that smaller companies may lose clients or get pushed out of the market over time, while larger players gain the most if benefits are not shared in a fair way (Cruijssen et al., 2007b,c).

A fifth challenge in the establishment of sustainable horizontal collaborations deals with the implementation of the necessary supporting ICT. The majority of organisations active in the logistics and transport industry are small and medium-sized enterprises (SMEs). Generally, these companies do not have the required financial resources at their disposal to make the required ICT investments, which can hamper those forms of cooperation that require intensive data exchange (Cruijssen et al., 2007b,c).

Finally, companies engaging in a horizontal collaboration project need to consider the applicable legislation on market competition. Legally binding rules prevent companies from working too closely together as this may restrict competition on the market at hand. European competition rules not only prohibit explicit cooperations, such as price-setting agreements, production limits or entry barriers, but also forbid any multi-company arrangements that have similar effects. According to the Antitrust procedure, a market share of more than 40% is considered to be dominant (European Commission, 2013a). In this way, the extent to which cooperation advantages may be valorised by attracting a significant amount of partner companies might be limited (Cruijssen, 2006).

1.3 Research objectives and outline of the thesis

Global Commerce Initiative and Capgemini (2008) state that the future supply chain architecture requires a structural change combining individual improvement solutions and integrated collaboration concepts. In this context, horizontal collaboration between LSPs has become an important and relevant research area. As demonstrated in Section 1.2.1, engaging in a horizontal logistics cooperation provides various efficiency improving opportunities. However, collaboration projects also have significant failure rates due to their inherent complexity (cf. Section 1.2.2). It is thus essential to approach every partnership from a business perspective to overcome its main impediments and leverage its opportunities.

Current research on horizontal logistics collaboration mainly focuses on describing its opportunities, challenges and structure or demonstrates its cost reduction potential. However, the extent and long-term sustainability of collaborative benefits highly depend on the characteristics of the collaboration, its partners and the applied allo-

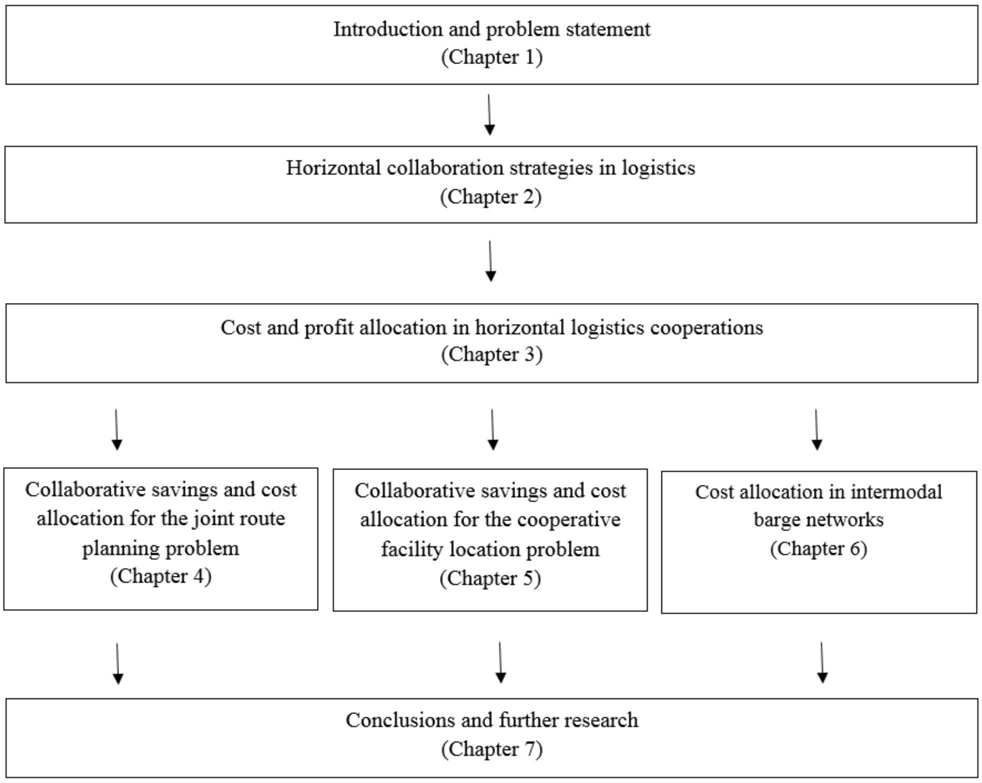

Figure 1.1: Outline of the thesis

cation mechanisms. In this context, the research contribution of the doctoral thesis is twofold. First, the benefits associated with horizontal logistics cooperation are quantified within differing collaborative environments. Second, the conditions necessary to achieve collaborative synergy are investigated. More specifically, the impact of various collaboration strategies, partner characteristics and allocation mechanisms on collaborative performance and stability is investigated. This thesis is the first to numerically analyse the impact of partner selection and cost allocation decisions on collaborative performance and stability within different horizontal logistics collaboration settings.

On the one hand, the partner selection and cost allocation decisions associated with horizontal cooperation between transport carriers are quantified (Chapters 4 and 5). On the other hand, the horizontal cooperation problem is investigated from the perspective of shippers participating in collaborative intermodal barge transport (Chapter 6). The outline of the thesis is visualised schematically in Figure 1.1.

Various types of cooperative supply chain relationships in the field of transport and logistics have been discussed in both professional and academic literature. Both vertical cooperation in supply chains and lateral cooperation in supply networks have been the focus of a multitude of research efforts over the last decades. In comparison, the literature on horizontal cooperation in logistics remains scarce and scattered across various research domains. In this context, **Chapter 2** provides a structured overview of the existing literature concerning horizontal logistics cooperation. Both horizontal cooperations between carriers and shippers are discussed. A description of the main problem characteristics related to carriers and shippers cooperating horizontally is given first. Next, literature is classified according to the different collaboration strategies or techniques that LSPs can exploit in practice and their characteristic solution approaches mentioned in current research. The aim of this chapter is to identify research gaps and opportunities for future research.

Besides the choice of a suitable collaboration strategy, another key question is how to distribute the collaborative profits or costs among the participating LSPs. Since every company is guided by its own self-interest and the contributions of the partners to the collaborative goal are often quite different, the proposed allocation method should be a collectively and individually desirable solution that is perceived as fair, reasonable and easy to implement. Moreover, distrust and doubts among the participants about the cost or profit allocations have caused many collaborations to break up. For these reasons, **Chapter 3** is devoted to the identification of allocation mechanisms suitable in a horizontal logistics cooperation context by providing a structured overview of techniques described in current literature. Existing allocation mechanisms are situated in a classification framework and associated with their respective fairness criteria.

The literature review of Chapter 2 reveals that current research on collaborative logistics mainly focuses on demonstrating the cost reduction potential of various horizontal collaboration strategies. However, in relation to the cooperation challenges defined in Section 1.2.2, the extent of the collaborative gains is highly dependent on the characteristics of the collaboration, its partners and the applied allocation mechanisms. In this context, **Chapter 4** adds value to the existing research work on joint route planning, a generally accepted carrier collaboration strategy. The novelty of the chapter consists of numerically analysing the influence of cooperation structure on partnership performance and the impact of cost allocation mechanisms on coalition stability. As opposed to previous work providing joint route planning savings calculations, Chapter 4 supports LSPs considering collaboration when confronted with partner selection and cost allocation decisions.

Chapter 5 remedies a second shortcoming of current collaborative logistics research. Existing studies on horizontal carrier cooperation all focus on collaboration opportunities within a transport context. In line with the broad definition of logistics including both the movement and storage of freight, this chapter presents a new approach to carrier cooperation: the sharing of warehouses or distribution centres (DCs) with collaborating partners. By jointly and optimally deciding on two types of decisions, namely first which DCs to open and second how to allocate the quantity of product flows to each open DC, partnering companies aim to minimise their total logistics cost. This cost minimisation problem may be classified and mathematically formulated as a facility location problem under cooperation. Similar to the joint route planning research in Chapter 4, numerical experiments are conducted based on an experimental design to analyse the relative benefits of different coalition structures and cost allocation mechanisms.

The importance of a collectively and individually desirable allocation mechanism in any collaborative logistics environment is stressed in Chapter 3. A great deal of scientific literature reports on the behaviour of cost or savings allocation methods in collaborations between shippers or carriers making use of unimodal road transport. However, research on allocation mechanisms in collaborative intermodal transport is scarce. Existing work focuses exclusively on the investigation of game theoretic allocation methods within an intermodal collaboration environment. **Chapter 6** tries to fill this research gap by analysing the performance of three additional allocation techniques used to share cost savings amongst shippers who bundle freight flows in order to reach economies of scale in intermodal barge transport. In this way, a comparison is made between simple and straightforward allocation mechanisms and more advanced techniques based on cooperative game theory. Special attention is paid to the stability of the solutions obtained and their sensitivity to different partner and cooperation characteristics.

Finally, **Chapter 7** discusses general conclusions and opportunities for future research.

Chapter 2

Horizontal collaboration strategies in logistics

2.1 Introduction

In comparison to research on other types of cooperative supply chain relationships, the literature on horizontal cooperation in logistics remains scarce and scattered across various research domains. Existing studies on horizontal logistics cooperation mainly emphasise the illustration of potential cost savings through collaboration or provide a theoretic overview of drivers, impediments and structure of these horizontal alliances between carriers and/or shippers (Leitner et al., 2011). Following this research gap on the operational consequences of horizontal cooperation and its growing relevance in practice to increase performance of LSPs, the focus of this chapter (Figure 2.1) is to study horizontal logistics cooperation in depth on a strategic and operational level. Relevant scientific literature is classified and structured according to the different collaboration strategies transport organisations can exploit in practice and their characteristic solution approaches mentioned in current research. Information is also provided on the collaborative environment in which these strategies are applied and the amount of economic benefits they may yield. Section 2.2 describes the search strategy used to gather the collaborative logistics literature discussed in this chapter.

Section 2.3 [1] presents a thorough study of horizontal cooperation strategies suit-

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[1] This section is based on the paper: Verdonck, L., Caris, A., Ramaekers, K., Janssens, G., 2013. Collaborative logistics from the perspective of road transportation companies. Transport Reviews 33 (6), 700–719.

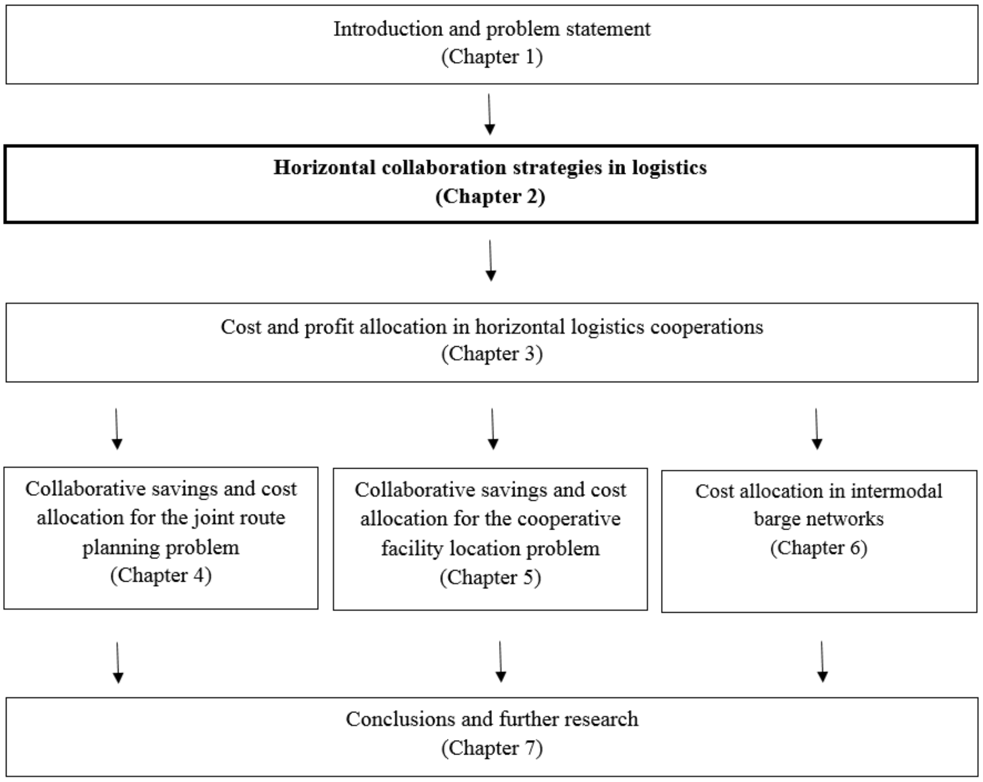

Figure 2.1: Outline of the thesis

able for transport carriers. These organisations receive orders from different types of customers concerning the transport of goods to specified locations at customers' sites (Cruijssen et al., 2007a). As mentioned in Chapter 1, LSPs are faced with fierce competition and very thin profit margins in a continuously growing, globalised market. Concerning freight carriers, large companies remain quite competitive in comparison to their smaller alternatives due to their wider portfolio of disposable resources and a higher position in the market power structure. A possible remedy for medium- and small-sized carriers is to establish horizontal collaborations in order to extend their resource portfolio and reinforce their market position. The purpose of these collaborations is to create a more efficient transport planning through the balancing of transport orders or the sharing of vehicle capacity.

In order to provide a complete overview of horizontal cooperation strategies suitable in transport and logistics, Section 2.4 describes the main elements of horizontal cooperation from the perspective of shippers by summarising relevant scientific literature. Carriers receive transport orders from various shippers and determine a price for the execution of these orders on the basis of their transport network. An important influential factor on the operational costs and therefore on the prices suggested by the serving carriers is the degree of asset repositioning. Asset repositioning, also defined as deadheading, consists of empty truck transport from a delivery location to a pickup location (Özener and Ergun, 2008). Because this deadheading is mainly a consequence of the imbalance of orders received from different shippers, shippers may consider collaborating in order to get more favourable carrier rates (Ergun et al., 2007b). By cooperating and sharing order information with fellow shipper companies, shippers may identify sequences of continuously loaded transport modes. These can be submitted to carriers as a set, reducing the degree of asset repositioning by the carrier and increasing his capacity utilisation, thereby cutting down his costs which may be reflected in lower rates for the shippers (Lynch, 2001; Ergun et al., 2007a).

To conclude this chapter, Section 2.5 identifies research gaps and opportunities for future research.

2.2 Literature search strategy

The goal of this chapter is to provide a representative and structured review of the scattered amount of scientific research on strategic and operational aspects of horizontal logistics cooperation. For this purpose, a three-phased computerised search strategy was employed. The first phase of the research consisted of a systematic review of electronic bibliographic databases (e.g. EBSCOHost and Web of Knowledge). Next, the search was supplemented with reviews of electronic journals concerning logistics and/or transport to include articles not covered in the databases. Finally, information was gathered by pursuing papers cited in already obtained literature (ancestry approach).

In order to ensure that relevant studies were not overlooked, initial search terms remained broad. Articles with 'cooperation', 'collaboration', 'coalition', 'alliance', 'partnership', 'transport', 'freight' and/or 'logistics' in title, abstract or as main topic were identified in this way. Next, a detailed examination of papers was executed to filter out articles focusing on the operations of horizontal carrier and shipper cooperations. Search terms used for this purpose were, among others, 'horizontal', 'operational', 'transport organisations', 'logistics service providers', 'carriers', 'shippers', 'sharing', 'combining' and/or 'exchanging'. Papers were excluded if they only presented a theoretical overview of operational or strategic issues associated with horizontal logistics cooperation.

2.3 Collaborative logistics from the perspective of carrier companies

Scientific literature on carrier collaboration may be divided into two main research streams. The majority of articles concerning horizontal carrier cooperation are devoted to carrier alliances in which customer orders are exchanged between the participating organisations through various techniques. The main purpose of this order re-allocation is to achieve a better match between demanded and available transport resources (Bloos and Kopfer, 2011). Through order sharing, carriers may improve their efficiency and profitability because of an increase in capacity utilisation, improved asset repositioning capabilities and a reduction in total transport costs due to improved transport planning (Kopfer and Pankratz, 1999; Dai and Chen, 2011). The different solution approaches carriers may use to solve the order sharing problem, as mentioned in current research studies, are reviewed in Section 2.3.1.

Instead of sharing customer orders, carriers may also cooperate horizontally through the sharing of vehicle capacities. Since owning a transport vehicle involves a considerable capital investment and low capacity utilisation reduces a company's efficiency, carriers may cooperate horizontally to share capacity and its associated costs (Agarwal and Ergun, 2010). Capacity sharing provides a suitable alternative for order sharing, especially in environments where private order information cannot be communicated between alliance partners. Section 2.3.2 provides an overview of appropriate strategies that may be employed to determine the most efficient and profitable way of sharing vehicle capacities.

2.3.1 Order sharing

Carriers have the possibility to horizontally cooperate with partner organisations through the sharing or exchanging of customer orders in order to improve their efficiency and profitability. Current research studies address different techniques to tackle this problem of optimal re-allocation of orders. Since the majority of the articles present joint route planning or auction based mechanisms to optimally share orders between cooperating carriers, Sections 2.3.1.1 and 2.3.1.2 are devoted to these solution approaches. In addition, more specific techniques based on bilateral lane exchanges, load swapping and dispatching policies are described in Sections 2.3.1.3, 2.3.1.4 and 2.3.1.5 respectively. Section 2.3.1.6 puts Sections 2.3.1.1 until 2.3.1.5 into perspective and formulates a number of conclusions. Table 2.1 provides an overview of relevant references related to operational techniques for the order sharing problem. Moreover, information is provided on the problem formulation and solution approach discussed in each paper. In relation to the 'Problem formulation' column, subtitles are added to the following subsections in order to improve their overall readability and structure.

2.3.1.1 Order sharing through joint route planning

A first approach to share customer orders between collaborating carriers is joint route planning. In general, this order sharing method denotes that customer orders from all participating carriers are collected in a central pool and efficient route schemes are set up for all these orders simultaneously using appropriate vehicle routing techniques (Cruijssen et al., 2007a). In this way, scale economies, in terms of reduced travel distance, empty vehicle movements and number of required trucks, may be obtained by merging the distribution regions of all collaboration partners (Cruijssen and Salomon, 2004; Cruijssen et al., 2007a). Since joint route planning constitutes an NP-hard problem, the solution approaches described in the following paragraphs all have a heuristic nature. In the next sections, joint route planning literature is organised according to the underlying problem formulation considered in each of the described papers.

Vehicle Routing Problem (VRP)
Cruijssen and Salomon (2004) consider a transport network with multiple carriers and multiple customers. Customer orders represent shipments that need to be transported from a carrier distribution centre to a customer location. The authors assume that customer orders consist of deliveries only. The purpose of the study is to compare transport costs of individual carriers with total transport costs in a system where orders are shared and a joint route planning is established. To solve the joint route planning problem, customer orders are combined over all carriers and an appropriate Vehicle Routing Problem (VRP) is formulated. This VRP is solved heuristically with RitOpt. RitOpt, a heuristic defined by Fleuren and Janse (1993), forms the foundation of the route planning software RitPlan commonly used in the Dutch freight transport sector. The authors demonstrate the efficiency of their order sharing procedure by means of a case study in the Dutch flower transport industry. The cost difference is calculated between the situation in which each carrier only performs transport

Table 2.1: Order sharing techniques

Order sharing technique	References	Problem formulation	Solution approach
Joint route planning	Cruijssen and Salomon (2004)	VRP	Ritopt
	Cruijssen et al. (2007a)	VRPTW	Modified savings heuristic, route elimination procedure, local search operators
	Nadarajah and Bookbinder (2013)	VRPTW	Guided local search, local search heuristics
	Juan et al. (2014)	CVRP	Clarke and Wright's savings algorithm
	Pérez-Bernabeu et al. (2015)	MDCVRP	Iterated local search
	Krajewska et al. (2008)	MDPDPTW	Local search method
	Dahl and Derigs (2011)	MDPDPTW	Router heuristic
	Liu et al. (2010b)	MDCARPFTL	Two-phase heuristic procedure
	Fernández et al. (2016)	CUARP	Branch-and-cut
	Bailey et al. (2011)	(M)IP	Greedy heuristic, tabu search
	Caballini et al. (2016)	BILP	Cplex ILP solver
Auction based mechanisms	Song and Regan (2004)	Static carrier cooperation	Combinatorial auctions
	Krajewska and Kopfer (2006a)	Static carrier cooperation	Modified matrix auctions
	Schwind et al. (2009)	Static carrier cooperation	Combinatorial auctions

Order sharing technique	References	Problem formulation	Solution approach
	Berger and Bierwirth (2010)	Static carrier cooperation	Vickrey auctions, combinatorial auctions
	Ackermann et al. (2011)	Static carrier cooperation	Combinatorial auctions
	Wang and Kopfer (2014)	Static carrier cooperation	Combinatorial auctions
	Figliozzi (2006)	Dynamic carrier cooperation	Dynamic auction mechanism
	Dai and Chen (2011)	Dynamic carrier cooperation	Iterative combinatorial auctions
	Wang and Kopfer (2015)	Dynamic carrier cooperation	RHP, combinatorial auctions
Bilateral lane exchanges	Özener et al. (2011)	MCLCP	Commercial solver
Order swapping	Clifton et al. (2008)	Space-filling curves	OROD, swap algorithm
Shipment dispatching policies	Zhou et al. (2011)	Freight dispatching model	Time-and-quantity dispatching policies

orders of its own customers and the situation in which orders from all cooperation partners are combined and optimally assigned to appropriate routes. Results reveal that joint route planning leads to cost reductions between 5% and 15%. The level of savings from order sharing may be influenced by a number of problem characteristics like average order size, number of collaborating carriers and so on.

Similarly, Cruijssen et al. (2007a) define a framework based on the VRP with time windows (VRPTW) to determine the synergy value of horizontal carrier cooperation through joint route planning. For the purpose of using vehicle routing, the carrier system is translated into a distribution network consisting of nodes and arcs. Each node represents a delivery location and there is one node in the centre of the plane, which refers to the distribution centre. Each pair of nodes is connected by an arc with a certain Euclidean distance. Travel times, proportional to these distances, are used to determine synergy values because customer orders have time windows and working days of drivers are of limited length. The authors define the joint route planning problem as a VRPTW with the objective of minimising the number of routes, taking into consideration the fact that each route starts and ends at the origin node, each destination node is visited exactly once, time windows are respected and the demand of customers visited along a route does not exceed the capacity of the vehicle in use. An appropriate heuristic is constructed to solve this minimisation problem. In a first step, the heuristic constructs an initial solution based on the Liu and Shen (1999) application of the original savings heuristic designed by Clarke and Wright (1964). Subsequently, by looping through all the generated routes, the heuristic aims to reduce the number of routes. Finally, two local search operators ICROSS (based on the CROSS operator) and IOPT (based on the Or-opt operator), both described in Bräysy et al. (2004), are iteratively applied after the elimination procedure until no further cost reductions are possible. Case study results show that joint planning of routes between three frozen food distributors saves about 30% in distance travelled. Moreover, the authors examine the sensitivity of collaborative savings to various operational characteristics (e.g. number of orders, average order size, etc.).

Nadarajah and Bookbinder (2013) also employ a VRPTW formulation in their two stage framework for carrier collaboration within urban regions. In a first stage, goods are optimally exchanged at the entrance of a city making use of guided local search. Second, transshipment point location and collaborative routing within a city are performed applying novel local search heuristics. Computational experiments indicate distance savings up to 15% when collaborating at the entrance of the city and additional reductions in kilometres driven up to 15% when carriers are involved in intra-city collaboration.

Juan et al. (2014) discuss horizontal collaboration between transport companies through backhaul strategies. The goal of the joint route planning is to minimise both distance and emission based costs of the partners' distribution activities. For this purpose, a meta-heuristic combining the savings heuristic (Clarke and Wright, 1964), an iterated local search process (Lourenço et al., 2010) and the SR-GCWS-CS (SimuRoute Generalised Clarke and Wright's Savings algorithm with Cache and Splitting) algorithm, developed by Juan et al. (2011), is applied to an appropriate VRP with backhauls. Numerical experiments demonstrate average reductions in distance and environmental costs of 16% and 24% respectively.

Pérez-Bernabeu et al. (2015) translate the joint route planning problem into a multi-depot capacitated VRP. This cooperative scenario is compared with various non-cooperative scenarios, differing in geographical customer distribution, in terms of distance-based and environmental costs. An iterated local search algorithm is applied to the cooperation problem while the non-collaborative scenarios are solved using the well-tested SR-GCWS-CS algorithm (Juan et al., 2011). Numerical experiments on classical multi-depot VRP benchmark instances demonstrate distance and emission cost reductions between 5% and 90% depending on the geographical customer distribution.

Pickup and Delivery Problem (PDP)

A variant of the traditional VRP used to model the collaborative carrier order sharing problem is the multi-depot pickup and delivery problem (MDPDP), as described in Krajewska et al. (2008) under time windows. To solve the order sharing problem by means of a PDPTW, the authors make use of the 'multi-depot' property to translate the pooling of orders from different carriers. The MDPDPTW consists of finding a set of vehicle routes that minimise total costs, making sure that all orders are executed within their time windows, vehicle capacity is never exceeded and each vehicle starts and ends at its respective depot. The local search method developed by Ropke and Pisinger (2006) based on the large neighbourhood search heuristic from Shaw (1998) is used to solve the problem. The heuristic moves from the current solution to another in its neighbourhood through the removal and insertion of customer orders, for which several removal and insertion operators are used. Krajewska et al. (2008) test their approach both on artificial instances and real-life data from a German freight forwarder. Results reveal that coalition participants may realise significant cost savings through the sharing of orders.

In line with the previous article, Dahl and Derigs (2011) formulate the order sharing problem in a collaborative network of independent carriers as a MDPDPTW. Since carriers considered in this paper only perform express customer orders, they operate in a highly dynamic environment in which at no point in time a fixed set of orders may be planned. The problem is therefore solved from a dynamic perspective. The planning situation may be described as follows. Each partner carrier in the network is located at a specific depot and operates a set of vehicles, which can be assigned to different vehicle classes with distinct physical and technical characteristics. Every carrier needs to serve a set of customer orders, defined by a pickup location, a delivery location, a capacity requirement and a time window. On the basis of the capacity requirement, an appropriate vehicle class is assigned to each customer order. In line with these vehicle class assignments, a transport rate per kilometre for external customers and an internal cost rate per kilometre driven when an order is exchanged, may be identified for each customer order. To find a solution for this dynamic MDPDPTW the heuristic solver Router is modified and applied. Router is an indirect search heuristic developed to solve a special pickup and delivery VRPTW (Derigs and Döhmer, 2005). Based on a simulation study using real data from 50 European express carriers, Dahl and Derigs (2011) demonstrate that cost reductions up to 13% may be achieved when applying joint route planning.

Arc Routing Problem (ARP)

Liu et al. (2010b) address the joint route planning problem of cooperating carriers from a different viewpoint. They formulate the problem as a multi-depot capacitated arc routing problem with full truckloads (MDCARPFL). Arc Routing Problems (ARPs) are a variant of VRPs in which the vehicles are constrained to traverse certain arcs, rather than visit certain nodes as in a standard VRP. A capacitated ARP (CARP) covers the identification of a set of vehicle routes of minimum cost, taking into consideration that every required arc is serviced by a single vehicle, each route starts and ends at the depot and total demand served in a route does not exceed vehicle capacity (Golden and Wong, 1981). Because the joint route planning problem considered here consists of multiple carriers providing only full truckload transport, the multi-depot FTL (full truckload) version of the CARP (MDCARPFL) is solved. The goal of the considered joint route planning problem is to determine tours for vehicles located at different carriers that serve all customer orders and minimise total distribution costs. By pooling all FTL orders and defining a collaborative route plan, the number of empty movements from delivery to consecutive pickup locations could be significantly reduced. To solve the MDCARPFL the authors propose a two-phase heuristic procedure. In the first phase, a set of cycles is created to cover all lanes (arcs in the distribution network). For this purpose, Liu et al. (2010b) extend the greedy algorithm 'generating cycles first, choosing cycles second' described by Ergun et al. (2007b). In the second phase, vehicle tours are constructed based on the cycles from the previous step through the use of a closed chain construction algorithm. Local search techniques are employed to improve the initial solution. Liu et al. (2010b) analyse the performance of their heuristic for a number of test problems. Results show that the solution procedure yields robust and high-quality solutions in a reasonable computing time.

Fernández et al. (2016) also model carrier collaboration by means of the ARP. They consider a centrally managed joint route planning cooperation in which each carrier identifies customers it needs to serve and customers it wants to share. Based on the assumption that all vehicles are uncapacitated, the authors label their problem CUARP (Collaboration Uncapacitated Arc Routing Problem). Two variants of the model are investigated: (1) maximisation of the total collaborative profit, (2) additional inclusion of a lower bound on the individual profit of each carrier. Both problems are formulated as mixed integer linear programs (MILPs) and solved using a branch-and-cut algorithm. Numerical experiments demonstrate the positive effect of carrier collaboration for both models and reveal that collaborative synergy increases when the number of shared arcs is increased. However, average collaborative profit is smaller in model (2) than in (1) due to model (2)'s added constraints.

Integer Program (IP)

Contrary to the previous articles considering the entire carrier transport network for collaboration, Bailey et al. (2011) focus on order sharing opportunities for the backhaul routes of partnering companies. The authors investigate possible reductions in a carrier's empty backhauls by adding customer orders of collaborative partners to its backhaul transport. Since the empty transport back to the depot often constitutes a significant cost factor, backhaul freight collaboration may lead to a considerable increase in the carrier's efficiency and profitability. Two optimisation models are developed to find cost minimising opportunities for rerouteing the carrier's empty backhaul transport to serve pickup or delivery orders from collaborative partners. Both models account for restrictions on truck capacity and vehicle driver hours. In the first model, which is formulated as an integer program (IP), each truck serves at most one partner order on its backhaul route. This model may be classified as a constrained matching problem and is solved with a greedy heuristic. The second model is more complex since it allows multiple pickup and delivery orders to be performed by a single truck on its backhaul route. This model is formulated as a mixed integer programming problem (MIP). The authors develop a heuristic based on tabu search to solve their problem. Computational experiments on both models reveal that freight collaboration may lead to backhaul cost savings between 13% and 28%.

Finally, Caballini et al. (2016) make use of the backhaul strategy in the context of cooperating carriers in seaport containerised transport. Due to the large number of empty transports surrounding ports, joint route planning between trucking companies could lead to both economic and environmental benefits. The authors model the collaborative drayage [2] problem as a binary linear program (BILP) and use Cplex as BILP solver. Based on a numerical experiment with real data from the port of Genoa, Italy, they demonstrate that all partners experience a profit increase by sharing orders with fellow drayage carriers.

2.3.1.2 Order sharing through auction based mechanisms

In the application of joint route planning, all customer orders from participating carriers are gathered in a central pool and assigned optimally on the basis of appropriate solution techniques used in the context of VRPs. Concerning order sharing through auction-based mechanisms, each individual carrier first defines which customer orders may be exchanged in a cost efficient manner by applying optimisation methods similar to those used in joint route planning. In a next step, appropriate customer orders are shared employing various profit maximising auction mechanisms. By implementing auction-based order sharing, most often collaborating organisations compensate their partners immediately for executing their transport orders. On the contrary, with joint route planning, additional effort needs to be invested in the identification of a fair collaborative profit allocation scheme. In the next sections, auction based literature is organised according to the static or dynamic nature of the described carrier collaboration. While the static perspective assumes all customer order information is given at the start, a dynamic collaborative environment is characterised by customer demand stochastically revealing itself during the planning period.

Static carrier collaboration

Song and Regan (2004) propose an auction based order allocation mechanism for small and medium sized carriers. When a carrier receives a new customer order, he first applies a set of optimisation routines to identify whether it is profitable to serve this order himself. If not, he determines a reservation price for the order and informs

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[2] Short-haul transport of containers by trucks between seaports and inland terminals.

his cooperation partners that the customer order is open for bidding. The reservation price refers to the maximum value that the carrier is willing to pay to a partner carrier for the execution of the order. The other carriers then apply the same optimisation techniques to determine whether they can serve the offered order efficiently and at which cost. Finally, the carrier who submitted the order compares the bids with his reservation price and chooses the lowest bid if satisfactory. The authors suggest the use of combinatorial auctions to assign orders so multiple orders may be exchanged simultaneously and bidders are allowed to bid on combinations or bundles of orders. They also pay considerable attention to the complex carrier decision whether or not an order should be offered for exchange. The answer to this problem depends on the carrier's capacity, current demand, historical demand, risk-taking behaviour and anticipation of future customer orders.

Krajewska and Kopfer (2006a) describe an order allocation procedure consisting of three phases based on combinatorial auctions and game theory to optimise and share collaborative profit, respectively. Each carrier receives a set of transport orders from its customers which needs to be served. For each order every carrier has to choose individually whether he fulfils it within the usage of his own resources or whether he includes it in the collaboration process so that partnering carriers may execute it. The authors suggest basing this choice on a minimisation of total freight costs. In the first phase of the collaboration process, the pre-processing phase, every carrier stipulates the lowest execution cost for each order he decides to offer to his partners. These costs reflect the costs for fulfilling the order making use of own disposable resources, which correspond to the lower amount of either the costs of self-fulfilment or the costs of subcontracting. This cost is labelled 'potential self-fulfilment cost' of the orders. Next, in the profit optimisation phase, customer orders are exchanged between cooperating carriers such that general profit of the entire collaboration is maximised. For this purpose, each partner defines and declares bundles of orders he wants to fulfil and determines the potential fulfilment costs of executing them. A modified matrix auction, based on a first-price sealed-bid auction, is used to identify the most profitable bundle combination for the collaboration project and to assign the bundles to the participating carriers (De Vries and Vohra, 2003). Finally, in the profit sharing phase, the collaborative profit is divided among the partnering carriers based on game theory concepts, which are dealt with in more detail in Chapter 3.

In line with the procedure developed by Krajewska and Kopfer (2006a), Ackermann et al. (2011) combine auction-based order sharing with a fair allocation of collaborative profits. Customer orders of competing LTL (less than truckload) carriers are exchanged in bundles via combinatorial auctions and profits are shared using the Shapley value (Shapley, 1953). The authors also pay special attention to data privacy of coalition participants, in order to avoid sensitive data from leaking via the order exchange system.

Schwind et al. (2009) present an order exchange procedure applying combinatorial auctions as well. The authors propose an order reallocation mechanism within the context of a medium-sized logistics company consisting of multiple independent profit centres. As the delivery areas of these profit centres overlap, distribution costs may be reduced by cooperating horizontally through the exchange of customer orders. The developed order reallocation mechanism, labelled ComEx, consists of four phases. In the initialisation phase, each profit centre determines the delivery costs of his initial customer order set. For this purpose, an extended version of cooperative simulated annealing (Wendt, 1995) is developed to solve the time-dependent VRPTW associated with the profit centres' initial order sets. Next, during the outsourcing phase, each profit centre determines sets of orders representing candidates for exchange on the basis of their cost level and notifies the other profit centres of the orders it wants to share. Subsequently, each profit centre has the opportunity to bid on sets of orders that may be integrated with his own orders taking into account time windows and order coordinates. During this insourcing phase, combinatorial bid prices are determined on the basis of the difference in delivery costs resulting from excluding and including respective order sets. Lastly, after each profit centre has submitted its bids, a combinatorial auction is performed in the final evaluation phase. This auction is aimed at identifying the allocation of order sets to profit centres that minimises the total delivery costs for the entire logistics company. By means of a simulation study using real-world transport data from a medium-sized logistics company, it is demonstrated that the ComEx mechanism may achieve cost reductions up to 14%.

Also Berger and Bierwirth (2010) consider the exchange of customer orders through auction based mechanisms. Similar to Ackermann et al. (2011), their framework accounts for the amount of information transfer between collaborating carriers, because carriers disclose some customer and cost information unwillingly to their cooperation partners. For this purpose, a distinction is made between carriers collaborating though a decentralised approach with only confidential exchange of relevant information and carriers collaborating through a central planning approach in which full information transfer is necessary. The reassignment of transport orders to the different participating carriers is achieved through the use of Vickrey auctions or combinatorial auctions depending on how many orders are reassigned at a time. The reassignment procedure differs for the centralised and decentralised approach with respect to the information shared by the participating carriers. For the decentralised strategy, at the start every carrier selects and submits appropriate orders on an individual and independent basis to the central authority, which then sets up applicable auction mechanisms. In the centralised case, every carrier submits its complete order portfolio to a confidential authority, which performs optimal order allocation on a central basis. As opposed to the decentralised strategy, where the authority merely has a supporting role and each carrier maximises its individual profit level, the centralised strategy aims to maximise the total profit of the entire collaborative network. Following the optimisation phase, a simple uniform allocation of the cooperative profit level among partner carriers is performed to create a win-win situation for every participant. Based on a computational study, the authors demonstrate that the decentralised method is clearly superior to carriers operating on their own (no collaboration) considering profit level. However, the results are mostly dominated by collaborative profit acquired through the centralised approach. The success of order sharing between collaborating carriers thus increases in line with the degree of information sharing.

In contrast to the majority of the auction based order sharing mechanisms, Wang and Kopfer (2014) propose a combinatorial auction based method for order allocation where partnering carriers exchange complete vehicle routes instead of arbitrary bundles of single transport orders. Customer orders correspond to pickup and delivery tasks with time windows, so the underlying routing problem is the PDPTW. The route exchange procedure consists of three stages. In the pre-processing phase, the authors assume that all carriers offer all their acquired customer orders for exchange. The problem to be solved by each carrier at this stage is the determination of the route transfer prices. For this purpose every participant solves the appropriate PDPTW for his own order portfolio. The second and third phases are constituted by the bid generation process for the bidding carriers on the one hand and the winner determination problem for the auctioning carriers on the other hand. The bid generation process starts with the selection of orders the bidding carrier wants to serve and the creation of vehicle routes (bids) for the execution of selected orders. This two sided problem can be solved through a combined order selection and routing problem. On the basis of the submitted bids, the auctioneer then solves the winner determination problem in which orders are assigned to bids that result in an optimal level of collaborative profit. Wang and Kopfer (2014) assess the performance of their cooperation mechanism by means of computational experiments on artificially generated instances. Results indicate that collaborative planning may achieve cost reductions between 2% and 18%.

Dynamic carrier collaboration

Figliozzi (2006) studies the order sharing problem within a dynamic environment. In particular, the author focuses on collaborative mechanisms (CMs) that are incentive compatible (IC). IC mechanisms have the distinct property that carriers have the incentive to submit their cost estimations honestly. They do not have the intention to cover the real value of their offers considering the possible reactions of cooperating competitors. The proposed collaborative order allocation procedure progresses as follows. When a carrier receives a new customer order, he submits a reservation value to the CM. The CM then communicates the order to partner carriers, who subsequently submit their reservation cost. This cost corresponds to the minimum value that carriers are willing to charge other carriers for serving the order sent to the CM. Finally, the CM reassigns orders or bundles of orders using the second-price-based dynamic collaborative mechanism (SPDCM), which is based on the workings of a one-item second-price auction (Krishna, 2010). The proposed auction mechanism is budget balanced (BB), individually rational (IR) and IC. The BB property means that no carrier ever pays more than his reservation value, while the IR property refers to the fact that reservation values and costs are always respected. The mechanism is also IC because it is optimal for the participating carriers to put forward their true service costs as reservation values and costs. The objective of the CM is to optimally reassign customer orders and maximise collaborative profits subject to these three properties such that efficiency of the cooperation is guaranteed. To demonstrate the savings that could be attained applying the SPDCM, a simulation study is carried out on a hypothetical coalition of four identical carriers. Results clearly state that the collaborative system outperforms an environment where carriers operate on an individual basis.

