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„Profit sharing and strategic behaviour in an auction-based collaborative carrier network“

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Contents

1 Introduction

Collaborative networks are getting more and more important for logistic companies in order to stay competitive in the fast-moving, highly-competitive transportation industry. In contrast to vertical cooperation, where entities along a supply chain (suppliers, manufacturers, customer, etc.) collaborate (Krajewska et al, 2007) we are examining cooperation on the same level in the market. Cruijssen et al (2007) refer to this as horizontal cooperation. They argue that there is many literature about vertical cooperation, whereas in the research about horizontal cooperation, especially in logistics, there is still much potential for further examinations.

Such collaborations can be formed by using an auction-based mechanism, where carriers can exchange requests that cannot be efficiently integrated into their existing tour. The carriers try to reach a composition of requests which allows them to act more efficiently. As a result of the reassignment of requests the carriers avoid empty trucks, make use of back-hauls and in general utilize their capacities better. The aim of such an auction is to maximize the profit of the whole network, firstly without decreasing the individual profit of the carriers and secondly with as little information transfer as possible (Berger and Bierwirth, 2010). The latter refers to the fact, that the participants are still competitors.

The central element of cooperation is formed by an auction-process. In brief, this procedure can be divided into the following phases. In the first phase each participant has to decide which requests to forward to the auction pool and which ones to keep. In the second phase a combinatorial auction is conducted which allows to exchange bundles of requests. The bundles are reassigned according to the outcome of the auction in the next phase. In the last phase the generated profit has to be distributed fair among all participants (Gansterer and Hartl, 2015).

Gansterer and Hartl (2015) focus on the first phase of the auction. They examine how to build up the request candidate set, which are those requests that are offered to the other participants. They create request evaluation strategies in order to disclose which requests to pick and forward to the auction pool.

In this thesis the same framework is used, but emphasis is put on the last phase, the profit sharing, as this was not yet treated in Gansterer and Hartl (2015). Within this phase the additionally generated profit has to be split among the carriers. This phase is significantly involved into the crucial question, whether such collaborative networks come off, at all, which was the main motivation for this thesis. Firstly, the allocation scheme has to provide an incentive for each carrier to join the coalition at all, and in addition stay in the collaborative network such that a long-term collaborative carrier network (CCN) can emerge. Thus an appropriate profit sharing method should provide a financial advantage for each carrier. Furthermore the profit allocation has to ensure that the individual contribution of each carrier is taken into account (Krajewska et al, 2007).

Out of the multitude of cost or profit allocation methods, that exist in literature, several ones are analyzed and evaluated according to their applicability in the underlying framework. As Šimenc (2014) provides an overview of existing cost allocation (CA) methods and a detailed experimental analysis, it is taken as indication for this thesis. Concerning applicability the most challenging fact was to bear in mind incomplete information. Many terms used in various profit allocation methods, such as the initial profit before the auction starts, or the profit after all auction rounds are done, are not disclosed in the underlying framework, because carriers still act as competitors and want to reveal as little private information as possible.

Although anticipating the further examination throughout this thesis, it can be said, that none of the existing methods could be applied. This forces the author to look for alternatives and adapt existing methods or create new ones. Indeed, a method which fulfills all requirements, is created and therefore undergo some further research within the computational study of this thesis. To assess the quality of the self-created method it is compared to an existing method, in order to have a reference value.

A profound assumption that is made in the underlying framework of Gansterer and Hartl (2015) as well as in a similar framework of Berger and Bierwirth (2010), is about the bids that the carriers set for the bundles of requests inside the auction pool. It is assumed that they bid exactly their marginal profit for the bundles. The whole auction procedure is based on this assumption. But the design of the auction somehow incites the carriers not to bid their marginal profit, but a different value, in order to possibly make themselves better off. This is the motivation for the second part of this thesis, which deals with strategic behaviour. In regard to strategic behaviour this thesis just takes the first step to open a broad topic. Different values for bidding higher are tested. This study does not claim for completeness, but just touches the behaviour of the carriers and starts the discussion and hopefully some future research towards examining strategically behaving participants is done.

The thesis is structured in the following way. Section 2 provides an overview of the existing literature that deals with similar questions and problems in horizontal cooperation, such as auction-mechanisms, profit sharing and strategic behaviour.

In Section 3 the underlying framework as well as the assumptions and prerequisites are explained in detail. Here the different steps during the auction-process are examined. Within this section emphasis is put also on incomplete information.

Chapter 4 is dealing with profit sharing and profit sharing methods. First of all some aspects of cooperative game theory are used to give the technical background for profit sharing methods. Then an overview of CA methods is presented which are in a second step transformed into profit sharing methods. As incomplete information plays an important role not all of the presented methods are applicable, which leads to adapted and self-created methods. Further the computational study is examined, where firstly the test instances are introduced and then the results are reported and discussed.

Strategic behaviour is treated in Chapter 5. This is followed again by a computational study. A conclusion and an outlook at some possible future research is given in Chapter 6.

2 Literature review

This section gives an overview of related literature. Firstly there are two papers (Berger and Bierwirth, 2010 and Gansterer and Hartl, 2015) discussed in more detail, because they directly refer to a similar or in the latter case even the same framework. In the further subsections a broad overview of existing literature dealing with combinatorial auctions in logistics, profit/cost allocation and strategic behaviour in CCN is shown.

The underlying framework, where an auction forms the central element, was for the first time presented in Berger and Bierwirth (2010). They analyze solutions to the request reassignment problem in CCN. They are discussing a pickup and delivery service in the less-than-truckload (LTL) market, where capacity restrictions are not considered. Three strategies are compared: firstly no collaboration, secondly a decentralized planning approach where they test a Vickrey Auction and a combinatorial auction and thirdly a centralized planning approach, where full information is needed. The Vickrey Auction is conducted with single request reassignment (SRRA) and the combinatorial auction with bundle request reassignment (BRRA). The former means that one can just bid on single requests and no bundles of requests are formed, whereas the latter allows to benefit from synergies of forming bundles of requests. Furthermore the occurring optimization problems in the tour building are solved by an exact method, namely a branch and cut algorithm. They use instances with 3 requests per carrier acting in adjacent, overlapping or identical customer areas, which reflects different degrees of competition.

The framework of Berger and Bierwirth (2010) is forming the basement for Gansterer and Hartl (2015). Several adaptions and extensions are made. They are replacing the exact algorithm in the tour building procedure by a heuristic, which enables them to solve instances with an increased number of requests per carrier in a reasonable time. The main question Gansterer and Hartl (2015) focus on, is to find strategies how the carriers select their request which they forward to the request candidate set. It was shown that strategies that take geographical aspects into account clearly dominate pure profit-based strategies.

2.1 Horizontal cooperation

Bengtsson and Kock (2000) use the word "coopetition" as a mixture of cooperation and competition, which perfectly describes the situation in horizontal cooperation. They analyze situations in business networks where two or more competitors compete and cooperate with each other at the same time. They distinguish between cooperation-dominated, equal and competition-dominated relationships. Within their experimental study they focus on lining and brewery industry in Sweden and the dairy industry in Finland.

In 2007, Cruijssen et al formed propositions about opportunities and impediments to horizontal cooperation. E.g. horizontal cooperation increases the the company's productivity for core activities and reduces the costs of non-core activities, it is hard to find proper partners for collaboration, it is hard to determine the benefits/savings beforehand, etc. They did a survey on these propositions among logistics service providers in Flanders, Belgium. They address the need for a proper cost/savings allocation method.

Zigmas and Benas (2007) deal with horizontal cooperation among competitors in the international transportation industry. They evaluate and validate the key factor of building a successful horizontal cooperation. They apply their findings in the Lithuanian market, considering multiple alliance partner situations.

Structural concepts for horizontal cooperation in logistics are presented in Leitner et al (2011). They analyze different forms and levels of horizontal cooperation, such as purchasing cooperation, transport cooperation or lateral supply chain cooperation. Furthermore the authors discuss the design of cross-company logistic concepts and the definition of an optimal logistic concept in order to create synergies.

Motives, structure and performance of horizontal cooperations between logistics service providers are discussed in Schmoltzi and Wallenburg (2011). They collected empirical data of German logistic companies and applied several statistical methods during their analysis. They focus on an analytical classification model and distinguish between six types of cooperation: contractual, organizational, functional, geographical, service and resource scope.

Wang and Kopfer (2011) discuss chances and challenges of collaborative transport planning in general. In 2014a, Wang and Kopfer consider collaborative transportation planning and compare three scenarios: a decentralized request exchange mechanism, isolated planning without collaboration and a heuristic approach for the centralized planning problem. They include capacity limitations as well as restrictions on the exposure of information. They conclude that the first scenario is very efficient and effective in terms of realizing cost-savings.