Dai and Chen (2011) formulate order sharing as two decision problems. On the one hand, carriers have to select orders they do not want to serve themselves, which corresponds to the 'outsourcing requests selection problem'. On the other hand, the 'requests bidding problem' concerns the identification of desirable orders to be acquired from other carriers. The authors study the carrier collaboration problem in LTL transport with orders constituting pickup and delivery orders in a dynamic context. In the horizontal cooperation, multiple carriers with their own depot and a fleet of capacitated vehicles operate in a common transport network. Each transport organisation acquires orders from its customers specified by a pickup location with a time window, a quantity and a delivery location with a time window. To maximise collaborative profit, these orders are exchanged between partners. A solution to the order sharing problem is defined by a set of orders to be fulfilled by each carrier, a set of optimal vehicle tours for the carrier to execute the orders and the outsourcing price of each order outsourced by each carrier to partnering carriers. To initiate order sharing among carriers, each partner must select which of his acquired customer orders he does not want to serve himself. The outsourcing requests selection problem is formulated as a MIP in which the objective function reflects the surplus profit that the carrier obtains from executing orders by himself. Each carrier solves this outsourcing requests selection problem when he receives new customer orders or when he acquires orders from partner carriers. All the outsourced orders and their respective prices are gathered in a pool that is available to every carrier. Each partner may then decide to bid on certain orders in this pool, which corresponds to the requests bidding problem, also formulated as a MIP. This auction based order sharing framework proposed by Dai and Chen (2011) has some distinct features. First of all, multiple auction processes of multiple outsourcing orders may happen simultaneously. These processes interact with each other through orders outsourcing or acquisition events and through carrier adaptations of outsourcing prices based on placed bids. Second, each carrier plays two roles in the procedure. When he outsources an order on the basis of the solution to the outsourcing requests selection problem, he will act as an auctioneer and start the auction of his outsourced order(s). Each of the other carriers, however, solving their requests bidding problem, acts as a bidder on possible desirable customer orders. Dai and Chen (2011) evaluate the performance of their auction-based approach by means of a simulation study on 20 randomly generated instances. Results reveal that the collaborative profit level achieved by means of auction-based order sharing is significantly larger than the total profit gained in a carrier environment without cooperation.

In 2015, Wang and Kopfer extended their 2014 research described previously with a dynamic perspective (Wang and Kopfer, 2015). The dynamic approach assumes a long time horizon during which order information is gradually revealed. The authors describe two rolling horizon planning (RHP) approaches that solve the static collaboration problem periodically based on updated order information. The first approach constitutes a RHP framework with a fixed time interval. As such, the entire time horizon is divided into a series of planning periods, all with the same length. At the end of each planning period, a new plan for all future periods is made based on the dynamically released orders during the execution of the previous plan. The second RHP approach does not update the future plans based on a fixed time schedule but after each change in the order portfolio. Simulations demonstrate that the results of the second approach are worse than those of the first. Reason is that the high frequency of planning results in an increase of the cost of the solution obtained and a loss of efficiency of the order exchange procedure.

2.3.1.3 Order sharing through bilateral lane exchanges with information sharing and side payments

Özener et al. (2011) develop a fairly specific order sharing mechanism where lanes are exchanged bilaterally (between two carriers). As opposed to the focus on sharing LTL pickup and/or delivery orders in the previous sections, this article considers the exchange of FTL origin-destination orders (lanes). Different procedures for the transfer of these lanes are created on the basis of different degrees of information sharing and side payments between the participating carriers. In general, a lane exchange mechanism corresponds to the identification of the optimal assignment of lanes to participating carriers and the optimal set of cycles covering these lanes. This optimisation problem is formally defined as the multi-carrier lane covering problem (MCLCP) and can be formulated as an ILP. The objective is to minimise the sum of the lane covering costs and the repositioning costs of all carriers. A solution to the MCLCP provides an optimal assignment of lanes to carriers and optimal routes for serving these lanes and can be found through the use of a heuristic approach. The authors state that information sharing between carriers and whether or not side payments are paid for lane exchanges are the two most important elements defining a lane exchange mechanism. On the basis of these two factors, they propose four different, but similar collaboration environments and appropriate exchange mechanisms based on the MCLCP: no information sharing and no side payments, no information sharing with side payments, information sharing without side payments and information sharing with side payments. Following computational experiments, it turns out that, contrary to allowing side payments which do not always have a positive effect, information sharing is always beneficial for the cooperation. Sharing information permits carriers to identify the best possible lane exchanges on the basis of anticipated offers from partner carriers. Side payments, however, may be used by carriers to make their offered lanes seem more attractive in the exchange mechanism. While increasing the side payment of a lane increases its likelihood of acceptance, it also decreases the marginal benefits from the lane exchange.

2.3.1.4 Order sharing through information secured swapping

In the context of collaborative order sharing, Clifton et al. (2008) suggest a technique based on efficiency improving load swaps between partnering transport companies. The problem studied may be described as follows. Each partner company has a certain number of customer orders that needs to be picked up or dropped off at a specific location. The goal is to identify a sequence of order swaps between partnering organisations that results in reduced transport costs and optimises travelled distance. To solve the problem the authors first map all customer loads in one dimension making use of a space-filling curve. Then they develop the one-dimensional relative outlier detection (OROD) algorithm to identify optimal swaps. This algorithm swaps load points on the space-filling curve until total travelled distance cannot be lowered any more. In the development of their solution method, Clifton et al. (2008) pay special attention to the amount of information sharing between cooperating partners. Since transport organisations prefer minimal data disclosure when cooperating with fellow companies, the OROD algorithm ensures that no information is shared other than what can be deduced from the final swaps. Applying the algorithm to an empirical dataset and analysing computational results reveals that significant cost savings could be attained both on an individual company level and a collaboration level with minimal customer information sharing.

2.3.1.5 Order sharing with shipment dispatching policies

Zhou et al. (2011) consider collaboration opportunities between transport organisations applying time-and-quantity dispatching policies. The situation at hand may be described as follows. Each company has a freight consolidation centre and customer orders arrive following a known rate. A truck could be dispatched on the basis of two conditions. On the one hand, a truck may leave for its destination when the accumulated order volume reaches a predetermined dispatching limit. On the other hand, the delivery deadline of an order may cause a dispatch when the time constraint is about to be violated. Zhou et al. (2011) investigate two plausible partnership modes: strategic alliance and full collaboration. When organisations form a strategic alliance, order sharing takes place if a carrier receives a shipment deadline expiration and his accumulated order volume is lower than the truck's capacity. In this case, the dispatching truck picks up appropriate orders from alliance partners to improve vehicle fill rates. When organisations are fully collaborating, they operate like a single entity. Dispatching of trucks now depends on the total freight quantity accumulated at all collaboration participants. As a consequence, orders are transferred continuously from organisations with less freight to organisations with more freight to achieve predetermined dispatching limits as soon as possible and avoid shipment deadline expiration. By means of an illustrative example based on industry data from China, Zhou et al. (2011) demonstrate that collaborating carriers gain significantly more profit than independent organisations. Moreover, results reveal that more orders are shared under full collaboration than under a strategic alliance.

2.3.1.6 Order sharing in perspective

By reviewing Sections 2.3.1.1 until 2.3.1.5 and comparing all articles describing order sharing techniques, a number of conclusions could be drawn. First, concerning the practical and operational application of the discussed order sharing approaches, it may be stated that the majority of examined literature studies horizontal cooperation within generalised transport environments. Few authors consider rich problem formulations with real-world constraints. As a consequence, the choice between different order sharing techniques could be made independently from the market situation companies operate in. Selecting an appropriate collaboration strategy may be based on the type and amount of information organisations are willing to share with partners, their experience with certain solution methods and so on. Second, the majority of carrier collaboration literature considers the sharing of LTL orders as their consolidation within a single vehicle may create economies of scale. However, some authors develop order sharing approaches specifically for FTL environments. Sharing orders in an FTL context focuses on the reduction of empty vehicle movements. By serving orders from partner companies, geographical synergies between orders increase which in turn reduces empty travel between consecutive orders. Third, reviewing the articles presenting auction-based collaboration mechanisms reveals that in a horizontal cooperation context combinatorial auctions are the most commonly applied auction technique. With combinatorial auctions organisations are able to bid on bundles of customer orders. In this way, complementarities between orders may be exploited and larger cost reductions may be achieved.

2.3.2 Capacity sharing

Instead of exchanging customer orders, carriers may also cooperate by sharing vehicle capacities. In this way, capital investments, associated with vehicles, may be split among partners and utilisation rates of vehicles may be improved. Sections 2.3.2.1 and 2.3.2.2 provide an overview of various techniques that may be used to determine the most efficient and profitable way of sharing vehicle capacities between cooperating carriers, as proposed in current scientific literature. Section 2.3.2.3 puts Sections 2.3.2.1 and 2.3.2.2 into perspective and formulates some conclusions and remarks. Table 2.2 presents an outline of relevant references related to horizontal cooperation through capacity sharing. Moreover, information is provided on the problem formulation and solution approach discussed in each paper.

Table 2.2: Capacity sharing techniques

Capacity sharing technique	References	Problem formulation	Solution approach
Mathematical programming	Agarwal and Ergun (2010)	Multi-commodity flow problem	Greedy heuristic, column generation, Benders decomposition
	Houghtalen et al. (2011)	Multi-commodity flow problem	Inverse optimisation
	Hernández et al. (2011)	Multi-commodity minimum cost flow problem	Branch-and-cut
	Hernández and Peeta (2014)	Multi-commodity minimum cost flow problem	Branch-and-cut
	Sprenger and Mönch (2012)	Rich VRP	Decomposition heuristic, greedy heuristic, ant colony optimisation
Negotiation protocol	Fischer et al. (1996)	Dynamic VRP	Bargaining protocol

2.3.2.1 Capacity sharing using mathematical programming

Agarwal and Ergun (2010) study the problem of capacity sharing in the liner shipping industry. Liner shipping carriers cooperating horizontally pool their fleets to operate them together and share capacity on ships. This context may be considered equivalent to road transport companies sharing trucks. On the basis of his customer orders an individual carrier first determines appropriate service routes. Then he assigns the applicable ships from the collaborative pool to these routes. In this way the capacity of each ship is allocated among the different collaborating carriers. As a consequence of this capacity sharing, the ship utilisation improves and carriers may offer higher sailing frequencies to their customers. To solve this capacity sharing problem to optimality, the individual carriers' fleet is replaced by the aggregated fleet of all carriers and the aggregated demand of all carriers serves as a replacement of the individual demand sets. Next, the simultaneous ship scheduling and cargo routing problem is formulated as a multi-commodity flow problem. A solution to this problem simultaneously identifies an optimal set of service routes to operate, the set of cargo to deliver and the paths to deliver the selected cargo on. In Agarwal and Ergun (2008), three different heuristics and linear programming-based algorithms are developed and tested to solve the problem: a greedy heuristic, a column generation-based algorithm and a Benders decomposition-based algorithm. Because the main goal of an individual carrier in the cooperation remains the maximisation of his own profits, the authors also propose a mechanism based on game theory to determine capacity exchange costs (side payments) to motivate the individual carriers to act in the best interest of the overall cooperation project. Computational experiments, using real data from the liner shipping industry, demonstrate that significant revenue improvements may be achieved when collaborating with partner carriers.

Houghtalen et al. (2011) address the capacity sharing problem for air cargo carriers. The authors model carrier behaviour in the context of a horizontal cooperation with fellow organisations through partial integration of transport networks and sharing of resources. The authors state that in order to attain maximal collaborative profit, cooperating carriers need to be encouraged to make cargo acceptance and routing decisions in line with the collaborative optimal solution. The possible identification of incentives suitable to influence the behaviour of carriers in an appropriate manner depends on the understanding of the decision process of an individual carrier in the cooperative network. In this context, two approaches, modelling the behaviour of an individual carrier, are formulated and analysed. The goal of both approaches is to ensure that individual carriers' cargo accept-reject and routing decisions are in accordance with the collaborative solution. To achieve this goal, carriers receive payments, labelled capacity exchange prices, in exchange for capacity used by other cooperation participants. On the one hand, Houghtalen et al. (2011) develop the Limited Control model where the decisions available to an individual carrier are restricted and the use of vehicle capacity is limited for each carrier. Thus, the units of capacity that every carrier may use on a certain route is restricted. This model is formulated as a multi-commodity flow program with an objective function maximising the difference between the total revenue earned from serving orders and the sum of paid capacity exchange prices. On the other hand, the Strict Control model assumes that a single carrier has full control over the decisions of other carriers in the sense that all the orders associated with other carriers are included in the model for the carrier of interest. Similar to the Limited Control model, this model can also be formulated as a multi-commodity flow program. For both models capacity exchange prices can be found using inverse optimisation techniques. A comparison of both models shows that, using the Strict Control model, the aggregated individual carrier solutions may be infeasible from a collaborative viewpoint. The increased carrier control thus leads to behaviour inconsistent with the overall cooperation goal. The Limited Control model guarantees collaborative feasibility.

Hernández et al. (2011) address the capacity sharing problem for road transport carriers. They discuss a dynamic LTL carrier cooperation in which capacity is shared on collaborative routes in order to minimise costs. The problem is dynamic in the sense that the availability of collaborative capacity is time-dependent. The authors label the problem as the deterministic dynamic single carrier collaboration problem (DDSCCP). The overall goal is to determine a time-dependent collaborative strategy for a single carrier in the cooperation through the identification of a set of collaborative routes that minimises the total cost to serve customer demands. For this purpose, the carrier may acquire capacity from his cooperation partners based on their time-dependent availability. The authors assume that every carrier first uses his own available capacity before sharing capacity with other carriers. In the context of shared capacity the loading, unloading and holding costs associated with an order are divided equally between the carrier of interest and his collaborative partners. The DDSCCP may be mathematically formulated as a multi-commodity minimum cost flow problem which is solved using a branch-and-cut algorithm. Following computational experiments, it is clear that carriers need to make a trade-off between waiting for more affordable collaborative capacity and incurring higher holding costs.

Hernández and Peeta (2014) address a similar LTL carrier collaboration problem from a static perspective. The mathematical formulation and solution of the problem are similar to those developed in Hernández et al. (2011). The goal of the research is twofold: (1) comparing the benefits of collaborative capacity sharing with the non-collaborative short-term leasing approach and (2) examining the ability of capacity sharing to mitigate the impact of rising fuel prices. Experimental results demonstrate that the potential of collaborative capacity sharing compared to a non-collaborative approach increases with the degree of collaboration.

Finally, Sprenger and Mönch (2012) consider capacity sharing within the food industry. Several manufacturers with overlapping customer locations and complementary products cooperate horizontally by sharing their vehicle fleets either at the main manufacturing plant or at intermediate distribution centres. In this way, they aim to reduce delivery costs and improve on-time delivery performance. The co-operative transport planning problem described is solved in two phases. First, a heuristic is proposed that decomposes the overall transport problem, related to the entire distribution network and containing customer orders of all manufacturers, into VRP subproblems each associated with a specific network zone. Next, both a simple greedy heuristic and ant colony optimisation are suggested to solve these subproblems to optimality by sharing distribution fleets. By means of a simulation study using real-world data from food manufacturers in Germany, it is demonstrated that sharing capacity is beneficial for the manufacturers as it may lead to reductions both in travelled kilometres and number of time window violations.

2.3.2.2 Capacity sharing using a negotiation protocol

A different approach to capacity sharing is presented by Fischer et al. (1996). The authors investigate the application of their carrier cooperation technique on the MARS environment. MARS stands for the Modelling Autonomous coopeRating Shipping companies system which models cooperative planning within a society of logistics service providing companies (Kuhn et al., 1994). These organisations have to serve dynamically arriving customer orders using a set of trucks. A distinctive characteristic of the system is that the organisations do not schedule orders themselves, the trucks are responsible for local plans. Therefore, the collaborative solution emerges from the local truck decisions employing an automated decision support system. This makes the system flexible so that quick reactions are possible to unanticipated events, such as traffic jams or new transport orders, without global replanning. Concerning the cooperating shipping organisations of the MARS system, optimisation of capacity utilisation is one of their main goals. In this context, capacity sharing may be beneficial due to spatial and temporal spread of incoming orders. On the basis of information received from the trucks concerning capacity use, a carrier may communicate free transport capacities to its cooperating partners. Based on their local state, other carriers have to decide whether or not to accept the offer. If the answer is positive, a bargaining protocol starts based on an auction-like negotiation. First, the offering carrier will send a bid, which the other carrier can accept, reject or modify by making a counteroffer. This process continues until both parties agree on a transfer value or until it becomes clear that a compromise cannot be reached. Decisions made by the carriers during the procedure are based on truck information concerning capacities and costs, utility of customer orders and information they have about the decision criteria of the other parties.

2.3.2.3 Capacity sharing in perspective

By reviewing Sections 2.3.2.1 and 2.3.2.2 and comparing all articles describing capacity sharing techniques, some general remarks can be made. First, it can be observed that the articles discussed in the capacity sharing section do not exclusively focus on road transport. Section 2.3.2.1 presents capacity sharing techniques in the liner shipping and air cargo industry. Since clear similarities exist between the collaborative contexts described in the respective papers, the cooperation strategies developed for these other logistics industries could be adapted to the road transport sector. Although maritime and aviation assets are more capital intensive, similar to the road perspective capacity sharing among ocean and airline carriers aids in improving service frequency and leads to higher load factors. However, the different market environments impede the generalisation of conclusions among all logistics industries and thus justify the analyses performed in this thesis. For example, market power considerations are much less prevalent for land-side logistics as this sector is characterised by an abundance of players in comparison to the aviation and maritime industry. Second, equivalent with the joint route planning problem for order sharing, mathematical programs for capacity sharing constitute NP-hard problems. As a consequence, the majority of solution techniques presented in Section 2.3.2.1 are heuristics.

2.4 Collaborative logistics from the perspective of shipper companies

The main goal of a horizontal shipper collaboration is the identification of transport orders that may be submitted as a bundle to carriers, hopefully resulting in more favourable rates. The majority of shipper collaboration literature considers the shippers' orders to consist of lanes in a transport network. A lane can be interpreted as a FTL delivery from an origin to a destination, a truck transports the order directly from origin to destination without stopping at intermediate sites (Özener and Ergun, 2008). By combining truckload movements from multiple shippers, carriers experience better asset utilisation and lower empty vehicle trips. The underlying optimisation problem, which is labelled the lane covering problem (LCP), seeks to find a set of tours (cycles) covering all lanes submitted by the collaborating shippers at a minimum cost. More formally, given a directed Euclidean graph $G = (\mathcal{N},A)$ with node set $\mathcal{N}$, arc set A and lane set $L \subseteq A$, find a set of directed cycles covering the lanes in L with a minimum total length (Ergun et al., 2004).

In this context, a multitude of articles concerning horizontal shipper cooperation are devoted to defining suitable solution techniques for the collaborative LCP. A first solution technique for the LCP is developed by Ergun et al. (2007a). A distinctive property of their approach is that they explicitly consider a time dimension. For this reason the studied problem is labelled the time-constrained LCP (TCLCP). Timing considerations are reflected in tour dispatch time windows which need to be respected and in the general objective of minimising the sum of the duration of all tours. The TCLCP is formally defined as a set covering problem, which the authors solve in three steps. In a first phase, a greedy heuristic is employed to generate a large number of cycles, all feasible with regards to the enforced time windows. Next, the heuristic greedily selects a fraction of these cycles to cover the lanes on the basis of the attractiveness of a cycle. This attractiveness can be measured by the cover ratio, which is the ratio of the sum of travel times of the lanes covered by a cycle and the duration of the cycle (travel and waiting times). A more desirable cycle has a higher cover ratio. After iteratively performing this phase until all lanes are covered by a cycle, a local improvement technique is implemented to improve the solution by means of merging cycles in order to further reduce the total duration. Based on real data from a group purchasing organisation procuring services like truckload transport, cost savings range between 6% and 13% when applying the developed LCP solution technique. Ergun et al. (2007b) consider another variant of the LCP, namely the cardinality constrained lane covering problem (CCLCP). In this constrained variant of the LCP the number of arcs in a cycle has to be less than or equal to a specified integer. This cardinality constraint is based on the practical consideration that there might be a restriction on the maximum number of arcs within a tour. Like the TCLCP, this problem may be formulated as a set covering problem and is solved using a greedy heuristic that chooses cycles maximising the cover ratio in each iteration. As opposed to the two previous articles, Özener and Ergun (2008) and Agarwal et al. (2009)

formulate the LCP as an ILP to find the optimal lane cover. Both articles consider the standard version of the LCP, but explicitly take into account asset repositioning costs, next to lane covering costs, when minimising total transport costs.

Recent research on shipper collaboration goes beyond the LCP idea and considers collaboration characteristics and environments with realistic features. In addition, collaboration strategies studied in a carrier context are now applied to shipper alliances. Yilmaz and Savasaneril (2012) study horizontal collaboration opportunities between small shippers with stochastic transport needs. The authors describe a coalition in which shippers consolidate their customer orders with the purpose of sharing vehicle capacity. Customer orders are considered to arrive totally random. As such, a trade-off needs to be made between dispatching vehicles quickly, in this way avoiding high waiting costs, and improving vehicle fill rates. The dispatch problem is modelled as a Markov decision process. Computational experiments demonstrate that horizontal shipper collaboration outperforms two scenarios in which shippers operate independently. Wang et al. (2014) consider horizontal collaboration with fellow shippers as an alternative to forwarding orders to subcontractors. The goal is to realise the full cost-saving potential of using external resources by integrating both subcontracting and collaborative order sharing into the operational planning of shippers. The subcontracting problem is modelled as a set partitioning problem or a set covering problem and is solved using an iterative heuristic based on adaptive large neighbourhood search (Ropke and Pisinger, 2006). The collaborative problem is modelled in a similar way and is solved by an agent minimising the total costs of the coalition. Computational results show that, in comparison to considering subcontracting exclusively, collaborative order exchange could reduce costs further by more than 10%. Adenso-Díaz et al. (2014) describe a joint route planning approach for shipper collaboration. Transport orders of all partners are pooled in order to be able to define links between deliveries based on geographical and time compatibilities. The collaborative problem is modelled as a quadratic integer program and solved using a greedy randomised adaptive search procedure (GRASP, Feo and Resende (1995)). Tinoco et al. (2016) study collaborative shipping in combination with joint inventory policies for two horizontally cooperating shippers. By synchronising their replenishments using the can-order policy, shippers aim to benefit more from joint order transport. The authors investigate the impact of collaboration both on transport and inventory costs.

In general, the initiative to establish a horizontal shipper collaboration lies with the shippers who want to cut their transport costs by enjoying more favourable carrier rates as a consequence of decreasing the operational costs of these logistics service providers. Cruijssen et al. (2010), however, propose a procedure, labelled insinking, where the serving carrier is the initiator of a horizontal cooperation between his shipping customers. The general idea behind this carrier-initiated shipper collaboration is that a carrier proactively selects a group of shippers with a strong synergy potential whose distribution networks can be merged very efficiently. The insinking procedure, based on both operations research and game theory, consists of three steps. In a first phase, the carrier selects a subset of shippers he wants to serve from his total set of potential customers. This choice is based on the synergy potential that exists between the shipper organisations. Because horizontally cooperating shippers have to work with competitors, the initiating carrier needs to ensure that the collaboration savings (price reductions for the shippers) are shared equally and in a fair manner. For this purpose, in the second phase, the carrier needs to accurately quantify the contributions of each shipper to the total collaborative gain and thereby their respective price reductions on the basis of game theory concepts. In the final phase, the carrier selects the most appropriate sequence in which he proposes his price offers to the participating shippers in order to reach the collaborative solution.

While the collaboration techniques applied in a shipper cooperation context show clear analogies with horizontally cooperating carriers, one important difference exists between shipper and carrier alliances. In a horizontal *carrier* collaboration customer orders need to be treated and integrated into the cooperation implementation as given. Carriers have to fulfil customer expectations and thus need to meet their terms of delivery. On the contrary, *shipper* collaborations may benefit from partner flexibility. Shippers may allow changes to the terms of delivery (e.g. delivery postponement, split orders) in order to increase the number of collaboration opportunities (Vanovermeire and Sörensen, 2014). In this way, as is demonstrated in Vanovermeire and Sörensen (2014) and Vanovermeire et al. (2014a), a flexible shipper attitude could significantly increase the collaborative gain. However, the remark needs to be made that, since cooperating shippers still behave opportunistically and flexibility may be associated with additional costs, incentives (e.g. by means of a suitable cost allocation mechanism) are necessary to enjoy these additional benefits (Vanovermeire et al., 2014a).

2.5 Conclusions and further research

Due to the increasing competitive and global pressures to operate more efficiently, collaborative logistics has become an important and relevant research area. Various types of cooperative supply chain relationships have been discussed in both professional and academic literature. In comparison, the literature on horizontal cooperation in logistics remains scattered across various research domains and mainly emphasises the illustration of potential collaborative cost savings. Following this research gap on the strategic and operational consequences of horizontal cooperation, this chapter classifies and structures relevant literature according to the different collaboration strategies carriers and shippers can exploit in practice and their characteristic solution approaches mentioned in current research.

Based on the literature review provided in this chapter some interesting directions for **future research** could be identified. First, considering the vast amount of both carrier and shipper collaboration strategies, a comparative analysis could be performed evaluating the efficiency of the developed techniques. KPIs that are useful in this analysis are, among others, cost reduction potential, capacity utilisation impact and customer service effect. Related to this analysis, a second research opportunity consists of creating an overview of advantages and disadvantages associated with each of the discussed strategies. Then, as mentioned in several papers summarised in this chapter, a suitable collaboration strategy needs to be accompanied by a fair cost or savings allocation mechanism in order for a collaboration to be sustainable in the long run. Since every company is guided by its own self-interests and the contributions of the partners to the collaborative goal are often quite different, the proposed allocation method should be a collectively and individually desirable solution. For this reason, an interesting research direction is to provide a structured overview of allocation mechanisms suitable in a horizontal logistics cooperation context. In addition, the advantages and disadvantages of applying different cost allocation mechanisms in logistics cooperations with varying characteristics should be investigated. Next, the majority of collaborative logistics research focuses on demonstrating the cost reduction potential of various collaboration strategies. In relation to the cooperation challenges defined in Chapter 1, however, the success of achieving collaborative benefits also strongly depends on the degree of fit between the cooperation participants. Similar or complementary strategic orientations, managerial practices, organisational characteristics and partnership goals could significantly influence collaborative performance (Parkhe, 1993; Lambert et al., 1999). A research opportunity is to provide insight in the impact of coalition characteristics on the collaborative profit level of horizontal logistics alliances. In addition to this profit impact analysis, future research could also investigate which collaboration strategies yield the highest benefits considering the characteristics of the coalition and its partners. In this way, recommendations could be made to LSPs considering horizontal collaboration on the collaboration strategy decision. Furthermore, existing studies on horizontal logistics cooperation all focus on collaboration opportunities within a transport context. In line with the broad definition of logistics including both the movement and storage of freight, novel approaches to horizontal cooperation, such as the sharing of warehouses or distribution centres with alliance partners, could add value to the current research field. Finally, another avenue of research is to extend the strategic and operational analysis of horizontal logistics cooperation to the context of collaborative intermodal transport. Applying the collaboration strategies which have been thoroughly studied in a unimodal context may not be so straightforward in an intermodal environment.

Chapters 3 to 6 deal with a number of the research directions described above. Chapter 3 provides a structured overview of allocation techniques suitable in a horizontal logistics cooperation context. Existing allocation mechanisms are situated in a classification framework and associated with their respective fairness criteria. Chapter 4 aims to provide a deeper understanding of joint route planning, a generally accepted carrier collaboration strategy. Besides the development of a formal mathematical problem formulation, the main contribution is to analyse the relative benefits of different coalition structures and cost allocation mechanisms. Chapter 5 presents a new approach to carrier cooperation: the sharing of warehouses or distribution centres with collaborating partners. Similar to the research in Chapter 4, numerical experiments based on an experimental design are conducted to investigate the impact of different coalition characteristics and cost allocation techniques. Finally, Chapter 6 investigates horizontal cooperation within intermodal barge networks. Since research on allocation mechanisms in collaborative intermodal transport is scarce and focuses exclusively on game theoretic techniques, this chapter analyses the performance of three additional allocation techniques used to share cost savings amongst shippers who bundle freight flows in intermodal barge transport. Special attention is paid to the stability of the solutions obtained and their sensitivity to different partner and cooperation characteristics.

Chapter 3

Cost and profit allocation in horizontal logistics cooperations

3.1 Introduction

As the goal of a horizontal logistics cooperation is to increase participants' logistics efficiency and since collaboration often results in additional profits or cost savings, a great deal of scientific literature on collaborative logistics devotes its research attention to the identification of efficient allocation mechanisms (Krajewska and Kopfer, 2006b). However, no comprehensive review of allocation mechanisms applicable within a collaborative logistics context exists in current literature. Dividing the coalition costs or gains in a fair manner constitutes a key issue, since the proposed allocation mechanism should induce partners to behave according to the collaborative goal and may improve cooperation stability. Moreover, distrust and doubts among the participants about the cost or profit allocations might be the cause of a horizontal cooperation to break up. For these reasons, this chapter [1,2] (Figure 3.1) focuses on the identification of allocation mechanisms that can be used in a horizontal logistics cooperation context by providing a structured overview of techniques described in scientific lit-

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[1] This chapter is based on the paper: Verdonck, L., Beullens, P., Caris, A., Ramaekers, K., Janssens, G., 2016a. Analysis of collaborative savings and cost allocation techniques for the cooperative carrier facility location problem. Journal of the Operational Research Society 67 (6), 853–871.

[2] An overview of the symbols used in Chapters 3 to 6 can be found at the beginning of the thesis.

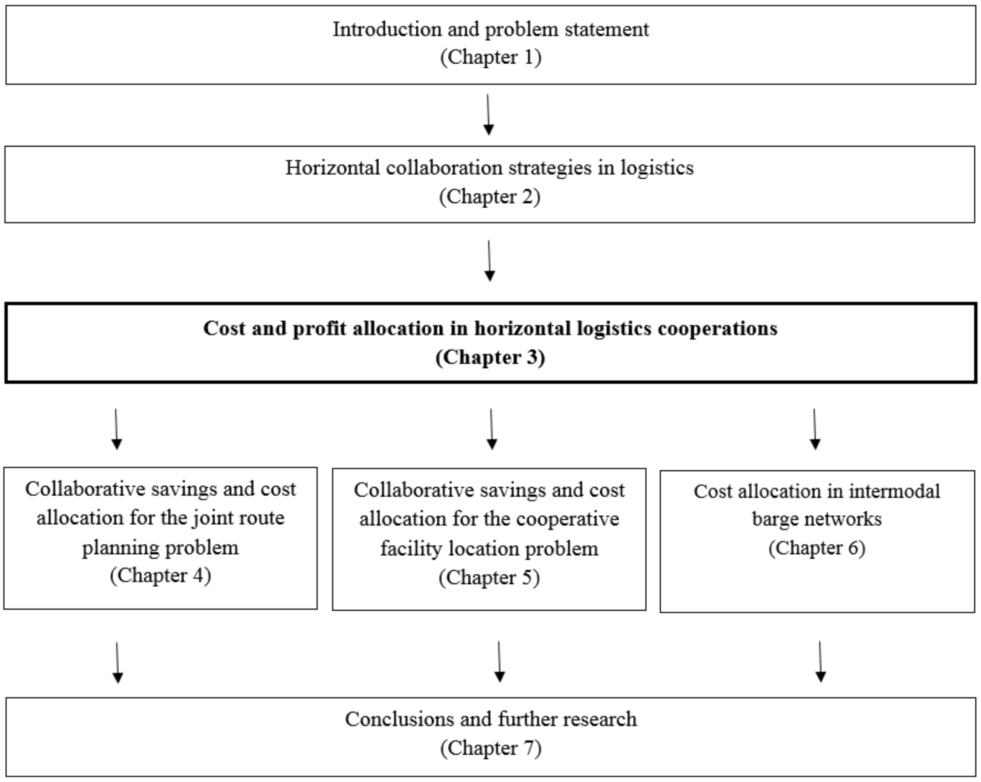

Figure 3.1: Outline of the thesis

erature. Existing allocation mechanisms are situated in a classification framework and associated with their respective fairness criteria. Chapters 4, 5 and 6 build on this knowledge by numerically examining the applicability and suitability of various allocation mechanisms in different collaboration environments.

Within this chapter, the terms 'cost allocation' and 'profit sharing' are used interchangeably. Allocating the collaborative cost level is similar to dividing the total collaborative profit level, since the sum of the profits of all coalition partners equals the difference between the sum of all stand-alone costs and the total collaborative cost.

Considering the characteristics of a horizontal logistics cooperation, it is essential that any proposed mechanism for benefit or cost division is desirable on a collaborative and individual level. Not only should the overall collaborative profit level improve, also the individual profitability levels of all participating companies need to be maintained or, even better, enhanced. In practice, the selection or design of a suitable allocation mechanism that may achieve this twofold objective is confronted with a few challenges. For an allocation technique to be effective, it needs to be perceived by the cooperating partners as reasonable, easy to understand and simple to implement. In addition, it is important to ensure a fair allocation which quantifies and accounts for the contributions of all coalition participants. If not, the mechanism will not induce or motivate the participating organisations to engage in the collaboration voluntarily (Krajewska and Kopfer, 2006b; Liu et al., 2010a). Moreover, the design and implementation of the developed division procedure is influenced by the distribution of power among the cooperating partners, their degree of interdependency, independency and willingness to make compromises (Krajewska and Kopfer, 2006b; Krajewska et al., 2008). Finally, the designed mechanism needs to be able to attract and preserve suitable collaboration partners and enable a smooth communication between and coordination of cooperating competitors (Özener and Ergun, 2008). Accounting for these challenges, a general definition of a 'fair' allocation mechanism is difficult to develop. As such, Section 3.2 provides an overview of basic allocation properties (fairness criteria) desirable in the context of a horizontal logistics cooperation.

A review of current cooperation literature on the allocation topic reveals that various techniques may be distinguished to share collaborative profits or costs. Section 3.3 provides an overview covering proportional sharing mechanisms (3.3.1), allocation mechanisms using game theory concepts (3.3.2) and allocation techniques designed to cope with additional cooperation properties (3.3.3). Finally, conclusions and opportunities for further research are formulated in Section 3.4.

To improve clarity and understandability of the allocation mechanisms and properties described throughout this chapter, Table 3.1 first summarises the relevant notation.

Table 3.1: Notation

N	Grand coalition, cooperation of all partners
$i, j \in N$	Individual coalition partner
$S \subseteq N$	Subcoalition, subset of partners of the grand coalition
$c(N), c(S)$	Cost of a (sub)coalition
$c(\{i\})$	Stand-alone cost of partner i
y_i	Cost allocated to partner i

3.2 Basic allocation properties

In the context of cooperative game theory several characteristics have been developed that are associated with the 'fairness' of allocation mechanisms. Table 3.2 provides an outline of basic allocation properties, useful in horizontal logistics cooperations and based on definitions found in scientific literature (Shapley, 1971; Osborne, 2004; Frisk et al., 2010; Liu et al., 2010a).

Table 3.2: Basic allocation properties

Allocation property	Definition
Efficiency (group rationality)	The total cooperative cost is shared as the grand coalition forms: $\sum_{i \in N} y_i = c(N)$
Individual rationality	No partner pays more than his stand-alone cost: $y_i \leq c(\{i\}), \forall i \in N$
Subgroup rationality	Partners are never better off forming a subgroup by excluding other partners: $\sum_{i \in S} y_i \leq c(S), \forall S \subseteq N$
Stability	No single participant or subcoalition of participants of the collaboration would benefit from leaving the grand coalition: $\sum_{i \in S} y_i \leq c(S)$ and $\sum_{i \in N} y_i = c(N)$
Symmetry (anonymity)	The identity of the participants does not change the resulting allocation, each partner gains the same amount when cooperating in the same way with fellow organisations: $c(S \cup \{i\}) = c(S \cup \{j\}) \rightarrow y_i = y_j$
Dummy	Participants, who add zero benefits to the coalition they join, should not be allocated a share of the collaborative savings
Additivity	The cost allocation of a combination of several separate coalitions is equal to the sum of the separate allocation values of these coalitions: $y(i \cup j) = y(\{i\}) + y(\{j\})$

3.3 Collaborative allocation mechanisms

A review of current cooperation literature on the topic of allocation mechanisms reveals that various techniques may be distinguished to share collaborative profits or costs. In this section, allocation mechanisms that can be applied in horizontal logistics collaborations are subdivided in three categories, namely: proportional sharing mechanisms (3.3.1), allocation mechanisms using game theory concepts (3.3.2) and allocation techniques designed to cope with additional cooperation properties (3.3.3). In Table 3.3 relevant references related to these allocation mechanisms are summarised together with the cooperation contexts in which they have been applied. In order to ensure that relevant studies were not overlooked, initial search terms remained broad (e.g. 'allocation', 'collaboration', 'logistics'). Next, a detailed examination of papers was executed to filter out articles focusing on the development or implementation of allocation mechanisms within the context of horizontal logistics collaboration. To conclude, Section 3.3.4 puts Sections 3.3.1 to 3.3.3 into perspective and visualises whether the described allocation mechanisms possess any of the basic fairness properties discussed in Section 3.2.

3.3.1 Proportional allocation of profits or costs

In practice, the most commonly used profit or cost division mechanism is the proportional allocation method (Liu et al., 2010a). In this case, the collaborative profit is allocated to the cooperating organisations equally, on the basis of their individual cost level (stand-alone cost) or the volume they have to transport as a consequence of their engagement in the cooperation. The reason for the widespread use of the proportional allocation technique lies in the fact that it is easy to understand, compute and implement. However, it does not guarantee long-term collaboration stability as it is possible that a subgroup of participants leaves the partnership considering the fact that it is allocated a higher cost than its individual cost (Özener, 2008).

A variation on the classic proportional allocation is the Kalai-Smorodinsky (KS) solution, defined by Kalai and Smorodinsky (1975) in the context of bargaining games. The KS allocation mechanism minimises the difference between the proportional allocation ratios of any two partners. The allocation ratio of each partner is defined as the partner's collaborative profit increase divided by its maximal possible profit increase. The main advantage of the KS solution compared to the traditional proportional allocation is that it incorporates stability constraints and thus guarantees cooperation sustainability in the long run.