Adenso-Díaz et al (2014) show how to create savings in horizontal cooperation by planning linked deliveries. By doing so empty returns can be avoided. Additionally they focus on how these savings change depending on specific factors. For example they found that when adding more partners to the cooperation the benefits decrease.

In 2014, Juan et al discuss not only the reduction of costs through horizontal cooperation, but also the reduction of environmental pollution due to CO_2 emissions in logistics. The main aspect to reach this reduction is to make use of backhauls. The authors talk about green logistics and point out the need for a global objective function. They conclude with some numerical examples that underline the advantage of horizontal cooperation.

Vornhusen et al (2014) discuss horizontal cooperation including transshipment. This means that vehicles involved in transferring the same request are synchronized at the so-called transshipment points. Using this framework they point out considerable cost-savings.

Similarly Wang et al (2014b) consider horizontal coalitions where emphasize is put on including external resources (subcontractors). By introducing subcontracting the routing of own vehicles is extended to an integrated operational transportation planning problem. Furthermore they present planning strategies which intend to increase the profitability by exchanging requests. They found considerable cost reductions.

2.2 Combinatorial auctions in logistics

Cruijssen et al (2004) compare a system with order sharing and a system without order sharing within a case study in the Dutch flower transportation sector. They follow a three-phase model that consists of the selection of suitable partners, the estimation on the savings in transportation costs due to cooperation and an algorithm for allocating the realised synergy benefits. Focusing on the second phase they find savings up to 15 percent. They point out the need for a fair allocation mechanism for splitting these savings among all participants.

Another paper of Krajewska et al (2006) presents a combinatorial auction between freight forwarding companies. They find themselves in a LTL market with pickup and delivery requests and time windows. The request allocation and the profit sharing phase are examined in detail. The model that they consider, allows the participants to choose for each transportation request whether they want to conduct it on their own (self-fulfillment) or they want to forward the request to an external carrier (subcontractor), who then receives a fee for subcontraction. Profit can be generated from the difference between the price the customer is paying and the costs for fulfillment (either self- or external-fulfillment). The collaboration process is described in three phases: preprocessing, profit optimization and profit sharing. In the first phase each carrier defines the potential self-fulfillment costs as the minimal costs of execution with own vehicles. In the second phase the carriers define their potential fulfillment costs for all bundles of offered requests. For those he does not want to fulfill at all, a carrier may set infinity. Then a modified Matrix auction based on a first price sealed bid auction is conducted such that the most profitable bundle combination is identified. Then the requests are reallocated according to this auction outcome. In the profit sharing phase each offering carrier holds the payment of the customer. If the carrier forwards the request to the coalition he pays the self-fulfillment costs and receives a part of the residual profit. Then the transfer price, which is the payment the company receives for fulfillment is determined. The profit then amounts to the transfer price minus the minimal fulfillment costs, which is always positive. The residual profit is then divided among the participants by using the so-called collaboration-advantage-index.

Abrache et al (2007) give an insight into the design of combinatorial auctions. The paper presents a classification of combinatorial auctions including their formulation. Further they focus on the expression of combinatorial bids and the design of multi-round mechanisms. In the latter case they face the problem of incomplete information. Furthermore they discuss the decision problems faced by the participants.

Ackermann et al (2011a) argue that combinatorial auctions are a promising approach to exchange transportation requests and form cooperations beyond enterprise boundaries. They examine LTL transportation with pickup and delivery requests. The main reason behind using a combinatorial auction is the chance of creating synergies. The carriers either want all requests in a bundle, or none of them, in order to benefit from complementary requests. The modelling goals of Ackermann et al (2011a) are to require minimal information of the participants, to leave as much authority as possible at the carriers' side, to provide an easy profit sharing and to make the outcome somehow predictable, which means that there are no surprises happening, which contradict the planning of the carrier. Further goals are to provide incentives for the participation in the network, such as participation for free and outcomes that only improve the carriers' situation, but never worsen it.

2.3 Profit sharing and cost allocation

What still needs intensive examination, is the procedure after the auction is done, namely the profit sharing phase. The thesis of Šimenc (2014) deals with CA between customers in LTL transportation. It provides a game-theoretic approach and gives an overview and classification of existing CA methods. The classification splits the methods into trivial ones, classical (accounting-based) methods, wherein between total gain repartition and separable/non-separable costs is distinguished, and more sophisticated methods such as the Shapley allocation. 11 methods are undergone an experimental study. This study uses a step-wise methodology which is split into four phases: definition of the experimental setting, representation of the cooperative game, CA and a follow-up analysis. It was shown that specific simpler approaches even perform as well as the more sophisticated ones. The presented CA methods form the baseline for finding an appropriate profit sharing methods for the present thesis.

The Shapley value a widely used solution concept for sharing costs or profit goes back to "Notes on the n-person game, II: The value of a n-person game" from Shapley in 1951.

In Young (1979) different CA methods are applied to a case of Swedish water resource management. Hereby proportional methods, the core, nucleolus, Shapley and the Separable Cost Remaining Benefits method (SCRB) play an important role. Young et al (1981) express the need for a fair cost/profit allocation and analyze 5 methods in detail: 3 nucleolus variants, the Shapley value and SCRB. Further they conduct a computational study to compare them. In 1985, Young discusses CA in general. Further he states the principles of CA: additivity, monotonicity, consistency and efficiency.

Banker (1981) takes an axiomatic approach to analyze traditional cost allocation methods and newer concepts. He points out inadequacies and shortcomings of the Shapley value. Further he discusses other approaches such as the maximum entropy criterion, the core criterion and Moriarity. With an axiom system he identifies differences as well as similarities between them.

Lemaire (1984) presents the classical CA methods such as equal/proportional repartition of the total gain, equal/proportional repartition of the non-marginal costs and the repartition proportional to the claim amounts. According to Lemaire a fair allocation has to satisfy individual rationality and collective rationality. Applying both properties, the five beforehand mentioned methods have to be rejected. Then he presents four new CA methods, namely Shapley, nucleolus, and proportional/disruptive nucleolus.

Tiejs and Driessen (1986) give a survey of CA methods based on the nucleolus and the Shapley value. Further they introduce the cost gap method (CGM) which is based on the τ-value.

In 1996, Engevall presented the core and the nucleolus in a travelling salesman game and a vehicle routing game within his masterthesis. Some common concepts from cooperative game theory such as nucleolus, the Shapley value and the τ-value are then discussed in Engevall et al (1998) within a study for the Norsk Hydro case. Additionally they introduce the demand nucleolus as a new concept. The former three methods yield almost the same result, whereas the demand nucleolus is criticized, because when formulating a game and defining the characteristic function, all relevant information of the game has to be included. Therefore it is advised to find other ways to take demand into consideration.

The California Bay-Delta Authority (CBDA, n.d.), working on a real-life application in the field of environmental management and hydro-engineering, provide an overview of several CA methods. Additionally they provide eight criteria for evaluating those CA methods (e.g. consistency, fairness, flexibility, rationality, reliability, etc.) and ranking them accordingly. Out of seven methods SCRB and Shapley turned out to be the most promising ones for their special application.

An axiomatic approach to the CA problem is given by Krus and Bronisz (2000). They explain eight axioms that define a proper game, which means that superadditivity is satisfied and present a proposition that assures a unique solution. They discuss the core, nucleolus concepts and Shapley, as well. In a computational study they compare Shapley and four nucleolus variants to the traditional method SCRB.

Sakawa et al (2001) are applying the nucleolus to a transportation planning problem occurring in a cooperation among multiple production and sales bases.

Pekeč and Rothkopf (2003) study the design of combinatorial auctions. The summarize the desirable properties, such as allocative efficiency, overall economic efficiency, revenue maximization or cost minimization, low transaction cost, fairness, failure freeness and transparency. The presented combinatorial auction mechanisms are single-round (sealed bid) first-price combinatorial auctions, Vickrey-Clarke-Groves mechanisms and uniform mechanisms. Further they discuss iterative combinatorial auctions.

Similarly de Vries and Vohra (2003) sum up the properties an auction design should fulfill: incentive compatibility, no bidder is worse off and the seller maximizes expected revenues. Satisfying these characteristics an auction design is called optimal.

Bartholdi III and Kemahlıoğlu-Ziya (2005) use the Shapley value to allocate profit that was generated by a inventory-pooling coalition of retailers and suppliers. They remark that the allocation is individually rational, but nevertheless perceived as unfair in some situations. As an outlook for some further research they mention to include truth-inducting properties into their model.

Matsubayashi et al (2005) study CA in a hub-spoke network system. Applying the core concept they faced the problem of the potential emptiness of the core. Thus they derived a sufficient condition to satisfy non-emptiness of the core. They showed that the core firstly exists and secondly includes the CA proportional to the traffic generated by the node.

A technical background of game theory and the formulation of cooperative games is given in Parrachino et al (2006). They discuss solution concepts like the core, the nucleolus, the Shapley value, etc. as well as cost-sharing methods like Alternative Cost Avoided (ACA) or SCRB.

Krajewska et al (2007) study horizontal cooperation among freight carriers. They discuss the resulting profit and a fair allocation of these profit margins. They propose the Shapley value as a fair allocation. The main reasons for choosing the Shapley value is besides fairness, uniqueness and ease of implementation, although the disadvantage of a solution that does not lie in the core, may occur.

Okamoto (2008) provides algorithms to compute fair allocations in polynomial time. He has chosen the core, the nucleolus, the τ-value and the Shapley value. He gives insights to the relationship of algorithm theory with cooperative games.

Özener and Ergun (2008) discuss CA in collaborative transportation procurement networks. Besides the well-known properties, such as budget balance (efficiency), stability and cross monotonicity they define a new set of properties. Those contain a minimum liability restriction, a minimum percentage deviation from stability and guaranteed positive benefits.

Serrano (2009) describes the basic elements of cooperative game theory and then focuses on the core and the Shapley value.

The profit allocation problem is also treated in Xu et al (2009) whereby well-known profit allocation concepts as e.g. Shapley, proportional allocation, nucleolus are explained. A new method, weighted relative savings model (WRSM) is presented and the effectiveness is shown in a computational study.

Frisk et al (2010) are testing several CA methods in collaborative forest transportation. They examine the Shapley value, the nucleolus, an allocation based on volumes, an allocation based on separable and non-separable costs (equal charge method (ECM), CGM, ACA) and an allocation based on shadow prices. Further they propose a new allocation method, the equal profit method (EPM), that satisfies that relative profits of the participants are as equal as possible. ACA and ECM give sometimes unstable solutions, whereas the rest yields stable solutions. They found that volume-based and ECM are less suitable. Further they argue that simpler methods are easier understandable and therefore may be preferred to more sophisticated methods, such as Shapley. They conclude, that in the underlying study of forest companies the proposed EPM approach is accepted and in use, but for other applications with other characteristics the applicability has to be examined.

Ackermann et al (2011a) argue that, when discussing profit sharing methods, it is not possible to achieve all desired properties together. Therefore they focus on three properties: budget balance, individual rationality and fairness. Budget balance means that the total amount paid by the offering carriers has to match the amount received by the winning carriers and fairness refers to the core-property. Ackermann et al (2011b) support their decision to go for the Shapley value.

Yilmaz and Savasaneril (2012) discuss shipper collaborations. They show that shippers always benefit from coalitions, but the allocations of the benefits is not always budget-balanced, which would be elementary for the sustainability of the coalition.

Beyond the fact, that collaborative planning in logistic operations creates substantial savings, Audy et al (2012) try to answer the questions, how to split these savings among the participants and how to form collaborative networks. They perform their analysis with four different business models within a case study including eight forest companies. Two models consider CA, whereas the other two follow a savings allocation rule. Furthermore they distinguish between altruistic and opportunistic behaviour by the so-called leading companies, that initiate and drive the planning process. The allocation rule is based on the same scheme over all models, namely an allocation according to the proportion of the stand-alone costs of each participant, because it is easy to understand and easy to compute.

Three allocation methods, including Shapley, proportional allocation and contribution-based allocation are presented in Dai and Chen (2012). They consider pickup and delivery requests, but use a centralized collaboration framework. All three methods guarantee a solution in the core, if the core is not empty. As they cannot say that one mechanism is better than another one, they recommend to determine this by the common preference of all participants.

Out of the existing cooperative game theory solution concepts Lozano et al (2013) pick the Shapley value, the minmax core, the least core and the τ-value for their computational study. The results of the methods are similar in case of stability and fairness, but they do not coincide. Due to their simplicity least core and minmax suit best to the underlying application.

Vanovermeire and Sörensen (2014) propose a model that integrates a CA method directly into the planning and optimization phase. The method they use is the Shapley value. They argue that their model is rather a proof-of-concept implementation than an implementation usable in practice. Vanovermeire et al (2012) show in their analysis that a proper CA is highly dependent on the characteristics of the coalition. They analyze several methods in various situations (e.g. varying the number of partners, the number of pallets, flexibility, etc.) and give a detailed suggestion which ones are reasonable in which situation.

Sun et al (2015) present typical allocation methods, such as proportional allocation, the Shapley value, the moat model and the contribution constrained packing model. The first three violate the stated fairness criteria, for which reason the latter one is modified, such that the desired properties are fulfilled.

2.4 Strategic behaviour

Within his dissertation Parkes (2001) deals with mechanism design, which considers solutions to a system with multiple self-interested agents with private information about their preferences. He discusses desirable properties such as efficiency, strategy-proofness, individual rationality and budget-balance and points out the advantages and disadvantages of Groves mechanisms.

Finnish treasury auctions are examined in Keloharju et al (2005). They focus on strategic behavior and underpricing in uniform auctions with a small number of bidders.

Referring to a real-life example, Edelman and Ostrovsky (2007), analyze strategic behavior in sponsored search auctions run by Yahoo! and Google between 2002 and 2003. They present evidence of strategic bidder behavior in these auctions and provide an alternative mechanism that could reduce strategizing by bidders, increase the revenue and increase the overall efficiency of the market.

Vytelingum et al (2008) present a bidding strategy in continuous double auctions, based on short and long-term learning effects. The adaption of the aggressiveness of the bidding behaviour, based on market information observed after every transaction, enables the bidder to respond to market fluctuations in short terms and to long term trends.

Carlos and Saraiva (2009) examine strategic behaviour in Brazilian transmission auctions using real-life data from 2000 to 2008. Their empirical study showed that many factors have impact on the winning bids, such as the number of competitors, technology features of the lines, the location of the lines, etc. They provide an alternative design for the Brazilian transmission auction that would improve the situation for the transmission companies.

Gonzalez et al (2009) analyze strategic behavior in eBay auctions. The two used formats in these auctions are an English auction with a hard stop time and a Dutch auction. They estimate several bidding functions and test which bidding strategy the bidders use.

Another evidence on eBay auctions is presented in Pages and Mochon (2010). Strategic behaviour and final price evolution are the two topics under examination. The two strategies used in order to maximize profit are cross-bidding and sniping. The former one means that the bidder monitors several competing auctions and the latter one refers to last minute bidding. Rezvani and Analoui (2011) discuss strategic behavior based on auction mechanism design in overlay multicast networks. Arguing that selfish behavior in such networks is unavoidable they focus on the question how to exploit this selfishness in order to maximize the aggregate throughput.

Landscape auctions are analyzed in Valle et al (2012) during a research project. They examine strategic behaviour during theses sequential auctions and tested their ideas in a laboratory setting. Their focus on the difference of auctions offering multi-period contracts or single-period contracts.

2.5 Incentive compatibility

Holmström and Myerson (1983) analyze six concepts of efficiency for economies with incomplete information. These concepts contain three notions of domination (ex ante, interim, ex post) and two notions of feasibility (classical and incentive feasibility) which together form the six concepts. Hereby different incentive compatibility constraints are bared in mind. They show that efficient, durable decision rules exist.

Vohra (1999) discusses incentive compatibility in an exchange economy with incomplete information. He analyzes a framework where communication of private information is permitted, but whether this information is the truth is not verifiable. They apply the notion of the core and show that it is not generally true that in some cases the incentive compatible core is non-empty.

Forges et al (2002) focus on exchange economies with asymmetric information. They are studying the concept of the core at the ex ante and interim stage, the non-emptiness of the core and incentive compatibility.

McLean and Postlewaite (2003) study incentive compatibility and provide conditions under which the ex ante incentive compatible core is non-empty.

Bartal et al (2003) deals with incentive compatible mechanisms for multi-unit combinatorial auctions. They examine a generic algorithm in the matter of incentive compatibility, validity and approximation ratio.

Babaioff and Walsh (2004) discuss the auction mechanism design problem and introduce incentive-compatible, budget-balanced and individually rational auctions in supply chain formations.

2.6 Incomplete information

Aspremont and Gérard-Varet (1977) present a game with incomplete information where they focus on the problem of incentives for correct revelation of information and the budgetary problem. They use two approaches, a first where the individual beliefs are introduced and a second where they are not.

Wilson (1978) discusses the definition of efficiency and the core where he puts emphasize on the role of communication and incomplete information. He demonstrates in two examples that the core may be empty and one may fail to find an efficient allocation.