Table 3.3: Collaborative allocation mechanisms

Allocation mechanism	References	Area of application
Proportional	Kalai and Smorodinsky (1975)	Two-person games
	Özener (2008)	Horizontal shipper cooperation
	Frisk et al. (2010)	Collaborative forest transport
	Liu et al. (2010a)	Horizontal carrier cooperation
	Vanovermeire (2014)	Horizontal shipper cooperation
	Guajardo and Rönnqvist (2016)	Collaborative transport
Cooperative game theory	Shapley (1952)	General n-person games
	Shapley (1953)	General n-person games
	Gillies (1959)	General non-zero-sum games
	Schmeidler (1969)	Characteristic function games
	Krajewska and Kopfer (2006a)	Horizontal carrier cooperation
	Krajewska et al. (2008)	Horizontal carrier cooperation
	Agarwal et al. (2009)	Carrier alliances in liner shipping
	Agarwal and Ergun (2010)	Carrier alliances in liner shipping
	Drechsel and Kimms (2010)	Cooperative inventory games
	Frisk et al. (2010)	Collaborative forest transport
	Liu et al. (2010a)	Horizontal carrier cooperation

Allocation mechanism	References	Area of application
	Drechsel and Kimms (2011)	Cooperative lot sizing problems
	Houghtalen et al. (2011)	Horizontal carrier cooperation
	Dai and Chen (2012)	Horizontal carrier cooperation
	Lozano et al. (2013)	Horizontal shipper cooperation
	Vanovermeire (2014)	Horizontal shipper cooperation
	Guajardo and Rönnqvist (2016)	Collaborative transport
Additional cooperation properties	Tijs and Driessen (1986)	General cost games
	Özener and Ergun (2008)	Horizontal shipper cooperation
	Frisk et al. (2010)	Collaborative forest transport
	Liu et al. (2010a)	Horizontal carrier cooperation
	Audy et al. (2011)	Cooperation in furniture industry
	Xu et al. (2013)	Horizontal carrier cooperation
	Vanovermeire (2014)	Horizontal shipper cooperation
	Defryn et al. (2016)	Horizontal shipper cooperation
	Guajardo and Rönnqvist (2016)	Collaborative transport
	Hezarkhani et al. (2016)	Horizontal carrier cooperation

3.3.2 Allocation mechanisms based on cooperative game theory concepts

A horizontal logistics cooperation clearly matches the structure of a cooperative game. Collaborating partners exchange orders or resources and receive or make payments in return. This cooperation process results in an allocation of benefits or costs to each participant that may be considered equivalent to the outcome of a cooperative game (Houghtalen et al., 2011). Moreover, Cruijssen et al. (2007b) state that the advantage of applying game theory in a logistics cooperation context is that these allocation methods most often account for the different contributions of the alliance participants and that they define allocations that distribute the collaborative benefits based on certain fairness properties, listed in Table 3.2.

The workings of a horizontal logistics cooperation may be formally described in terms of game theory concepts as follows. The grand coalition N coincides with all participating companies i in the cooperation, while a coalition S denotes a subset of collaborators. When a coalition S collaborates, they realise a certain amount of collaborative costs that can be captured using the function $c(S)$. As such, the benefits or cost savings generated by a coalition $S, \forall S \subseteq N$, denoted by the characteristic function $v(S)$, are equivalently calculated as $\sum_{i \in S} c(\{i\}) - c(S)$. The cost amount allocated to partner i, assuming all players cooperate, is defined by y_i $(i \in N)$.

A relevant concept in the context of logistics cooperation is the notion of the core of a cooperative game (Shapley, 1952; Gillies, 1959). The core of a game consists of all allocations that are budget balanced (efficient) and guarantee that no single participant or coalition of participants benefits from leaving the cooperation (stability). A drawback of this solution concept is the fact that the core of a cooperative game may be empty. To compensate for this shortcoming, several extensions have been developed that relax inequalities defining the core. Examples include the least core (Drechsel and Kimms, 2010) and the minmax core (Drechsel and Kimms, 2011). In relation to this core, the excess can be computed for each coalition S. This excess is defined as the difference between the total cost of a coalition and the sum of the costs allocated to its participants: $-c(S) + \sum_{i \in S} y_i, \forall S \subseteq N$. For a given cost allocation, any strictly positive value of the excess may be seen as a measure of how far the allocation lies from the core (Frisk et al., 2010; Liu et al., 2010a).

A well known allocation method based on the foundations of game theory is the Shapley value (Shapley, 1953). This value allocates to each participant the weighted average of his contributions to all (sub)coalitions, assuming the grand coalition is formed one company at a time. The Shapley value provides a unique allocation with characteristics that are beneficial in the context of a horizontal logistics cooperation. However, the Shapley value has an important disadvantage, namely that this allocation may not lie in the core of the game and thus may not lead to a stable collaboration (Krajewska et al., 2008; Frisk et al., 2010; Liu et al., 2010a; Guajardo and Rönnqvist, 2016). For this reason, Dai and Chen (2012) propose an allocation mechanism which unites the Shapley value with the concept of the core. They develop a linear programming model aimed at defining a feasible allocation that is as close as possible to the Shapley value but belongs to the core thus guaranteeing stability.

Another basic allocation mechanism supported by game theory is the nucleolus. This profit or cost sharing procedure, developed by Schmeidler (1969), has the distinct property of minimising the maximal excess, as defined above. The nucleolus is unique and if the core is not empty, it lies in the core and provides a stable allocation. However, this allocation mechanism does not consider the individual participants' contributions to the coalition (Frisk et al., 2010; Liu et al., 2010a). In comparison with the Shapley value, the calculation of the nucleolus is rather intricate as it involves solving a series of linear programs (Guajardo and Rönnqvist, 2016).

Lozano et al. (2013) compare the performance of the Shapley value, the least core and the minmax core with respect to the allocation of savings in the context of horizontal shipper collaboration. If the core of a cooperative game is empty, the least core guarantees efficient and stable allocations by penalising partners for quitting the grand coalition. This penalty can be seen as the minimum amount that partners need to be charged in order to impede opportunistic behaviour (Drechsel and Kimms, 2010). The minmax core approximates the core by means of the minmax principle. The benefit of a subcoalition is measured relatively to its assigned cost: the lower the assigned cost, the higher the collaborative benefit. The minmax core then calculates cost allocations such that the worst benefit over all subcoalitions is maximised (Drechsel and Kimms, 2011). Based on a numerical experiment, the authors conclude that, due to their simplicity of calculation and fairness values, the least core and minmax core are most suited in the collaborative environment under study. Fairness is defined as the maximisation of the minimum satisfaction of all subcoalitions. The authors calculate the satisfaction of a subcoalition S as the excess of the sum of their allocated cost savings if the grand coalition is formed over the cost savings if subcoalition S acts independently.

Krajewska and Kopfer (2006a) propose a more complex profit sharing model based on game theory in combination with auction mechanisms. First, collaborative profits are maximised using combinatorial auction techniques to exchange customer orders optimally (see Section 2.3.1.2 for more details). Then, transfer prices are used to divide collaborative savings among partnering carriers such that the current financial situation of each partner is at least maintained (individual rationality). In addition, residual profits created during the collaboration process are shared between the cooperating partners on the basis of collaboration advantage-indexes. These indexes account for the individual contribution of the different participants to the cooperation.

In line with the previous article, Dai and Chen (2012) develop an allocation mechanism accounting for the contribution of each individual carrier to the coalition. The goal is to find profit allocations that minimise the difference between contribution-based allocation ratios of any two carriers. Moreover, the authors ensure allocation stability through the application of core characteristics.

Finally, in Agarwal et al. (2009) and Agarwal and Ergun (2010) the division of collaborative profit is considered in the context of capacity sharing in the liner shipping industry. Both articles propose a similar procedure, fitting in the game theory framework and applying inverse optimisation techniques, to determine capacity exchange costs or side payments. As in a cooperative game, these payments have the purpose of motivating the individual cooperating partners to act in the best interest of the overall cooperation project and to pursue the solution suggested by the collaborative optimisation model. Special attention is also paid to the stability of the allocation values obtained.

3.3.3 Allocation mechanisms with additional desirable properties

Basic game theoretic allocation mechanisms may raise questions among collaborating organisations concerning mathematical complexity, applicability, fairness transparency and stability in practice. As such, several authors have developed distinct, more intuitively clear allocation mechanisms which account for certain specific cooperation characteristics, some of them partly based on game theory. An overview of additional desirable allocation characteristics is provided in Table 3.4 together with related references and the allocation methods they are associated with. Each of the listed properties and methods is explained in more detail throughout the rest of this section.

Tijs and Driessen (1986) point out that a suitable allocation mechanism may be based on the division of total collaborative costs in separable and non-separable costs. In the first step of the allocation procedure, each participant i is allocated its separable or marginal cost m_i, which reflects the increase in total collaborative costs when this

Table 3.4: Additional allocation properties and methods

Allocation property	References	Allocation method
Separable / non-separable cost division	Tijs and Driessen (1986)	ECM, ACAM, CGM
	Defryn et al. (2016)	CND weighted allocation
Allocation differences minimisation	Frisk et al. (2010)	EPM
	Liu et al. (2010a)	WRSM
	Audy et al. (2011)	Modified EPM
Minimum liability guarantee	Özener and Ergun (2008)	Minimum liability allocation
	Audy et al. (2011)	Modified EPM
Cross-monotonicity guarantee	Özener and Ergun (2008)	Cross-monotonicity allocation
Positive benefit guarantee	Özener and Ergun (2008)	Positive benefit allocation
Coordination costs significance	Xu et al. (2013)	CPWV
Competitive position guarantee	Hezarkhani et al. (2016)	Competitiveness allocation

company joins the collaboration: $m_i = c(N) - c(N \backslash \{i\})$. Second, the remainder of the total costs, labelled non-separable costs and equal to $c(N) - \sum_{i \in N} m_i$, is distributed among the cooperating organisations according to specific weights. In this way, the allocation mechanism accounts for the different impacts collaborating companies may have on the total logistics cost level. The authors describe three versions of non-separable cost allocation methods: the Equal Charge Method (ECM), the Alternative Cost Avoided Method (ACAM) and the Cost Gap Method (CGM) that correspond to differences in chosen weights. The ECM distributes the non-separable costs equally, while the weights used in the ACAM account for the individual contributions of each partner. Since the ECM and the ACAM do not provide cost allocations satisfying the stability property, the authors develop a third allocation mechanism, the CGM. The CGM calculates the weight for participant i taking part in coalition S according to $w_i = \mathrm{Min}_{i \in S}\ g(S)$, with $g(S) = c(S) - \sum_{i \in S} m_i$. The explanation for this weight choice is as follows. Tijs and Driessen (1986) consider the separable cost m_i as a lower bound for the collaboration cost allocated to partner i. In contrast, the sum of the separable cost and the entire non-separable cost may be perceived as an upper bound for the allocated cost of partner i, given that he will be charged for this amount when his partners only pay their separable cost. The weights used for the allocation of the non-separable costs are then based on the gap between the lower bound and the cost of coalition S. Defryn et al. (2016) also develop an allocation mechanism based on the idea of separable and non-separable costs. In the context of a collaborative selective VRP in which not all customer orders can be served, the authors introduce a compensation for non-delivery (CND). CND is the cost that a company needs to pay for not servicing a customer order. Every company in the collaboration can define the CND for each of its customer orders itself. The result might be that the CND values are high, since each partner wants to ensure that as many of his orders as possible are included in the collaborative solution. Consequently, the total collaborative costs increase as expensive customer orders remain unserved. Following this reasoning, a CND weighted cost allocation mechanism, that divides the non-separable costs based on the total CND of the customers of each partner, could be used to punish opportunistic partner behaviour.

In the early phases of a growing horizontal cooperation, it may be helpful for communication and negotiation purposes to have an initial allocation where the relative benefits of the participating organisations are as similar as possible. For this purpose, Frisk et al. (2010) develop the Equal Profit Method (EPM). This profit sharing technique has the goal of finding a stable allocation that minimises the largest relative difference in cost savings between any pair of cooperating partners. Liu et al. (2010a) develop a similar procedure, labelled Weighted Relative Savings Model (WRSM), which additionally takes the different contribution levels of the cooperators into account.

Based on the EPM, Audy et al. (2011) develop a cost allocation mechanism that they apply to a horizontal cooperation in the Canadian furniture shipping industry. Regarding the business context and the nature of transport operations in this industry, they adapt the EPM in two ways. A first modification is the addition of a minimum cost savings percentage for every partner. The actual applied percentage depends on the bargaining power of the different partners and the negotiation process between them. Second, the modified version of the EPM appoints three types of costs as non-transferable between collaborating partners, namely the charged volume rate, the additional costs that a company has to pay to his carrier as a consequence of its specific delivery requirements and the cost for the upstream transport to the carrier terminal. Similar to the original EPM, this modified allocation method is formally defined as a linear program and satisfies the stability property. Because the second modification consists of the exclusion of certain costs in the allocation process, the authors propose a separate procedure to share these costs between cooperating partners. In this case, the division technique is based on the ACAM (Tijs and Driessen, 1986). The purpose of the modified ACAM is to allocate the largest fraction of the additional special requirements costs to the partner with the most expensive special requests. Similar to the original ACAM, the additional separable costs are first allocated to their respective shippers, after which the non-separable costs are divided among all shippers according to their respective contributions in the total additional costs.

In some situations it might be desirable to relax the stability or efficiency properties of a cost or profit sharing technique in order to create an allocation mechanism with other advantageous characteristics. In this context, Özener and Ergun (2008) develop three allocation mechanisms based on the lane covering problem of a horizontal shipper collaboration, each satisfying an additional fairness property. First, cross-monotonicity ensures that when a new transport company enters the horizontal cooperation, the allocated benefit of the existing partners does not decrease. Second, the minimum liability concept guarantees that every cooperation participant pays at least its original lane cost (the cost of performing its original FTL deliveries). In this way, only the asset repositioning costs are distributed among the shippers and situations where shippers have to cover truckload expenses of partners and others become free riders with zero allocated costs are avoided. Third, mechanisms are created that generate positive benefit cost allocations. Every participating company expects to gain when entering a horizontal cooperation. So it may be desirable to identify cost allocations ensuring that each partner is charged less than his stand-alone cost, which is equal to the sum of its original lane costs and asset repositioning costs. As Özener and Ergun (2008) prove that it is not possible to find core allocations satisfying these additional constraints, they relax efficiency and stability properties, respectively.

Setting up a horizontal logistics collaboration may involve additional coordination costs. Examples include costs associated with required ICT investments, communication between partners, and so on. The majority of current collaboration research considers these costs to be negligible. However, in some cases coordination costs cannot be ignored. In this context, Xu et al. (2013) develop allocation mechanisms both for coalitions with negligible and significant coordination costs. The basic idea is to create a gain sharing mechanism accounting for the following factors: contribution of participants to collaborative profit, bargaining power of partners, stability of the coalition and significance of coordination costs. When coordination costs are negligible and, by this, the grand coalition is the optimal coalition structure, partner allocations are calculated applying the contribution-and-power weighted value (CPWV), which is formulated as a linear program. When the coordination cost is significant, the CPWV is adapted accordingly.

Finally, Hezarkhani et al. (2016) develop a gain sharing method accounting for the highly competitive nature of the freight transport market. The authors introduce a competitiveness property which guarantees that allocations preserve the competitive positions of cooperation participants. Allocations satisfying this property equalise the ratios of average costs of fulfilment of the players before and after cooperation. The average cost of fulfilment for a set of orders is the minimum cost of its fulfilment divided by the amount of kilometres involved.

3.3.4 Allocation mechanisms in perspective

The overview provided in the previous sections demonstrates that a wide range of allocation mechanisms exists. Since each method has its specific benefits and drawbacks, it remains ambiguous which technique(s) could guarantee sustainability of a horizontal cooperation. In order for partners to make an informed decision on the allocation mechanism that suits their collaborative needs, Table 3.5 shows the basic fairness properties (Table 3.2) of the allocation techniques described in Sections 3.3.1, 3.3.2 and 3.3.3. In addition, the 'Guaranteed solution' column indicates whether or not the allocation method always provides a feasible solution, irrespective of the characteristics of the coalition game. Collaborating partners need to decide which properties are regarded the most important to ensure long-term viability of the considered cooperation project. For example, in some cases it might be desirable to relax basic stability or efficiency properties in order to create an allocation mechanism with other advantageous characteristics such as a positive benefit or cross-monotonicity guarantee.

Table 3.5: Allocation methods and their characteristics

Allocation mechanism	Efficiency	Individual rationality	Subgroup rationality	Stability	Symmetry	Dummy	Additivity	Guaranteed solution
Proportional	✓							✓
Core	✓	✓	✓	✓				
Shapley	✓	✓			✓	✓	✓	✓
Nucleolus	✓	✓	✓	✓	✓	✓		✓
Sep. and non-sep.	✓				✓			✓
EPM	✓	✓	✓	✓	✓			
WRSM	✓	✓	✓	✓	✓			
Özener and Ergun (2008)		✓	✓		✓	✓		✓
CPWV	✓	✓	✓	✓				✓
Hezarkhani et al. (2016)	✓							✓

3.4 Conclusions and further research

According to a large-scale survey among logistics service providers, deciding on a fair allocation mechanism is perceived as one of the most severe impediments when establishing a horizontal cooperation (Cruijssen et al., 2007b). As such, a great deal of scientific literature on collaborative logistics devotes its research attention to the identification of fair allocation schemes. The focus of this chapter is to provide a structured overview of the work done so far by situating existing allocation mechanisms in a classification framework and associating them with their respective fairness criteria. A review of current cooperation literature reveals that allocation mechanisms could be subdivided in three categories, namely: proportional sharing mechanisms, allocation mechanisms using game theory concepts and allocation techniques designed to cope with additional cooperation properties.

Several opportunities for **future research** on the allocation topic may be identified. As shown in Section 3.3.4 none of the allocation methods possesses all basic fairness characteristics and designing a cost allocation method that has all the desired properties may not be possible. Consequently, future research could investigate which properties are regarded the most important considering the characteristics of the studied cooperation project. In this context, Chapters 4, 5 and 6 perform extensive comparative analyses to examine the applicability and suitability of various allocation mechanisms in joint route planning, cooperative facility location and intermodal barge network environments, respectively. In addition, this chapter underlines the importance of a collectively and individually desirable allocation mechanism in any collaborative logistics environment. While a great deal of scientific literature reports on the behaviour of cost or savings allocation methods in collaborations between shippers or carriers making use of unimodal road transport, research on allocation mechanisms in collaborative intermodal transport is scarce. As such, Chapter 6 tries to fill this research gap by analysing the performance of four allocation mechanisms used to share cost savings fairly amongst shippers who bundle freight flows in order to reach economies of scale in intermodal barge transport. In this way, a comparison is made between simple and straightforward allocation methods and more advanced techniques based on cooperative game theory. Finally, the selection of an allocation technique is typically done at the start of the collaboration project based on its characteristics at that time. However, a horizontal logistics cooperation most often has a dynamic character as its appearance and structure might change over time (Verstrepen et al., 2009). The collaboration might consider broadening its scope of activities or might attract additional players, for example. Future research could address the allocation decision using a dynamic approach allowing for modifications to the sharing mechanism as the characteristics of the coalition evolve over time.

Chapter 4

Collaborative savings and cost allocation for the joint route planning problem

4.1 Introduction

Although transport companies become increasingly aware of the inevitable character of collaboration, surveys report failure rates from 50 to 70 percent for starting partnerships (Schmoltzi and Wallenburg, 2011). Because every partner of a horizontal cooperation remains independent, the risk of opportunism remains real. Besides that, the success of achieving collaborative benefits strongly depends on the degree of fit between cooperation participants (Verstrepen et al., 2009; Martin et al., 2016). Similar or complementary strategic orientations, managerial practices, organisational characteristics and partnership goals could significantly influence collaborative performance (Parkhe, 1993; Lambert et al., 1999). While a growing body of collaboration research acknowledges the importance of partner characteristics (Cruijssen et al., 2007a; Lozano et al., 2013; Guajardo and Rönnqvist, 2015; Guajardo et al., 2016), no extensive study has been performed on the numerical relationship between specific company traits and the performance of the alliances in which these organisations are involved. The first goal of this chapter (Figure 4.1) is thus to provide practical recommendations on which partnership structures may provide the highest collaborative

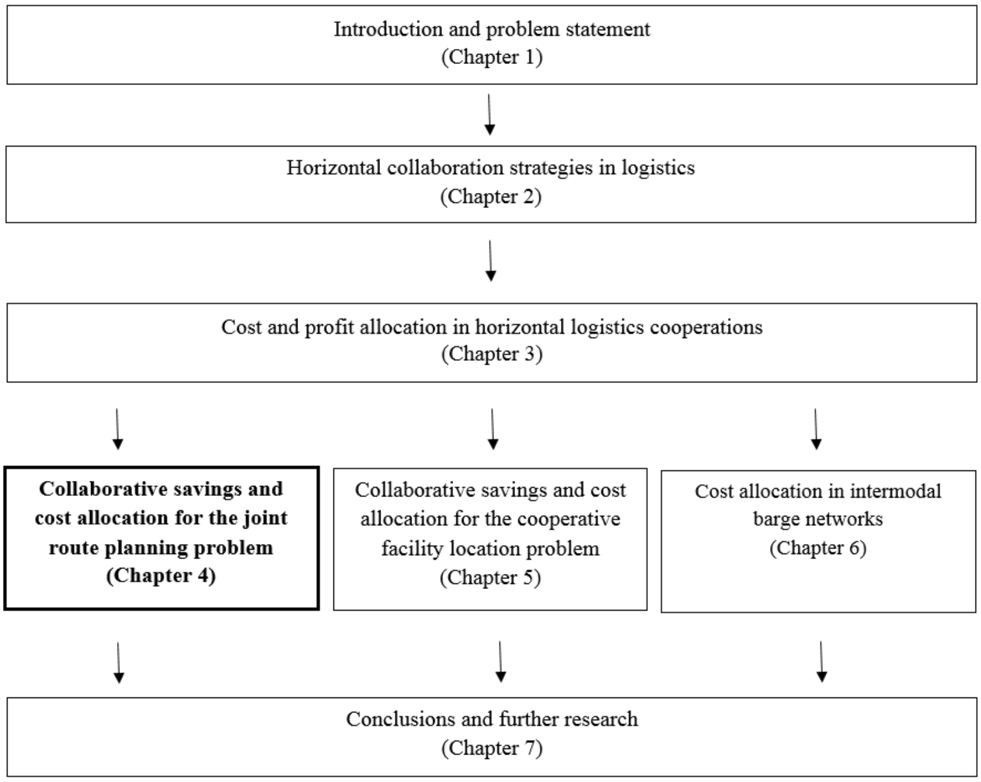

Figure 4.1: Outline of the thesis

benefits [1].

Although selecting the right partners is crucial for the success of any horizontal alliance, it is not sufficient to guarantee long-term coalition stability. As discussed in Chapter 3, dividing the collaborative gains in a fair manner constitutes a key issue. Any allocation technique should induce partners to behave according to the collaborative goal and should strive to improve cooperation stability. However, the overview provided in Chapter 3 demonstrates that a wide range of possible allocation mechanisms exists, each with its specific benefits, drawbacks and fairness properties. In this context, the second goal of this chapter is to perform an extensive comparative anal-

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[1] This chapter is based on the papers: Verdonck, L., Beullens, P., Caris, A., Ramaekers, K., Janssens, G., 2016a. Analysis of collaborative savings and cost allocation techniques for the cooperative carrier facility location problem. Journal of the Operational Research Society 67 (6), 853–871 **and** Verdonck, L., Ramaekers, K., Depaire, B., Caris, A., Janssens, G., 2016b. Analysing the effect of partner characteristics on the performance of horizontal carrier collaborations. Submitted to Networks & Spatial Economics.

ysis examining the applicability and suitability of different cost allocation methods in varying cooperation scenarios (Figure 4.1).

The influence of different coalition characteristics and cost allocation mechanisms will be investigated in an order sharing context (cf. Chapter 2). In the majority of literature on horizontal carrier alliances customer orders from all participating companies are combined and collected in a central pool and efficient route schemes are set up for all orders simultaneously using appropriate vehicle routing techniques. This collaboration approach may be labelled joint route planning. In this way, scale economies, in terms of reduced travel distance, empty vehicle movements and number of required trucks, could be obtained by merging the distribution regions of all collaboration partners (Cruijssen and Salomon, 2004; Cruijssen et al., 2007a) [2]. Since existing studies mainly focus on demonstrating the benefits associated with joint route planning, an empirical analysis of the influence of cooperation structure on partnership performance and the impact of cost allocation mechanisms on coalition stability could provide useful insights for transport companies considering collaboration.

In order to investigate the impact of coalition characteristics and cost allocation mechanisms in a joint route planning context, an extensive numerical experiment is set up. The first goal of the experimental design is to investigate whether there exists a significant relationship between specific cooperation characteristics and collaborative performance, using a well-known statistical research method. A factorial analysis of variance (ANOVA) provides insight into the effects and interactions between five coalition traits. In this context, the research work of Cruijssen et al. (2007a) and Palhazi Cuervo et al. (2016) is extended. As opposed to the more general impact analysis of coalition characteristics done by Cruijssen et al. (2007a), the goal of this chapter is to define which specific partner traits may complement each other in a joint route planning setting. Moreover, while Palhazi Cuervo et al. (2016) aim to determine the most profitable coalition structures in a shipper environment, as opposed to the carrier perspective of this chapter, their experiment is limited to the study of three company characteristics for coalitions of only two partners. The experimental design approach is useful not only for investigating the impact of partner characteristics on total cost savings achievable from collaboration, but also for investigating the relative differences between allocation methods. In the second part of the numerical study, special attention is paid to the significance of differences between three division mechanisms, the collaborative cost share allocated to the different participants and the stability of the allocation solutions obtained.

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[2] An extensive review of current scientific research on the joint route planning problem can be found in Section 2.3.1.1.

The main scientific contributions of this chapter can thus be summarised as follows. First, since the existing research work on joint route planning mainly focuses on demonstrating its cost reduction potential, a mathematical vehicle routing formulation is developed. The collaborative carrier environment studied in this chapter can be defined as a multi-depot pickup and delivery problem with time windows (MDPDPTW), a VRP that has only scarcely been researched (Montoya-Torres et al., 2015). Second, as proven by the recent increase in research on rich VRPs (Drexl, 2012; Schmid et al., 2013; Caceres-Cruz et al., 2014; Lahyani et al., 2015), consideration of practical applications related to vehicle routing becomes relevant in today's complex environment. For this reason, the novelty of this chapter lies in the application and empirical analysis of an existing routing problem in a practically relevant context with the aim of providing guidelines to practitioners. More specifically, the main contribution is to provide insight in the impact of coalition characteristics and cost allocation mechanisms on the collaborative performance and sustainability of carrier alliances, using a well-known statistical research method. In this way, recommendations are made to transport organisations considering collaboration on how they should tackle partner selection and gain sharing decisions.

The remainder of this chapter is organised as follows. First, the importance of partner fit in strategic alliances is discussed in Section 4.2. Second, Section 4.3 provides details on the cost allocation mechanisms compared for their efficacy in a joint route planning environment. Third, the joint route planning problem applicable in a carrier cooperation context is formally defined in Section 4.4, together with the solution approach used to solve this VRP. Fourth, the research methodology and design of the numerical experiment is described in Section 4.5. Next, Section 4.6 presents and discusses results on the impact of coalition characteristics and cost allocation mechanisms. Finally, conclusions and possible directions for future research are formulated.

4.2 The influence of collaboration characteristics

Existing studies on joint route planning mainly focus on demonstrating the benefits of order sharing compared to a non-collaborative environment. However, the amount of attainable collaborative savings is influenced by the degree of fit between the collaboration participants. As such, selecting the right partners constitutes a crucial phase in the development of a horizontal collaboration (Martin et al., 2016). According to Brouthers et al. (1995) cooperating with an unsuitable partner is more damaging to an organisation than not collaborating at all. Carriers also seem to be aware of the crucial importance of partner selection, as indicated in a survey by Cruijssen et al. (2007b).

Van Breedam et al. (2005) distinguish four key factors that should be considered when selecting possible collaboration partners: trust and engagement, operational fit, strategic fit and cultural fit. Trust refers to each company's conviction that the other partners will refrain from opportunistic behaviour. Engagement reflects the preparedness of each alliance partner to make a contribution to the collaboration, evoking a mutual sense of responsibility towards alliance success (Schmoltzi and Wallenburg, 2012). This contribution might take various forms, including financial resources, knowledge or material assets. Trust and engagement are necessary, but insufficient conditions to build a horizontal partnership. Other focal points are the operational, strategic and cultural fit with a potential partner. Operational fit concerns organisational characteristics on a financial and operational level such as company size, proprietary structure and profitability. In order for strategic fit to be present, the organisational strategies of the partners need to be compatible and mutually strengthen each other. A final key factor in partner selection is cultural fit. Compatibility between organisational cultures is crucial when a stable collaboration is aspired. Lambert et al. (1999) and Audy et al. (2011) also underline the importance of taking the cultural component into account. Given the intangibility of the corporate culture, cultural fit may be hard to verify. Possible indicators include the degree of customer focus, level of environmental awareness, management style and company reputation. In line with these four factors, Schmoltzi and Wallenburg (2011) define six dimensions associated with the structure of the cooperation that may impact its performance. First, the contractual scope defines the formality of the cooperation project. Second, the organisational scope refers to the number of companies taking part in the alliance. Third, the functional scope is associated with the activity domains in which organisations join forces. A cooperation might be limited to non-core activities or may involve core business operations. Fourth, the geographical scope is related to the markets that are covered by the alliance. Organisations may decide to cooperate with competitors serving the same customers to improve market strength or may extend their market coverage by partnering with competitors from different geographical areas. In line with this geographical dimension, the service scope defines the products or services offered by the collaboration, which may again be complementary or supplementary. Finally, the resource scope refers to the degree of resource overlaps between the cooperation participants. A distinction is made between overlaps in business activities, customer base and company size. As such the 'resource scope' defined by Schmoltzi and Wallenburg (2011) shows a degree of similarity with the 'operational fit' presented in Van Breedam et al. (2005). Based on the partner selection criteria discussed above in theoretical, qualitative collaboration literature, the effect of five measurable coalition characteristics on alliance performance is investigated and statistically analysed in this chapter: number of partners, carrier size, geographical coverage, order time windows and order size. In Section 4.5.1 the hypotheses studied are discussed in detail.

In summary, the first contribution of this chapter is to provide insight in the impact of coalition characteristics on the collaborative profit level of carrier alliances by determining the most profitable alliance structures in a joint route planning setting. In this context, the research work of Palhazi Cuervo et al. (2016), which is most related to this chapter, is significantly extended. First, their experiment is limited to two-partner coalitions as opposed to the experimental design developed in this chapter including two-, three-, four- and five-partner alliances. By incorporating the 'coalition size' factor, this chapter is able to investigate whether there exists a limit on the marginal synergy increase as the number of coalition partners grows (cf. Lozano et al., 2013). Second, while Palhazi Cuervo et al. (2016) focus on the impact of the number of orders and the average order size, the analyses described in this chapter additionally study the effect of the geographical service area and the order time window width with the aim of providing general insights on the partner selection decision. Finally, contrary to this chapter, Palhazi Cuervo et al. (2016) refrain from extending their cooperation characteristics analysis to the cost allocation topic of which the relevance is described in the next section.

4.3 Collaborative cost allocation

Although selecting the right partners is crucial for the success of any horizontal alliance, it is not sufficient to guarantee long-term coalition stability. As discussed in Chapter 3, dividing the collaborative gains in a fair manner constitutes a key issue. However, as visualised in Table 3.3, a wide range of possible allocation mechanisms exists. Since each method has its specific benefits, drawbacks and fairness properties, it remains ambiguous which technique(s) could guarantee sustainability in a joint route planning setting. In order for partners to make an informed decision on the allocation mechanism that suits their collaborative needs, the second contribution of this chapter is to perform an extensive comparative analysis examining the applicability and suitability of three different cost allocation methods in varying cooperation scenarios. The three allocation methods selected for their application in this chapter are the Shapley value, the ACAM and the EPM. For each of these techniques, a detailed theoretical description, mathematical formula and choice motivation is provided in the next sections.

4.3.1 Shapley value

The majority of collaborative logistics literature solves the allocation problem by means of game theory. A comparison with other techniques is thus interesting to explore. Moreover, basic game theoretic mechanisms may raise questions about mathematical complexity, applicability, fairness transparency and stability in practice. The most prevalent solution concepts within cooperative game theory are the Shapley value and the nucleolus (Moulin, 1988). The preference for the Shapley value may be explained by its ease of calculation. Applying the Shapley value means evaluating a formula, while finding the nucleolus requires the solution of a series of linear programs.

The Shapley value (Shapley, 1953) allocates to each participant the weighted average of his contributions to all (sub)coalitions, assuming the grand coalition is formed one company at a time. The Shapley allocation to participant i can be mathematically expressed as:

$$y_i = \sum_{S \subset N : i \in S} \frac{(|S|-1)!(|N|-|S|)!}{|N|!} [c(S) - c(S \backslash \{i\})] \tag{4.1}$$

with $|.|$ denoting the number of participants in the considered (sub)coalition, $c(.)$ the cost of the respective (sub)coalition, N the grand coalition and S a cooperation of a subset of partners of the grand coalition. The Shapley value provides a unique allocation with characteristics that are beneficial in the context of a horizontal logistics cooperation, as visualised in Table 3.5. However, the Shapley value has an important disadvantage, namely that this allocation may not lie in the core of the game and thus may not lead to a stable collaboration (Krajewska et al., 2008; Frisk et al., 2010; Liu et al., 2010a).

4.3.2 Alternative Cost Avoided Method

Considering the list of alternative allocation mechanisms discussed in Chapter 3, the mechanisms based on the division between separable and non-separable costs developed in Tijs and Driessen (1986) are easy to use and intuitively appealing. Of the three methods proposed, the ECM, ACAM and CGM, the preference for the

ACAM may be motivated by its transparency, ease of use and understandability. In addition, the ACAM, as opposed to the ECM, takes into account the different contribution levels of all coalition partners.

The ACAM allocation to participant i can be mathematically expressed as:

$$y_i = m_i + \frac{c(\{i\}) - m_i}{\sum_{j=1}^{n}[c(\{j\}) - m_j]} * (c(N) - \sum_{j=1}^{n} m_j) \tag{4.2}$$

with m_i denoting the separable or marginal cost of company i, which may be calculated as $c(N) - c(N \setminus \{i\})$. Similar to the Shapley value, ACAM allocations cannot guarantee stability of the grand coalition.

4.3.3 Equal Profit Method

In the early phases of a growing horizontal cooperation, it may be beneficial for communication and negotiation purposes to have an initial allocation where the relative benefits of the participating organisations are as equal as possible. For this reason, Frisk et al. (2010) and Liu et al. (2010a) develop the EPM and the WRSM, respectively. Both techniques guarantee stable allocations that minimise the maximum difference between the cost savings allocated to the cooperating partners. The reason for choosing the EPM, as opposed to the WRSM, is twofold. First, Vanovermeire et al. (2014b) demonstrate that allocations calculated by means of the EPM satisfy cross-monotonicity in contrast to WRSM allocations. Second, the importance of convenient implementation and interpretation in practice favour the use of the EPM.

In order to find the EPM allocations to all participants, the following linear program needs to be solved to optimality:

$$\text{Min } f \tag{4.3}$$

Subject to

$$f \geq \frac{y_i}{c(\{i\})} - \frac{y_j}{c(\{j\})} \qquad \forall i, j \in N \tag{4.4}$$

$$\sum_{j \in S} y_j \leq c(S) \qquad \forall S \subseteq N \tag{4.5}$$

$$\sum_{j \in N} y_j = c(N) \tag{4.6}$$

The first constraint set (4.4) measures the pair wise difference between the relative savings of the participants. The objective function (4.3) minimises the largest difference using variable f. Constraint sets (4.5) and (4.6) ensure that the allocation is stable and belongs to the core. As such, the cost allocation guarantees that no subcoalition S exists in which a set of partners would be better off (4.5) and that the total collaborative cost is shared as the grand coalition forms (4.6).

4.4 Model construction and solution approach

4.4.1 Problem statement

The joint route planning problem of collaborating transport companies studied in this chapter can be defined as follows. Carriers receive pickup and delivery orders from different types of customers. In a static context, it is assumed that customer demand is known and fixed at the start and no additional orders are acquired during the execution of already determined transport schedules. Each route has to satisfy coupling and precedence constraints, meaning that for each order, the origin must precede the destination and both locations need to be visited by the same vehicle. In addition, hard time windows are associated with each order. In a non-cooperative environment, the routing problem associated with each individual carrier, may be classified as a single depot PDPTW. The objective of the PDPTW is to identify an optimal set of routes for a fleet of vehicles to serve all customers without violating vehicle capacity, time windows, precedence and coupling constraints. The optimality characteristic coincides with an objective function that minimises total customer service time, distance travelled, number of used vehicles or a weighted combination of these goals (Mitrović-Minić, 1998; Li and Lim, 2003; Krajewska et al., 2008; Parragh et al., 2008b; Ropke and Cordeau, 2009).

If carriers cooperate horizontally, pooling all their customer orders to achieve potential savings, additional constraints have to be added to the PDPTW in order to optimally solve the joint route planning problem. The most important modification that needs to be made, is the adoption of a multi-depot perspective. As orders from all carriers are considered simultaneously, they may now be served by each of the alliance partners. The joint route planning problem may thus be defined as a multi-depot PDPTW with the general purpose of identifying optimal routes for all customer orders simultaneously. This set of routes minimises total cost, guarantees that all orders are served within their time windows, all vehicles return to their respective depots and vehicle capacities are never exceeded (Krajewska et al., 2008).

4.4.2 Mathematical problem formulation

The multi-depot VRPTW with pickup and delivery has only scarcely been researched (Montoya-Torres et al., 2015). As such, an appropriate MDPDPTW formulation is developed for the joint route planning problem based on the description provided by Krajewska et al. (2008) and combinations of PDPTW and MDPDP formulations proposed in current literature (Mitrović-Minić, 1998; Ropke and Pisinger, 2006; Parragh et al., 2008b; Ropke and Cordeau, 2009; Liu et al., 2010b; Sombuntham and Kachitvichyanukul, 2010; Ben Alaïa et al., 2013).

The problem is defined over a directed graph $G = (\mathcal{N},A)$ with node set $\mathcal{N} = \{\mathcal{I},\mathcal{Z}\}$ and arc set A. The node set $\mathcal{N}$ can be divided into a set of customer nodes $\mathcal{I} = \{P,D\}$ and a set of depot nodes $\mathcal{Z}$, coinciding with the different cooperating carriers. The customer nodes, ranging from 1 to $2n$, consist of a set of pickup locations $P = \{1,...,n\}$ and a set of delivery locations $D = \{n+1,...,2n\}$. The depot nodes $\mathcal{Z}$ can be split up in nodes representing the start location of a vehicle $\{\tau_1,...,\tau_m\}$ and nodes that correspond with the end station of a vehicle $\{\tau'_1,...,\tau'_m\}$. K is the set of vehicles (with index $k = 1,...,m$) with identical capacity C. Each vehicle is located at the depot owned by its respective carrier. The number of vehicles available is assumed equal to the number of customer orders ($m = n$) to guarantee problem feasibility. Every vehicle k needs to start and end its route at the same depot.

Each order submitted by a customer consists of a pickup node g and a delivery node $n+g$. The value q_g denotes the amount of demand (pickup) or supply (delivery) at these respective nodes. As such, pickup nodes are associated with a positive value (q_g), delivery nodes with a negative value ($-q_{n+g} = q_g$) and depots with a $q_\tau = 0$. A time window $[e_g, l_g]$ is defined to represent the earliest and latest time to start servicing node g and a service time s_g to cope with the duration of the pickup/delivery service at every node. Finally, to each arc $(g, h) \in A$ a distance-dependent cost $c_{gh} \geq 0$ and a corresponding travel time $t_{gh} \geq 0$ can be assigned.

The decision variables determined during the static joint route planning problem are the following:

$$x^k_{gh} = \begin{cases} 1 & \text{if arc } \textit{(g,h)} \text{ is traversed by vehicle } k, \\ 0 & \text{otherwise.} \end{cases}$$

Q^k_g = load of vehicle k when leaving node g

B^k_g = time at which vehicle k begins service at node g

Using these variables, the MDPDPTW studied in this chapter can be formulated as the following mathematical model:

$$Min \sum_{k\in K}\sum_{g\in\mathcal{N}}\sum_{h\in\mathcal{N}} c_{gh}x^k_{gh} \tag{4.7}$$

Subject to

$$\sum_{k\in K}\sum_{h\in\mathcal{N}} x^k_{gh} = 1 \qquad \forall g\in P \tag{4.8}$$

$$\sum_{h\in\mathcal{N}} x^k_{gh} - \sum_{h\in\mathcal{N}} x^k_{n+g,h} = 0 \qquad \forall g\in P, k\in K \tag{4.9}$$

$$\sum_{h\in P\cup\{\tau'_k\}} x^k_{\tau_k,h} = 1 \qquad \forall k\in K \tag{4.10}$$

$$\sum_{g\in D\cup\{\tau_k\}} x^k_{g,\tau'_k} = 1 \qquad \forall k\in K \tag{4.11}$$

$$\sum_{h\in\mathcal{N}} x^k_{hg} - \sum_{h\in\mathcal{N}} x^k_{gh} = 0 \qquad \forall g\in\mathcal{N}, k\in K \tag{4.12}$$

$$B^k_g + t_{g,n+g} \leq B^k_{n+g} \qquad \forall g\in P, k\in K \tag{4.13}$$

$$B^k_h \geq (B^k_g + s_g + t_{gh})x^k_{gh} \qquad \forall g\in\mathcal{N}, h\in\mathcal{N}, k\in K \tag{4.14}$$

$$Q^k_h \geq (Q^k_g + q_h)x^k_{gh} \qquad \forall g\in\mathcal{N}, h\in\mathcal{N}, k\in K \tag{4.15}$$

$$e_g \leq B^k_g \leq l_g \qquad \forall g\in\mathcal{N}, k\in K \tag{4.16}$$

$$Q^k_g \leq C \qquad \forall g\in P, k\in K \tag{4.17}$$

$$Q^k_g \leq C + q_g \qquad \forall g\in D, k\in K \tag{4.18}$$

$$x^k_{gh} \in \{0,1\} \qquad \forall g\in\mathcal{N}, h\in\mathcal{N}, k\in K \tag{4.19}$$

$$B^k_g \geq 0 \qquad \forall g\in P\cup D, k\in K \tag{4.20}$$

$$Q^k_g \geq q_g \qquad \forall g\in P, k\in K \tag{4.21}$$

$$Q^k_g \geq 0 \qquad \forall g\in D, k\in K \tag{4.22}$$

The objective function (4.7) minimises the sum of distance-dependent costs. Constraints (4.8) and (4.9) ensure that each customer order is served exactly once and that pickup and delivery nodes are visited by the same vehicle. Constraints (4.10) and (4.11) guarantee that the route of each vehicle k starts at its respective depot and returns there at the end of its route. Conservation of flow is expressed by equation (4.12). Constraints (4.13) ensure that delivery can occur only after pickup. Then, restrictions (4.14) and (4.15) make sure that consistency of time and load variables is ensured and eliminate the possibility of subtours. Constraints (4.16) guarantee that the solution of the problem does not violate the customer provided time windows.

Constraints (4.17) and (4.18) ensure that vehicle capacity is not exceeded throughout the tours, for pickup and delivery orders respectively. Finally, statement (4.19) enforces the binary nature of some of the decision variables used in the model, while constraints (4.20), (4.21) and (4.22) impose non-negativity restrictions on the other decision variables.

The problem formulation is non-linear due to constraints (4.14) and (4.15). Equivalent with Cordeau (2006), constants M_{gh}^k and W_{gh}^k are introduced to linearise these constraints as follows:

$$B_h^k \geq B_g^k + s_g + t_{gh} - M_{gh}^k(1 - x_{gh}^k) \qquad \forall g \in \mathcal{N}, h \in \mathcal{N}, k \in K \tag{4.23}$$

$$Q_h^k \geq Q_g^k + q_h - W_{gh}^k(1 - x_{gh}^k) \qquad \forall g \in \mathcal{N}, h \in \mathcal{N}, k \in K \tag{4.24}$$

Setting $M_{gh}^k \geq max\{0, l_g + s_g + t_{gh} - e_h\}$ and $W_{gh}^k \geq min\{C, C + q_g\}$ guarantees validity of constraints (4.23) and (4.24) respectively.

4.4.3 Solution approach

The MDPDPTW is a generalisation of the classical VRP and thus belongs to the class of NP-hard problems. Because of its complexity, heuristics are needed to solve the joint route planning problem associated with the different coalition structures studied.

Based on its high-quality performance for rich VRP problems (Parragh et al., 2008a), the solution procedure applied in this chapter is based on the Adaptive Large Neighbourhood Search (ALNS) heuristic, originally developed by Ropke and Pisinger (2006) and generalised in Pisinger and Ropke (2007). By applying an existing, well-established and high-performing meta-heuristic approach, good quality solutions are ensured within a reasonable time frame. The ALNS heuristic, described in pseudocode (Algorithm 1), is based on the LNS heuristic proposed by Shaw (1998). In LNS, an initial solution is gradually improved by alternately destroying and repairing the solution. Searching a large neighbourhood results in finding local optima of high quality and hence overall an LNS algorithm may return better solutions. The ALNS differs from the LNS in two important ways. First, the ALNS uses multiple removal and insertion heuristics during the same search, while LNS heuristics use only one method for removal and one for insertion. Selection of destruction and construction neighbourhoods is guided by a roulette wheel mechanism using statistics recording past performance of applied heuristics. Second, Pisinger and Ropke (2007) embed the search for high quality solutions in a simulated annealing meta-heuristic. While the original LNS only accepted solutions improving the goal function, ALNS also accepts gradually less deteriorating solutions. The specific algorithm components and implementation details of the ALNS meta-heuristic applied to solve the joint route planning problem are the following.

Algorithm 1 Adaptive Large Neighborhood Search

```
Given the collection of destroy ($\Omega^d$) and repair ($\Omega^r$) neighbourhoods, and;
Given the weights of the $n^d$ destroy ($w^d$) and $n^r$ repair ($w^r$) neighbourhoods;
Construct a feasible solution $x$;
$x^* = x; w^d = (\frac{1}{n^d}, ..., \frac{1}{n^d}); w^r = (\frac{1}{n^r}, ..., \frac{1}{n^r})$;
repeat
    Select destroy and repair heuristics $d \in \Omega^d$ and $r \in \Omega^r$ using $w^d$ and $w^r$ in roulette wheel selection;
    $x' = r(d(x))$;
    if $accept(x', x)$ then
        $x = x'$;
    end if
    if $c(x') < c(x^*)$ then
        $x^* = x'$;
    end if
    update $w^d$ and $w^r$;
until stop criterion is met;
return $x^*$
```

First, as suggested by Pisinger and Ropke (2007), an initial feasible solution is generated using a regret-2 heuristic. Regret-k heuristics try to improve the short-sighted behaviour of greedy heuristics. For each order a regret value is calculated equal to the difference in cost between inserting the order in its best route and its kth-best route. Then, orders with the highest regret values are inserted first in the solution (Ropke and Pisinger, 2006).

Second, in order to destroy and repair solutions, five removal (random removal, worst removal, related removal, time-oriented removal and neighbour graph removal) and five insertion heuristics (greedy sequential, greedy parallel, regret-2, regret-3 and regret-4) are implemented. The random removal heuristic removes β randomly selected orders from the solution, while the worst removal heuristic aims at removing orders associated with high solution costs. The related removal heuristic removes orders that are related to each other with respect to distance. The smaller the distance between two orders, the more related they are. The time-oriented removal heuristic works in a similar way, but in this case relatedness between two orders is determined by their respective times of pickup and delivery. Neighbour graph removal decides on order removal based on the historical success of visiting two nodes immediately after each other in a route. The greedy insertion heuristics repeatedly insert orders at their minimum cost positions, either sequentially (considering available routes one by one) or parallel (considering all routes simultaneously). More detailed information on each of the search operators can be found in Ropke and Pisinger (2006) and Pisinger and Ropke (2007). The reasons for selecting the above described search operators for the meta-heuristic are the following. Corstjens et al. (2016) investigate the effect of various ALNS parameters on algorithm performance using an extensive statistical methodology. Their results demonstrate that the regret heuristic proves to be the best performing insertion operator. As such, three regret heuristics are implemented to add value to the insertion process. Two greedy heuristics complement the order insertion process in order for the results to be comparable with those of Krajewska et al. (2008), as described in Section 4.6.1. Concerning the removal operators, the analysis of Corstjens et al. (2016) states that the combination of worst and random removal results in the lowest solution cost. However, combining these with related, time-oriented and neighbour graph removal led to a reduction in runtime of more than 50%, while solution quality only decreased with 1%, when applied to the joint route planning scenarios. Moreover, adding these destroy operators again improved comparability of the meta-heuristic with benchmark results. For the purpose of diversifying the search, a noise parameter is added to the objective function of the insertion heuristics. In each iteration, the decision whether to use the 'original' or 'noise' heuristic is taken based on an adaptive mechanism keeping track of the past performance of the respective heuristics with and without noise.

Third, different from the Pisinger and Ropke (2007) ALNS, deterministic, instead of simulated, annealing is chosen as the master local search framework. According to Dueck and Scheuer (1990), who introduced deterministic annealing (DA) or threshold accepting, the success of simulated annealing is sensitive to the choice of the annealing schedule. Moreover, DA offers greater simplicity but reaches similar good results in previous research (Bräysy et al., 2008; Caris and Janssens, 2010). The difference between simulated and deterministic annealing lies in their different solution acceptance rules. Using DA, a neighbouring solution with a worse objective value than the current solution is accepted if the deterioration is less than a deterministic threshold value T. It is not necessary to compute probabilities or to make random decisions. The algorithm threshold value T is gradually lowered until no more deteriorations are allowed. The DA applied in the ALNS is based on the implementation strategy of Bräysy et al. (2008) and Caris and Janssens (2010). Solution acceptance with DA can be described as follows. The threshold value T is initially set at a maximum value T_{max}. In each iteration without improvement in objective function value the value T is lowered with the reduction parameter ΔT. The threshold value is reset to $r \times T_{max}$ whenever it reaches zero, with r representing a random number between zero and one. When after a predefined number of iterations no improvements have been found and T reaches zero again, the algorithm restarts from the current best solution found. The process is repeated for a predefined number of iterations.

4.5 Research design

To investigate the impact of specific coalition characteristics on attainable collaborative savings, the statistical approach of experimental design is used. The primary goal of an experimental design is to investigate a causal relationship between the independent and dependent variables at hand. This relationship is statistically derived with the use of ANOVA by examining the value of the performance measure associated with various levels of the independent parameters or factors. Lozano et al. (2013) and Vanovermeire et al. (2013) have already demonstrated that this technique is suitable to analyse the influence of different parameters in a horizontal shipper collaboration setting. The experimental design approach is useful not only for investigating the impact of factor combinations on total cost savings achievable from collaboration, but also for investigating the relative differences between the applied cost allocation methods. In the second part of the numerical study, special attention is paid to the significance of differences between the three division mechanisms, the collaborative cost share allocated to the different participants and the stability of the allocation solutions obtained.

Based on the partner selection criteria discussed in Section 4.2, the effect of five measurable coalition characteristics on alliance and cost allocation performance is investigated and statistically analysed. In Section 4.5.1 the studied hypotheses are discussed in detail. Since no test instances are available for the specific collaboration problem investigated in this chapter, the method used to generate artificial instances is described in Section 4.5.2, together with a presentation of the experimental factors coinciding with the relevant cooperation characteristics. With regards to the impact analysis of coalition characteristics on collaborative performance, distance-dependent cost results with and without joint route planning are compared exclusively. The use of a single performance measure to compare benefits the clarity and comprehensibility of the insights provided to practitioners. Moreover, this choice is consistent with existing literature on the joint route planning problem (cf. Table 2.1).

4.5.1 Research hypotheses

In the first part of the numerical experiment, the effect of specific coalition characteristics on alliance performance is investigated. For this purpose, the following five hypotheses based on theoretical, qualitative collaboration literature are analysed.

First, the influence of the number of partners (organisational scope) on cooperation performance is examined. In this way, it can be determined whether it is better to share orders with a large or a limited number of fellow transport companies. The statements made by Park and Russo (1996), Griffith et al. (1998) and Lozano et al. (2013) lead to the following hypothesis:

Hypothesis 1. *The number of collaborating partners has a positive impact on coalition performance.*

Second, in line with the operational fit concept described by Van Breedam et al. (2005), the impact of similarity in size of the collaborating companies is studied. Size of a carrier is measured in terms of the amount of customer orders it initially needs to serve before considering the cooperation. The question to be answered here is whether a carrier is better off cooperating with equally sized organisations or if more savings may be achieved in an alliance consisting of companies differing in size. In accordance with experimental results of Cruijssen et al. (2007a) and Vanovermeire et al. (2013), the following hypothesis is investigated:

Hypothesis 2. *Coalition performance is higher for cooperations established between equally sized carriers compared to collaborations between organisations differing in size.*

Third, the effect of resource overlaps between alliance partners, as discussed by Schmoltzi and Wallenburg (2011), is analysed in three ways. The resource scope is first defined as the degree of overlapping geographical coverage between cooperating carriers, leading to a third hypothesis:

Hypothesis 3. *Coalition performance is higher for cooperations established between carriers operating within the same geographical area compared to collaborations between companies active in unrelated customer markets.*

Next, the effect of equalities and differences in customer base characteristics is investigated. This concept is translated in two partner characteristics. On the one hand, the impact of overlap between cooperation participants in terms of customer order time windows is studied:

Hypothesis 4. *Coalition performance is higher for cooperations formed by partners with different order time windows compared to collaborations established between carriers serving orders with equal time windows.*

On the other hand, the effect of similarities and differences in average order size of partners is investigated:

Hypothesis 5. *Coalition performance is higher for cooperations formed by partners with different order sizes compared to collaborations established between carriers serving orders of similar size.*

Throughout all these hypotheses the dependent variable is defined as:

$$\text{Coalition performance (CP)} = \sum_{i \in N} c(\{i\}) - c(N) \qquad \forall i \in N \tag{4.25}$$

with N denoting the total number of coalition partners, $c(\{i\})$ the stand-alone distance-dependent costs of an individual company i and $c(N)$ the total distance-dependent cost of the coalition. The absolute character of the dependent variable can be motivated based on a comparison of the hypotheses results considering an absolute versus a relative $(\frac{CP}{\sum_{i \in N} c(\{i\})})$ dependent variable and the insights provided by Palhazi Cuervo et al. (2016). Analysing the impact of the considered cooperation characteristics on the relative coalition performance may lead to erroneous conclusions. For example, both in the analyses performed in the context of this chapter and those performed by Palhazi Cuervo et al. (2016), the largest relative CP was observed for coalitions comprised of partners serving a small number of orders. However, it is clear that the largest absolute profits can be generated when a large number of orders are combined. Although these profits might represent a smaller percentage of the total stand-alone costs, they are associated with a better coalition performance.

The goal of the second part of the numerical experiment is to examine the applicability and suitability of the three **cost allocation methods** described in Section 4.3 in varying joint route planning scenarios. By analysing the Shapley, ACAM and EPM allocation values over all factor combinations discussed in the next section, the following research questions are investigated:

- Do any of the five experimental factors have an effect on the stability of the grand coalition, considering costs to be allocated by means of the Shapley value, the ACAM and the EPM?

- Do there exist significant differences between the allocation values defined by means of the Shapley value, the ACAM and the EPM?
- Do there exist interdependencies between the characteristics of the cooperation and the cost share allocated to its participants by means of the Shapley value, the ACAM and the EPM?

4.5.2 Generation of test instances and alliance structures

First, test instances are created for individual carriers differing in terms of the partner characteristics presented in the previous section. Table 4.1 provides an overview of the characteristics associated with these individual carrier instances together with their implementation details. Regarding the chosen implementation values, experienced practitioners were consulted in order to create realistic partnership structures fitting in a joint route planning setting. Second, the individual carrier instances are combined in a factorial experiment to represent horizontal alliances with varying structures. All generated instances are available from the authors upon request. Moreover, detailed information on their generation can be found in Appendix A.

Considering the individual carrier instances (Table 4.1), organisations of three different sizes are created. 'Small' carriers have to serve between 15 and 25 customer orders, 'medium' carriers are responsible for 60 to 70 customer orders and 'large' carriers are assigned 100 to 120 orders. This implementation is in line with the European logistics environment comprised of a significant amount of SMEs and excludes express couriers (e.g. DHL, UPS). In addition, these factor values extend the work of Palhazi Cuervo et al. (2016) who consider the number of orders per partner to be between 5 and 35. To examine the impact of resource overlaps between alliance partners, within each of the three carrier categories just described, distinct carrier profiles are created. First, the Li and Lim (2003) distinction between LR (randomly distributed customers) and LC (clustered customers) instances is used to cope with the geographical coverage associated with individual carriers. Second, a distinction is made between carriers serving customers with broad time windows and carriers performing orders with narrow time windows. The average time window width of customer orders characterised by 'broad' time windows is two to three times larger than that of orders with 'narrow' time windows. Third, carrier instances may differ in terms of the average size of the orders that need to be served. A 'small' order takes up 5% to 15% of vehicle capacity, while a 'large' order occupies 30% to 40% of vehicle space. Transported goods and used vehicles are considered to have homogeneous characteristics among participating transport organisations.

Table 4.1: Characteristics of individual carrier instances

Characteristic	Categories	Implementation
Carrier size	Small	U(15,25) orders per carrier
	Medium	U(60,70) orders per carrier
	Large	U(100,120) orders per carrier
Geographical coverage	R	Customer locations: random
	C	Customer locations: clustered
Order time windows	1	Narrow order time windows
	2	Broad order time windows
Order size	Small	Order size: U(0.05,0.15) * vehicle capacity
	Large	Order size: U(0.30,0.40) * vehicle capacity

The five experimental factors and their associated factor levels are listed in Table 4.2. Horizontal carrier alliances with different coalition characteristics are generated by combining the individual carrier instances as follows. Regarding the number of partners in a coalition, two-carrier, three-carrier, four-carrier and five-carrier partnerships are considered. By incorporating the 'coalition size' factor into the experimental design, the statement made by Lozano et al. (2013) that there exists a limit above which the synergy increase generated by adding another company to the collaboration is negligible, could be accounted for. Next, due to the stated importance of operational fit between coalition partners (e.g. Van Breedam et al., 2005), a distinction is made between alliances consisting of equally sized organisations and alliances comprised of companies differing in size for each of the studied coalition sizes. As such, 'equal size' coalitions are established either between small carriers, medium-sized carriers or large carriers. In order to get a balanced experimental design, for the 'different size' coalitions a random selection is made of three coalition structures containing a mix of small, medium and large carriers. As a consequence, the experimental design can be considered fractional instead of full since not all factor level combinations are included. The motivation behind this approach is to reduce the size of the experiment in order to be able to solve it within a reasonable computation time. Including all carrier size combinations for the three-partner coalitions alone would already increase the number of test instances by 192, for example. Within each of these 24 alliance classes, coalitions are then created between carriers operating in the same geographical area (combination of LR instances) and carriers serving customers in different regions

Table 4.2: Experimental factors and factor levels

Factors	Factor levels (number of levels)
Number of partners	Two, three, four, five (4)
Carrier size	Small, medium, large, mix$_1$, mix$_2$, mix$_3$ (6)
Geographical coverage	Random, clustered (2)
Order time windows	Equal, mix (2)
Order size	Small, large, mix$_1$, mix$_2$ (4)

(combination of LC instances). By joining instances comprised of customers that are randomly dispersed within the same area, savings can be calculated for cooperations established between carriers who have a strong overlap in geographical scope. On the contrary, collaborations between companies active in unrelated customer markets could be quantified by combining instances in which carriers serve customers located in unrelated clusters. For clarification purposes, both cooperation structures are visualised in Figure 4.2. In addition, a distinction is made between coalitions established between carriers who are similar in terms of average order time windows (combination of all 'narrow time windows' or all 'broad time windows' instances, each representing half of the number of instances) and carriers responsible for customers with different time window widths (mix of 'narrow time windows' and 'broad time windows' instances, divided equally within every instance). The total time horizon, the time period between the earliest time window start and latest time window end, of all developed instances remains within the same range (on average 2500 time units). In order to avoid the positive effect of broad time windows on performance (Li and Lim, 2003) interfering with the effect analysis performed in this chapter, no separate instances have been created for the '1' and '2' carrier categories of Table 4.1. Finally, both alliance structures with only small or large average order sizes and coalitions servicing a mix of small and large orders are created. For comparison and analysis purposes, three instances are generated for each of the described coalition profiles, leading to a total of 1152 test instances.

4.6 Results

This section is devoted to the presentation and discussion of the joint route planning outcomes, both in terms of collaborative savings (Section 4.6.2) and allocation values

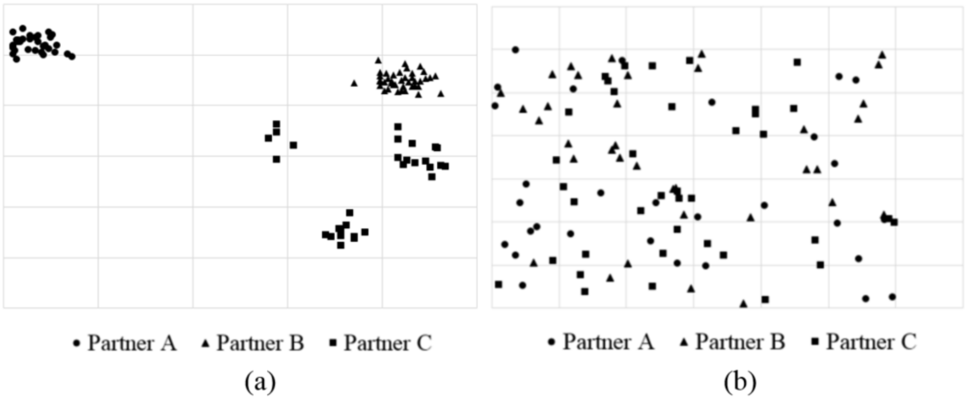

Figure 4.2: Geographical customer locations for a three-partner (a) 'clustered' and (b) 'random' coalition instance

(Section 4.6.3). The effects of coalition characteristics on collaborative performance are analysed by factorial ANOVA. In the cost allocation analyses paired t-tests are used. All statistical experiments are performed using SPSS for Windows Release 24 and are carried out on a Xeon CPU at 2.8 GHz with 64GB of RAM.

Coalition performance of all considered cooperation structures is determined using the ALNS with DA (see Section 4.4.3), implemented in Python. The parameter tuning and performance on benchmark instances of the meta-heuristic is discussed in Section 4.6.1. Next, Section 4.6.2 discusses the main and interaction effects of the five experimental factors on the collaborative savings level. By testing the hypotheses described in Section 4.5.1, it is determined which coalition characteristics have the most profound impact on collaborative performance. Finally, Section 4.6.3 describes the applicability and suitability of the three cost allocation methods described in Section 4.3 accounting for the studied factor combinations.

4.6.1 Parameter tuning and algorithm performance

Based on its high-quality performance for rich VRP problems, almost the same parameter setting is used for the ALNS with DA as determined in Ropke and Pisinger (2006), with the exception of the deterministic annealing parameters. Applying an iterative parameter tuning strategy, Ropke and Pisinger (2006) calibrated the removal, acceptance, roulette wheel and noise parameters of the ALNS with the use of a tuning set of 16 instances. This instance set contained Li and Lim (2003) benchmark problems, multi-depot problems and problems with orders that can only be served by a subset of the vehicle fleet. The deterministic annealing parameters were tuned as follows. First, three values were chosen for each parameter using a trial-and-error procedure. Then, parameter values were determined by testing all possible combinations on 24 instances and selecting the combination that resulted in the lowest distance-dependent costs. The tuning instance set consisted of 24 randomly selected instances, each related to a distinct alliance class considered in the experimental design (4 levels of 'number of partners' × 6 levels of 'carrier size'). The algorithm is restarted from the current best solution after 20 iterations without any improvements. The maximum threshold value T_{max} equals 1.5, with a change in threshold value ΔT of 0.045. Similar to Ropke and Pisinger (2006), the entire ALNS process is repeated for 25000 iterations.

Before investigating the effect of different cooperation structures on collaborative savings and cost allocation mechanisms, the performance of the ALNS with DA is evaluated. Running times of the algorithm are not discussed. The reason for this is that the meta-heuristic has been implemented in Python. Python-based programs tend to execute slower than other compiled programs (e.g. in C), but this interpreted language allows for rapid development of object-oriented programs especially suitable to examine algorithm potential in terms of solution quality (Pérez-Bernabeu et al., 2015). Since the joint route planning problem presented here is most closely related to the description provided in Krajewska et al. (2008), their computational results are used as a benchmark to validate the quality of the meta-heuristic against the original ALNS developed by Ropke and Pisinger (2006). Based on a selection of 35 instances received from the authors and belonging to the instance sets $T1$, $T2$ and $T3$, a comparison was made between the collaborative cost results as presented in Krajewska et al. (2008) and those produced by the ALNS with DA for the same instances. ALNS with DA results for $T1$, $T2$ and $T3$ instances display an average gap of 0.09% in terms of objective function value in comparison to the results of Krajewska et al. (2008). This comparative analysis confirms the competitiveness of the meta-heuristic framework developed in this chapter. Combining the well-established ALNS with the efficiency of deterministic annealing ensures good quality solutions for the joint route planning problem studied in this thesis.

4.6.2 Collaborative savings results

4.6.2.1 Main effects of coalition characteristics on collaborative savings

The savings level associated with joint route planning ranges from 1.64% to 38.57% over all experiments, with an average savings level of 17.14% in distance-dependent transport costs. Horizontal collaboration through order sharing can hence produce large operational benefits to carriers. However, because of the wide spread in possible savings and because 1.64% may not be a sufficient gain to compensate for additional overhead of collaboration, a further investigation of the main effects of the five factors on the savings attained by the collaboration is in order.

Table 4.3 presents the ANOVA results for the main effects of the considered alliance characteristics on coalition performance. For each of the studied characteristics the ω^2 value (Olejnik and Algina, 2000) is also reported, indicating their respective effect size. The mean coalition performance for the studied factor levels are displayed in Table 4.4. Bonferroni and Games-Howell post hoc t-tests were used to define the statistical significance of the different factor levels (Field, 2013).

The assumptions under which the ANOVA F statistic is accurate and reliable are independence of observations, homogeneity of variance and normally distributed observations. First, since all coalition instances are created by combining randomly generated carrier instances, observations may be considered independent. Second, regarding the homoscedasticity assumption, Levene's test has been applied, which tests the null hypothesis that the variances of the groups are equal. In case of violations of the homogeneity assumption, Welch's F is used to decide on the significance of factor effects (Field, 2013). Third, since the sample size is considerably large, it is assumed that the Central Limit Theorem is applicable which states that the distribution of the observations approaches normality.

Table 4.3: Fractional ANOVA on coalition performance: main effects

	SS	*df*	*MS*	*F*	*p*	ω^2
Number of partners	14428828902.876	3	4809609634.292	120.002	0.0000*	0.242
Carrier size	12133112998.734	3	4044370999.578	97.262	0.0000*	0.281
Geographical cov.	3102055233.864	1	3102055233.864	61.825	0.0000*	0.052
Order time wind.	354122195.226	1	354122195.226	6.727	0.0096*	0.005
Order size	1628977171.835	2	814488585.918	18.608	0.0000*	0.039

Note: * Significant at $\alpha = 0.01$

Table 4.3 indicates that all of the main effects exhibit a statistical significance of less than 0.01. As such, each of the five studied coalition characteristics has a significant impact on coalition performance. The next paragraphs will discuss the

Table 4.4: Mean coalition performance associated with studied factor levels

Number of coalition partners	Mean CP	Carrier size	Mean CP	Geographical coverage	Mean CP
2	3892.209	Small	3187.501	Random	10725.294
3	7232.228	Medium	9015.907	Clustered	7390.856
4	10950.386	Large	14797.365		
5	13511.741	Mix	8882.020		
Order time windows	Mean CP	Order size	Mean CP		
Equal	8494.768	Small	8243.017		
Mix	9621.381	Large	6890.533		
		Mix	10233.673		

experimental factors and the proposed hypotheses (see Section 4.5.1) independently.

Reviewing the ω^2 values reveals that the **size of the carriers** involved in the coalition has the most profound impact on its performance. In accordance with experimental results of Cruijssen et al. (2007a) and Vanovermeire et al. (2013), coalitions with the largest profits are achieved when a lot of orders are combined. The larger the pool of joint orders, the larger the potential to find a more profitable route plan for the collaboration. Hypothesis 2 thus needs to be expounded upon in the joint route planning setting under study in this chapter. While large transport organisations best seek for partners that are equal in size, small companies best join forces with a significant amount of equal-sized organisations and/or attract a large partner in order to enjoy savings levels associated with large order pools. Next, Hypothesis 1, which states that the **number of partners** in a collaboration influences its performance in a positive way, can be confirmed in a joint route planning context. Increasing the coalition size from two to five partners leads to a more than tripled profit level. However, companies need to be aware that coalition size cannot be enlarged infinitely. Collaborating with a large number of partners also increases alliance complexity and may dilute the strength of mutual partner relationships. In this context, Lozano et al. (2013) proof that there exists a limit above which the synergy increase generated by adding another company to the collaboration is negligible. Then, results demonstrate that coalitions between partners operating within the same **geographical service area** gain on average 45% more compared to collaborations between companies active in completely unrelated customer markets, confirming Hypothesis 3. Increased geographical coverage may provide more cooperation opportunities and could thus lead to larger cost reductions. Overlapping customer markets seem to constitute an important aspect of coalition sustainability, as was also stated by Van Breedam et al. (2005), Cruijssen et al. (2007a), Schmoltzi and Wallenburg (2011) and Guajardo and Rönnqvist (2015). In line with Hypothesis 5, transport organisations involved in joint route planning best seek for partners that serve **orders** differing in **size**. A company with large orders may experience difficulties combining them in a single trip. As such, small orders can be useful to fill the remaining vehicle capacity. Moreover, organisations with small orders could avoid performing a multitude of routes, possibly with many detours, to deliver all its orders by combining them with larger ones. Following these statements, coalitions formed by partners with differing order sizes may gain on average 26% more compared to collaborations established between carriers serving orders of similar size. Similar results were found by Vanovermeire et al. (2013) and Palhazi Cuervo et al. (2016) for two-partner shipper coalitions. Finally, Table 4.3 suggests that differences in **order time windows** complement each other and may increase the number of possible improvement opportunities for the joint route plan. This confirmation of Hypothesis 4 is supported by Schmoltzi and Wallenburg (2011) who found that, in practice, the majority of multi-lateral horizontal cooperations between logistics service providers are characterised by complementary customer portfolios of partners. However, the remark needs to be made here that, although the main effect of the time window width is significant, its explaining power is rather limited as shown by its low ω^2 value.

4.6.2.2 Interaction effects of selected coalition characteristics

Since the ω^2 values of the experimental factors 'number of partners' and 'carrier size' are prominently larger than the other ones, it is investigated whether either of these two factors show a significant two-way interaction effect with one or more of the other collaboration characteristics, as presented in Table 4.5. In this way, possible dependencies between the number of coalition partners and their respective characteristics on the one hand and between the number of joint orders and their respective characteristics on the other hand are defined.

Table 4.5: Fractional ANOVA on coalition performance: interaction effects

	SS	*df*	*MS*	*F*	*p*
Number of partners x carrier size	1185221477.536	9	131691275.282	4.649	0.0000*
Number of partners x geographical coverage	400973975.977	3	133657991.992	3.606	0.0130*
Number of partners x order time windows	177230740.989	3	59076913.663	1.486	0.2166
Number of partners x order size	351925332.179	6	58654222.030	1.822	0.0920
Carrier size x geographical coverage	338079621.970	2	169039810.985	4.576	0.0107*
Carrier size x order time windows	91224438.759	2	45612219.379	1.114	0.3291
Carrier size x order size	595458083.763	4	148864520.941	4.823	0.0008*

Note: * Significant at $\alpha = 0.05$

ANOVA results demonstrate that the positive main effect of the coalition size is significantly influenced by the number of orders the partnering companies need to serve (p value = 0.0000). As Figure 4.3 visualises, a high number of orders, pooled by a significant number of partners, implies that the number of kilometres driven could be reduced to a greater extent. The positive effects of coalition and carrier size significantly enforce each other in a joint route planning context. As such, large transport organisations considering horizontal collaboration best seek for multiple partners that are equal in size. Moreover, small carriers best join forces with a significant amount of equal-sized organisations to attract large partners and enjoy savings levels associated with large order pools.

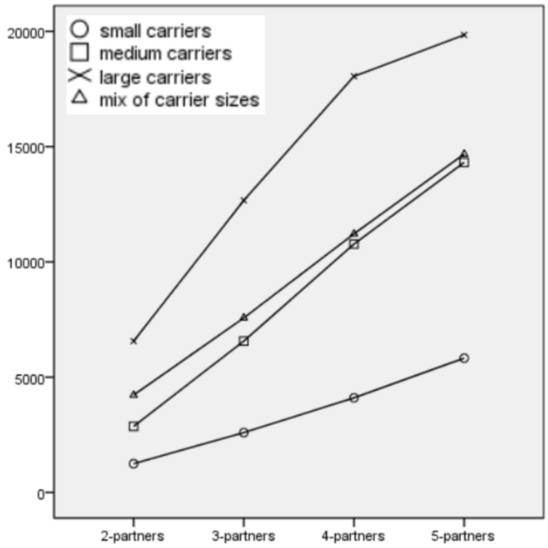

Figure 4.3: Average profit level for each combination of number of partners and carrier size

Next, Figure 4.4 demonstrates how the positive effect of increased geographical coverage has the most profound profit impact when coalition size grows (p value = 0.0130). Given the complementarity of the geographical area that is served by the partnering companies, the larger the service region of the coalition, the more opportunities for efficient order sharing emerge. Moreover, when the supply areas of the companies overlap each other the average transport distances decrease (Guajardo and Rönnqvist, 2015). Figure 4.5 confirms the importance of broad geographical coverage for alliance profitability. As more orders are joined when large carriers cooperate, overlapping service regions provide more opportunities for collaborative synergy (p value = 0.0107).

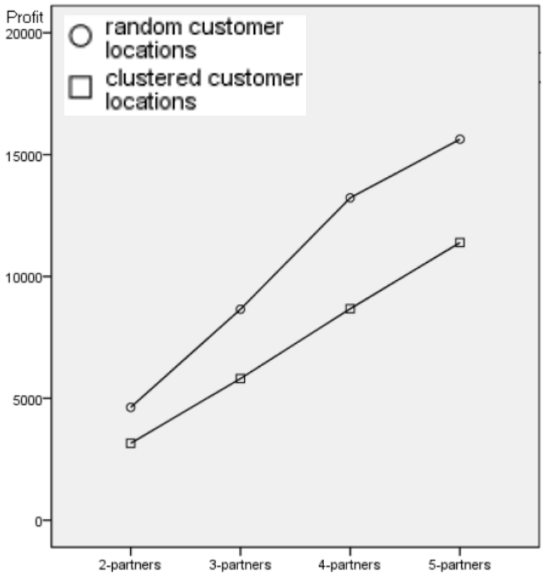

Figure 4.4: Average profit level for each combination of number of partners and geographical coverage

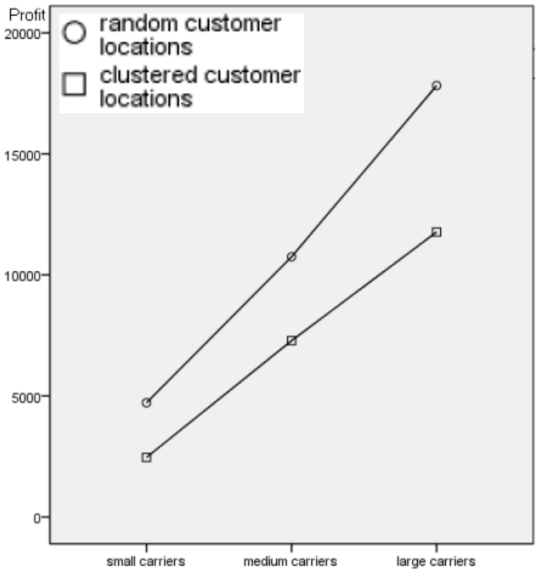

Figure 4.5: Average profit level for each combination of carrier size and geographical coverage

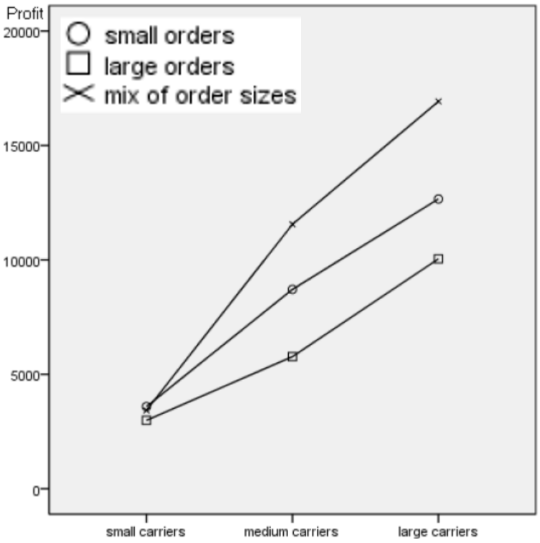

Figure 4.6: Average profit level for each combination of carrier size and order size

Finally, Figure 4.6 visualises the significant interaction effect between the partners' number of orders and their average order size (p value = 0.0008). As already mentioned, coalitions with large profits are achieved when a lot of orders are combined. In order to enjoy even higher collaborative savings, it is best that large carriers seek companies of similar size, but with different order sizes in order to take full advantage of unused vehicle capacity. Similar to conclusions drawn by Vanovermeire et al. (2013) and Palhazi Cuervo et al. (2016) for two-partner shipper coalitions, the positive effects of number of orders and different order sizes significantly enforce each other in a joint route planning context.

4.6.3 Cost allocation results

In order to ensure sustainability of the joint route planning project, incurred costs need to be divided in a fair way among the participants. For this reason, the collaborative costs, calculated by means of the ALNS with DA for all studied factor combinations, are now allocated to the carriers applying the Shapley value, the ACAM and the EPM.