The bullwhip effect in supply chains is treated in Lee et al (1997). They present four sources of this phenomenon, which describes the increasing information distortion as one moves upstream in the supply chain, namely demand signal processing, rationing game, order batching and fluctuating prices.

Nisan (2001) deals with communication complexity in combinatorial auctions. He claims that any combinatorial auction that produces efficient allocations requires an exponential amount of information transfer. This exponential blowup in communication considers several aspects, such as valuation determination, bid communication and information revelation.

Fiala (2005) concentrate on information sharing in supply chains. They argue that asymmetric information is one of the most important sources of the bullwhip effect, which describes the growing variation upstream in a supply chain.

Another issue Abrache et al (2007) tackle, is about incentive-compatibility. They discuss the risk of misreported valuations and how to set incentives for participants to bid truthfully. If bidding true values is a dominant strategy for any participant, no matter what strategies the other participants are pursuing, then the authors talk about a strategy-proof mechanism. The Vickrey-Clarke-Groves auction fulfills this property, but at the same time it requires complete information.

Problems occurring within cooperative games with incomplete information are listed in Forges and Serrano (2013). They focus on situations where players face both, informational and strategic externalities.

3 Framework

The following section deals with the assumptions and prerequisites in the underlying model. Furthermore the different phases during the auction process are explained. The whole section refers to both Berger and Bierwirth (2010) and Gansterer and Hartl (2015).

3.1 Assumptions and prerequisites

The underlying framework considers several carriers. Each carrier has one depot and owns several transportation requests. In the initial situation each carrier holds the same number of requests. As the requests are pickup and delivery requests and the goods transported take just a small fraction of the truck one faces a LTL pickup and delivery problem. The capacity constraints are formed by restrictions in tour length. They come to the fore during the next paragraph. As it was stated in the beginning the carriers collaborate via an auction-based exchange mechanism.

3.2 Auction-based exchange mechanism

The auction-based exchange mechanism consists of several phases:

1. Forming a request candidate set
2. Composition of all possible bundles
3. Determination of marginal profits (bid = marginal profit)
4. Assignment of bundles to carriers
5. Profit sharing

In the first phase each carrier has to decide which requests he wants to put into the request candidate set. They select those requests which do not fit perfectly into their tour and therefore they want them to be forwarded and eventually be overtaken by an other carrier. There are different strategies for which requests to be forwarded, evaluated in Gansterer and Hartl (2015). Throughout this thesis the strategy that takes the requests with the lowest marginal profit to be put into the request candidate set is considered. The number of requests for the request candidate set is fixed and the same for each carrier. In this thesis the value is set to two. Except the number of requests for a carrier would go beyond a certain predefined value, then he can just forward less requests or even no request. This value is adapted according to the overall number of requests in the respective instances.

In phase two all possible subsets of the requests inside the request candidate set are formed. This has to be done, because BRRA instead of SRRA is considered. The main advantage of BRRA is of course the creation of synergy effects.

In the next phase the bid matrix for the combinatorial auction is created. Each participant has to bid for all the bundles of requests inside the request candidate set. The framework demands from the carriers that they bid exactly their marginal profit for the bundles. For the moment this is taken for granted, but in Chapter 5 the problem that occurs, if someone does not bid his true value, is discussed. The auction is conducted by a central authority. The combination that yields the highest collaborative profit wins. This highest profit is either positive or at least zero. If the highest profit is just zero, this means that it is most advantageous if every carrier stays with his own requests and therefore buys back the requests that he has forwarded to the request candidate set by himself. All combinations that would result in a collaborative profit lower than before the auction are excluded anyway.

After determining the winning combination the requests are allocated accordingly in phase four. The requests that are bought are included into the own portfolio, and those sold are forwarded to the carrier that has bought the request.

Step one to four form an auction round, whereas step one and three are done by each carrier autonomously, and the other steps are conducted centrally by the central authority. It of course may happen that a particular carrier is worse off after an auction round, e.g. if he has simply just sold requests but did not buy any request. But what is not acceptable, and therefore excluded in the auction (as it was stated before), is an auction round that would lead to a collaborative profit less than in the previous round. Auction rounds are repeated until no more improvement is possible. If an auction round just yields a gain of zero (as described above), then in the next round other requests are put into the request candidate set to give the auction another try. The capacity of the carriers is restricted by 1.3 times the original tour length, this has to be taken into account during the auction.

After the last auction round is completed the resulting collaborative gain is positive or at least zero. But as it was stated before, a single carrier out of the collaboration network can of course have less profit than in the initial situation. This is the reason why phase five is needed, the profit sharing which is conducted just once, after all auction rounds are done. Table 11 - 21 in the appendix show how the situation after all auction rounds are done, but before the profit sharing phase starts, looks like. It is shown that the collaborative gain is positive or at least zero in all instances, but the individual gain happens to be zero or negative as well. The underlying instance sets are explained in Section 4.5.1.

The following flowchart visualizes the auction procedure by means of a simple numerical example. The first auction round in instance i80 is shown. The example considers three carriers where each of them owns three transportation requests in the beginning. Carrier 1 owns request 1, 2 and 3 with a negative marginal profit of -10,74. Carrier 2 owns requests 4, 5 and 6 with a marginal profit of 150,30. Carrier 3 owns requests 7, 8 and 9 with a marginal profit of 100,46. In sum the whole network achieves a profit of 240,02 without any collaboration. In step 1 each carrier puts two requests with the lowest marginal profits into the auction pool. They are marked in bold in Figure 1. Then all possible subsets out of those six requests are built in step 2. In the next step the bids b_i of the carriers for the bundles S_k are set and summarized in the bid matrix. Then the combinatorial auction is conducted and the highest combination wins. The winner allocation is the following: carrier 1 buys the bundle 2, 5, 9 which yields a profit of 204,06, carrier 2 buys 1, 6 with a profit of 146,96 and carrier 3 buys back his own request 7 which yields a profit of 29,77. In step 4 the reassignment of the bundles is visualized. Combining the requests bought and sold, with the one request that each carrier still holds, the first auction rounds yields a profit of 161,18, 150,45 and 39,76 for the carriers 1, 2 and 3. This means that carrier 1 improves his situation quite remarkable from approximately -10 to +200. The situation of carrier 2 stays at a profit of 150, whereas the situation for carrier 3 changes dramatically: having a profit of 100 in the beginning, he is just left with about 40 after the first auction round. But what counts is the profit of the whole network which increases from approximately 240 up to 350. Step 1 to 4 form an auction round which is repeated until no more improvement is possible and then the last step, the profit sharing has to be conducted.