To identify whether the cost allocations defined for the studied experiments guarantee cooperation **stability**, compliance of the Shapley and ACAM solutions with individual, subgroup and group rationality needs to be verified. A cost allocation satisfying the individual rationality property guarantees that no carrier pays more than his stand-alone cost: $y_i \leq c(\{i\}), \forall i \in N$. Subgroup rationality avoids that players leave the grand coalition to form a subgroup because they could be better off excluding certain partners: $\sum_{i \in S} y_i \leq c(S), \forall S \subseteq N$. Group rationality, also labelled efficiency, ensures that the total cooperative cost is shared as the grand coalition forms: $\sum_{i \in N} y_i = c(N)$. Since core constraints are included in the EPM linear program, feasibility of the EPM solution indicates whether the grand coalition is stable. In case of a non-stable grand coalition, additional allocations are calculated for comparison purposes, namely the 'Stability relaxation EPM' and 'ϵ-EPM'. Regarding the calculation of these cost allocations for non-stable collaborations, two modifications are applied to the EPM in order to find a feasible solution. First, allocation values are calculated while relaxing core constraints that could not be satisfied for the respective cooperative game. Second, EPM is combined with the ϵ-core concept, as suggested by Frisk et al. (2010). Applying the ϵ-core, cooperation participants are penalised with a cost $\epsilon > 0$ for quitting the grand coalition. In this way, stable cost allocations may be calculated for cooperative games with an empty core (Shapley and Shubik, 1966).

Analysing cost allocations over all instances reveals that stability of the grand coalition is guaranteed in 73% of the studied experiments. In the remaining 27% the core of the cooperative game is empty. If the grand coalition is stable, then no subgroup of partner companies has the incentive to leave the grand coalition and be better off acting alone. Results demonstrate that in the experimental design stability either holds or not, that is, that this outcome is independent of the allocation technique applied in this chapter. The non-stable coalition instances demonstrate the influence of cooperation structure on the longevity of joint route planning projects. The analysis reveals that increasing the number of coalition participants has a negative impact on its long-term sustainability. While two-carrier cooperations are always related with stable outcomes, only 45% of the five-carrier cooperations are associated with stability. Although increasing the coalition size from two to five partners leads to a more than tripled profit level (see Section 4.6.2), companies need to be aware that collaborating with a large number of partners also increases alliance complexity and may dilute the strength of mutual partner relationships. Regarding the other experimental factors, the influence on coalition stability is not so clear. When cooperations with varying levels of partner size, order size, geographical coverage or customer order time windows are compared the number of stable versus unstable experiments is divided almost equally.

Investigating the **allocation values** defined by means of the Shapley value, the ACAM and the EPM variations over all instances, the following observations can be made. First, when comparing over the division mechanisms using paired t-tests, no significant differences exist in the allocation values. The share of logistics costs allocated to the cooperation participants is thus fairly similar with respect to the allocation technique used here. On average, the smallest differences are associated with coalitions of limited size between equal partners. This is illustrated in Figure 4.7 in which the allocation results of the three methods on a coalition of three similar partners A, B and C are shown. For all two-partner coalitions, Shapley and ACAM even lead to identical cost allocations.

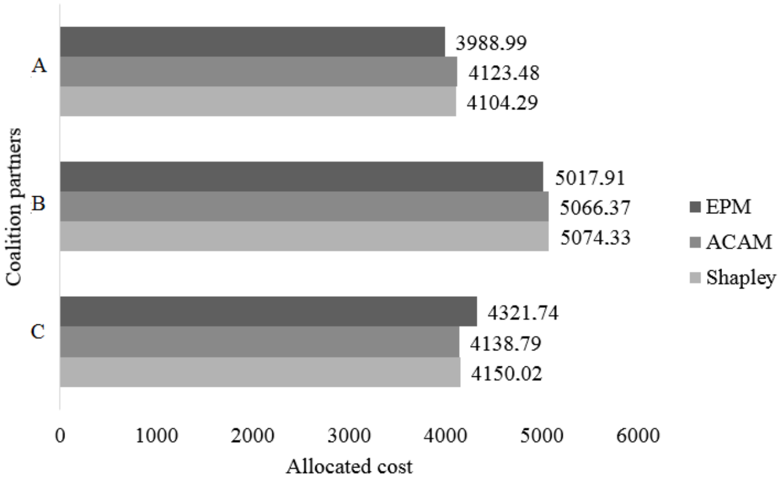

Figure 4.7: Cost allocation results for coalition of three companies with similar characteristics

Second, examining the cost share allocated to the different cooperation participants reveals that the division of cost savings is related to the collaborative efforts made by the participants, regardless of the used sharing mechanism. As such, organisations that contribute more to the partnership receive a higher share of the collaborative savings. For example, consider a coalition of three partners A, B and C joining their orders. When partner A has to serve significantly more shared orders than partner B and C when executing the joint route plan, partner A is rewarded for this effort with a higher share in the collaborative gains. Third, the original EPM and the EPM with relaxed stability constraints provide the most equally spread cost savings among the partners of the coalition, as visualised in Figure 4.8 for a coalition of three partners A, B and C. Although the ϵ-EPM also aims to minimise maximal pair wise differences between allocated savings, increased variation in carrier savings

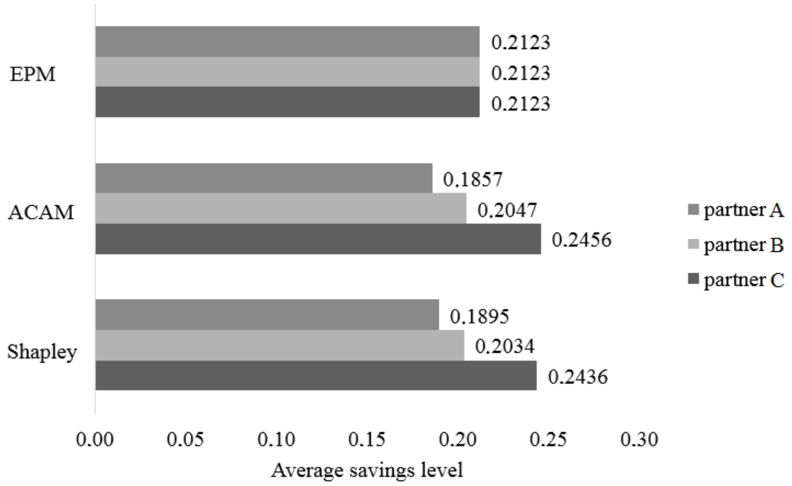

Figure 4.8: Average savings levels for coalition of three companies with similar characteristics

is caused by adding ϵ-core constraints.

Finally, the Shapley value benefits small carriers in case of a coalition comprised of participants of different size. On average, collaborative savings of companies with a smaller amount of customer orders are highest when costs are divided by means of the Shapley value. This is illustrated in Figure 4.9 in which the average savings levels for a coalition of three unequal partners A, B and C are shown. Considering the fact that partner C is a small carrier, as opposed to partners A and B, its associated savings level is highest when costs are allocated using the Shapley value.

4.7 Conclusions and further research

Although transport companies become increasingly aware of the inevitable character of horizontal collaboration, surveys report failure rates up to 70 percent for starting strategic partnerships (Schmoltzi and Wallenburg, 2011). While a growing body of collaboration research acknowledges the importance of partner characteristics (Cruijssen et al., 2007a; Lozano et al., 2013; Guajardo and Rönnqvist, 2015; Guajardo et al., 2016), no extensive study has been performed on the numerical relationship between specific company traits and the performance of the alliances in which these organisations are involved. The first goal of this chapter is thus to provide practical recommendations on which partnership structures may provide the highest collabo-

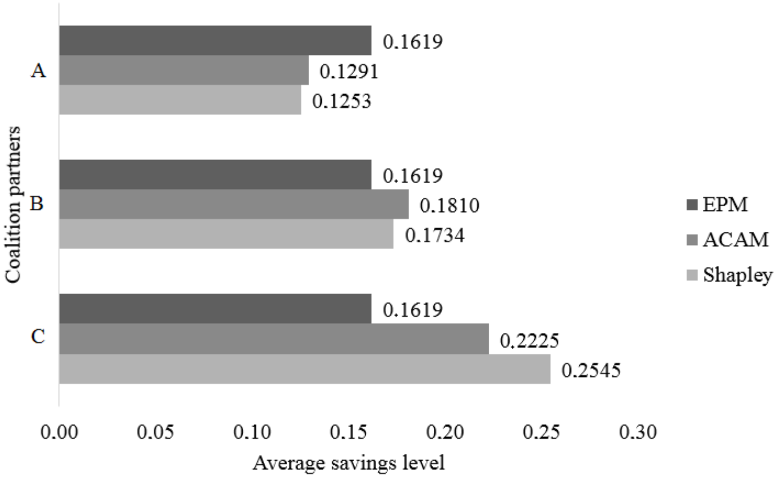

Figure 4.9: Average savings levels for coalition of three companies of different size

rative benefits by means of analysing the results of an extensive experimental design. Although selecting the right partners is crucial for the success of any horizontal alliance, it is not sufficient to guarantee long-term coalition stability. As discussed in Chapter 3, dividing the collaborative gains in a fair manner constitutes a key issue. In this context, the second contribution of this chapter is to perform an extensive comparative analysis examining the applicability and suitability of three different cost allocation methods in varying cooperation scenarios.

Based on the literature review described in Chapter 2, the assumed influence of different coalition characteristics and cost allocation mechanisms is investigated in a joint route planning context. Joint route planning implies that customer orders from all alliance partners are combined and collected in a central pool and efficient route schemes are set up for all orders simultaneously using appropriate vehicle routing techniques. The routing problem associated with horizontally cooperating carriers may be classified and mathematically formulated as a MDPDPTW. Due to the complexity of the MDPDPTW, a meta-heuristic method based on ALNS and deterministic annealing has been applied to solve large problem instances.

Based on extensive numerical experiments analysing the influence of alliance characteristics on the amount of attainable **collaborative savings** using factorial ANOVA, the following managerial insights may be formulated. First, results reveal that coalitions with the largest profits are achieved when a lot of orders are combined. The larger the pool of joint orders, the larger the potential to find a more profitable route plan for the collaboration. While large transport organisations best seek for partners that are equal in size, small companies best join forces with a significant amount of equal-sized organisations and/or attract a large partner in order to enjoy savings levels associated with large order pools. Second, considering the positive influence of the number of partners on collaborative performance, the importance of the total number of orders is confirmed. However, companies need to be aware that coalition size cannot be enlarged infinitely. Collaborating with a large number of partners also increases alliance complexity and may dilute the strength of mutual partner relationships. Third, broad geographic coverage and/or overlapping customer markets seem to constitute an important aspect of coalition sustainability. The larger the service region of the coalition, the more possibilities for efficient order sharing there are. Moreover, when the supply areas of the companies overlap each other the average transport distances decrease. Finally, transport organisations involved in joint route planning best seek for partners that serve orders differing in size. In this way, the coalition can take full advantage of unused vehicle capacity.

When participants have to decide on the mechanism of how to share collaborative savings, the following observations can be made. Regardless of the used sharing mechanism, **allocation techniques** account for differences in partner contributions to the collaborative goal. Participants that make notable efforts to execute the joint route plan are rewarded with a higher share of the collaborative savings. The original EPM and the EPM with relaxed stability constraints may be most useful in collaborations between carriers with similar characteristics as they provide the most equally spread cost savings. In addition, both allocation techniques may also be valuable in the early phases of a growing horizontal cooperation, in which having an initial allocation with similar benefits for all participating organisations may suit communication and negotiation purposes. Small carriers may prefer costs to be allocated by means of the Shapley value. This division mechanism favours companies with a smaller share in customer demand by allocating them a higher percentage of collaborative savings in comparison with the ACAM and the EPM. Next, results show that although increasing the coalition size from two to five partners leads to a more than tripled profit level, increasing the size of the alliance has a negative impact on its long-term sustainability. Companies need to be aware that collaborating with a large number of partners increases alliance complexity and may dilute the strength of mutual partner relationships. Finally, the most striking finding is that no significant differences were observed in the allocation values when comparing over the division mechanisms.

Overall, the experiments suggest that carriers may reap significant operational benefits from sharing orders. However, the extent and longevity of these benefits highly depend on the characteristics of the partnering organisations and the allocation mechanism applied, stressing the importance of careful and thought through partner selection and gain sharing decisions. In terms of practical recommendations on collaborative performance, the most profitable coalitions consist of a sufficient, but not too large, amount of transport companies pooling a large number of orders that differ in size. In addition, the larger the service region of the coalition, the more opportunities for efficient order sharing emerge. Furthermore, intuitively appealing and operationally simple cost sharing techniques may well be utilised, which could reduce alliance complexity and enforce the strength of mutual partner relationships.

To conclude, the following relevant suggestions for **future research** can be made. First, when exploring joint route planning, the focus may be expanded from considering cost minimisation exclusively to account for customer service effects. Besides its impact on cost and efficiency levels, cooperation with fellow transport companies may also have an influence on the service that can be provided by each participating carrier. Although the offered service in terms of lead-time may improve for some of the cooperating partners, it may decline for others as a consequence of sharing customer orders. Second, the MDPDPTW developed in this chapter considers fairly basic problem assumptions. There is significant scope for extending the model to a more complex freight delivery setting. The joint route plan could be subject to a heterogeneous vehicle fleet or limitations on the number or type of customer orders that can be exchanged between coalition partners, for example. Third, a similar impact study of cooperation characteristics and allocation mechanisms could be done in other collaborative logistics environments. Following this observation, Chapter 5 performs a similar analysis in the context of horizontally cooperating organisations sharing warehouses or distribution centres and Chapter 6 investigates cost allocation mechanisms in intermodal barge networks. Fourth, considering the overview of Chapter 3 another natural avenue of research is to examine the efficacy of other cost allocation techniques in a joint route planning setting. Finally, the limitations of the experimental study are acknowledged. The consideration of specific factors and factor levels may influence the general validity of the findings. As such, a new experimental design with other experimental factors (e.g. market share of carriers) and/or factor levels (e.g. different factor level values) could be the subject of future research work.

Chapter 5

Collaborative savings and cost allocation for the cooperative facility location problem

5.1 Introduction

Considering the literature review of Chapter 2, existing studies on horizontal carrier cooperation all focus on collaboration opportunities within a transport context. In line with the broad definition of logistics including both the movement and storage of freight, this chapter [1] (Figure 5.1) presents a new approach to carrier cooperation: the sharing of warehouses or distribution centres (DCs) with collaborating partners. By jointly and optimally deciding on two types of decisions, namely, first which DCs to open and second how to allocate the quantity of product flows to each open DC, partnering companies aim to minimise their total logistics cost. This total cost consists of fixed costs of keeping DCs open and all costs of primary transport (between company depots and DCs) and secondary transport (between DCs and customer zones). In addition, variable costs incurred in each DC for each type of product can be added to the primary transport costs and variable costs incurred in each customer zone upon delivery of each type of product can be added to the secondary transport costs.

The cost minimisation problem described above can be classified as a facility

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[1] This chapter is based on the paper: Verdonck, L., Beullens, P., Caris, A., Ramaekers, K., Janssens, G., 2016a. Analysis of collaborative savings and cost allocation techniques for the cooperative carrier facility location problem. Journal of the Operational Research Society 67 (6), 853–871.

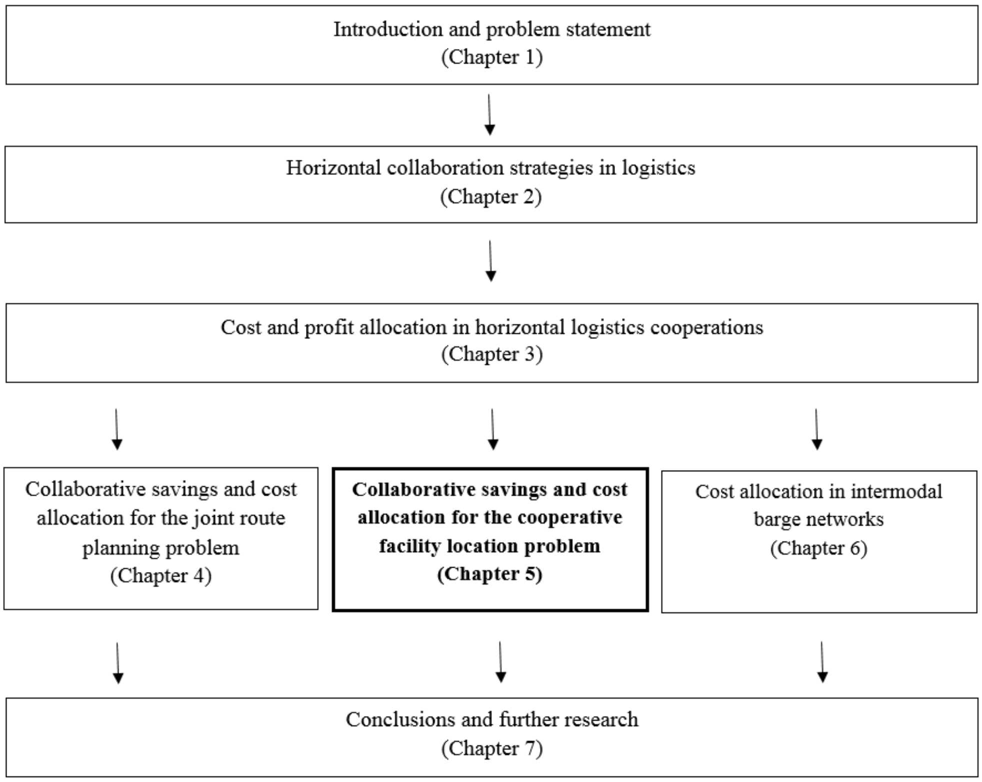

Figure 5.1: Outline of the thesis

location problem under cooperation (Goemans and Skutella, 2004). In the traditional facility location problem an optimal set of locations has to be selected for building facilities and the total minimum location costs are allocated to the customers. The context of horizontal carrier collaboration requires a different focus. Not only will the set of customers but also the set of potential locations vary with the selection of partners. Moreover, the cost allocation has to occur between the carriers in the coalition instead of between the customers. As a consequence, the issues of partner complementarity and partner selection become integral parts of the decision process. To this end, this chapter presents an innovative mathematical model that allows such investigations to be carried out using a single MILP.

As demonstrated in Chapter 4, selecting the right partners is not sufficient to guarantee long-term coalition stability. Dividing the coalition gains in a fair manner between the participants constitutes a key issue. Any allocation mechanism should induce partners to behave according to the collaborative goal and should strive to improve cooperation sustainability. In current customer-centred facility location literature, the allocation problem is solved exclusively by applying game theory (Tamir, 1993; Chardaire, 1998; Goemans and Skutella, 2004; Mallozzi, 2011). As these game theoretic mechanisms, like the Shapley value, may raise questions from transport companies about mathematical complexity, applicability, fairness transparency and stability, two additional cost allocation techniques are applied to the cooperative facility location problem under study in this chapter.

The main scientific contributions of this chapter can be summarised as follows. First, the literature on horizontal carrier collaboration is extended to the case of sharing DCs. Second, the cooperative facility location model is reformulated to make it fit this context and such that it can be easily applied to investigate partner selection. Partner selection is a feature that is absent from the current customer-centred cooperative facility location literature, but an important aspect in horizontal logistics collaboration. Third, similar to Chapter 4, numerical experiments are conducted based on an experimental design applied to a U.K. (United Kingdom) case study to analyse the relative benefits of different coalition structures and cost allocation mechanisms. In this way, recommendations are made to transport organisations considering collaboration on how they should tackle partner selection and gain sharing decisions.

The remainder of this chapter is organised as follows. Section 5.2 summarises the current research field of cooperative facility location. Moreover, differences between existing research work and models and applications presented in this chapter are clarified. A mathematical model is presented for the cooperative carrier facility location problem (CCFLP) in Section 5.3. In Section 5.4 details are provided on the cost allocation mechanisms that are compared for their efficacy in a cooperative facility location environment. The research methodology and design of the numerical experiment is described in Section 5.5. The goal of the experimental design is to investigate a number of hypothetical relations introduced in current collaboration literature between cooperation characteristics, collaborative performance and cost allocation results using a well-known statistical research method. Then, numerical results on the impact of coalition characteristics and cost allocation mechanisms are presented and discussed in Section 5.6. Finally, Section 5.7 formulates conclusions and directions for future research.

5.2 The cooperative facility location problem

In general, the facility location problem may be described as follows. Given a set of possible locations for facilities and a set of customer locations to serve, the goal is to locate facilities in such a way that the total cost for keeping these facilities operational while satisfying customer demand is minimised. The facility location problem may be classified into different categories, depending on the assumed restrictions. As such, a distinction can be made between the uncapacitated and the capacitated version of the problem, based on the existing capacity limits of each facility. In addition, the single-source and multi-source problem can be discerned, depending on the number of facilities that are allowed to serve each customer (Holmberg et al., 1999). Reviews of the facility location problem can be found in Klose and Drexl (2005) and ReVelle et al. (2008).

Analysing current facility location literature, the horizontal cooperation approach of carriers sharing DCs can be classified as a facility location problem under cooperation. Until now, the cooperative facility location problem has been studied exclusively in a customer-centred context. The goal of the cost allocation problem is to allocate the optimised location cost to the customers such that no coalition of customers has the incentive to build their own facilities or to ask a competitor to service them. It is well-known from this literature that the core of the game may well be empty and that there could thus be problems related to achieving stable outcomes for the grand coalition. Tamir (1993) studies the allocation of costs to the customers in a general facility location framework applying game theory. Chardaire (1998) investigates optimised facility location and fair sharing of total costs to the end-users of telecommunication networks. Goemans and Skutella (2004) consider the cost minimising location of public facilities (e.g. libraries, fire stations) or private facilities (e.g. distribution centres, supermarkets) in order to provide a certain level of service to customers. Mallozzi (2011) studies a single-facility location problem for which the location cost depends on the region where the new facility is located.

The existing research work on the cooperative facility location problem focuses on a customer-centred approach where out of a given set of potential locations an optimal set has to be selected for building facilities and the total minimum location costs so achieved are then to be allocated to customers in a fair manner using game theory concepts. In the context of horizontal carrier collaboration, not only will the set of customers but also the set of potential locations of DCs vary with the selection of partners and the cost allocation has to occur not between customers but the carriers in the coalition. The issues of partner complementarity and partner selection are now integral parts of the decision process. Following these observations, a contribution of this chapter is thus the novel applicability of the cooperative facility location model in a carrier collaboration environment, requiring a different focus.

5.3 Mathematical formulation of the cooperative carrier facility location problem

The cooperative carrier facility location problem (CCFLP) handled in this chapter can be defined as a multi-company, two-stage, capacitated facility location problem in which multiple sourcing is allowed. The latter means that demand in one customer zone for a particular product type can be fulfilled from more than one DC. It is in essence an extension of the multi-product, capacitated facility location problem, where each product serves a certain given demand in the market and where this product now originates from a specific independent carrier who owns a set of DCs that may or may not be used in the cooperation. For this reason, additional decisions need to be made on a fair cost allocation among participating companies. The supply network considered consists of logistics service providers, labelled carriers, transporting compatible products to multiple customer zones. This transport activity comprises of two stages, namely primary transport from each carrier's central depot to a number of DCs and secondary transport from these DCs to the different customer zones. In Figure 5.2 an example of a multi-company, two-stage supply network is visualised. Here, carrier A initially owns four DCs. However, consequential to its engagement in a cooperation with carriers B and C, carrier A could also transport its goods to the different customer zones via DCs owned by its partners. The goal of the cooperative facility location model is to share DCs between participating carriers with the aim of reducing both fixed and variable logistics costs.

The following model assumptions are made. Freight transport is modelled in terms of product flows and not in terms of individual vehicles with capacity constraints. This assumption is supported by the practice that carriers are typically able to hire additional third-party transporters. Each carrier has its own central depot from which freight is distributed to DCs and customer zones. Fixed costs, maximum capacities as well as the locations of the DCs are known and the throughput capacity of each DC is constant. The customer zone locations and their demand for transport from each carrier are also known in advance. Each customer zone may be served by more than one DC. The transport between carrier depots and DCs is called the primary transport. Its cost is a linear function of the actual flow of products from the depots

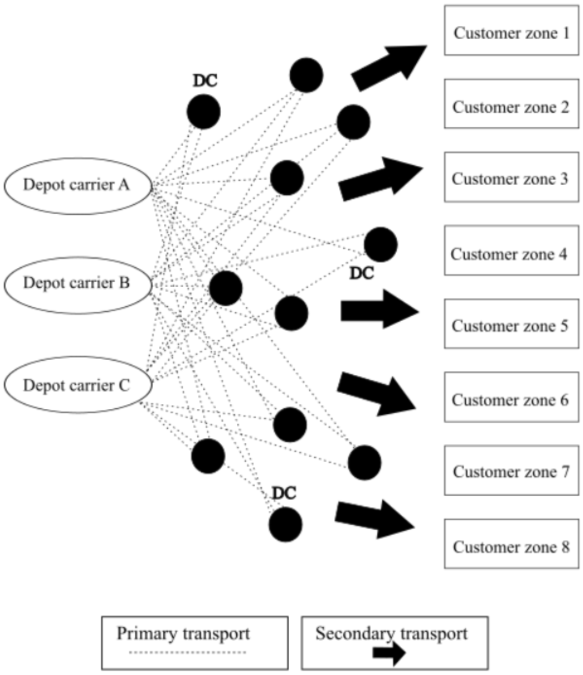

Figure 5.2: Multi-company two-stage supply network, with primary transport between carrier depots and DCs and secondary transport between DCs and customer zones

to the DCs. Products are transported from DCs to customer zones through secondary transport, which has a linear character as well. In addition to the variable transport costs, costs can be increased to account for the fixed DC-related costs and a local delivery charge for each customer zone, respectively. Since a cooperative facility location problem is modelled, all DCs can be supplied by more than one carrier and each DC can supply multiple product units to more than one customer zone. In this way, if a carrier participates in the cooperation, he can share his DCs with the other partnering carriers.

Similar to traditional facility location problems, the objective is to minimise a total cost function, accounting for both fixed costs of keeping DCs open and all primary and secondary transport costs. The decisions to be taken relate to which cooperative partnership is formed (carrier selection), which DCs to open and the assignment of product flows. Considering the first decision, it is fixed beforehand which carriers take part in the coalition and allow to share their DCs. As such, the impact of horizontal collaboration may be evaluated for various cooperation structures using an experimental design.

The problem is mathematically formulated as an MILP, making use of the following notation:

Table 5.1: Notation

Data	
I	Set of carriers (index i)
$\mathcal{A}$	Set of DCs (index a)
$\mathcal{B}$	Set of customers (index b)
$\mathfrak{c}_{iab}$	Cost of transporting a single product unit from carrier i to DC a and on to customer b
F_a	Fixed cost of operating DC a
D_{ib}	Demand for products of carrier i in customer zone b
T_a	Capacity or throughput limit of DC a
g_{ia}	Indicator that equals 1 if DC a belongs to carrier i, 0 otherwise
w_i	Indicator that equals 1 if carrier i takes part in the cooperation, 0 otherwise
Decision variables	
z_{iab}	Total number of product units transported from carrier i to customer zone b via DC a
o_a	Equals 1 if DC a is operational, 0 otherwise

The goal is to open a subset of DCs associated with the cooperating partners. Moreover, for each operational DC, a decision needs to be made on the total number of product units transported from the carriers' central depots to the DC and the total number of product units transported from the DC to the different customer zones. Using the decision variables, the CCFLP can be translated into the following mathematical model:

$$Min \sum_{a \in \mathcal{A}} F_a o_a + \sum_{i \in I} \sum_{a \in \mathcal{A}} \sum_{b \in \mathcal{B}} \mathfrak{c}_{iab} z_{iab} \tag{5.1}$$

Subject to

$$\sum_{a \in \mathcal{A}} z_{iab} \geq D_{ib} w_i \qquad \forall b \in \mathcal{B}, i \in I \tag{5.2}$$

$$\sum_{i \in I} \sum_{b \in \mathcal{B}} z_{iab} \leq T_a o_a \qquad \forall a \in \mathcal{A} \tag{5.3}$$

$$o_a \leq w_i + 1 - g_{ia} \qquad \forall i \in I, a \in \mathcal{A} \tag{5.4}$$

$$o_a \in \{0, 1\} \qquad \forall a \in \mathcal{A} \tag{5.5}$$

$$z_{iab} \geq 0 \qquad \forall i \in I, a \in \mathcal{A}, b \in \mathcal{B} \tag{5.6}$$

The objective function (5.1) minimises the sum of fixed costs associated with operating DCs and transport costs to distribute products from central depots to DCs and on to customer zones. Constraint set (5.2) guarantees that the total demand of all customer zones is satisfied. Constraints (5.3) ensure that the total amount of product units distributed from carrier depots does not exceed the throughput limit of open DCs. Constraint set (5.4) reflects the issue of opening and closing DCs when carriers take part in the coalition and want to share facilities. Statement (5.5) enforces the binary nature of decision variable o_a, while constraints (5.6) impose non-negativity restrictions on the other decision variable z_{iab}.

It is worthwhile to note that, for any given set of partners considered or, hence, choice of values for w_i, constraints (5.4) can be eliminated and the model can be reduced to the classic formulation of a multi-product two-stage capacitated facility location model. As professional commercial MILP solvers eliminate redundant constraints and variables as part of preprocessing a model, there is no real loss of computational efficiency in comparison with building tailored MILP models for each (sub)coalition separately. The current formulation facilitates analysis in that only a single model needs to be constructed and can then be run for various coalition structures. In addition, this formulation has the advantage in showing explicitly how a change in partners also changes the set of available potential locations for DCs as well as the demand to be satisfied.

The cooperative game corresponding to the CCFLP is superadditive [2] and this is proven as follows. Consider any two disjoint coalitions $S \subseteq N$ and $T \subseteq N$ (where $S \cap T = \emptyset$) and let the optimal objective function value of CCFLP(I) for any coalition $I \subseteq N$ be $Z^* \equiv c(I)$. It then holds that $c(S) + c(T) \geq c(S \cup T)$ since the solution space of CCFLP($S \cup T$) includes the solution spaces of the two disjoint set models CCFLP(S) and CCFLP(T) and therefore (optimal) feasible solutions of these disjoint set models

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[2] Superadditivity: The cost allocation of a combination of several separate coalitions is less than or equal to the sum of the separate allocation values of these coalitions: $c(i \cup j) \leq c(\{i\}) + c(\{j\})$

combined also forms a feasible solution for CCFLP$(S \cup T)$. Unless the companies would operate in completely separated geographical areas, it is also clear that the game will typically be individually rational, i.e. that $\sum_{i \in I} c(\{i\}) > c(I)$. These two observations imply that the total cost gains from collaboration should increase with the number of participating partners. However, in practice more partners may complicate the process of selecting a cost allocation method that is perceived fair to all partners and may in addition increase managerial complexity and costs for maintaining the collaborative relationships. Furthermore, in order to share DCs, there must exist compatibility between the types of functions a DC needs to perform for each of the collaborating carriers, which will limit the pool of available partners.

The CCFLP can be expected to lead to particular outcomes that differ from a traditional facility location setting. In the traditional application of facility location models, a large number of potential sites are considered, out of which typically a small number of sites are opened. In a DC sharing context, however, it is assumed that each carrier starts from a set of open DCs of which the number and locations are already (near to) optimal for this carrier when working independently. When considering collaboration, this set of opened facilities provides the starting point and the model will investigate whether savings can be achieved from collaboration. These savings can only result from either keeping all existing DCs open, but finding a better allocation of transport routes, or from closing a number of DCs and reoptimising the allocation of transport routes.

Mathematically speaking, it is possible to include additional potentially relevant cost components in the CCFLP. This includes any managerial costs, which could be a function of the number of participants in the coalition. However, in this case, the game may no longer be superadditive and the issue of selecting partners would then account for the trade-off between operational costs and managerial costs. In addition, the model may be extended by including an annuity stream value of proceeds that would be gained from selling a DC when closing it or by incorporating the possibility that any coalition might want to identify new potential locations to build new (jointly used) DCs. These refinements are not implemented here as the value of collaboration may then be heavily influenced by the one-off revenues or investments. Instead, the model is deliberately kept simple by focussing on the operational fixed and variable costs only, so that the operational value of collaboration between existing carriers can be established.

5.4 Collaborative cost allocation

As in any collaboration, dividing the coalition gains in a fair manner between the participants of a cooperative facility location alliance constitutes a key issue. The applied allocation mechanism should induce partners to behave according to the collaborative goal and should strive to improve cooperation stability. However, as visualised in Table 3.3, a wide range of possible allocation mechanisms exists. Since each method has its specific benefits, drawbacks and fairness properties, it remains ambiguous which technique(s) could guarantee sustainability in a cooperative facility location setting. In this context, an extensive comparative analysis based on an approved statistical technique, applying three different allocation mechanisms to a U.K. case study, is performed in Section 5.6.

The three methods selected for their application in this chapter are the Shapley value, the Alternative Cost Avoided Method (ACAM) and the Equal Profit Method (EPM) [3] for the following reasons. First, as current customer-centred facility location literature solves the allocation problem exclusively with game theory, a comparison with other techniques is interesting to explore. Moreover, basic game theoretic mechanisms may raise questions about mathematical complexity, applicability, fairness transparency and stability in practice. The most prevalent solution concepts within cooperative game theory are the Shapley value and the nucleolus. The preference for the Shapley value may be explained by its ease of calculation. Second, considering the list of alternative allocation techniques discussed in Chapter 3, the mechanisms based on the division between separable and non-separable costs developed in Tijs and Driessen (1986) are easy to use and intuitively appealing. The motivation for choosing ACAM is based on its transparency, understandability and the fact that it takes into account the different contribution levels of all coalition partners. Finally, in the early phases of a growing horizontal cooperation, it may be beneficial for communication and negotiation purposes to have an initial allocation where the relative benefits of the participating organisations are as equal as possible. For this reason and considering its stability guarantee, EPM constitutes the third allocation technique under study.

In addition to the above reasoning, the choice for Shapley, ACAM and EPM is also related to the joint route planning research performed in the previous chapter. By applying the same allocation mechanisms in distinct collaboration environments, their general validity in horizontal logistics cooperation could be investigated. Moreover,

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[3] Details on the theoretical description and mathematical formulas of Shapley, ACAM and EPM can be found in Section 4.3.

based on the results of the analyses performed, recommendations could be formulated to collaborating partners on the applicability of different allocation techniques taking into account the characteristics of the cooperation project.

5.5 Research design

Considering the significant failure rates for starting partnerships, several studies have investigated the conditions influencing the success of horizontal logistics collaboration (Cruijssen et al., 2007a; Schmoltzi and Wallenburg, 2011; Audy et al., 2012; Vanovermeire et al., 2013). To investigate the impact of the collaborative characteristics on attainable savings, the statistical approaches of experimental design and factorial ANOVA are very useful, as explained in Section 4.5. Moreover, these techniques can also be used to investigate the relative differences between cost allocation methods. According to Cruijssen et al. (2007b) and Cruijssen et al. (2007c), distrust and doubts about the applied cost or profit allocation mechanisms have caused many horizontal logistics collaborations to break up.

The case study presented in this chapter demonstrates the applicability of the CCFLP model for investigating partner selection and cost allocation decisions. The reason for developing an experimental design environment is that, in this way, it can be studied whether the various relationships hypothesised in current collaboration literature between cooperation parameters, collaborative performance and cost allocation results indeed transfer to a cooperative facility location setting. While the limitations of the presented case study are acknowledged, the aim of the numerical analyses is to provide insights on which partnership structures may yield significant collaborative benefits and how coalition stability could be influenced by the applied cost allocation mechanism.

The remainder of this section is organised as follows. Section 5.5.1 describes the U.K. case study developed for the numerical analyses. This case study constitutes the basis for the experimental design. Interested readers are referred to the authors for more details on the case study data. Section 5.5.2 presents the hypotheses studied, defines the experimental factors coinciding with the relevant cooperation parameters and explains how the experiments relate to the case study data.

5.5.1 Case study

Extensive numerical experiments are performed on a case study consisting of an artificial set of carriers distributing similar products in two phases (see Figure 5.2) and employing multiple sourcing. Three carriers A, B and C with their central depots located in Scotland, London and Wales, respectively, distribute products in two phases. The assumption is made that they distribute products that are compatible in that they require a similar type of DC. These carriers can hence embark on a project whereby they would share their DCs. The ownership and location of all DCs, central depots and customer zones are visualised in Figure 5.3. Fixed costs and maximum capacities of the ten DCs are known, as well as primary and secondary transport costs. Transport demand stems from ten different customer zones representing large geographical areas in the United Kingdom and is also known beforehand.

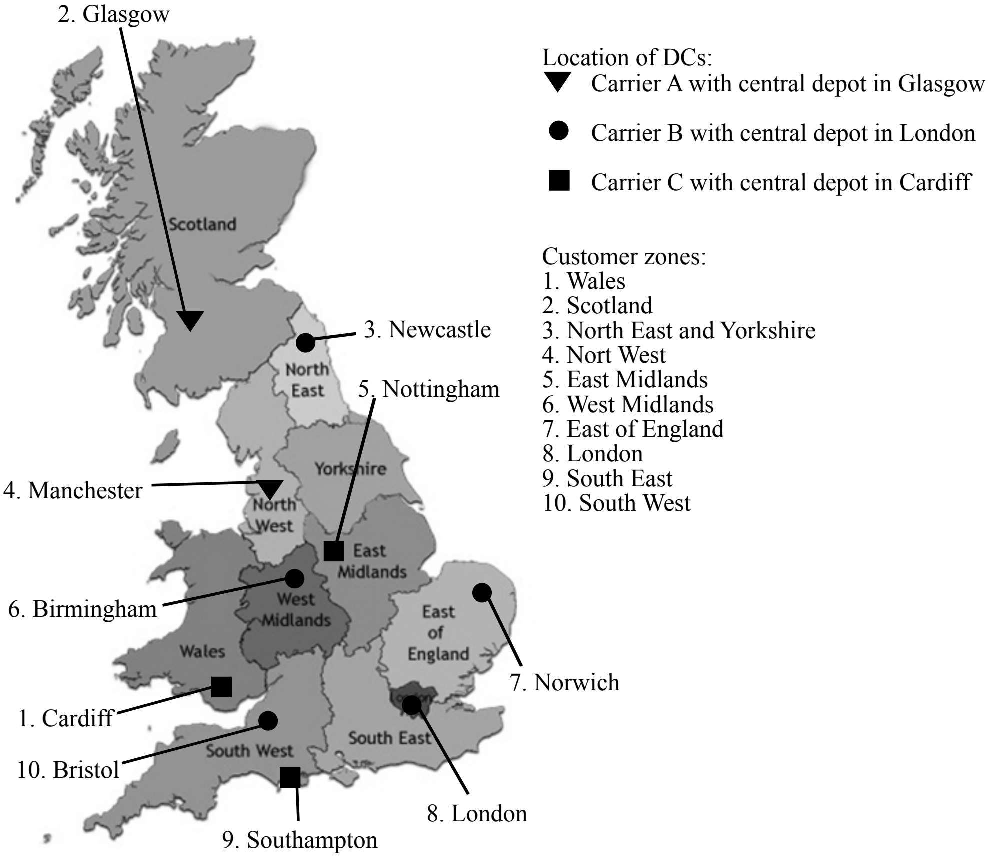

Figure 5.3: Geographic locations of central depots, DCs and customer zones for carriers A, B and C

While the case study data used in the analyses is fictitious, its numerical values are based on real logistics settings in the U.K.. Numerical values for transport costs are based on travel distances on the U.K. road network, fuel and driver wages and average speeds derived from legal speed limits. In addition, variable operating costs at DCs and customer demand points can be added to the transport costs in the CCFLP model. The fixed costs levels at DCs depend on the functions of a DC and the associated level of automation needs for storage and retrieval, order picking, order tracking, and so on. While high levels of investment in automation increase fixed costs, they may also reduce the overall variable operating costs at the DC leading to an increased contribution of fixed costs relative to variable costs. Because of the resulting variation in relative levels of fixed and variable DC cost components, the fixed cost data is calibrated towards being able to represent two extreme situations. In the first situation, the total DC costs of carriers not cooperating constitutes approximately 50% of the total transport costs. In the other situation, total transport costs in the case of no cooperation are 50% of the total DC costs. According to practitioners' experience, most realistic settings fall within these two boundaries (Zollinger, 2001; Rantasila and Ojala, 2012).

5.5.2 Research hypotheses and experimental design

In the first part of the numerical experiment, the effect of specific coalition characteristics, discussed in the previous section, on alliance performance is investigated. Based on statements made in current scientific literature and the design of the case study, the following research hypotheses are analysed here in a cooperative facility location setting.

First, transport companies may be obliged to work under different settings of fixed DC costs relative to transport costs, depending on the functions of their DCs. As such, it is examined whether collaborative performance is sensitive to the two extreme situations introduced earlier with respect to this ratio, which leads to the following hypothesis:

Hypothesis 1. *Coalition performance is significantly influenced by the level of fixed DC costs of its partners.*

Second, according to Van Breedam et al. (2005) and Schmoltzi and Wallenburg (2011), broad geographic coverage constitutes an important aspect of collaborative gains and sustainability. In this context, the following hypothesis is investigated:

Hypothesis 2. *The number of served customer zones has a positive impact on coalition performance.*

Third, the influence of the number of partners (organisational scope) on coalition performance is examined. In this way, it can be determined whether it is better to share DCs with a large or a limited number of fellow transport companies. The statements made by Park and Russo (1996) and Griffith et al. (1998) in a general joint venture setting lead to the following hypothesis:

Hypothesis 3. *The number of collaborating partners has a positive impact on coalition performance.*

Fourth, in line with the operational fit concept described by Van Breedam et al. (2005), the impact of similarity of collaborating companies on alliance performance is analysed. The level of equality of firms is measured in terms of the fraction of total demand each carrier needs to serve and the relative number of DCs a carrier contributes to the coalition. In this way, a comparison of gains achievable when changing the initial level of market consolidation across participating carriers can also be made. The following hypothesis is studied:

Hypothesis 4. *Coalition performance is higher for cooperations between partners differing in terms of DC ownership and demand distribution, compared to collaborations established between equal participants.*

Finally, DC sharing affects both the location of opened DCs and the allocation of transport flows. Given the increased attention for environmental impacts of transport (e.g. emissions, congestion), the following hypothesis is investigated:

Hypothesis 5. *Sharing DCs positively affects total transport cost and distance travelled.*

Throughout these hypotheses collaborative performance (CP) is mathematically defined as:

$$\text{CP} = \sum_{i \in N} c(\{i\}) - c(N) \qquad \forall i \in N \tag{5.7}$$

with N denoting the total number of coalition partners, $c(\{i\})$ the stand-alone costs of an individual company i and $c(N)$ the total cost of the coalition. All costs are determined by applying the CCFLP, given by Equations (5.1)-(5.6), to all instances of the case study with the use of LINGO 10.0 software. The motivation for the absolute character of the dependent variable is similar to the motivation provided in Section 4.5.1 for the joint route planning experiments.

The goal of the second part of the numerical experiment is to examine the applicability and suitability of the three **cost allocation methods** in varying cooperative facility location scenarios. By analysing the Shapley, ACAM and EPM allocation values over all factor combinations discussed next, the following research questions are investigated:

- Do any of the four experimental factors have an effect on the stability of the grand coalition, considering costs to be allocated by means of the Shapley value, the ACAM and the EPM?
- Do there exist significant differences between the allocation values defined by means of the Shapley value, the ACAM and the EPM?
- Do there exist interdependencies between the characteristics of the cooperation and the cost share allocated to its participants by means of the Shapley value, the ACAM and the EPM?

Based on the hypotheses described above, the following experimental design is developed. As explained in Law (2007), a 2^4 factorial design is set up. In this way, the main and interaction effects of four factors related to Hypotheses 1 to 4 can be derived by examining the value of the dependent variable CP associated with each of the two factor levels, labelled '+1' (high) and '-1' (low). Following the research hypotheses discussed above, the experimental factors or cooperation characteristics considered in the analyses, are: fixed DC costs (F1), number of served customer zones (F2), number of participating carriers (F3) and degree of inequality of participating carriers (F4). In Table 5.2 an overview is provided of studied cooperation characteristics and their associated level values. With respect to the factor 'fixed DC costs', level '+1' is equal to the level '-1' fixed DC cost multiplied by five. With this multiplication, the effect of a sufficiently large difference in fixed DC costs relative to transport costs and approximately capturing the 50% ratios discussed earlier, can be investigated. Concerning level '-1' of factor two, the customer zones not considered are North East and Yorkshire (3), West Midlands (6), South East (9) and South West (10). The reason for choosing to ignore these four customer zones is their significance in the distribution activities of the considered carriers. Leaving out customer zones that only represent a small fraction of customer demand would not sufficiently influence collaborative performance. With regards to factor three, carrier A is left out in the two-partner coalition. Leaving out carrier B or C would lead to insufficient DC capacity to cope with total customer demand. It is important to point out that in the B and C two-partner instances, the demand of carrier A is reallocated to B and

Table 5.2: Experimental factors and factor levels

Factor	Level -1	Level +1
1. Fixed DC costs	Low	High
2. Number of customer zones	Six	Ten
3. Number of carriers	Two	Three
4. Degree of inequality	Equal	Different

C, while the DCs that belong to carrier A are eliminated from the set of potential DCs available to B and C. In this way, the influence of the level of consolidation in the carrier market could be studied. The factor 'degree of inequality' is measured in terms of DC ownership and demand distribution of partnering carriers. As such, 'equal' carriers in a two-partner coalition each own 50% of all DCs and are responsible for the same percentage of demand. On the contrary, 'different' partners own 30% and 70% of all DCs, respectively, and execute the same amount of customer zone orders. In a three-partner coalition, 'equal' carriers each own approximately 33.33% of all DCs and serve 33.33% of demand. 'different' partners own 20%, 30% and 50% of all DCs, respectively, and account for the same amount of customer demand.

Based on these factor levels, 16 experiments, coinciding with different cooperation settings, are created. Table 5.3 lists all studied experiments and the factor levels they are associated with. For comparison and analysis purposes, 30 instances are generated for each experiment, leading to a total of 480 test instances. Regarding these 30 instances per experiment, it can be stated that they differ in terms of demand data and fixed DC costs, which are random observations drawn from a normal distribution coinciding with realistic U.K. data. Transport costs are left unchanged throughout the experiments since they are based, among others, on the real geographical locations of customer zones.

5.6 Results

This section is devoted to the presentation and discussion of the CCFLP outcomes, both in terms of collaborative savings (Section 5.6.1) and allocation values (Section 5.6.2). The main and interaction effects of the studied cooperation characteristics on collaborative performance are analysed by factorial ANOVA. The assumptions under which the ANOVA statistics are accurate and reliable are similar to those described in Section 4.6.2.1 within the context of joint route planning. Next, the effects of

Table 5.3: Experiments of full factorial design

Experiment	Factor 1	Factor 2	Factor 3	Factor 4
1	-1	-1	-1	-1
2	+1	-1	-1	-1
3	-1	+1	-1	-1
4	+1	+1	-1	-1
5	-1	-1	+1	-1
6	+1	-1	+1	-1
7	-1	+1	+1	-1
8	+1	+1	+1	-1
9	-1	-1	-1	+1
10	+1	-1	-1	+1
11	-1	+1	-1	+1
12	+1	+1	-1	+1
13	-1	-1	+1	+1
14	+1	-1	+1	+1
15	-1	+1	+1	+1
16	+1	+1	+1	+1

applying the Shapley value, the ACAM and the EPM are analysed and compared. All statistical experiments are performed using SPSS for Windows Release 24.

5.6.1 Collaborative savings results

5.6.1.1 Main effects of cooperation characteristics on collaborative savings

The savings level associated with cooperative facility location ranges from 1.75 to 24.52% over all experiments, with an average savings level of 9.35% (Table 5.4). Horizontal collaboration through DC sharing can hence produce large operational benefits to carriers. However, because of the wide spread in possible savings and because 1.75% may not be a sufficient gain to compensate for additional overhead costs of collaboration (which are not accounted for in these experiments), a further investigation of the main effects of the four factors on the savings attained by the collaboration is in order.

Table 5.5 presents the ANOVA results for the main effects of the considered alliance characteristics on coalition performance. For each of the studied characteristics the ω^2 value (Olejnik and Algina, 2000) is also reported, indicating their respective

Table 5.4: Collaborative savings level of factorial experiments

Experiment	Average savings	Minimum savings	Maximum savings
1	0.046	0.018	0.084
2	0.055	0.020	0.090
3	0.057	0.036	0.093
4	0.062	0.021	0.098
5	0.054	0.039	0.081
6	0.075	0.032	0.139
7	0.059	0.046	0.075
8	0.090	0.044	0.136
9	0.178	0.155	0.203
10	0.123	0.083	0.181
11	0.210	0.155	0.245
12	0.135	0.102	0.176
13	0.069	0.036	0.106
14	0.102	0.062	0.166
15	0.071	0.055	0.104
16	0.109	0.080	0.151
Total	0.094	0.018	0.245

Table 5.5: Full factorial ANOVA on coalition performance: main effects

	SS	df	MS	F	p	ω^2
F1	101751981120859.000	1	101751981120859.000	1120.900	0.000*	0.365
F2	2040380407329.000	1	2040380407329.000	22.477	0.000*	0.007
F3	7635569410297.500	1	7635569410297.500	84.113	0.000*	0.027
F4	79749939166410.500	1	79749939166410.500	878.526	0.000*	0.286

Note: * Significant at $\alpha = 0.01$

effect size. The mean coalition performance for the studied factor levels are displayed in Table 5.6. Bonferroni and Games-Howell post hoc t-tests were used to define the statistical significance of the different factor levels (Field, 2013).

Table 5.6: Mean coalition performance (in k€) associated with studied factor levels

F1	Mean CP	F2	Mean CP	F3	Mean CP	F4	Mean CP
-1	788.683	-1	1183.901	-1	1375.224	-1	841.490
+1	1709.516	+1	1314.298	+1	1122.975	+1	1656.709

Table 5.5 indicates that all of the main effects exhibit a statistical significance of less than 0.01. As such, each of the four studied coalition characteristics has a significant impact on coalition performance. The next paragraphs will discuss the experimental factors and the proposed hypotheses (Section 5.5.2) independently.

Reviewing the ω^2 values reveals that the **fixed DC costs (F1)** parameter has the most profound impact on collaborative performance. Moving factor one from its '-1' level to its '+1' level, while holding all other factors fixed, leads to a more than doubled savings level, confirming Hypothesis 1. Collaboration incentives thus improve significantly if carriers are faced with heightened DC investments. To compensate for the increase in operating costs, carriers improve their collaborative distribution by enhancing the efficiency of their product distribution network connecting depots, DCs and customer zones. In line with Hypothesis 4, the factor **degree of inequality (F4)** shows a significant positive impact on realised cost reductions. A coalition with partners differing in terms of DC ownership and demand distribution will gain on average 97% more than a partnership comprised of fairly equal participants. As partner differences may complement or supplement each other, the number of possible improvement opportunities significantly increases. This is compatible with the results by Vanovermeire et al. (2013) in an order consolidation context, who found that shippers differing in average order size and/or number of orders leads to better results in terms of collaborative profit in a significant amount of cases. While these findings indicate that the overall relative gains achievable may be greater when firms are complementary on the one hand, Verstrepen et al. (2009) advise on the other hand that it is better to select partners of approximately similar size and market power in order to avoid unilateral dominance when it comes to cost sharing arrangements. This underlines an important dilemma between total cost savings achievable, which are higher with the degree of inequality rising, versus the practical implementation of fair allocations of total gains, which may be hampered with a rising degree of inequality between carriers. Next, Hypothesis 3 can be expounded upon in a cooperative facility location setting. As discussed earlier in Section 5.3, it should be expected that including more partners increases total savings achieved. For this, comparisons cannot, however, be made based on factor three CP levels, but the characteristic cost function values of subcoalitions in the experiments of three carriers need to be studied. As such, no subcoalition can do equally well or better than the grand coalition. In this sense, economies of scale as intended in Park and Russo (1996) and Griffith et al. (1998) also apply in a cooperative facility location context. However, with respect to the third factor, Table 5.6 shows that the **number of coalition partners** affects the amount of collaborative savings in a negative way when considering a DC sharing coalition. As such, a two-partner coalition will enjoy cost savings that are on average 18% higher than those of a collaboration with three partners. If the market is more consolidated such that two carriers serve the same total demand rather than three carriers and despite having access to less potential DC sites, collaboration in the two carrier market setting thus leads to significantly higher cost savings. Collaborating with a limited number of partners also reduces alliance complexity and may enforce the strength of mutual partner relationships. Hypothesis 2 can be confirmed in the cooperative facility location setting under study. Serving ten **customer zones** instead of six adds, on average, 11% to the collaborative savings level, leaving all other cooperation characteristics unchanged. Increased geographical coverage can provide more cooperation opportunities and could thus lead to larger cost reductions. The value of broad geographical coverage in terms of potential savings, discussed by Van Breedam et al. (2005) and Schmoltzi and Wallenburg (2011) in a general logistics collaboration context, is thus confirmed in a cooperative facility location environment. However, the remark needs to be made here that, although the main effect of factor two is significant, its explaining power is rather limited, as shown by its low ω^2 value. Finally, with respect to the **impact of DC sharing on transport** (Hypothesis 5), results demonstrate that jointly and optimally deciding on the location of DCs and the allocation of product flows not only reduces total logistics costs, but is likely to also improve transport efficiency. It is clear that this is in general not necessarily true, in particular when as a result of collaboration many DCs would be closed. It is assumed, however, that most DC sharing partnerships will start from a similar situation as in the experiments considered here whereby as a result of the collaboration a relatively small number of DCs (two, on average) will close. The average decrease in transport costs is 10% for the case study. In 89% of all studied instances, sharing DCs with fellow transport companies decreases both fixed DC costs and transport costs. The cases where transport costs increase are, as expected, all for situations where the fixed DC costs are high, as this stimulates the closure of DCs and thus could increase transport costs as a result. As such, cooperative facility location does not only benefit participating carriers but might reduce congestion and CO_2 emissions as well. An external effects analysis needs to be performed, however, to validate this statement.

5.6.1.2 Interaction effects of selected coalition characteristics

Since the ω^2 values of the experimental factors 'fixed DC costs' and 'degree of inequality' are prominently larger than the other ones, it is investigated whether either of these two factors shows a significant two-way interaction effect with one or more of the other collaboration characteristics, as presented in Table 5.7. In this way, the explanatory power of the analysis could also be increased.

Table 5.7: Full factorial ANOVA on coalition performance: interaction effects

	SS	*df*	*MS*	*F*	*p*
Fixed DC costs x No. of customer z.	185232115856.719	1	185232115856.719	2.041	0.154
Fixed DC costs x No. of carriers	8969553823255.670	1	8969553823255.670	98.809	0.000*
Fixed DC costs x Degree of ineq.	1047942225758.800	1	1047942225758.800	11.544	0.001*
Degree of ineq. x No. of customer z.	60636720357.019	1	60636720357.019	0.668	0.414
Degree of ineq. x No. of carriers	32885140820193.000	1	32885140820193.000	362.263	0.000*
Note: * Significant	at $\alpha = 0.01$				

ANOVA results demonstrate that the positive main effect of the fixed DC costs is significantly influenced by the number of carriers taking part in the coalition (p value = 0.000). As Figure 5.4 visualises, heightened DC investments have the most profound impact on collaborative performance when three partners cooperate. The reason for this is that, on average, the number of closed DCs consequential to their increase in fixed operating costs is significantly higher for three-partner coalitions compared to two-partner coalitions. When more partners decide to share their DCs, high fixed cost levels thus constitute a strong collaboration incentive.

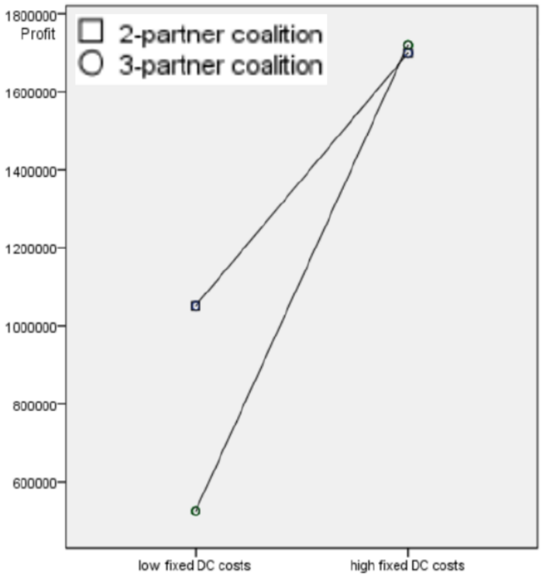

Figure 5.4: Average profit level for each combination of fixed DC costs and number of carriers

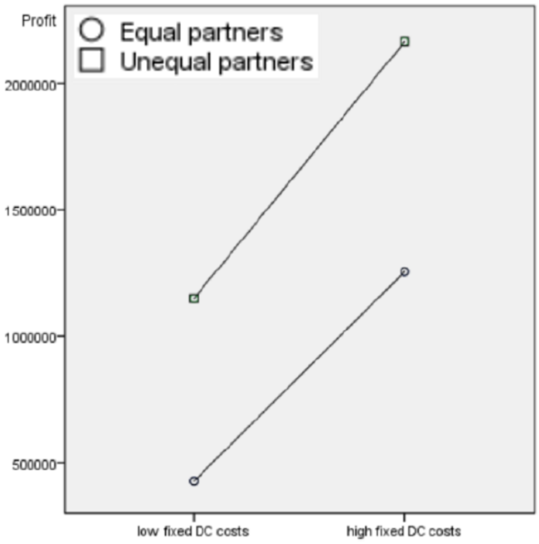

Figure 5.5: Average profit level for each combination of fixed DC costs and degree of partner inequality

Next, Figure 5.5 visualises the significant interaction effect between the level of fixed DC costs and the degree of inequality between the collaboration partners (p value = 0.001). The positive main effects of fixed costs associated with DC functioning and partner inequality slightly enforce each other in a cooperative facility location setting. As such, carrier organisations considering horizontal collaboration best seek for partners differing in terms of DC ownership and demand distribution, but with a sufficiently large fixed DC cost level (e.g. automated warehouses).

Finally, Figure 5.6 demonstrates how the positive effect of different partner characteristics has a larger impact on collaborative performance when coalition size is limited to two carriers (p value = 0.000). Coalitions of two participants who complement each other in terms of DC ownership and demand distribution gain significantly more savings than collaborations between three differing partners. This finding is in line with Verstrepen et al. (2009) stating that collaborative synergy may be hampered with a rising degree of inequality between participating carriers. Collaborating with a limited number of partners reduces alliance complexity leading to significantly higher cooperative cost savings.

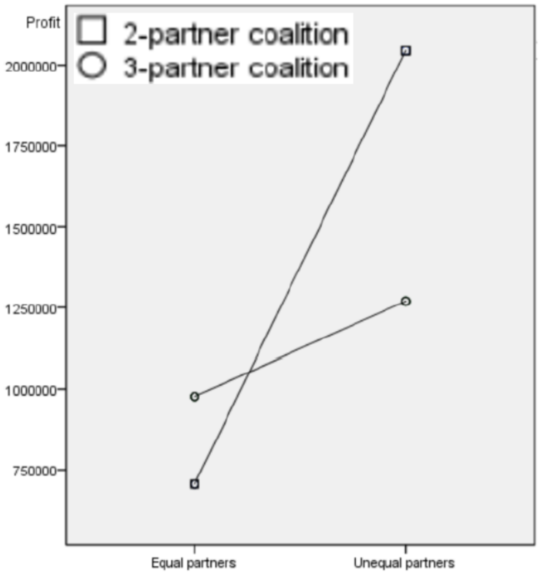

Figure 5.6: Average profit level for each combination of degree of partner inequality and number of carriers

5.6.2 Cost allocation results

In order to ensure sustainability of the cooperation project, incurred logistics costs need to be divided in a fair way among the participants. For this reason, the collaborative costs, calculated by means of the proposed CCFLP, are now allocated to the carriers applying the Shapley value, the ACAM and the EPM.

Similar to the stability analyses performed in Chapter 4, compliance of the Shapley and ACAM solutions with individual, subgroup and group rationality needs to be verified. Moreover, two modifications have been applied to the EPM ('Stability relaxation EPM' and 'ϵ-EPM') in order to find a feasible solution for non-stable collaborations. For more details on both topics, the reader is referred to Section 4.6.3.

Analysing cost allocations over all instances reveals that **stability** of the grand coalition is guaranteed in 91% of the studied experiments. In the remaining 9% the core of the cooperative game is empty. If the grand coalition is stable, then no subgroup of partner companies has the incentive to leave the grand coalition and be better off acting alone. Results demonstrate that in the experimental design stability either holds or not, that is, that this outcome is independent of the allocation technique used in this chapter. The non-stable coalition instances demonstrate the influence of cooperation structure on the longevity of cooperative facility location alliances. Increasing the number of coalition participants has a negative impact on its long-term sustainability. While two-carrier cooperations are always related with stable outcomes, only 82% of the three-carrier cooperations are associated with stability. As such, the number of coalition partners not only affects the collaborative savings in a negative way, increasing the coalition size also decreases its sustainability. This finding once again confirms the statement that a limited number of partners reduces alliance complexity and enforces the strength of mutual partner relationships. Besides the size of the coalition, the degree of inequality between its partners also influences collaborative stability. Although a coalition with partners differing in terms of DC ownership and demand distribution leads to an almost doubled profit level compared to an alliance between equal partners, a rising degree of partner inequality may impede longevity of the collaboration project. Moving factor four from its '-1' to its '+1' level, while holding all other factors fixed, results in a decrease of the number of stable instances by 9%. Regarding the other experimental factors, the influence on coalition stability is not so clear. When cooperations with varying levels of fixed DC costs or customer zones are compared the number of stable versus unstable experiments is divided almost equally.

Investigating the **allocation values** defined by means of the Shapley value, the

ACAM and the EPM variations over all instances, the following observations can be made. First, when comparing over the division mechanisms using paired t-tests, no significant differences exist in the allocation values. The share of logistics costs allocated to the cooperation participants is thus fairly similar with respect to the allocation technique used here. On average, the smallest differences are associated with coalitions between equal partners. This is illustrated in Figure 5.7 in which the allocation results of the three methods on a coalition of three similar partners A, B and C are shown. For all two-partner coalitions, Shapley and ACAM even lead to identical cost allocations. Similar results were found by Vanovermeire et al. (2014b) in a collaborative order consolidation context.

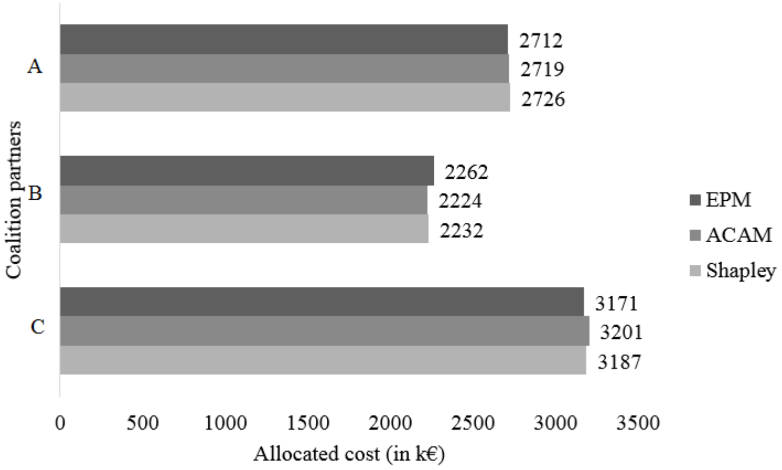

Figure 5.7: Cost allocation results for coalition of three companies with similar characteristics

Second, examining the cost share allocated to the different cooperation participants reveals that the allocation of cost savings is related to the cooperation structure, regardless of the used division mechanism. As such, in two-partner coalitions consisting of equal carriers, collaborative cost savings are almost equally divided among both companies, irrespective of possible differences in partner contributions in terms of DC closure and/or changes made in distribution activities consequential to the set-up of the collaboration. On the contrary, in three-partner coalitions comprised of equal participants, the highest share of collaborative savings is allocated to the organisation that has contributed most to the partnership. For example, in one of the instances of Experiment 7 carrier B receives up to 5.11% of collaborative cost savings while carriers A and C enjoy cost savings up to 3.47% and 3.80%, respectively. The explanation for this result may be found in the design of the collaborative product distribution network connecting carrier depots, DCs and customer zones. Owing to the establishment of the collaborative facility location project, the London DC, owned by carrier B, is closed to save on total logistics cost. As a consequence, because this DC is also the location of the central depot (or factory), carrier B had to make the most profound changes in its distribution activities. The allocation techniques account for these contributions by rewarding carrier B with the highest share in the collaborative savings. Investigating coalition values for collaborations comprised of different partners demonstrates that in all these cases division of cost savings is related to the collaborative efforts made by the participants, regardless of the other cooperation characteristics or the allocation mechanism applied in this chapter. Third, the original EPM and the EPM with relaxed stability constraints provide the most equally spread cost savings among the partners of the coalition, as visualised in Figure 5.8 for a coalition of three partners A, B and C. Although the ϵ-EPM also aims to minimise maximal pair wise differences between allocated savings, increased variation in carrier savings is caused by adding ϵ-core constraints. Finally, it is found that the Shapley value slightly benefits small carriers in case of a three-partner coalition with different participants. On average, collaborative savings of companies with a smaller share in customer demand are highest when costs are divided by means of the Shapley value. This is illustrated in Figure 5.9 in which the average savings levels for a coalition of three unequal partners A, B and C are shown. Considering the fact that partner C is a small carrier, as opposed to partners A and B, its associated savings level is highest when costs are allocated using the Shapley value. A similar result was found by Vanovermeire et al. (2014b) in a collaborative order consolidation context.

5.7 Conclusions and further research

Chapter 2 demonstrates that existing studies on horizontal carrier cooperation all focus on collaboration opportunities within a transport context. In line with the broad definition of logistics including both the movement and storage of freight, this chapter presents a new approach to carrier cooperation: the sharing of warehouses or DCs with collaborating partners. The problem considered can be classified as a cooperative carrier facility location problem and can be formulated as an MILP. The CCFLP formulation presented models the cooperative carrier facility location problem as a multi-commodity, two-phase, location-allocation problem. The practical advantage of the CCFLP exists in that the model and data is to be prepared a single time

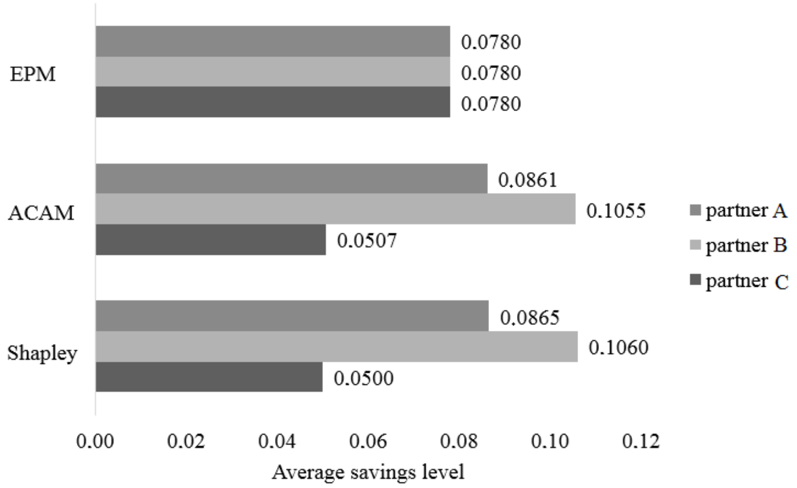

Figure 5.8: Average savings levels for coalition of three companies with similar characteristics

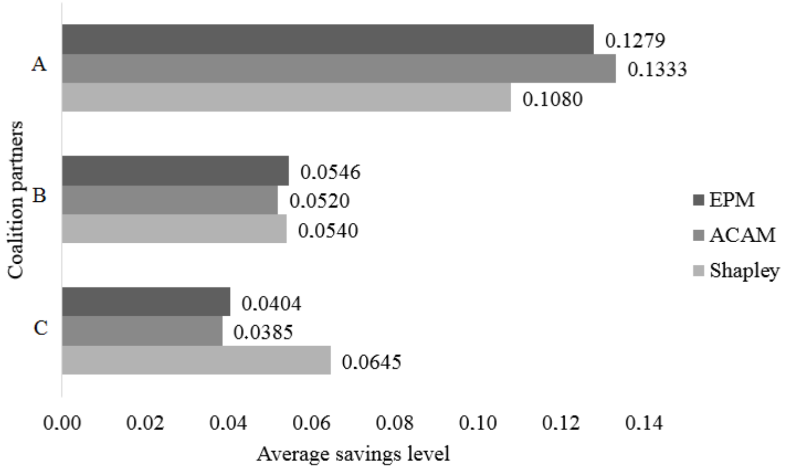

Figure 5.9: Average savings levels for coalition of three companies of different size

only and is then easy to use for deriving the optimal location-allocation decisions and characteristic function values for each possible (sub)coalition. The CCFLP presented in this form also has the benefit of clearly showing that the decision problem differs from current cooperative facility location literature in that the number of potential DC locations as well as the customer demand changes with the choice of partners in the coalition. In addition, the allocation of costs is not to be between the customers served, but between the participating carriers and issues of complementarity and selection of partner carriers become important. The CCFLP formulation facilitates the investigation of partner selection. Moreover, to ensure cooperation sustainability, the collaborative costs need to be allocated to the different participants in such a manner that the firms have no incentive to leave the coalition and that the distribution of savings is considered fair. In current cooperative facility location literature the allocation problem is solved exclusively by applying game theory. The rationale of applying alternative cost allocation techniques in the context of carrier collaboration is discussed and the value of applying the ACAM and the EPM is demonstrated.

Based on extensive numerical experiments statistically investigating **collaborative savings** at the level of DC sharing, the following managerial insights may be formulated. Results demonstrate that jointly and optimally deciding on the location of DCs and the allocation of product flows not only reduces total logistics costs in a range from 1.75 to almost 25%, but is very likely to also decrease total kilometres driven. Sharing DCs can hence introduce significant improvements in distribution efficiency. Results also indicate that benefits from DC sharing depend on operational characteristics of the partners. The relative level of fixed DC costs has a profound positive impact on collaborative performance. Collaboration incentives improve significantly if carriers are faced with heightened DC investments. In addition, the statement made in joint venture literature that more partners create more savings is elaborated on. Economies of scale hold in the sense that subcoalitions cannot achieve higher total savings than the grand coalition. Moreover, it is investigated how the initial level of consolidation in the carrier market influences collaborative savings. This factor has not been investigated previously. The experiments indicate that the virtual firm comprising of three smaller carriers may not be able to out-compete the virtual firm comprising of two larger carriers serving the same demand, since savings are on average 18% higher for a collaboration between two larger carriers, despite having less DC sites available. Regarding partner selection, existing literature states that, from a practical point of view, it may be best to choose partners equal in resources and growth opportunities. However, in the context of DC sharing value lies in partner complementarity. A coalition of partners differing in terms of DC ownership and demand distribution will gain on average almost 97% more savings than a coalition of equal partners.

When participants have to decide on the mechanism of how to share collaborative savings, the following observations can be made. For two- and three-partner collaborations comprised of unequal partners and for three-partner alliances between equal carriers, **allocation techniques** account for differences in partner contributions to the grand coalition. For coalitions consisting of two equal partners, however, Shapley and ACAM lead to identical splits of total gains. The original EPM and the EPM with relaxed stability constraints may be most useful in collaborations between carriers of equal size as they provide the most equally spread cost savings. In addition, this characteristic may also be valuable in the early phases of a growing horizontal cooperation, in which having an initial allocation with similar benefits for all participating organisations may suit communication and negotiation purposes. Small carriers participating in three-partner coalitions may prefer costs to be allocated by means of the Shapley value. This division mechanism favours companies with a smaller share in customer demand by allocating them a higher percentage of collaborative savings in comparison with the ACAM and the EPM. Next, results show that although a coalition with partners differing in terms of DC ownership and demand distribution leads to an almost doubled profit level compared to a partnership comprised of fairly equal participants, a rising degree of partner inequality may impede sustainability of the collaboration project. As such, findings indicate an important dilemma between total cost savings achievable from horizontal carrier collaboration, which are higher with the degree of inequality rising, versus the practical implementation of fair allocations of total gains, which may be hampered with a rising degree of inequality between the carriers. Then, stability analyses confirm the statement that a limited number of partners reduces alliance complexity and enforces the strength of mutual partner relationships. While two-partner cooperations are always related with stable outcomes, only 82% of the three-partner cooperations are associated with stability. Finally, the most striking finding is that no significant differences were observed in the allocation values when comparing over the division mechanisms applied in this chapter.

Overall, the experiments suggest that with a limited number of partners, if chosen carefully, carriers may reap significant operational benefits from DC sharing. A small number of coalition participants has practical benefits in terms of keeping managerial and communication efforts within limits. Furthermore, for a limited number of partners, intuitively appealing and operationally simple cost sharing techniques may well be utilised. In terms of collaborative performance, the most profitable two-carrier coalitions consist of complementary partners with sufficiently large fixed DC costs. The limitations of the experimental study are acknowledged in terms of general validity of these findings. These conclusions, together with the observation that gains achievable can range between a few percent to 25% in the experiments, however, underline the value of using operational research models such as the CCFLP to help carriers investigate the value of careful partner selection.

Several opportunities for **future research** on the cooperative carrier facility location problem may be identified. One natural avenue of research is to consider other cost allocation techniques and to extend the analysis to more partners and cooperation characteristics. Second, in order to establish the logistics benefits of horizontal collaboration, the consideration of possible gains from selling closed DCs or building new additional DCs in a coalition is excluded, but it is possible to extend the presented MILP in order to consider such opportunities. Third, the cooperative facility location model could be expanded by considering additional objectives besides cost minimisation. In this context, the trade-off between cost savings versus customer service levels achievable as a consequence of DC sharing could be investigated. Finally, the consideration of a specific case study setting may influence the general validity of the findings. Investigating the sensitivity of the results towards variations in, for example, customer demand or DC locations could be the subject of future work. In this way, insight can be gained into the robustness of the experimental results described in this chapter.

Chapter 6

Cost allocation in intermodal barge networks

6.1 Introduction

Chapters 3, 4 and 5 underline the importance of a collectively and individually desirable allocation mechanism in order to guarantee long-term sustainability of the grand coalition in any collaborative logistics environment. While a great deal of scientific literature reports on the behaviour of cost or savings sharing methods in collaborations between shippers or carriers making use of unimodal transport (see Table 3.3), research on allocation techniques in collaborative intermodal transport is scarce and focuses exclusively on the investigation of game theoretic allocation methods. This chapter [1] (Figure 6.1) tries to fill this research gap by analysing the performance of four allocation techniques used to share cost savings fairly amongst shippers who bundle freight flows in order to reach economies of scale in intermodal barge transport.

Policy makers at European as well as regional levels express the need to stimulate intermodal transport chains (European Commission, 2011). Macharis and Bontekoning (2004) define intermodal transport as the combination of at least two modes of transport in a single transport chain, without a change of container for the goods, with most of the route travelled by rail, inland waterway or ocean-going vessel and with

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[1] This chapter is based on the paper: Ramaekers, K., Verdonck, L., Caris, A., Meers, D., Macharis, C., 2016. Analysis of cost allocation techniques for freight bundling networks in intermodal transport. In: Proceedings of the seventh International Conference on Computational Logistics (Lecture Notes in Computer Science, volume 9855), September 7-9 2016, Lisbon, Portugal.

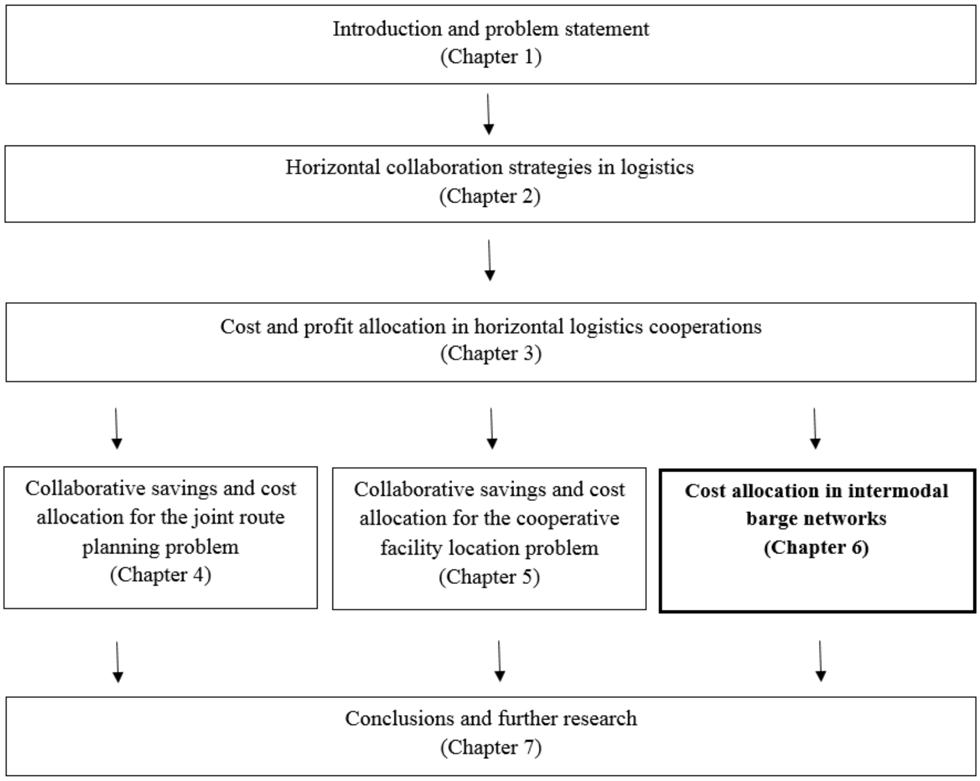

Figure 6.1: Outline of the thesis

the shortest possible initial and final journeys by road. A growing market share for intermodal transport should mean a shift towards more environmental friendly transport modes, less congestion and a better accessibility of seaports. In order to improve the competitive position and efficiency level of intermodal transport, consolidation of freight flows is often suggested as it creates denser freight flows and leads to economies of scale. As freight flows have become smaller and more frequent due to flexibilisation, globalisation and changing production principles, collaborative bundling is needed for inland waterway transport to stay competitive (Hesse and Rodrigue, 2004).