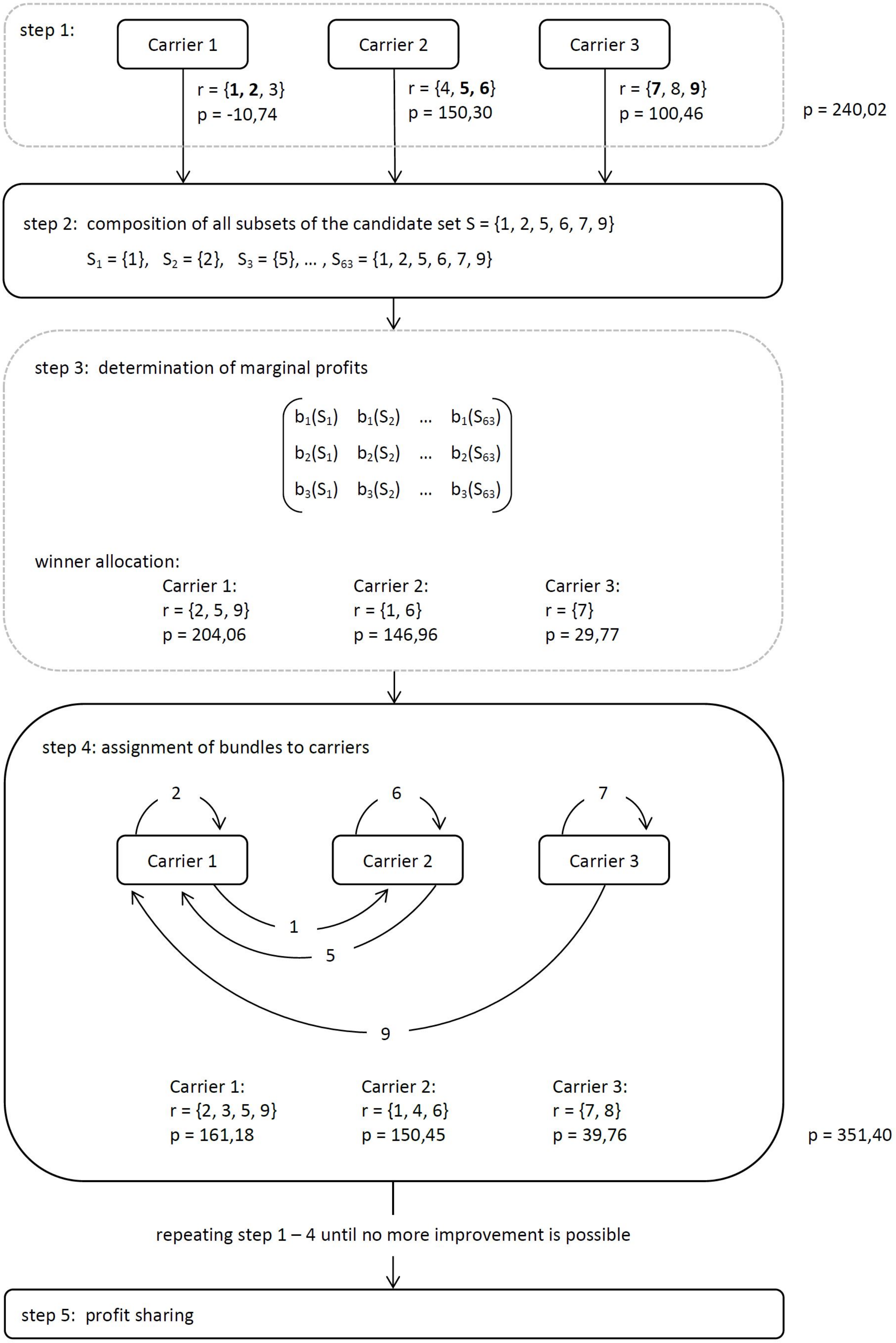

Figure 1: Flowchart of the auction procedure

The last phase that starts when all the auction rounds are done is the profit sharing. The question that is treated here, is how to split the additional gain that was achieved by the whole network during the auction fair among all participants, such that no-one is worse off.

As already mentioned it can happen in every auction round that a carrier is worse-off than before the respective round, as long as the overall network profit is higher than before. If these carriers end up with less profit than in the initial state at the end of all auction rounds, they would of course not be willing to participate in this auction at all. Therefore the profit sharing phase is needed, to ensure that each carrier is at least equal-off or better off than in the initial state. This is done by splitting either the overall network profit or the collaborative gain among all participants. This distribution should be perceived as fair from all carriers. The profit sharing method applied, should guarantee that each carrier has an incentive to participate in the auction. So profit sharing is a crucial aspect, because it decides whether the CCN comes into existence or not. In Section 4 several profit sharing methods and concepts are explained in detail.

3.3 Incomplete information

Although carriers collaborate with each other they are still competitors and therefore want to disclose as little private information as possible, so a framework with incomplete information is considered. It is assumed that carriers just know where the depots of the other carriers are located, but not more. Further the carriers do not provide any information about their requests in the initial situation. This means the central authority that conducts the auction does neither know the requests that the carriers own initially, nor the initial profit they have. The central authority just knows which requests are put into the request candidate set and what each bundle is worth for each carrier. And finally it knows how the requests are reallocated. The central authority does not know the profit of each carrier after an auction round and therefore also the profit at the end of all rounds is unknown. But what is known is the gain of the grand coalition itself, because it is known what was bought and sold in each round. This is especially important for the applicability of the methods in Section 4.3.

4 Profit sharing methods

In this section it is tried to find a proper profit sharing method that fits to the underlying framework, explained in Section 3.

There are some profit sharing methods that directly distribute the total network profit among all participants. In some other methods profit sharing is divided in two stages. Firstly, each carrier receives his initial profit, and secondly the remaining profit, namely the collaboration gain is split. For the moment the second option is considered and it is assumed that each carrier has received his initial profit already. Therefore the only question is how to split the collaboration gain.

To be able to write down profit or cost allocation methods properly we take the concept of cooperative game theory. It allows to formalize the rules which the allocation scheme has to follow, as simple constraints.

4.1 Cooperative game theory

Similar to Krajewska et al. (2007) an approach of cooperative game theory is used to deal with profit sharing. To define a cooperative game one needs:

- a set of players $N = \{1, \dots, n\}$
- and a characteristic function $v(S)$ that assigns to each possible coalition of players S ($S \subseteq N$) a numerical value.

The conditions that the characteristic function has to satisfy are the following:

- **zero-condition:** $v(\emptyset) = 0$
- **superadditivity:** $v(S \cup T) \geq v(S) + v(T) \qquad \forall S, T \subseteq N, S \cap T = \emptyset$

The zero-condition states that an empty coalition has a value of zero. Superadditivity means that it is always more profitable or at least equal profitable when two coalitions join.
To explain some further properties a vector $x = (x_1, \dots, x_n)$ is defined. It is called a vector of players' outcomes if it satisfies the following two conditions:

- **individual rationality:** $x_i \geq v(i) \qquad \forall i \in N$
- **group rationality:** $\sum_{i=1}^{n} x_i = v(N)$

An allocation is individually rational if each players' outcome is greater or at least equal to what he could obtain by acting alone. Group rationality means that the whole profit is fully split among the carriers. The set of outcome vectors X is then the set of feasible agreements.

Applied to the underlying framework, where the characteristic function is the gain, these properties translate into:

- **zero-condition:** $\text{gain}(\emptyset) = 0$
- **superadditivity:** $\text{gain}(S \cup T) \geq \text{gain}(S) + \text{gain}(T) \quad \forall S, T \subseteq N, S \cap T = \emptyset$
- **individual rationality:** $x_i \geq \text{gain}(i) = 0 \qquad \forall i \in N$
- **group rationality:** $\sum_{i=1}^{n} x_i = \text{gain}(N)$

As a single carrier can not obtain any additional profit besides his standalone profit, individual rationality takes the form $x_i \geq 0$. Equipped with this baseline construct a closer look at existing cost/profit sharing methods can be taken.

4.2 Cost allocation methods adapted for profit sharing

If either costs or profit is shared among participants of a collaboration is conceptually speaking not much difference. Therefore existing CA methods are examined and then adapted to profit sharing as it is necessary in the underlying model. As Šimenc (2014) provides an reasonable overview and classification of existing CA methods, some of those methods come into consideration in this thesis. The following figure shows the classification of existing CA methods according to Šimenc (2014).

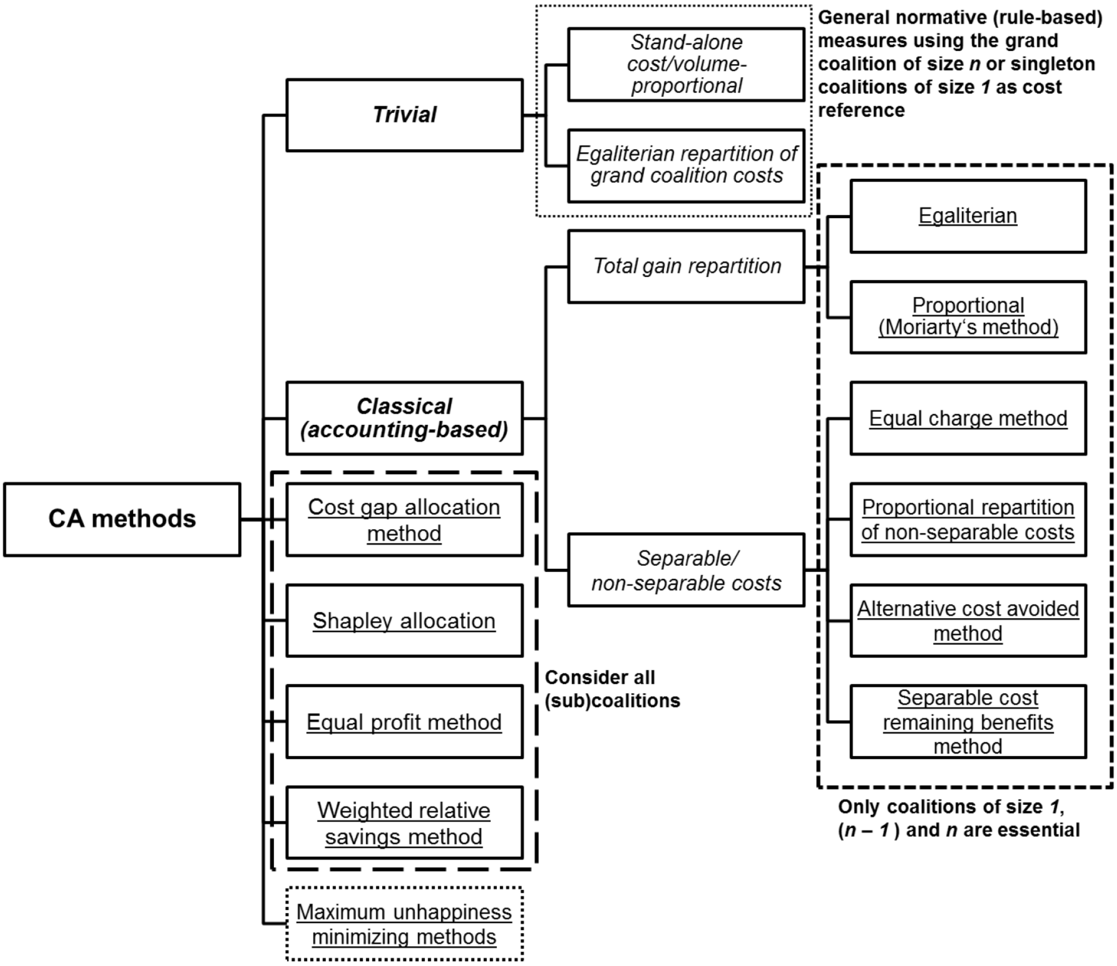

Figure 2: Classification of cost allocation methods, Šimenc 2014

The presented methods there, are examined regarding their suitability for profit sharing in our underlying framework.
The trivial methods use the grand coalition costs to be split among all participants, which would refer in the language of profit sharing to the grand coalition profit. As not the grand coalition profit should be split, but just the grand coalition gain, the trivial methods are not further considered.
As Šimenc (2014) states that SCRB, ACA and CGM are perfectly correlated with each other, just ACA is examined here. Further the two methods formulated by a linear program, EPM and the weighted relative savings method (WRSM), are not treated here, but left over for some possible future work.
First, the CA formula is presented and second, the formula is adapted and converted into the profit sharing mode. The following notation is used:

Notation

N	set of carriers, $N = \{1, 2, \ldots, n\}$
x_i	profit sharing outcome of carrier i
$c(i)$	standalone costs of carrier i
$c(N)$	cost of the grand coalition
$p_{\text{initial}}(i)$	initial (standalone) profit of carrier i
$p_{\text{after}}(N)$	profit after the last auction round of the grand coalition N
$cm(i)$	marginal costs of carrier i
$pm(i)$	marginal profit of carrier i
$g_c(N)$	non-separable costs
$g_p(N)$	non-separable profit

4.2.1 Classical cost allocation methods

Egalitarian repartition of the total gain

The Egalitarian repartition of the total gain evenly distributes the total gain among all carriers. So each participant receives exactly the same share. In CA each carrier has to pay his standalone costs minus an equal share of the total savings. Converted into profit sharing this means that the carrier receives his standalone profit plus an equal share of the total gain.

$$\text{cost allocation: } x_i^E = c(i) - \frac{1}{n} \underbrace{\left[\sum_{j=1}^{n} c(j) - c(N) \right]}_{\text{total savings}}$$

$$\text{profit sharing: } x_i^E = p_{\text{initial}}(i) + \frac{1}{n} \underbrace{\left[p_{\text{after}}(N) - \sum_{j=1}^{n} p_{\text{initial}}(j) \right]}_{\text{total gain}}$$

As this method does not take into account any individual contribution it is not perceived as fair and therefore no further investigations are done in this regard.

Proportional repartition of the total gain - Moriarity

Proportional repartition of the total gain, which is also called Moriarity method takes the standalone costs minus a share of total savings too. But the share is the ratio of an individual players standalone costs of the sum of all standalone costs. In profit sharing this is the standalone profit plus a share of the total gain, whereby the share is the ratio of an individual players standalone profit of the sum of all standalone profits.

$$\text{cost allocation: } x_i^M = c(i) - \frac{c(i)}{\sum_{j=1}^n c(j)} \underbrace{\left[\sum_{j=1}^n c(j) - c(N)\right]}_{\text{total savings}}$$

$$\text{profit sharing: } x_i^M = p_{\text{initial}}(i) + \frac{p_{\text{initial}}(i)}{\sum_{j=1}^n p_{\text{initial}}(j)} \underbrace{\left[p_{\text{after}}(N) - \sum_{j=1}^n p_{\text{initial}}(j)\right]}_{\text{total gain}}$$

Equal charge method

The equal charge method takes separable and non-separable costs into account. By using the marginal costs of each carrier, the non-separable costs can be calculated. Each carrier is allocated his marginal costs plus an equal share of the non-separable costs. In the world of profit sharing this translates into marginal profit of one player (=separable profit) plus an equal share of the non-separable profit (grand coalition profit minus separable profit of all players).

$$\text{marginal costs of carrier i:} \quad cm_i = c(N) - c(N \setminus i)$$

$$\text{non-separable costs:} \quad g_c(N) = c(N) - \sum_{i=1}^n cm_i$$

$$\text{cost allocation: } x_i^{EC} = cm_i + \frac{1}{n} g_c(N)$$

$$\text{marginal profit of carrier i:} \quad pm_i = p_{after}(N) - p_{\text{after}}(N \setminus i)$$

$$\text{non-separable profit:} \quad g_p(N) = p_{\text{after}}(N) - \sum_{i=1}^n pm_i$$

$$\text{profit sharing: } x_i^{EC} = pm_i + \frac{1}{n} g_p(N)$$

Proportional repartition of non-separable costs

This method is the same as the previous one, except that the share is not just 1/n, but more sophisticated: an individual player's marginal costs over sum of all marginal costs. In profit sharing the share means an individual player's marginal profit over sum of all players' marginal profit.

$$\text{cost allocation: } x_i^{PC} = cm_i + \frac{cm_i}{\sum_{j=1}^n cm_j} g_c(N)$$

$$\text{profit sharing: } x_i^{PC} = pm_i + \frac{pm_i}{\sum_{j=1}^n pm_j} g_p(N)$$

Alternative cost avoided method
Again this method uses marginal costs plus a share of the non separable costs, but the share is more complicated and calculated as follows.

$$\text{cost allocation: } x_i^{ACA} = cm_i + g_c(N)\frac{c(i) - cm_i}{\sum_{j=1}^{n}(c(j) - cm_j)}$$

$$\text{profit sharing: } x_i^{ACA} = pm_i + g_p(N)\frac{p_{\text{initial}}(i) - pm_i}{\sum_{j=1}^{n}(p_{\text{initial}}(j) - pm_j)}$$

4.2.2 Shapley allocation

The Shapley allocation is a more sophisticated allocation method. It is according to Šimenc, and many other papers, the most important and widely used solution concept. Therefore more investigations are done related to this method. The information in this paragraph refers to Šimenc (2014) and Krajewska et al (2008). The Shapley value can be interpreted as the expected marginal contribution of every player i.

The Shapley value selects a single outcome vector out of the set of feasible solutions that satisfies:

- **fairness:** similar players are treated equally (symmetry)
- **efficiency:** $\sum_{i=1}^{n} x_i = v(N)$
- **additivity:** $(v + w)(S) = v(S) + w(S)$
- **dummy-axiom:** a player who does not contribute anything, is assigned zero

The Shapley value is calculated according to the following formula, which allocates to each player the weighted sum of his contributions.

$$x_i^{SH} = \sum_{S, i \in S} \frac{(|S| - 1)!\,(|N| - |S|)!}{|N|!}\,(v(S) - v(S \setminus i))$$

$$\text{cost allocation: insert } v(S) = c(S)$$

$$\text{profit sharing: insert } v(S) = p_{\text{after}}(S)$$

An often mentioned aspect in relation to Shapley is the core of a cooperative game. If a vector of player's outcomes lies in the core then there exists no coalition that can yield a better result. So the core includes all undominated outcome vectors and therefore refers to a stability property. The core does not deliver one single result, but it can be either empty or contain several allocation vectors. The following property describes the core.

- **core:** $\sum_{i \in S} x_i \geq v(S) \qquad \forall S \subseteq N$

The above condition looks somehow as in-between individual and group rationality. It is a generalization of individual rationality. A disadvantage of the Shapley allocation is, that the outcome vector selected by Shapley may not lie in the core.

4.3 Applicability of methods with regard to incomplete information

In this section the applicability of the mentioned methods is analyzed. Referring to Chapter 3.3, where incomplete information is mentioned, it is known that neither the initial profit nor the profit after the auction is known to the central authority in our framework. This means that M is not applicable, because the formula requires the initial profit. As well as EC, PC, ACA and Shapley are not applicable, because they use the profit after the auction.

This leads to finding some new methods or adapting existing ones, such that they would become applicable. This is explained in the next section.

4.4 Adapted and self-created methods

As M, EC, PC and ACA do not give much leeway for adaptation, the author tried to adapt Shapley and further created a completely new method, as follows in the next two subsections.