Improving the efficiency of the hinterland by means of complex freight bundling networks contributes to the competitiveness of intermodal transport. In addition, these networks improve the hinterland access of ports. In regions with an extensive waterway network, such as Western Europe, intermodal barge transport provides a suitable alternative for unimodal road transport (Caris et al., 2011). However, further investments and research are necessary to enhance its modal share, as proven by the

European NAIADES (Navigation and Inland Waterway Action and Development in Europe) and NAIADES II action programmes (European Commission, 2006, 2013b). In Belgium, inland navigation plays an important role in the hinterland access of the Port of Antwerp (Notteboom, 2007). Notteboom and Rodrigue (2005) introduce a regionalisation phase in port development. In their perspective, ports are considered as nodes in intermodal networks and competition exists between transport chains instead of ports. Moreover, intermodal collaborations play a role in these hinterland transport chains (Caris et al., 2014).

Within this intermodal freight bundling context, the focus of this chapter is on how to create long-term sustainable intermodal collaborations by means of appropriate cost allocation mechanisms. Bundling freight of multiple shippers offers the opportunity to achieve economies of scale and boost the competitiveness of intermodal barge transport, but bundling networks require cooperation between multiple partners in the intermodal transport chain. Questions rise as to which type of bundling network is manageable and how benefits may be allocated among the participants in the cooperation. While economies of scale are an obvious advantage for the consolidation of freight flows as a whole (as opposed to the sum of the stand-alone costs of the partners), the benefits for a single partner are not always clear. Caris et al. (2014) indicate that research into which business models are appropriate for this complex cooperation environment can support the integration of inland navigation in the intermodal supply chain. Business models provide insights into the strategic orientations of the cooperation partners regarding, among others, the offered service, the internal collaboration organisation and its financial aspects. Although research on the analysis of bundling networks is extensive, research on business models in this context is rather scarce. Moreover, literature on business models mainly deals with rail transport operations and the roles that different actors can perform along the supply chain (Lehtinen and Bask, 2012; Flóden and Sorkina, 2014). As a number of actors can be involved in the organisation of intermodal transport, also the business model analysis can be centred on these different actors, such as shippers (Flóden and Sorkina, 2014), transport operators (Flóden and Woxenius, 2013), port authorities, terminal operators and shipping lines (Van den Berg, 2015). In a market study, Rijkswaterstaat (2013) identify five intermodal barge transport business models, with differing initiators: a barge operator, a shipping line, a port terminal, a neutral orchestrator and the combination of an inland terminal operator with shipper(s). The business model in place clearly determines the actors' bargaining power and whether and how gains of cargo bundling can be divided among shippers.

As discussed in Chapter 1, incentive alignment is a crucial facilitator for horizontal cooperation in transport and logistics. Realigning the benefits and burdens among the partners results in an individual responsibility for the attainment of overall coalition profitability. One such realignment mechanism is the fair division of cooperation related costs or savings in such a manner that partners are induced to behave according to the collaborative goal. A vast amount of scientific literature discusses cost or savings allocation methods in collaborations between shippers or carriers making use of unimodal transport (cf. Chapter 3). In intermodal barge transport various types of vessels with differing price structures may be considered for the bundling network. Moreover, the magnitude of the economies of scale resulting from consolidation in barge transport significantly exceeds that of the results obtained in road transport. As such, applying the allocation methods which have been thoroughly studied in a unimodal context is not so straightforward in an intermodal environment. In addition, research on cost or savings allocation methods in intermodal transport is scarce. The only scientific contributions which study allocation mechanisms in intermodal transport are Theys et al. (2008) and Soons (2011). Both papers apply game theoretic methods to allocate costs fairly in a cooperative intermodal project consisting of terminal operating companies bundling freight. No comparative studies have been performed yet on allocation methods applied in the context of collaboration between shippers making use of intermodal barge transport.

Considering the statements made above, the main contributions of this chapter are the following. First, since game theoretic allocation mechanisms may raise questions from partnering companies about mathematical complexity and fairness transparency, three additional allocation techniques are applied to the intermodal freight bundling problem. Second, special attention is paid to the savings division amongst the coalition partners and the stability of the allocation solutions obtained. Finally, all allocation and stability analyses are performed within the context of two case studies. In this way, recommendations could be formulated to shippers considering intermodal freight bundling on how they should tackle the allocation challenge considering the characteristics of the cooperation and its partners. The first case study is carried out within the Aggregate-Disaggregate-Aggregate (ADA) framework (Maes et al., 2011) and uses real data from a freight transport model for Flanders. Since the ADA assumptions may not always be realistic and could prevent shippers from optimally bundling their freight flows, a second case study, situated in the hinterland of the Port of Antwerp, is studied.

The remainder of this chapter is organised as follows. In Section 6.2, relevant literature on intermodal freight bundling is discussed. Details are provided on the cost allocation mechanisms compared for their efficacy in an intermodal freight bundling environment in Section 6.3. Next, Section 6.4 presents two case studies in which shippers cooperate to bundle their freight flows and make use of intermodal barge transport. Based on these case studies, Section 6.5 discusses the numerical comparison between simple and straightforward allocation methods and more advanced techniques based on cooperative game theory. Finally, conclusions and directions for future research are formulated.

6.2 Intermodal freight bundling

Multiple research efforts have been undertaken to investigate bundling networks in intermodal transport. The basic idea is to consolidate loads for efficient long-haul transport (e.g. by rail, inland waterway barge or ocean-going vessel), while taking advantage of the efficiency of local pickup and delivery operations by truck (Bektas and Crainic, 2008). Kreutzberger (2010) analyses in which transport landscape which bundling network types ensure the lowest operational cost and which of the lowest cost bundling networks may be competitive with unimodal road transport. Kreutzberger and Konings (2013) propose a new concept to bundle the container hinterland transport flows of the seaports of Rotterdam and Antwerp in order to increase the size of train loads, the service frequency or the network connectivity and hence to improve the cost performance and quality of rail hinterland transport.

Bundling networks in intermodal barge transport, which are the focus of this chapter, have been studied amongst others by Caris et al. (2011), Caris et al. (2012) and Konings et al. (2013). Caris et al. (2011) suggest that there exist two options for freight bundling in intermodal barge transport. Freight may be consolidated in the hinterland network or could be bundled in the port area. The focus of this chapter is on the first alternative considering shippers who offer bundled freight flows to terminals and in this way improve intermodal efficiency and achieve economies of scale. As Trip and Bontekoning (2002) describe, this bundling of relatively small flows requires bundling networks which are more complex than those for conventional point-to-point bundling. Using complex bundling via intermediate nodes, load factors of barges may be increased and transport frequency could be improved. However, complex bundling networks also require complex node operations and thus depend on the quality of the terminals involved in the network. Braekers et al. (2013) present a decision support tool for bundling freight in a corridor network in intermodal barge transport. Barge operators, logistics service providers or shipping lines that want to offer regular round-trip barge services between a number of ports located along the same waterway may use this model to determine vessel capacity and frequency of these round-trips. Van Lier et al. (2016) discuss bundling of freight activities at the operational level. Shippers attain scale economies and a better utilisation of transport equipment through consolidation of freight inside a loading unit. The cost of freight transport may be decreased by raising the fill rate of loading units. This may on the one hand reduce the costs of pre- and end-haulage by road and on the other hand increase the attractiveness of intermodal freight transport for further continental distribution.

Considering the business models of Rijkswaterstaat (2013), the focus of this chapter is on intermodal freight bundling in barge transport initiated by collaborating shippers possibly in combination with a neutral orchestrator. Not only contributes this type of horizontal collaboration to the competitiveness of intermodal transport, it could also add value to the development of recent trends in freight transport like the synchromodality concept. The distinctive characteristic of synchromodality is the horizontal integration of the whole transport system balancing the transport service of different modalities. In this way, a service can be provided that is no longer dependent on the type of modality that is used. The main value of synchromodality lies in the increased alignment of supply to demand, based on dynamic information about customer preferences and expected transport service performance (Tavasszy et al., 2015).

6.3 Collaborative cost allocation

As the goal of a logistics cooperation is to increase the participants' efficiency and since collaboration often results in additional profits or cost savings, Chapter 3 demonstrates that a great deal of scientific literature on unimodal collaborative logistics devotes its research attention to the identification of efficient allocation schemes. Since various types of vessels with differing price structures may be considered for bundling networks in intermodal barge transport and economies of scale resulting from barge consolidation exceed those associated with road transport, applying the allocation methods which have been thoroughly studied in a unimodal context is not so straightforward in an intermodal environment. Moreover, the only scientific contributions which study allocation mechanisms in intermodal transport are Theys et al. (2008) and Soons (2011) applying game theoretic allocation methods. No comparative studies have been performed yet on allocation methods applied in the context of collaboration between shippers making use of intermodal barge transport. Accounting for the statements made above, in Section 6.5 four different allocation mechanisms are applied to divide logistics costs after bundling within the context of two case studies. A comparison is made between two simple and straightforward cost allocation methods often used in practice and two more advanced techniques based on cooperative game theory. The following paragraphs provide more details on their choice motivation and calculation approach.

The reasons for choosing the proportional, decomposition, Shapley and Equal Profit method (EPM) in the allocation analyses are the following. Up to now only game theoretic methods have been applied to allocate costs fairly in a cooperative intermodal network. The most prevalent solution concepts within cooperative game theory are the Shapley value (Shapley, 1953) and the nucleolus (Schmeidler, 1969). The preference for the Shapley value may be explained by its ease of calculation. However, practitioners consider the mathematical complexity of these techniques to be an impediment for their applicability in practice. As such, the importance of convenient implementation and interpretation in practice favours the use of the proportional and decomposition methods. Moreover, a drawback of using the Shapley value is that, in case of a non-empty core, Shapley allocations may not lie in the core of the game and thus do not satisfy the stability property. By incorporating stability constraints, EPM allocations guarantee that no subgroup of partner companies has the incentive to leave the grand coalition and be better off acting alone. The remark can be made that, contrary to Chapters 4 and 5, the Alternative Cost Avoided Method (ACAM) is not applied here. Instead of calculating ACAM allocations, proportional and decomposition allocations are defined. In this way, allocation results explicitly take into account two characteristics of the numerical experiments: the number of shipments per partner and the considered barge trajectory.

Regarding the Shapley value and the EPM, a detailed theoretical description and relevant mathematical formulas can be found in Section 4.3. The proportional allocations computed in the numerical experiments are volume based. This volume is expressed as the number of shipments z_i per year that each coalition partner i requires along the same trajectory. Total collaborative savings are weighted with each participant's volume as follows:

$$y_i = w_i \times v(N) \qquad \forall i \in N \tag{6.1}$$

with y_i the savings allocated to partner i, $w_i = \frac{z_i}{\sum_{i \in N} z_i}$ and $v(N)$ the total cost savings amount of the grand coalition. Finally, the decomposition method is a gain sharing mechanism especially suited for intermodal freight transport. This allocation technique is based on a decomposition of the total trajectory in common links of the participants. A volume based proportional allocation, as described above, is then applied on each of these links separately. For example, in a cooperation between three shippers A, B and C, the total transport chain may be divided in two common links. On the first common link shippers A and B bundle their freight. On the second link, the freight of all three participants is consolidated. The proportional allocation method will share collaborative savings on the first link between shippers A and B according to their number of shipments. Along the second link, coalition savings will be shared proportionally according to the number of shipments of participants A, B and C, respectively.

6.4 Case studies

To demonstrate the use of cost allocation methods in an intermodal barge context, two case studies are introduced in this section. The first case study is carried out within the framework of the ADA model of Ben-Akiva and de Jong (2013), an activity-based freight transport model. The ADA model is originally developed for the Netherlands but the concepts have also been applied to Flanders (Maes et al., 2011). Because this first case study is implemented in the ADA framework, the ADA assumptions are taken into account. However, these assumptions may not always be realistic and could prevent shippers from optimally bundling their freight flows. Therefore, a second case study is presented in which the assumptions of the ADA model are relaxed. In this second case study, barge freight is bundled in the hinterland of the Port of Antwerp. In Section 6.4.1 the ADA-based case study is described. In Section 6.4.2 the case study in the hinterland of the Port of Antwerp is discussed.

The limitations of the numerical experiments are acknowledged. The consideration of a distinct intermodal transport business model (cf. Rijkswaterstaat, 2013) and the use of specific case study data could influence the general validity of the findings. The conclusions, however, demonstrate the influence of cooperation characteristics on allocation results and underline the value of carefully selecting allocation mechanisms when long-term stability of the intermodal barge collaboration is aspired.

6.4.1 ADA-based case study

The ADA model is an activity-based freight transport model developed by Ben-Akiva and de Jong (2013) for the Netherlands. Freight transport models are used on an international, national or regional level to forecast transport demand, to test transport policy measures and to predict the impacts of new infrastructure on traffic. In contrast to traditional transport models which handle all steps at the aggregate level, the ADA model uses disaggregate data to model logistics elements such as the choice of shipment size and transport chain including mode choice. For reasons of data availability, the other elements of the freight transport model, besides the logistics module, are specified at an aggregate level. These other elements are the production-consumption (PC) matrices that provide flows of goods by commodity type between two zones (e.g. municipalities) and the assignment of freight flows to the network. The PC matrices could be generated by spatial input-output models or spatial computable general equilibrium models. The PC flows serve as input for the logistics module, after disaggregation of the zone-to-zone flows to the level of firm-to-firm (sender-to-receiver) flows. The outputs of the logistics module consist of origin-destination (OD) vehicle flows, which are used in aggregate network assignment (De Jong and Ben-Akiva, 2007).

In the freight transport model for Flanders based on the ADA model, the 308 municipalities of Flanders are used as zones. The model starts from the PC flows per NSTR [2] category between the different zones. The NSTR classification is a standard goods classification for transport statistics, which is often used in Europe. In a first step, the disaggregation step, the PC flows are disaggregated to firm-to-firm flows, based on the number of producers of the commodity in the first zone, the number of consumers of the commodity in the second zone and the fraction of actually realised links between senders and receivers of the two zones. Next, all possible transport chains for every firm-to-firm flow are built and the Total Logistics Cost (TLC) is calculated for each transport chain. An average shipment size (based on the NSTR category) is used to build the transport chains. The TLC function exists of an ordering cost, an inventory cost, a capital cost of the goods in transport and in inventory and a transport cost. The transport cost is split into several components: a variable cost based on the distance of the links travelled and a loading and unloading cost for the different transport modes. The TLC is used to determine the optimal transfer points for chains which use several transport modes and to determine the best transport chain(s) for a given firm-to-firm flow.

The notation, data and formulas necessary for the TLC calculations of the numerical experiments discussed in Section 6.5.1 are provided in Table 6.1 and Table 6.2. Using the data listed in Table 6.1, the TLC is calculated as follows. Based on the fixed shipment size, first the number of shipments per year z is calculated and rounded up to the next integer number. Next, the order cost, the transport cost, the capital cost

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[2] NSTR stands for 'Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée', which can be translated as revised standard goods classification for transport statistics.

Table 6.1: Notation and data

Symbol	Description	Value
oc	Order cost	55€
Q	Yearly demand (in ton)	*Case specific*
q	Shipment size (in ton)	68.4 (273.6)
D_{ph}	Distance pre-haulage (in km)	*Case specific*
D_{mh}	Distance main-haulage (in km)	*Case specific*
D_{eh}	Distance end-haulage (in km)	*Case specific*
TC_r	Transport cost road	1€/km
TC_{iww}	Transport cost inland waterways	6 (9)€/km
TT	Total transport time	*Case specific*
Cap_r	Capacity truck (in ton)	27
MNT	Minimum number of trucks	*Case specific*
Cap_{iww}	Capacity vessel (in ton)	1000 (2000)
$UsedCap_{iww}$	Vessel fill rate	*Case specific*
L_r	Cost to (un)load truck	2€/ton
L_{iww}	Cost to (un)load vessel	0.4€/ton
d	Interest rate (per year)	4%
vg	Value of goods	672€/ton
wc	Warehouse cost	20%

of goods in transit, the inventory cost and the capital cost of inventory are calculated, using the formulas defined in Table 6.2. In this table, MNT represents the minimum number of trucks needed for the pre- and end-haulage, which is calculated as q/Cap_r and rounded to the next integer number, $UsedCap_{iww}$ represents the vessel fill rate and TT represents the total transport time, which is calculated as the sum of the travel time (road and inland waterways transport) and the waiting time for a truck or vessel to be available. For detailed calculations on all cost components, the reader is referred to Maes et al. (2011).

In this case study, all 'road - inland waterways - road' transport chains of the transport model are considered and the options for bundling are studied. The stand-alone cost is defined as the TLC for a specific partner when no bundling is performed.

Table 6.2: TLC formulas

Cost component	Formula
Order cost	$oc \times z$
Transport cost	$[D_{ph} \times TC_r \times MNT + D_{mh} \times TC_{iww} \times \frac{q}{UsedCap_{iww}} +$ $D_{eh} \times TC_r \times MNT + q \times (4 \times L_r + 2 \times L_{iww})] \times z$
Capital cost of goods in transit	$\frac{TT \times d \times vg \times Q}{365 \times 24}$
Inventory cost	$\frac{q}{2} \times wc \times vg$
Capital cost of inventory	$\frac{q}{2} \times d \times vg$

At this point, the barge capacity is not fully used and thus economies of scale can be achieved when bundling with other partners on the same barge trajectory. The firm-to-firm flows are then bundled for flows which have at least one terminal in common and the TLC of the bundled situation is calculated. Next, collaborative savings are determined as the difference between the TLC of the bundled situation and the sum of the stand-alone costs of the partnering shippers. Finally, the collaborative savings are shared among the participants of the coalition using the four methods described in Section 6.3. In the next paragraphs, an example is given of how the sharing of the collaborative savings is determined for the four different allocation methods.

Example: collaborative gain sharing

In this example, firm-to-firm flows which use the same end terminal for their barge transport are bundled. Three flows are studied: Aalst-Antwerp (partner A), Zaventem-Antwerp (partner B) and Mechelen-Antwerp (partner C). The barge trajectory (Figure 6.2) that is followed is Brussels-Vilvoorde-Willebroek-Deurne. These terminals are determined based on a minimisation of the TLC. The goods from Aalst start their barge transport in Brussels, the goods from Zaventem start their barge transport in Vilvoorde and the goods from Mechelen start their barge transport in Willebroek. All goods are unloaded from the vessel in Deurne. The number of shipments per year and the stand-alone cost for each partner are given in Table 6.3. The stand-alone cost is calculated as the annual TLC each partner incurs when performing the intermodal trajectory on an individual basis for all its shipments. The number of shipments per year is calculated in the ADA model based on the optimal shipment size, which is given for every NSTR category. Based on the ADA assumptions, the number of shipments cannot be changed when partners bundle their goods and thus, if one partner has three shipments per year and another partner has seven shipments per year, only

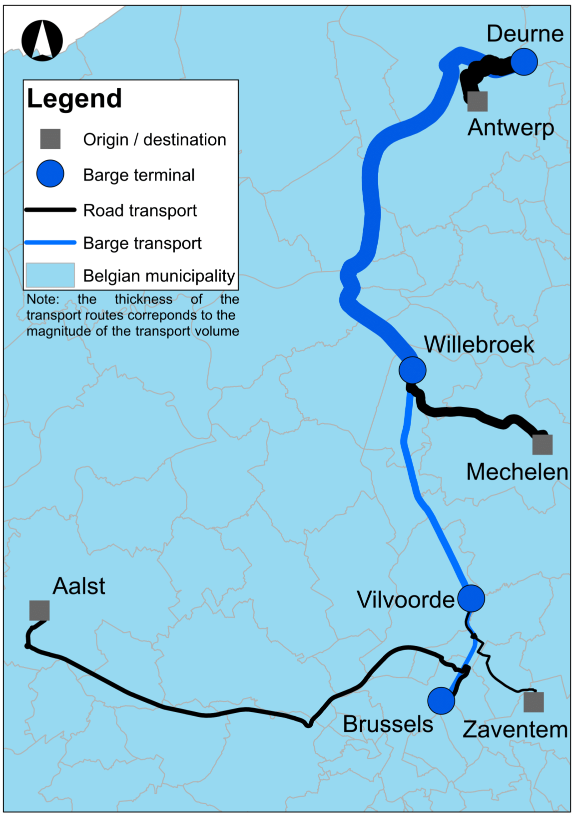

Figure 6.2: Barge trajectory of ADA-based case study

Table 6.3: Example: situation before bundling

Firm-to-firm flow	Number of shipments	Stand-alone TLC
Aalst-Antwerp	7	13112€
Zaventem-Antwerp	3	8461€
Mechelen-Antwerp	17	20792€

three shipments can be bundled and the second partner still has to transport four shipments alone.

The barge trajectory (Figure 6.2) can be divided in three parts for this example: Brussels-Vilvoorde, Vilvoorde-Willebroek and Willebroek-Deurne. The first part, Brussels-Vilvoorde, is only used by the flow Aalst-Antwerp and no bundling can take place on that part. The second part, Vilvoorde-Willebroek, is used by two partners: three shipments can be bundled for this part of the trajectory, the four residual shipments of Aalst-Antwerp cannot be bundled. The third part, Willebroek-Deurne, is used by all three partners: three shipments can be bundled for the three partners, an additional four shipments can be bundled for two partners (Aalst-Antwerp and Mechelen-Antwerp) and ten shipments of Mechelen-Antwerp cannot be bundled. The TLC for this situation equals 40311€ and the total gain is 2055€.

Using the proportional allocation method, the total savings amount is divided over the partners based on the number of shipments of each partner. This results in a relative cost saving of 4.06% for partner A, 2.70% for partner B and 6.22% for partner C. With the decomposition method, the cost savings amount is calculated for each part of the barge trajectory separately. In this example, the barge trajectory can be divided in three parts: Brussels-Vilvoorde, Vilvoorde-Willebroek and Willebroek-Deurne. The first part, Brussels-Vilvoorde, is only used by the flow Aalst-Antwerp so no bundling can take place on this part. In the second part, Vilvoorde-Willebroek, two participants can bundle freight. The benefit of 278€ is allocated to these two partners based on their number of shipments. In the last part of the trajectory, Willebroek-Deurne, the shipments of the three partners can be bundled. The benefit of 1777€ earned on this part of the trajectory is again divided over the three partners based on their respective number of shipments. In this way, the decomposition method results in savings percentages of 5.00%, 3.32% and 5.38% for partners A, B and C respectively. To determine the Shapley value for each partner, equation (4.1) is used. In this way, each participant is allocated the weighted average of his contributions to all possible (sub)coalitions. Shapley based relative savings are 6.48% for partner A, 5.84% for partner B and 3.42% for partner C. The EPM allocations are calculated using linear program (4.3)-(4.6). Besides their guaranteed stability, these allocations minimise the pair wise difference between the relative transport cost savings of the participants, being 8.44% for A, B and C. The results of applying the four cost allocation methods to the example are shown in Table 6.4.

Table 6.4: Example: cost allocation results

Firm-to-firm flow	Stand-alone	Proportional	Decomposition	Shapley	EPM
Aalst-Antwerp	13112	12580	12457	12263	12504
Zaventem-Antwerp	8461	8233	8180	7967	8224
Mechelen-Antwerp	20792	19498	19673	20081	19583

6.4.2 Case study in the hinterland of the Port of Antwerp

The assumptions of the ADA-based case study may not always be realistic and could prevent shippers from optimally bundling their freight flows. Therefore, a second case study is developed in which the assumptions of the ADA model are relaxed. As opposed to the first case study, shipment sizes of partnering shippers are not fixed in this second experiment. Partners are able to align their shipment frequencies z_i to increase the number of bundling opportunities and in this way improve collaborative synergy. Moreover, consequential to bundling freight, shippers aim to improve customer service by means of higher delivery frequencies.

In this second case study, barge freight is bundled in the hinterland of the Port of Antwerp. Firm-to-port flows that are studied are Aalst-Antwerp, Zaventem-Antwerp and Mechelen-Antwerp. The barge trajectory under consideration is Brussels-Vilvoorde-Willebroek-Antwerp (Figure 6.3). Since freight flows are now destined to the Port of Antwerp, end-haulage via road is avoided.

The data necessary for the TLC calculations of the numerical experiments discussed in Section 6.5.2 are provided in Table 6.5. The TLC formulas are equivalent to those listed in Table 6.2. Because of the hinterland setting, demand volumes are expressed in TEU (Twenty foot Equivalent Units), available vessel types have capacity levels of 96 and 165 TEU and cost levels are adapted accordingly.

6.5 Allocation results

In this chapter, a first insight is provided in the complexity of sharing collaborative cost savings fairly amongst shippers who bundle freight flows in order to reach economies of scale in intermodal barge transport. The impact of the number of partners, the equality of partners, the shipment size and shipment frequency on allocation values and coalition stability is examined. In Section 6.5.1 allocation and stability results are discussed for the ADA-based case study. Section 6.5.2 analyses the results for the case study setting in the hinterland of the Port of Antwerp.

6.5.1 ADA-based case study

In this case study, the impact of the number of partners, the equality of partners and the shipment size is examined. The situation of three, four and five partners is investigated, both for partners with an equal and an unequal amount of shipments. Two shipment sizes are examined: 68.4 tons and 273.6 tons. For each scenario the case of a common end terminal (Figure 6.2) is studied. The case of a common start

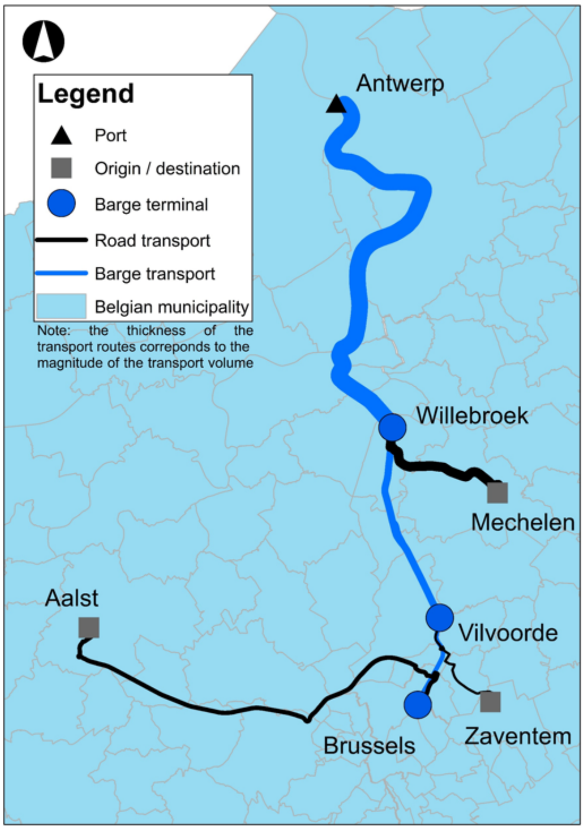

Figure 6.3: Barge trajectory of case study in the hinterland of the Port of Antwerp

terminal leads to analogue results and the case of a common barge trajectory (both terminals in common) is a special case of the one that is studied.

It is assumed that two vessel types are available: a vessel with a capacity of 1000 tons and a cost of 6€/km and a vessel with a capacity of 2000 tons and a cost of 9 €/km. The smallest vessel is used first, only if the bundled freight exceeds its capacity, the larger vessel is utilised. When the small vessel can be used for the bundled freight, bundling always leads to a higher fill rate and therefore, to a lower transport cost. In this case, important properties of cost allocation methods as individual rationality and stability are always satisfied. If the larger vessel needs to be used, adding more realistic characteristics of intermodal barge transport to the problem, attention needs to be paid to the properties of the allocation methods applied.

The results of the experiments with shipment size 68.4 tons are summarised in Tables 6.6 and 6.7. Analogue to the example described in Section 6.4.1, first the stand-

Table 6.5: Notation and data

Symbol	Description	Value
oc	Order cost	5.5€
Q	Yearly demand (in TEU)	*Case specific*
q	Shipment size (in TEU)	$\frac{Q}{z_i}$
D_{ph}	Distance pre-haulage (in km)	*Case specific*
D_{mh}	Distance main-haulage (in km)	*Case specific*
TC_r	Transport cost road	1€/km
TC_{iww}	Transport cost inland waterways	6 (9)€/km
TT	Total transport time	*Case specific*
Cap_r	Capacity truck (in TEU)	2
MNT	Minimum number of trucks	*Case specific*
Cap_{iww}	Capacity vessel (in TEU)	96 (165)
$UsedCap_{iww}$	Vessel fill rate	*Case specific*
L_r	Cost to (un)load truck	15€/TEU
L_{iww}	Cost to (un)load vessel	30€/TEU
d	Interest rate (per year)	4%
vg	Value of goods	33.6€/TEU
wc	Warehouse cost	20%

alone cost (the cost without bundling) is given. Next, the results after bundling are provided for each partner using the proportional allocation method, the decomposition method, the Shapley value and the EPM.

Table 6.6: Results: equal shipment volume, shipment size 68.4 tons (in euros)

	Firm-to-firm flow	Stand-alone	Prop.	Decomp.	Shapley	EPM
3 partners	Aalst-Antwerp	13112	12067	11959	11959	11963
	Zaventem-Antwerp	12466	11420	11312	11312	11419
	Mechelen-Antwerp	11792	10747	10963	10963	10852
4 partners	Aalst-Antwerp	13112	11855	11747	11747	11730
	Zaventem-Antwerp	12466	11208	11100	11100	11207
	Zaventem-Antwerp	12466	11208	11100	11100	11207
	Mechelen-Antwerp	11792	10535	10859	10859	10662
5 partners	Aalst-Antwerp	13112	11858	11685	11685	11704
	Zaventem-Antwerp	12466	11211	11038	11038	11184
	Zaventem-Antwerp	12466	11211	11038	11038	11184
	Mechelen-Antwerp	11792	10538	10797	10797	10641
	Mechelen-Antwerp	11792	10538	10797	10797	10641

Table 6.7: Results: unequal shipment volume, shipment size 68.4 tons (in euros)

	Firm-to-firm flow	Shipm.	Stand-alone	Prop.	Decomp.	Shapley	EPM
3 partners	Aalst-Antwerp	7	13112	12580	12457	12263	12504
	Zaventem-Antwerp	3	8461	8233	8180	7967	8224
	Mechelen-Antwerp	17	20792	19498	19673	20081	19583
4 partners	Aalst-Antwerp	7	13112	12276	12114	11868	12056
	Zaventem-Antwerp	3	8461	8102	8033	7876	8049
	Zaventem-Antwerp	9	14484	13408	13200	13062	13248
	Mechelen-Antwerp	17	20792	18760	19198	19741	19193
5 partners	Aalst-Antwerp	7	13112	12226	12043	11812	11970
	Zaventem-Antwerp	3	8461	8081	8003	7849	8015
	Zaventem-Antwerp	9	14484	13344	13108	13005	13146
	Mechelen-Antwerp	17	20792	18639	19024	19685	19193
	Mechelen-Antwerp	5	9988	9355	9468	9295	9321

If the partners are equal in size, the results of the decomposition method are equal to the results of the Shapley value (Table 6.6). Compared to the proportional allocation method, decomposition and Shapley favour partners that take part in more links of the barge trajectory, i.e. more benefit is granted to Zaventem-Antwerp and Aalst-Antwerp both taking part in two bundled links. In the three partner coalition, for example, Shapley and decomposition allocate a savings percentage of 8.79% to Aalst-Antwerp and 9.26% to Zaventem-Antwerp, compared to savings percentages of 7.97% and 8.39% for the proportional allocation method. If the partners are unequal in size, the four cost allocation methods lead to different results (Table 6.7). Compared to the proportional allocation method, the decomposition method favours partners that take part in more bundled links. Comparing the results of the Shapley value to those of the decomposition method for three partners, the partners taking part in more bundled parts are even more in favour. However, these participants are coincidentally also the smaller participants in the coalition and Shapley tends to favour smaller coalition participants. When an analogue comparison is made for coalitions established between 5 partners, insights can be improved and it can be concluded that the Shapley value especially favours the smaller partners. For example, the two flows from Zaventem to Antwerp both benefit from the Shapley value compared to the decomposition method but the smaller flow (three shipments, Shapley savings percentage = 7.23%, decomposition savings percentage = 5.41%) is more rewarded by the Shapley value than the larger flow (nine shipments, Shapley savings percentage = 10.21%, decomposition savings percentage = 9.50%). The difference between the Shapley value and the decomposition method is 1.9% for the smaller flow and only 0.8% for the larger flow. When comparing the results for the two flows from Mechelen to Antwerp, the results are even more distinct: although this flow only takes part in one bundled link, the Shapley value leads to favouring results compared to the proportional, decomposition and EPM allocation method for the smaller partner (five shipments). For the larger partner (17 shipments) the Shapley value grants the least relative benefit of all cost allocation methods to this partner. In this case, savings percentages are 10.36%, 8.50%, 5.32% and 7.69% for proportional, decomposition, Shapley and EPM allocations respectively. EPM provides the most equally spread transport cost savings among the partners of the coalition both for equal and unequal partners.

For the experiments with the shipment size of 68.4 tons, only the small vessel type is needed to transport the bundled freight and as a consequence, bundling always leads to a lower transport cost. Therefore, important properties of cost allocation methods as individual rationality and a stable cooperation are always satisfied. To

Table 6.8: Results: equal shipment volume, shipment size 273.6 tons (in euros)

	Firm-to-firm flow	Stand-alone	Prop.	Decomp.	Shapley	(ϵ-)EPM
3 partners	Aalst-Antwerp	28467	28168	28137	28137	28150
	Zaventem-Antwerp	28020	27722	27691	27691	27726
	Mechelen-Antwerp	27810	27511	27573	27573	27526
4 partners	Aalst-Antwerp	28467	28186	28195	28155	*28140*
	Zaventem-Antwerp	28020	27740	27706	27709	*27693*
	Zaventem-Antwerp	28020	27740	27706	27709	*27693*
	Mechelen-Antwerp	27810	27529	27588	27622	*27668*
5 partners	Aalst-Antwerp	28467	28171	28169	28130	28088
	Zaventem-Antwerp	28020	27725	27679	27673	27669
	Zaventem-Antwerp	28020	27725	27679	27673	27669
	Mechelen-Antwerp	27810	27514	27561	27586	27611
	Mechelen-Antwerp	27810	27514	27561	27586	27611

illustrate the use of the cost allocation methods when more vessel types are used, the same experiments are repeated with a shipment size of 273.6 tons. In this case, four and five partners can only bundle their freight if the larger type of vessel is used since the small vessel has a capacity of only 1000 tons. The results for the experiments with a shipment size 273.6 tonnes are summarised in Tables 6.8 and 6.9. Due to stability issues explained further on, EPM has been combined with the ϵ-core concept (cf. Section 4.6.3). ϵ-EPM allocations are indicated in *italic* font in Tables 6.8 and 6.9.

Compared to the results of the experiments with a shipment size of 68.4 tons, two important differences can be observed. First, when the coalition is extended from three to four partners, all partners have a higher allocated cost due to the use of the larger (and more expensive) vessel type. When the coalition is extended from four to five partners, the extra costs of the larger vessel type are spread over more partners and the cost allocated to each partner is lower than in the case of four partners. When comparing the results of five partners with those of three partners, it depends on the experiment and the partner considered whether the allocated cost is less than in the case with three partners. Therefore, it is important to look at the stability of these results. The second major difference is that the Shapley value now leads to

Table 6.9: Results: unequal shipment volume, shipment size 273.6 tons (in euros)

	Firm-to-firm flow	Shipm.	Stand-alone	Prop.	Decomp.	Shapley	(ϵ-)EPM
3 partners	Aalst-Antwerp	2	28467	28310	28272	28213	28282
	Zaventem-Antwerp	1	25023	24944	24925	24858	24937
	Mechelen-Antwerp	5	36432	36040	36098	36224	36076
4 partners	Aalst-Antwerp	2	28467	28336	28351	28264	*28262*
	Zaventem-Antwerp	1	25023	24957	24943	24984	*25089*
	Zaventem-Antwerp	3	30983	30788	30744	30691	*30601*
	Mechelen-Antwerp	5	36432	36105	36149	36248	*36235*
5 partners	Aalst-Antwerp	2	28467	28302	28314	28206	*28160*
	Zaventem-Antwerp	1	25023	24940	24924	24931	*24986*
	Zaventem-Antwerp	3	30983	30736	30688	30634	*30591*
	Mechelen-Antwerp	5	36432	36019	36056	36224	*36217*
	Mechelen-Antwerp	2	27772	27607	27622	27609	*27650*

allocation values differing from the decomposition method when equality of partners is assumed. This can be explained by the fact that the Shapley value rewards partners that contribute most to the collaborative goal. Since the partner Aalst-Antwerp has to perform the first part of the barge trajectory alone with the more expensive vessel type, its cost savings compared to the non-collaborative scenario become negative. As such, this partner has to make the most profound changes in its transport activities. The Shapley value accounts for this contribution by rewarding this partner with a higher share in the collaborative savings. In the five partner coalition, for example, Shapley allocates a savings percentage of 1.18% to Aalst-Antwerp, compared to a savings percentage of 1.05% for the decomposition method.

To identify whether the cost allocations defined for the experiments with a shipment size of 273.6 tons guarantee cooperation stability, compliance of the proportional, decomposition and Shapley solutions with individual, subgroup and group rationality is verified. Since stability constraints are included in the EPM linear program, feasibility of the EPM solution indicates whether the grand coalition is stable. Analysing cost allocations over all cases reveals that stability of the grand coalition is guaranteed in all three-partner collaborations. If the grand coalition is stable, then

Table 6.10: Stability of scenarios with two vessel types

Scenario	Proportional	Decomposition	Shapley	EPM
3 equal partners	✓	✓	✓	✓
3 unequal partners	✗	✓	✓	✓
4 equal partners	✗	✗	✗	✗
4 unequal partners	✗	✗	✗	✗
5 equal partners	✗	✗	✗	✓
5 unequal partners	✗	✗	✗	✗

✓: *stable* allocations could be calculated

✗: no *stable* allocations could be calculated

no subgroup of partner companies has the incentive to leave the grand coalition and be better off acting alone. In contrast, none of the four-partner coalitions are stable. As the shipment sizes considered in this case study result in a significant amount of excess capacity for the more expensive vessel type, collaborating becomes detrimental for the partnering shippers. Stability of the five-partner coalitions depends on the equality of the partners. When collaborating shippers are equal in terms of shipment sizes the grand coalition is stable when EPM is used as allocation method. Collaborations set up between five shippers with different shipment sizes do not ensure long-term stability in this case study. Although stability cannot be guaranteed for all four-partner coalitions and five-partner coalitions, cost savings still need to be allocated fairly. In this context, EPM has been combined with the ϵ-core concept, as explained in Section 4.6.3. Although the ϵ-EPM also aims to minimise maximal pair wise differences between allocated transport cost savings, increased variation in partner savings is caused by adding ϵ-core constraints. To summarise, Table 6.10 provides an overview of which allocation mechanisms generate stable allocations, indicated by ✓, for each of the studied scenarios.

6.5.2 Case study in the hinterland of the Port of Antwerp

In this case study, the impact of the number of partners, the equality of partners and the shipment frequency is examined. Similar to the ADA-based case study, the situation of three, four and five partners is investigated. For each of these coalition sizes, three scenarios are analysed. First, it is assumed that all partners are equal in terms of shipment frequency. Scenario one examines allocation and stability results when the stand-alone frequency of the partners is maintained after bundling. In scenario two, the delivery frequency of the partners is doubled after bundling. In this way, the trade-off between allocated costs and customer service could be investigated in an intermodal collaboration context. Finally, in the third scenario it is assumed that coalition partners differ in terms of stand-alone frequency. Scenario three analyses allocation and stability results when the shipment frequencies after bundling are equalised at the level of the highest stand-alone frequency. For each scenario, freight flows are destined to the Port of Antwerp (Figure 6.3).