4.4.1 Adapted Shapley method

The idea was to substitute $v(S) = p_{\text{after}}(S)$ as proposed before by $v(S) = \text{gain}(S)$, where S are all the possible subsets of carriers.

$$\begin{aligned} x_i^{SH_{adapted}} &= \sum_{S, i \in S} \frac{(|S|-1)!\,(|N|-|S|)!}{|N|!}\,(v(S) - v(S \setminus i)) \\ &= \sum_{S, i \in S} \frac{(|S|-1)!\,(|N|-|S|)!}{|N|!}\,(\text{gain}(S) - \text{gain}(S \setminus i)) \end{aligned}$$

The following calculation shows how the formula reduces, when applied to the underlying model, considering 3 carriers c0, c1 and c2. There exists 8 different subsets, in 4 out them carrier c0 takes part: $S_1 = \{c0, c1, c2\}, S_2 = \{c0, c1\}, S_3 = \{c0, c2\}, S_4 = \{c0\}$. The gain of one single carrier is of course zero, because he can just reach his standalone profit and can not make use of any collaboration. This is considered in the following calculation, where a closer look is taken at the outcome for carrier c0.

$$
\begin{aligned}
x_{c0}^{SH_{adapted}} &= \sum_{S, c0 \in S} \frac{(|S|-1)!\,(|N|-|S|)!}{|N|!}\,(v(S) - v(S \setminus c0)) \\
&= \frac{(|S_1|-1)!\,(|N|-|S_1|)!}{|N|!}\,(\mathrm{gain}(S_1) - \mathrm{gain}(S_1 \setminus c0)) \quad + \\
&+ \frac{(|S_2|-1)!\,(|N|-|S_2|)!}{|N|!}\,(\mathrm{gain}(S_2) - \mathrm{gain}(S_2 \setminus c0)) \quad + \\
&+ \frac{(|S_3|-1)!\,(|N|-|S_3|)!}{|N|!}\,(\mathrm{gain}(S_3) - \mathrm{gain}(S_3 \setminus c0)) \quad + \\
&+ \frac{(|S_4|-1)!\,(|N|-|S_4|)!}{|N|!}\,(\mathrm{gain}(S_4) - \mathrm{gain}(S_4 \setminus c0)) \\
&= \frac{(3-1)!\,(3-3)!}{6}\,(\mathrm{gain}(\{c0,c1,c2\}) - \mathrm{gain}(\{c1,c2\})) \quad + \\
&+ \frac{(2-1)!\,(3-2)!}{6}\,(\mathrm{gain}(\{c0,c1\}) - \mathrm{gain}(\{c1\})) \quad + \\
&+ \frac{(2-1)!\,(3-2)!}{6}\,(\mathrm{gain}(\{c0,c2\}) - \mathrm{gain}(\{c2\})) \quad + \\
&+ \frac{(1-1)!\,(3-1)!}{6}\,(\mathrm{gain}(\{c0\}) - \mathrm{gain}(\{\})) \\
&= \frac{1}{3}\,(\mathrm{gain}(\{c0,c1,c2\}) - \mathrm{gain}(\{c1,c2\})) \quad + \\
&+ \frac{1}{6}\,(\mathrm{gain}(\{c0,c1\}) - 0) + \frac{1}{6}\,(\mathrm{gain}(\{c0,c2\}) - 0) + \frac{1}{3}\,(0-0) \\
&= \frac{1}{3}\,(\mathrm{gain}(\{c0,c1,c2\}) - \mathrm{gain}(\{c1,c2\})) + \frac{1}{6}\,\mathrm{gain}(\{c0,c1\}) + \frac{1}{6}\,\mathrm{gain}(\{c0,c2\})
\end{aligned}
$$

Unfortunately the method does not fulfill the requirements stated in Section 4.1. The following numerical counter example instance i67 shows that the required conditions are violated.

$$
\begin{aligned}
x_1^{SH_{ad.}} &= \frac{1}{3}\Big(\mathrm{gain}(\{c0,c1,c2\}) - \ \mathrm{gain}(\{c0,c2\})\Big) + \frac{1}{6}\,\mathrm{gain}(\{c0,c1\}) + \frac{1}{6}\,\mathrm{gain}(\{c1,c2\}) \\
x_1^{SH_{ad.}} &= \frac{1}{3}\,(35,905 - 54,313) + \frac{1}{6}\cdot 0 + \frac{1}{6}\cdot 29,218 \\
&= -1,266
\end{aligned}
$$

The problem that is hidden within this formula is the following. The subtraction in the first term may turn out to become negative, because it may happen that two carriers reach a higher gain than all three carriers. This firstly means that superadditivity is violated and if the second and third term can not make the overall result positive, then a negative share would be the result, which means that individual rationality is hurt. This happened exactly in instance i67. Therefore this adapted Shapley method does not meet the requirements and can not be further used.

This leads to find a self-created method, explained in the next subsection.

4.4.2 Self-created method

The challenge was to build a method that satisfies individual rationality and group rationality. The terms that were not allowed to use are the initial profit and the profit after the auction both of each carrier and the whole network. The only term that could be used is the gain itself, either of each carrier or of the whole coalition. This gain can be separated into what was bought and what was sold. The first idea was to use the following expression

$$\frac{\text{bought}(i) + \text{sold}(i)}{\text{bought}(N) + \text{sold}(N)},$$

where $\text{bought}(i)$ means the absolute value of the marginal profit of all requests that were bought by carrier i during all auction rounds. The same goes for $\text{sold}(i)$, which expresses the absolute value of the marginal profit of all requests that were sold by carrier i during all auction rounds. Replacing i by N the same expression but for the whole network instead of just carrier i is meant. As the total gain has to be split, the share of carrier i would look like

$$x_i = \text{gain}(N)\,\frac{\text{bought}(i) + \text{sold}(i)}{\text{bought}(N) + \text{sold}(N)}.$$

Unfortunately it turned out that this formula just reduces to something that can not be used any more, which is expressed in the following calculation.

$$\begin{aligned} x_i &= \text{gain}(N)\,\frac{\text{bought}(i) + \text{sold}(i)}{\text{bought}(N) + \text{sold}(N)} \\ &= \text{gain}(N)\,\frac{\text{bought}(i) + \text{sold}(i)}{\text{gain}(N)} \\ &= \text{bought}(i) + \text{sold}(i) \\ &= \text{gain}(i) \end{aligned}$$

The problem is that it is not guaranteed that the individual gain of the carriers is greater or equal to zero.

This forces the author to look for alternatives. The next idea was to use terms like

$$\frac{\text{bought}(i)}{\text{bought}(N)}, \frac{\text{sold}(i)}{\text{sold}(N)}$$

in order to express the contribution of each carrier to what was sold and bought separated. What turns out was the following:

$$x_i = \frac{\text{gain}(N)}{2}\left(\frac{\text{bought}(i)}{\text{bought}(N)} + \frac{\text{sold}(i)}{\text{sold}(N)}\right).$$

Again the used expressions mean the sum of the absolute value of the marginal profits of all requests that were either bought or sold by either carrier i or the whole network N. For simplicity of implementing also those requests that are sold in one auction round and then bought back again in the same round or a later following one are counted as well. This means that also carriers that stay with their own requests until the end of all auction rounds will receive a share of the collaboration gain. To show that group rationality is satisfied one has to follow the following calculation which proves that $\sum_{i \in N} x_i = \text{gain}(N)$. It also explains why the 2 appears in the denominator.

$$\begin{aligned}
\sum_{i \in N} x_i &= \sum_{i \in N} \frac{\text{gain}(N)}{2}\left(\frac{\text{bought}(i)}{\text{bought}(N)} + \frac{\text{sold}(i)}{\text{sold}(N)}\right) \\
&= \frac{\text{gain}(N)}{2} \sum_{i \in N}\left(\frac{\text{bought}(i)}{\text{bought}(N)} + \frac{\text{sold}(i)}{\text{sold}(N)}\right) \\
&= \frac{\text{gain}(N)}{2}\left(\frac{\text{bought}(c0) + \text{bought}(c1) + \text{bought}(c2)}{\text{bought}(N)} + \right. \\
&\left. + \frac{\text{sold}(c0) + \text{sold}(c1) + \text{sold}(c2)}{\text{sold}(N)}\right) \\
&= \frac{\text{gain}(N)}{2}\left(\frac{\text{bought}(N)}{\text{bought}(N)} + \frac{\text{sold}(N)}{\text{sold}(N)}\right) \\
&= \frac{\text{gain}(N)}{2}(1+1) \\
&= \text{gain}(N)
\end{aligned}$$

During this thesis this allocation method is called BW. The abbreviation BW stand for the initials of the author. To sum up method BW fulfills all the requirements and is therefore tested with the test instances. The results are reported in the appendix in Table 22 - 32. To assess the plausibility of the self-created method one compares method BW with an existing method, namely the Moriarity method, explained in Section 4.2.1. Although Moriarity is not applicable in the underlying framework, because of incomplete information it is used just as a reference value. Just for computation the normally unknown terms are allowed to be known in order to measure whether the self-created method is somehow similar to an existing method. These findings are reported in the Tables 22 - 32 as well.