Similar to the ADA-based case study, it is assumed that two vessel types are available: a vessel with a capacity of 96 TEU and a cost of 6€/km and a vessel with a capacity of 165 TEU and a cost of 9 €/km. The smallest vessel is used first, only if the bundled freight exceeds its capacity, the larger vessel is utilised. As opposed to the first case study, shipment sizes of partnering shippers are not fixed in this second experiment. Partners are able to align their shipment frequencies z_i to increase the number of bundling opportunities and in this way improve collaborative synergy. However, as a consequence of this relaxed assumption, not only transport costs, but also order and inventory costs are influenced by the collaboration decision. Special attention thus needs to be paid to the fair savings division amongst the coalition partners and the stability of the allocation solutions obtained.

The results of the experiments with equal stand-alone frequencies are summarised in Tables 6.11 and 6.12. Table 6.11 shows the allocation results when the annual number of shipments is maintained after bundling (Scenario 1), while Table 6.12 visualises the results when customer service has improved due to bundling (Scenario 2). Next, it is assumed that coalition partners differ in terms of stand-alone frequency. Table 6.13 summarises the allocation results when the shipment frequencies after bundling are equalised at the level of the highest stand-alone frequency (Scenario 3). For clarification purposes, the 'SAF' column lists the stand-alone frequencies and the 'BF' column lists the frequencies after bundling. Analogue to the ADA-based case study, first the stand-alone cost (the cost without bundling) is given. Next, the results after bundling are provided for each partner using the proportional allocation method, the decomposition method, the Shapley value and the EPM.

Analysing the allocation results of the second case study leads to the following insights. First, Tables 6.12 and 6.13 reveal that intermodal freight bundling may not only provide cost related benefits, but could also result in improved customer service. Both tables indicate that shippers are able to increase their shipment frequencies and at the same time enjoy cost savings due to the consolidation of shipments with

Table 6.11: Results: equal stand-alone frequency, maintained service after bundling

	Firm-to-firm flow	SAF	BF	Stand-alone	Prop.	Decomp.	Shapley	EPM
3 part.	Aalst-Antwerp	25	25	123650	119846	121005	119356	118036
	Zaventem-Antwerp	25	25	46308	42504	40239	41743	44205
	Mechelen-Antwerp	25	25	295062	291257	292363	292507	291365
4 part.	Aalst-Antwerp	25	25	123650	118868	119235	119157	118036
	Zaventem-Antwerp	25	25	46308	41525	39595	40810	44205
	Zaventem-Antwerp	25	25	152056	147273	148102	147291	146442
	Mechelen-Antwerp	25	25	295062	290279	291013	290687	289262
5 part.	Aalst-Antwerp	25	25	123650	118745	119060	118694	117215
	Zaventem-Antwerp	25	25	46308	41402	39531	40669	43898
	Zaventem-Antwerp	25	25	152056	147150	147864	147150	146749
	Mechelen-Antwerp	25	25	295062	290156	290537	290224	288955
	Mechelen-Antwerp	25	25	82023	77117	77577	77833	77753

partner organisations. However, when shippers decide to enhance their service level, they must be aware of the fact that this leads to a reduction in attainable cost savings. Shippers thus need to make a trade-off between offering more barge departures and incurring higher logistics costs. Moreover, considering coalitions of four and five partners, increased shipment frequencies are associated with non-stable allocation results irrespective of the applied allocation mechanism. This is demonstrated in Table 6.14 which provides an overview of the stability of the studied scenarios. When deciding on the offered service level, partnering shippers need to account for the stability properties of the applied allocation mechanism. Second, contrary to the ADA-based case study, each of the applied allocation mechanisms leads to unique results over all studied scenarios. Differences of 1.61%, on average, exist between the allocation values when comparing over the division mechanisms. The share of logistics costs allocated to the cooperation participants is thus fairly similar with respect to the used allocation technique. Third, results reveal that the applied cost allocation methods grant the largest relative benefit to the smallest partner Zaventem-Antwerp ($Q = 400$), while the largest partner Mechelen-Antwerp ($Q = 3000$) is allocated the lowest relative benefit in each of the studied scenarios. This is due to the fact

Table 6.12: Results: equal stand-alone frequency, improved service after bundling

	Firm-to-firm flow	SAF	BF	Stand-alone	Prop.	Decomp.	Shapley	(ϵ-)EPM
3 part.	Aalst-Antwerp	25	50	123650	121329	121582	121769	121799
	Zaventem-Antwerp	25	50	46308	43987	43393	43914	45614
	Mechelen-Antwerp	25	50	295062	292740	293081	292373	290643
4 part.	Aalst-Antwerp	25	50	123650	122184	122297	121615	*119748*
	Zaventem-Antwerp	25	50	46308	44842	44250	43227	*44846*
	Zaventem-Antwerp	25	50	152056	150590	150844	151849	*152056*
	Mechelen-Antwerp	25	50	295062	293595	293821	294521	*294561*
5 part.	Aalst-Antwerp	25	50	123650	121412	121556	121533	*119127*
	Zaventem-Antwerp	25	50	46308	44070	43217	42327	*44466*
	Zaventem-Antwerp	25	50	152056	149818	150144	149384	*150495*
	Mechelen-Antwerp	25	50	295062	292824	292998	294561	*295062*
	Mechelen-Antwerp	25	50	82023	79785	79995	80104	*78760*

that these partners experience the highest (Zaventem-Antwerp) and lowest (Mechelen-Antwerp) savings percentages consequential to bundling in comparison to their stand-alone costs. Moreover, while the partner Mechelen-Antwerp only takes part in one bundled link, Zaventem-Antwerp bundles freight on two links of the barge trajectory. The remark could be made here that rewarding the partner who has added the smallest demand volume to the collaboration with the largest relative benefit may be perceived as unfair. Possibly, large shippers are not willing to collaborate considering the fact that they gain less than their smaller counterparts. For this reason, a fifth allocation method has been applied to the cost results of the second case study which takes the annual demand volumes of the partnering shippers into account. In Table 6.15 total collaborative savings are weighted with each participant's annual volume as follows:

$$y_i = w_i \times v(N) \qquad \forall i \in N \tag{6.2}$$

with y_i the savings allocated to partner i, $w_i = \frac{Q_i}{\sum_{i \in N} Q_i}$ and $v(N)$ the total cost savings amount of the grand coalition. In Table 6.15, the 'Scenario 1' column represents the allocations for the scenario in Table 6.11, 'Scenario 2' corresponds with the scenario in Table 6.12 and 'Scenario 3' lists the allocations for the scenario in Ta-

Table 6.13: Results: unequal stand-alone frequency, improved and maintained service after bundling

	Firm-to-firm flow	SAF	BF	Stand-alone	Prop.	Decomp.	Shapley	(ϵ-)EPM
3 part.	Aalst-Antwerp	25	50	123650	120464	120227	121337	121123
	Zaventem-Antwerp	25	50	46308	43122	41484	43481	45361
	Mechelen-Antwerp	50	50	297656	294470	296345	293237	291572
4 part.	Aalst-Antwerp	25	50	123650	119602	119299	120754	*119663*
	Zaventem-Antwerp	25	50	46308	42260	39693	42366	*44176*
	Zaventem-Antwerp	50	50	159789	155741	155893	153566	*152433*
	Mechelen-Antwerp	50	50	297656	293608	296326	294525	*294938*
5 part.	Aalst-Antwerp	25	50	123650	119347	119126	121017	*119129*
	Zaventem-Antwerp	25	50	46308	42005	39628	41810	*43335*
	Zaventem-Antwerp	50	50	159789	155486	155658	150801	*151058*
	Mechelen-Antwerp	50	50	297656	293353	295856	294694	*295626*
	Mechelen-Antwerp	25	50	82023	77719	77641	79587	*78762*

ble 6.13. While these allocation values account for the demand contributions of the coalition partners, they do not guarantee stability. In line with the ϵ-core, a cost $\epsilon > 0$ could be used to penalise cooperation participants for quitting the grand coalition. Fourth, EPM provides the most equally spread cost savings among the partners of the coalition for each of the studied scenarios, although increased variation in partner savings is caused by adding ϵ-core constraints. Finally, similar to the ADA-based case study, the coalition size needs to be aligned with the shipment sizes and vessel types available to ensure sufficient capacity utilisation. For example, increasing the coalition size from three to four partners in the first scenario leads to a higher vessel fill rate and thus yields a higher savings percentage. However, increasing the coalition size from three to four partners in the second scenario results in the use of the larger, more expensive vessel type and thus reduces the savings percentage.

Table 6.14: Stability of hinterland scenarios

Scenario	Proportional	Decomposition	Shapley	EPM
3 equal partners, SAF = BF	✗	✓	✓	✓
3 equal partners, SAF ≠ BF	✓	✓	✓	✓
3 unequal partners, SAF ≠ BF	✓	✓	✓	✓
4 equal partners, SAF = BF	✓	✓	✓	✓
4 equal partners, SAF ≠ BF	✗	✗	✗	✗
4 unequal partners, SAF ≠ BF	✗	✗	✗	✗
5 equal partners, SAF = BF	✓	✓	✓	✓
5 equal partners, SAF ≠ BF	✗	✗	✗	✗
5 unequal partners, SAF ≠ BF	✗	✗	✗	✗

✓: *stable* allocations could be calculated

✗: no *stable* allocations could be calculated

Table 6.15: Results: allocations based on annual shipment volume

	Firm-to-firm flow	Annual volume	Scenario 1	Scenario 2	Scenario 3
3 partners	Aalst-Antwerp	1100	120860	121948	121314
	Zaventem-Antwerp	400	45293	45689	45458
	Mechelen-Antwerp	3000	287453	290419	291284
4 partners	Aalst-Antwerp	1100	120143	122575	120682
	Zaventem-Antwerp	400	45033	45917	45229
	Zaventem-Antwerp	1500	147273	150590	155741
	Mechelen-Antwerp	3000	285496	292129	289560
5 partners	Aalst-Antwerp	1100	119682	121840	120170
	Zaventem-Antwerp	400	44865	45650	45042
	Zaventem-Antwerp	1500	146645	149588	155043
	Mechelen-Antwerp	3000	284240	290125	288163
	Mechelen-Antwerp	800	79137	80706	79491

6.6 Conclusions and further research

Policy makers at European as well as regional levels express the need to stimulate intermodal transport chains. In order to improve the competitive position and efficiency level of intermodal transport, consolidation of freight flows is often suggested. Bundling networks require cooperation between multiple partners in the intermodal transport chain. In this context, the question rises how benefits may be allocated fairly among the participants in the cooperation. A great deal of scientific literature reports on the behaviour of allocation methods in collaborations between shippers or carriers making use of unimodal transport. In intermodal barge transport various types of vessels with differing price structures may be considered for the bundling network. Moreover, the magnitude of the economies of scale resulting from consolidation in barge transport significantly exceeds that of the results obtained in road transport. As such, applying the allocation methods which have been thoroughly studied in a unimodal context is not so straightforward in an intermodal environment. In addition, research on cost or savings allocation methods in intermodal transport is scarce and focuses exclusively on the use of game theory. Practitioners consider the mathematical complexity of these techniques to be an impediment for their applicability in practice. The main contribution of this chapter is to fill this research gap by comparing simple and straightforward allocation mechanisms with more advanced techniques based on game theory. For this purpose, four different allocation methods have been applied to two realistic case studies. By analysing results in terms of savings division amongst the partners and collaborative stability, recommendations could be formulated to collaborating shippers on how they should tackle gain sharing decisions.

The first case study is carried out within the ADA framework and uses real data from a freight transport model for Flanders. Considering the scenarios with equal shipment sizes, Shapley allocations equal those of the decomposition method. If the partners are unequal in size, the decomposition method favours coalition partners that take part in more bundled links of the barge trajectory, while Shapley benefits partners with smaller shipment sizes. For the experiments with a shipment size of 273.6 tons, the use of a second, more expensive vessel type makes it important to look at the stability of the allocation results. Analysing cost allocations over all cases reveals that stability of the grand coalition is guaranteed in all three-partner collaborations. In contrast, none of the four-partner coalitions are stable. Stability of the five-partner coalitions depends on the equality of the partners.

Since the ADA assumptions may not always be realistic and could prevent shippers from optimally bundling their freight flows, a second case study, situated in the hinterland of the Port of Antwerp, is studied. Results reveal that intermodal freight bundling may not only provide cost related benefits, but could also result in improved customer service. However, when deciding on the offered service level, partnering shippers need to account for the stability properties of the selected allocation mechanism. The allocation mechanisms applied in this chapter reward partners who experience the highest savings due to bundling. Small partners who previously had to bear high logistics costs in comparison to their low demand volumes, now enjoy the highest savings consequential to their engagement in the collaboration. Since large partners may consider this to be unfair, a fifth allocation method has been applied which takes the annual demand volumes of the partnering shippers into account.

When a decision has to be made on the mechanism of how to share collaborative savings in an intermodal barge context, it is important to use transparent methods in order to improve collaboration sustainability. Based on the findings in this chapter, the following **managerial insights** may be formulated. For a limited number of partners, operationally simple cost sharing techniques like the proportional and/or decomposition mechanism may be utilised. Applying these straightforward techniques could reduce alliance complexity and enforce the strength of mutual partner relationships. The EPM provides the most equally spread cost savings. This characteristic may be particularly valuable in the early phases of a horizontal collaboration, in which having an initial allocation with similar benefits for all participating organisations may suit communication and negotiation purposes. Finally, it is important to think in advance about the number of coalition participants in combination with the size of the vessel. Adding more partners to the coalition is not always favourable, both in terms of stability and savings, since this might lead to the use of a larger (and more expensive) vessel.

The limitations of the experimental study are acknowledged. The consideration of a distinct intermodal transport business model and the use of specific case study data could influence the general validity of the findings. The conclusions, however, demonstrate the influence of cooperation characteristics on allocation results and underline the value of carefully selecting appropriate allocation mechanisms when long-term stability of the intermodal barge collaboration is aspired.

Several opportunities for **future research** on the intermodal allocation problem may be identified. One natural avenue of research is to add other cost allocation techniques from the literature to the experimental design. As demonstrated in the results discussion, none of the applied allocation techniques truly matched both experimental environments. Next, the analysis could be extended to include other intermodal perspectives besides barge transport. Third, the focus of this chapter is on analysing the cost allocation problem in an intermodal barge context. However, results reveal that partner characteristics may have a significant impact on collaboration outcomes. In line with the analyses done in Chapters 4 and 5, future research work could numerically investigate the impact of coalition structure and partner characteristics on the attainable savings of intermodal collaborations. A fourth avenue for further research relates to the applicability and use of the studied allocation techniques in different business model settings (cf. Rijkswaterstaat, 2013). Finally, problems of congestion and environmental concerns have led to an increasing need for alternative transport modes. While tackling the cost allocation problem could stimulate the establishment of sustainable intermodal collaborations, it is not sufficient to produce a modal shift. Considering the challenges related to logistics collaboration discussed in Section 1.2.2, future research could focus on resolving other difficulties. Moreover, based on the overviews of Zografos and Regan (2004), Vrenken et al. (2005) and Caris et al. (2008) describing the problems faced by intermodal freight transport, a vast amount of future research opportunities emerges.

Chapter 7

Final conclusions and further research

The purpose of this thesis was to study horizontal logistics cooperation in depth on a strategic and operational level. Special attention has been paid to the impact of partner selection and cost allocation decisions on collaborative performance and stability. In Chapters 2 and 3, detailed overviews of literature on collaboration strategies and cost allocation mechanisms are presented, respectively. The following chapters aim to provide a deeper understanding of different collaborative environments by studying the conditions necessary to achieve collaborative synergy. The influence of cooperation structure, partner characteristics and allocation techniques is statistically analysed in a joint route planning (Chapter 4), cooperative facility location (Chapter 5) and intermodal barge transport (Chapter 6) setting, consecutively. This final chapter (Figure 7.1) summarises the main conclusions and identifies directions for future research.

7.1 Final conclusions

Horizontal collaboration between logistics service providers has become an important research area, since severe competition in global markets, rising costs, a growing body of transport legislation and heightened customer expectations have caused profit margins of organisations to shrink. Engaging in a horizontal logistics cooperation provides various efficiency improving opportunities. However, collaboration projects also have significant failure rates due to their inherent complexity. It is thus essential to

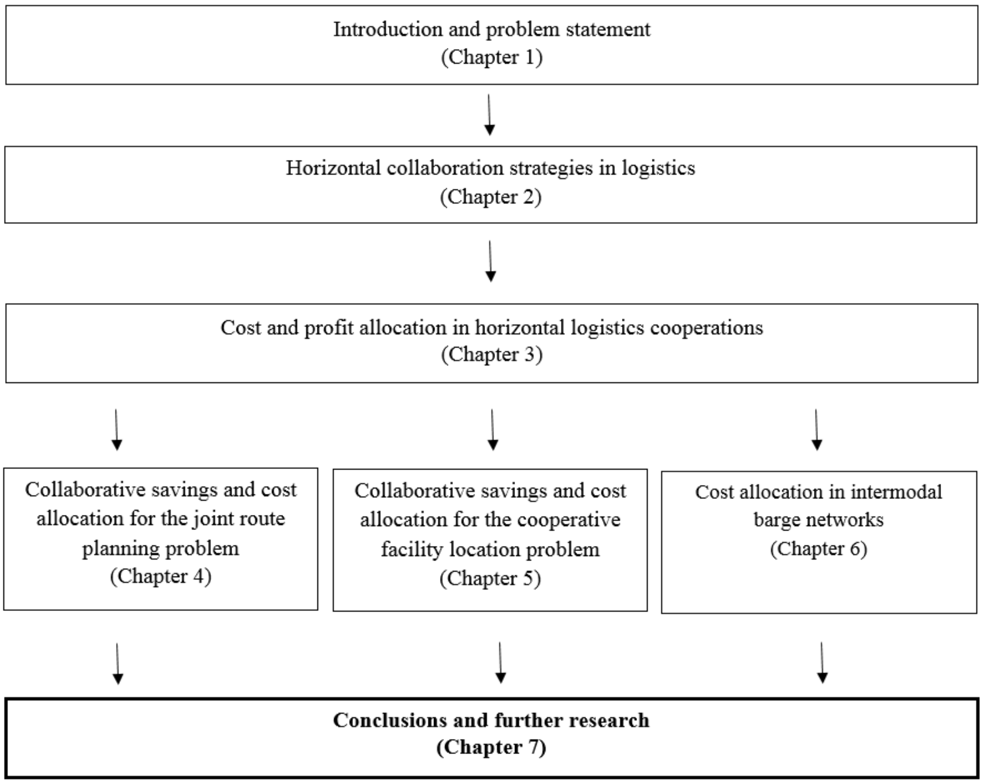

Figure 7.1: Outline of the thesis

approach every partnership from a business perspective to overcome its main impediments and leverage its opportunities.

In comparison to research on other types of cooperative supply chain relationships, the literature on horizontal cooperation in logistics remains scarce and scattered across various research domains. Most existing research emphasises the illustration of potential collaborative cost savings or provides a theoretic overview of cooperation drivers and impediments. Following this research gap on the operational consequences of horizontal cooperation and its growing relevance in practice to increase performance of logistics service providers, a literature review is performed to explore horizontal logistics cooperation in depth on a strategic and operational level. Existing research work is classified according to the different collaboration strategies that logistics service providers can exploit in practice and their characteristic solution approaches mentioned in current research. While carriers may consider a variety of order or capacity sharing techniques, shipper collaborations focus on the identification of transport orders that may be submitted as a bundle to logistics service providers. The literature review indicates that a suitable collaboration strategy needs to be accompanied by a fair cost or savings allocation mechanism in order for a collaboration to be sustainable in the long run. Moreover, in relation to the cooperation challenges defined in existing literature, the success of achieving collaborative benefits strongly depends on the degree of fit between the cooperation participants. Cost allocation and partner selection decisions serve as a general guideline throughout the entire thesis.

This thesis provides support on partner selection and cost allocation decisions by analysing three horizontal cooperation settings: two distinct unimodal carrier coalitions and one intermodal shipper coalition. First, in the majority of horizontal carrier alliances customer orders from all participating companies are combined and collected in a central pool and efficient route schemes are set up for all orders simultaneously using appropriate vehicle routing techniques. This collaboration approach may be labelled joint route planning. In this way, scale economies, in terms of reduced travel distance, empty vehicle movements and number of required trucks, could be obtained by merging the distribution regions of all collaboration partners. Second, in line with the broad definition of logistics including both the movement and storage of freight, a new approach to carrier cooperation is presented: the sharing of warehouses or DCs with collaborating partners. By jointly and optimally deciding on two types of decisions, namely, first which DCs to open and second how to allocate the quantity of product flows to each open DC, partnering companies aim to minimise their total logistics cost. Third, the cooperation challenges are tackled from an intermodal perspective. Bundling freight of multiple shippers offers the opportunity to achieve economies of scale, increase shipment frequencies and boost the competitiveness of intermodal barge transport.

Selecting the right partners constitutes a crucial phase in the development of any horizontal collaboration. Cooperating with an unsuitable partner can be more damaging to an organisation than not collaborating at all. In this context, the first goal of the thesis is to investigate the impact of coalition and partner characteristics on the performance of unimodal and intermodal logistics alliances. Based on extensive numerical experiments, the following managerial insights on partner selection are formulated. In line with the operational fit concept, the most profitable coalitions consist of partners complementary in terms of company size, resources and customer orders. While this means that large logistics service providers best seek for partners that are equal in size, small companies best join forces with a significant amount of equal-sized organisations to attract a large partner and enjoy savings levels associated with large order pools. Next, the statement that the number of partners in a joint venture influences its performance in a positive way needs to be expounded upon in a horizontal logistics cooperation setting. In a joint route planning context the statement can be confirmed, since the larger the pool of joint orders, the larger the potential to find a more profitable route plan for the collaboration. On the contrary, when carriers share DCs or warehouses, a higher level of market consolidation leads to higher cost savings, despite having access to less potential DC sites. Within an intermodal collaboration context, the coalition size needs to be aligned with the shipment sizes and vessel types available to ensure sufficient capacity utilisation. In addition to their main effect on collaborative performance, partner size and coalition size also significantly enforce each other in unimodal coalitions. Furthermore, broad geographic coverage and/or overlapping customer markets constitute an important aspect of coalition profitability. Increased geographical coverage may provide more cooperation opportunities and could thus lead to larger cost reductions in any collaboration setting. Finally, besides the above described observations applicable in all three collaboration environments under study, average order sizes, fixed DC costs and vessel types should be taken into account when deciding on the cooperation structure of joint route planning, cooperative facility location and intermodal barge coalitions, respectively.

Although selecting the right partners is crucial for the success of any horizontal alliance, it is not sufficient to guarantee long-term coalition stability. Dividing the collaborative gains in a fair manner constitutes a key issue. However, as demonstrated in the literature review, a wide range of possible allocation mechanisms exists. Since each method has its specific benefits and drawbacks, collaborating partners need to decide which properties are regarded the most important considering the characteristics of the cooperation project and its participants. In this context, the second goal of the thesis is to examine the suitability of different cost allocation methods in varying cooperation scenarios. More specifically, proportional, decomposition, Shapley, Alternative Cost Avoided Method (ACAM) and Equal Profit Method (EPM) allocations are compared within unimodal and intermodal collaboration environments. Based on extensive numerical experiments, the following observations provide decision support on the cost allocation topic. The EPM may be most useful in collaborations between companies with similar characteristics as it provides the most equally spread cost savings. In addition, the technique may also be valuable in the early phases of a growing horizontal cooperation, in which having an initial allocation with similar benefits for all participating organisations may suit communication and negotiation purposes. Small partners may prefer costs to be allocated by means of the Shapley value. This division mechanism favours companies with a smaller share in customer demand by allocating them a higher percentage of collaborative savings in comparison with the other allocation techniques. Within an intermodal context, Shapley may also stimulate shippers to behave according to the collaborative goal since it rewards partner contributions with a higher share in the collaborative benefits. This argument holds to a lesser extent in a unimodal environment, since differences in partner contributions are rewarded there regardless of the used allocation technique. Furthermore, for a limited number of similar partners, intuitively appealing and operationally simple cost sharing techniques may well be utilised, which could reduce alliance complexity and enforce the strength of mutual partner relationships. Finally, results show the influence of cooperation structure on the longevity of cooperation projects, both in a unimodal and intermodal environment. Expanding the size of a logistics alliance has a negative impact on its long-term stability in all three collaboration environments under study. Companies need to be aware that collaborating with a large number of partners increases alliance complexity and may dilute the strength of partner relationships. In addition, a rising degree of partner inequality may impede sustainability of a DC sharing or intermodal collaboration project. While stability of the studied unimodal collaborations is independent of the allocation technique used, in the intermodal experiments long-term sustainability of the grand coalition is related to the allocation mechanism applied.

7.2 Further research

Horizontal logistics cooperation constitutes a broad domain of research, including strategic, tactical and operational decisions. Although research attention for the horizontal collaboration perspective has increased in the last years, several opportunities for further research may be identified.

First, considering the vast amount of both carrier and shipper collaboration strategies, a comparative analysis could be performed evaluating the efficiency of the developed techniques. KPIs that are useful in this analysis are, among others, cost reduction potential, capacity utilisation impact and customer service effect. Related to this analysis, a second research opportunity consists of creating an overview of advantages and disadvantages associated with each of the discussed strategies. In this way, recommendations could be made to logistics service providers considering a horizontal partnership on the collaboration strategy they should implement.

Second, further research opportunities related to the partner selection and cost allocation analyses performed in this thesis, may be identified as well. Considering the literature review on collaboration strategies, a similar impact study of cooperation characteristics and allocation mechanisms could be done in other collaborative logistics environments. Another natural avenue of research is to investigate the efficacy of other cost allocation techniques from the literature or to develop allocation mechanisms especially suited in joint route planning projects, cooperative facility location cooperations or intermodal barge networks. Furthermore, the consideration of specific factors and factor levels within the studied experimental designs may influence the general validity of the findings. As such, the development and analysis of extended or adapted experimental designs could be the subject of future research work. The selection of an allocation technique is typically done at the start of the collaboration project based on its characteristics at that time. However, a horizontal logistics cooperation most often has a dynamic character as its appearance and structure might change over time. The collaboration might consider broadening its scope of activities or might attract additional players, for example. Future research could address the allocation decision using a dynamic approach allowing for modifications to the sharing mechanism as the characteristics of the coalition evolve over time.

Third, the mathematical models developed in this thesis for unimodal collaboration focus on relatively simple problem settings. There is significant scope for extending these models to more complex freight delivery systems. The joint route planning problem may take into account, for example, drivers' maximum working hours or a heterogeneous vehicle fleet. The cooperative carrier facility location problem could be extended by considering possible gains from selling closed DCs or building new additional DCs in a coalition. In addition, transport demand is assumed to be deterministic in both models, while in practice companies may have to rely on uncertain forecasts of transport demand. Future research could focus on the introduction of stochastic travel times, travel costs and demands with the aim of creating more robust collaboration models.

Fourth, considering the future supply chain architecture described by Global Commerce Initiative and Capgemini (2008), quantitative analyses similar to those performed in this thesis could be useful for specific logistics environments such as city distribution, for example. Since current transport infrastructure is subjective to increased congestion and the number of home deliveries grows significantly, collaborative models need to be applied to urban structures. Accounting for CO_2 emissions, the different streams that enter the city need to be consolidated. In this context, city hubs with a collaborative cross-docking operation could play a central role. Moreover, in order for horizontal logistics partnerships to sustain in the long run additional research is needed on the implementation and management of the collaborative supply chain. Special attention needs to be paid to, among others, the management of required investments, common social regulations and the information flow between partners.

Finally, despite its inherent multi-objective nature, the majority of current research considers horizontal logistics collaboration as a single-objective minimisation of, among others, total distance travelled, total transport costs or number of used vehicles. For the cooperation project to succeed and enjoy significant collaborative savings in the long run, however, accounting for the different objectives of the cooperation participants is essential. The development of a multi-objective optimisation approach to horizontal logistics collaboration could be the subject of future research. For example, when exploring joint route planning, the focus may be expanded from considering cost minimisation exclusively to account for customer service effects. Besides its impact on cost and efficiency levels, cooperation with fellow logistics service providers may also have an influence on the service that can be provided by each participating carrier. Although the offered service in terms of lead-time may improve for some of the cooperating partners, it may decline for others as a consequence of sharing customer orders.

Appendix A

Generation of joint route planning instances

Instances were created based on the problem instance generator described in Corstjens et al. (2016). A single instance consists of a combination of the values listed in Table A.1.

While the majority of the values are randomly determined, some are kept constant to avoid them having an impact on the effects analyses described in Chapter 4. The number of vehicles available is assumed equal to the number of customer orders to guarantee problem feasibility. The capacity of each vehicle is fixed at 200 units and the depot is determined to be open during a fixed time window, being [0, 2000] for instances with narrow time windows and [0, 3000] for instances with broad time windows.

The values that are randomly determined are all drawn from uniform distributions. The customer and depot coordinates are defined on a square grid of width 300. For clustered instances, a random number of cluster seeds is generated between 1 and (0.25 × number of customers + 1) which are used to determine clustered customer locations within the 300 × 300 area. The number of customer orders varies between 15 and 25 for small carrier instances, 60 and 70 for medium-sized carrier instances and 100 and 120 for large carrier instances. Average order sizes vary between 5% and 15% or 30% and 40% of vehicle capacity depending on the assumed level of the 'order size' factor. The service time for each order is randomly drawn from a uniform distribution between 10 and 40. The time window for each order is constructed as follows. First, the time window centre is determined as a random number between the earliest moment a vehicle can arrive at the customer location and the latest moment a vehicle can arrive there, given the time window of the depot and the service time of the order. Second, the time window width is randomly drawn from a uniform distribution between 10 and 70 for the 'narrow time window' level and between 150 and 210 for the 'broad time window' level. Moreover, the assumption of constant speed is made so that distances, travel times and travel costs are proportional (Corstjens et al., 2016).

Table A.1: Characteristics of problem instances

Characteristic	Value
Vehicle capacity	200
x/y-coordinates	$U(0,300)$
Number of customer orders	$U(15,25)$ for a small carrier
	$U(60,70)$ for a medium-sized carrier
	$U(100,120)$ for a large carrier
Order sizes	$U(10,30)$ for a small order
	$U(60,80)$ for a large order
Service time	$U(10,40)$
Time window depot	[0,2000] for narrow time window instances
	[0,3000] for broad time window instances
Time window customer order	[centre - 0.5 × width, centre + 0.5 × width]
- Centre	U(0 + distance, 2000/3000 - distance - service time)
- Width	$U(10,70)$ for narrow time window instances
	$U(150,210)$ for broad time window instances

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Samenvatting

De opkomst van producten met kortere levenscycli, de stijgende brandstof- en arbeidskosten, de toename in transportwetgeving en de verhoogde verwachtingen van klanten zijn maar enkele van de trends die ervoor hebben gezorgd dat de winstmarges van vervoerders en verladers sterk zijn gedaald. Bovendien worden logistieke dienstverleners steeds vaker geconfronteerd met de grenzen van winstverbetering op basis van interne procesoptimalisatie. Als gevolg realiseren de betrokken organisaties zich dat ze moeten investeren in sterkere relaties met gelijkgestemde bedrijven om te kunnen concurreren in globaliserende markten.

Verscheidene logistieke samenwerkingsvormen werden reeds onderzocht in de literatuur. Zowel verticale samenwerking in de keten tussen producenten, distributeurs en klanten als laterale samenwerking in netwerken vormden de focus van een aanzienlijk aantal academische studies. In vergelijking blijft het onderzoek naar horizontale samenwerking tussen partijen op hetzelfde niveau van de keten eerder schaars en benadrukt het vooral de potentiële kostenbesparingen van deze samenwerkingsvorm. Op basis van deze vaststelling heeft dit doctoraat als doel horizontale logistieke samenwerking te bestuderen en analyseren vanuit een strategisch en operationeel perspectief. Hierbij wordt gefocust op de impact van partnerselectie en kostenallocatie beslissingen op de prestaties en stabiliteit van de samenwerking.

Omwille van het gebrek aan onderzoek naar de operationele aspecten van horizontale samenwerking wordt een literatuurstudie uitgevoerd naar de samenwerkingsstrategieën die logistieke dienstverleners kunnen implementeren in de praktijk. Terwijl vervoerders de keuze hebben tussen een verscheidenheid aan technieken voor de uitwisseling van klantenorders of voertuigen, focussen samenwerkingen tussen verladers op het bepalen van klantenorders die als bundel kunnen aangeleverd worden aan vervoerders. Het literatuuroverzicht wijst er bovendien op dat een samenwerkingsstrategie steeds vergezeld dient te worden van een mechanisme voor het verdelen van kosten of baten geassocieerd met de samenwerking, opdat deze op lange termijn zou blijven bestaan. Daarnaast hangt het succes van de samenwerking in grote mate af van de compatibiliteit tussen de partners in termen van operationele, strategische en culturele kenmerken. Kostenallocatie en partnerselectie beslissingen vormen dan ook de rode draad doorheen het volledige doctoraat.

Het doctoraat ondersteunt kostenallocatie en partnerselectie beslissingen op basis van uitgebreide analyses uitgevoerd in drie horizontale samenwerkingsomgevingen: twee unimodale vervoerderscoalities en één intermodale verladerscoalitie. Ten eerste worden in de meerderheid van de vervoerderscoalities klantenorders verzameld van alle partners om zo een centrale rittenplanning te bepalen. Deze samenwerkingsstrategie wordt in de literatuur joint route planning genoemd. Door de distributieregio's van alle partners te combineren streeft men naar een daling in reisafstand, aantal vereiste voertuigen en lege kilometers. Ten tweede wordt, naar analogie met de algemene definitie van logistiek die zowel het transport als de opslag van goederen omvat, een nieuwe horizontale samenwerkingsvorm voor vervoerders geïntroduceerd: het delen van magazijnen of distributiecentra met coalitiepartners (cooperative facility location). Door gezamenlijk te beslissen over het al dan niet openen van distributiecentra en de allocatie van productstromen naar deze distributiecentra, kunnen partnerbedrijven hun totale logistieke kosten minimaliseren. Ten derde worden de uitdagingen verbonden aan een horizontale logistieke samenwerking geanalyseerd vanuit een intermodaal perspectief. Het bundelen van zendingen van meerdere verladers biedt schaalvoordelen, creëert opportuniteiten voor de verbetering van klantenservice en versterkt de competitiviteit van intermodaal binnenvaarttransport.

Het selecteren van de juiste partners vormt een cruciale fase in de ontwikkeling van elke horizontale samenwerking. Samenwerken met een ongeschikte partner kan schadelijker zijn voor een organisatie dan helemaal niet samenwerken. In deze context is het eerste doel van het doctoraat het analyseren van de impact van coalitie- en partnerkenmerken op de prestaties van unimodale en intermodale logistieke allianties. Op basis van uitgebreide numerieke experimenten en statistische analyses kunnen de volgende inzichten worden geformuleerd. De meest winstgevende coalities worden gevormd door partners complementair in termen van bedrijfsgrootte, resources en klantenorders. Dit impliceert dat, terwijl grote logistieke dienstverleners best zoeken naar partners van gelijke grootte, kleine organisaties best hun krachten bundelen met een significant aantal andere kleine bedrijven om zo te kunnen genieten van winsten verbonden aan de uitwisseling van veel klantenorders. Vervolgens dient de hypothese, die stelt dat het aantal partners een positieve invloed heeft op de prestaties van de samenwerking, genuanceerd te worden voor de bestudeerde horizontale samenwerkingen. In een joint route planning context kan de stelling bevestigd worden, aangezien een groter aantal gecombineerde orders zorgt voor meer opportuniteiten bij het bepalen van de centrale rittenplanning. Indien vervoerders daarentegen hun distributiecentra delen, leidt een hogere graad van marktconsolidatie net tot meer besparingen. In een intermodale context dient de grootte van de coalitie dan weer afgestemd te zijn op de betrokken verzendings- en scheepsgroottes om voldoende capaciteitsbenutting te kunnen garanderen. Verder vormen een brede geografische dekking en/of overlappende distributiegebieden een belangrijk aspect van de winstgevendheid van een horizontale samenwerking. Ten slotte dient, naast de hierboven beschreven algemene observaties, rekening gehouden te worden met ordergroottes, vaste magazijnkosten en scheepstypes wanneer wordt beslist over de structuur van, respectievelijk, een joint route planning, cooperative facility location of intermodale binnenvaartsamenwerking.

Hoewel het selecteren van de juiste partners cruciaal is voor het succes van elke horizontale samenwerking, is het niet voldoende om het bestaan van de samenwerking op lange termijn te garanderen. Het verdelen van de kosten en baten verbonden aan de samenwerking vormt hierin een kernaspect. Zoals blijkt uit het literatuuroverzicht bestaan er bovendien een brede waaier aan mogelijke allocatie mechanismen. Aangezien elke methode zijn specifieke voor- en nadelen heeft, moeten partners beslissen welke eigenschappen ze als meest belangrijk beschouwen. In deze context is het tweede doel van het doctoraat het analyseren van de geschiktheid van specifieke kostenallocatie mechanismen in verschillende samenwerkingsomgevingen. Specifiek worden proportionele, decompositie, Shapley, Alternative Cost Avoided Method (ACAM) en Equal Profit Method (EPM) allocaties vergeleken. Op basis van uitgebreide numerieke experimenten en statistische analyses bieden de volgende observaties ondersteuning bij het nemen van kostenallocatie beslissingen. De EPM blijkt zeer nuttig in samenwerkingen tussen bedrijven met gelijkaardige kenmerken, aangezien deze methode zorgt voor de meest gelijkmatige spreiding in relatieve kostenbesparingen van de partners. Bovendien zou deze techniek ook waardevol kunnen zijn in de beginfase van een groeiende horizontale samenwerking wanneer een gelijkmatige verdeling van baten de communicatie en onderhandelingen tussen partners kan vereenvoudigen. Kleine partners verkiezen Shapley als verdelingsmechanisme. Deze techniek gunt bedrijven met een kleiner aandeel in de samenwerking namelijk een hoger percentage in de besparingen. In een intermodale context stimuleert Shapley bovendien de verladers om zich in te zetten voor de samenwerking, aangezien deze methode partnerbijdragen beloont. Dit argument geldt in mindere mate in een unimodale omgeving aangezien verschillen in partnerbijdragen daar beloond worden ongeacht de gebruikte allocatie techniek. Verder kunnen mathematisch eenvoudige technieken nuttig zijn in coalities met een beperkt aantal gelijke partners. Ten slotte, tonen de resultaten dat de structuur van de samenwerking een invloed heeft op zijn levensduur. Het uitbreiden van een coalitie met meer partners heeft een negatieve invloed op de stabiliteit in alle drie de bestudeerde samenwerkingsomgevingen. Bedrijven moeten er zich van bewust zijn dat samenwerken met een groot aantal partners de complexiteit van de samenwerking doet toenemen en de intensiteit van partnerrelaties reduceert. Bovendien kan ongelijkheid in partnerkenmerken de duurzaamheid van een distributiecentra- of binnenvaartsamenwerking verminderen. Terwijl stabiliteit van de bestudeerde unimodale coalities onafhankelijk is van de gebruikte allocatie techniek, blijkt er wel een afhankelijkheidsrelatie te bestaan tussen de toegepaste allocatie techniek en stabiliteit in de intermodale experimenten.

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