4.5 Computational study

Within the computational study the profit allocation method BW, reported in Section 4.4.2 has been tested with the instances reported in the next subsection. Additionally the method BW is compared to Moriarity's method.

4.5.1 Test instances

The instance sets that are used for testing are the ones that were already used in Gansterer and Hartl (2015) and Berger and Bierwirth (2010).

Firstly three instance sets A, O and I, taken from Berger and Bierwirth are considered, which they have created themselves out of instances from Solomon. Each set contains 3 carriers that own 3 requests in the initial situation. These pickup and delivery requests are randomly drawn out of a predefined region. The difference in the sets is given by different degrees of competition. For the first set, set A the requests are randomly drawn out of adjacent regions. So each carrier acts in a separate region. Set O denotes requests out of overlapping regions and finally set I which indicates requests out of an identical region for all three carriers. For each set 30 instances are created. In set A, consisting of instance i1 - i30 the carriers have no competition, in set O (i31 - i60) they face moderate competition, whereas in set I (i61 - i90) they find themselves in a highly competitive environment.

Additionally bigger instances created by Gansterer and Hartl (2015) are used. Bigger is meant in the sense of a higher number of requests per carrier. They built the sets out of the existing requests from Berger and Bierwirth. Here one considers again 3 carriers, but they own 9 requests in the beginning in set I9, or 15 requests in the set I15. Those requests are mixed out of those from set I, so again identical regions are considered. Set I9 holds 10 instances (i91 - i100) as well as set I15 consists of instance i101 - i110.

Finally some some further instance sets from Gansterer and Hartl are adopted. They created sets with 3 carriers that have equidistant depots. The distance between the depots of the carriers is 200. Each carrier owns randomly drawn pickup and delivery requests out of a region with a certain radius around his own depot. The used radii are 150, 200 and 300 and therefore represent different degrees of overlapping areas. The carriers own either 10 or 15 requests in the initial state. This sums up to the following instance sets: O10_150, O15_150, O10_200, O15_200, O10_300 and O15_300. For each set 20 instances are created.

4.5.2 Computational results

Before the results of the profit allocation method BW are discussed, the need for a proper profit sharing method is expressed again: Table 11 - 21 in the appendix show the situation after all auction rounds are done, but before the profit sharing phase starts. A summary consisting of the mean collaborative gain and the mean individual gain for each set is presented in Table 1.

after auction, before profit sharing	coll_gain	gain_c0	gain_c1	gain_c2
set_a	13,04	-0,49	13,53	0,00
set_o	43,55	24,80	14,66	4,09
set_i	117,25	52,66	29,63	34,97
I9	115,61	25,12	36,51	53,98
I15	139,47	17,48	-33,05	155,04
O10_150	66,16	-3,19	-8,73	78,07
O10_200	177,68	32,60	101,38	43,70
O10_300	455,69	122,68	271,36	61,65
O15_150	61,07	7,62	54,12	-0,67
O15_200	242,51	83,14	40,98	118,39
O15_300	596,30	194,86	187,05	214,39

Table 1: Mean collaborative and individual gain (after all auction rounds are done, before profit sharing starts

One can find the collaborative gain always positive – as this is one of the demands on the auction – but the individual contributions of the carriers c0, c1 and c2 to the collaborative gain may be zero or negative too, e.g. if a carrier just sells requests but does not buy anything, as discussed at the end of Section 3. In many instances of set A there is no trade-off of requests at all. So the collaboration gain is zero and each carrier stays with his own requests. The reason is of course the setting. If the carriers act in adjacent regions it is more difficult to exchange requests, because of the longer distances and the resulting high costs. In the sets with more competition, instances with no exchange at all are becoming less or even do not happen at all, because the requests are drawn out of an overlapping or identical area. Summing up, there are carriers who are worse off, especially in the sets A, I15, O10_150 and O15_150, and therefore would not be willing to participate in this collaborative network. To avoid this a proper profit sharing method is needed.

Table 22 - 32 in the appendix show the results of the self-created profit allocation method BW as explained in Section 4.4.2. In Table 2 the mean shares that each carrier receives, when using method BW are summarized. The instances with no change happening during the auction process are not taken into account.

BW	coll_gain	share_c0	share_c1	share_c2
set_a	13,04	2,57	6,29	4,19
set_o	43,55	14,47	16,03	13,05
set_i	117,25	36,46	40,02	40,77
I9	115,61	42,94	37,40	35,27
I15	139,47	46,91	43,08	49,48
O10_150	66,16	18,45	32,72	14,99
O10_200	177,68	63,03	50,14	64,51
O10_300	455,69	160,71	135,64	159,34
O15_150	61,07	19,20	20,32	21,55
O15_200	242,51	80,13	85,53	76,85
O15_300	596,30	209,60	183,99	202,71

Table 2: Allocation of the collaborative gain according to method BW

To recapture, the formula for the carriers' shares uses amongst others the marginal profit of the requests bought and that of the requests sold during all auction rounds. This means the more the carriers sell and buy, the higher is their share of the collaborative gain. For all instances the result shows that individual rationality is guaranteed, because the share for each carrier is greater or equal to zero in each instance. The carriers receive this share additionally to their standalone profit. Further group rationality is satisfied, because the sum of shares of each carrier always sums up to the collaborative gain. Furthermore it is always more profitable if two coalitions join, which means that superadditivity is guaranteed. Thus one can argue that the method BW fulfills all the requirements and is therefore an applicable and useful method for profit sharing.

In order to rate the new created method and evaluate the acceptance, a comparison to a well-known and often-used method is done. As explained in the end of Section 4.4.2 the method BW is compared to Moriarity's method and the results are shown in Table 22 - 32 in the appendix. Moriarity's method allocates the gain according to the initial profit of the carriers, which may be in some instances negative. Those negative shares are not visible in the following table, as it shows the averaged values for each instance set. But nevertheless this is an indicator that individual rationality of Moriarity's method is not satisfied.

moriarity	coll_gain	share_c0	share_c1	share_c2
set_a	13,04	2,23	6,06	4,76
set_o	43,55	11,39	17,25	14,91
set_i	117,25	24,79	40,21	52,24
I9	115,61	34,83	39,56	41,22
I15	139,47	44,17	48,66	46,64
O10_150	66,16	21,63	26,38	18,14
O10_200	177,68	60,38	60,17	57,12
O10_300	455,69	163,99	133,81	157,88
O15_150	61,07	20,18	20,03	20,85
O15_200	242,51	80,37	87,61	74,53
O15_300	596,30	210,87	188,70	196,73

Table 3: Allocation of the collaborative gain according to Moriarity's method

As already mentioned, BW fulfills all the requirements, so this comparison just tries to specify the plausibility of the new created method. The numbers presented in the last two columns show the mean and maximum absolute percentage error of the share the carriers receive of BW compared to Moriarity to give a feeling how close the self-created method is to an existing one. The following table presents a summary of those two values aggregated over each instance set.

	mean_abs_ percent_error	max_abs_ percent_error
set_a	54,83	297,84
set_o	41,13	380,48
set_i	116,77	2087,94
I9	33,78	105,72
I15	18,04	90,00
O10_150	39,23	136,08
O10_200	31,04	144,90
O10_300	20,53	65,80
O15_150	32,47	80,81
O15_200	30,11	79,53
O15_300	23,27	65,40

Table 4: Mean and maximum absolute percentage error of the carriers' shares in BW vs. Moriarity

Having a look at the maximum absolute percentage error, the highest error occurs in instance i62 out of set I, where even a maximum deviation of more than 2000% comes up. In set A, the highest maximum absolute percentage error is about 300% as well as in set O about 380%. A closer examination shows the reason for this enormous deviation. In the initial situation before the auction starts there are carriers that can not generate any profit with their own requests, but they make a loss. As Moriarity's method allocates the gain according to the initial profit, this method would allocate a negative value to them. This firstly shows that Moriarity is not appropriate in the underlying model, because individual rationality is violated. Method BW completely ignores the initial profit of the carriers – as it is not even known, according to the assumptions of the model – and just takes into account the requests the carriers are trading. If a carrier that makes a loss in the initial state, buys and sells many requests, it means a negative share according to Moriarity, but a high share according to BW. This implies a high deviation, as it occurs e.g. in instance i62. The same goes for instance i55, where carrier c0 receives just a share of 6,8 according to his small marginal profit in the beginning, but would receive a share of about 32,7 according to method BW, because he sells and buys the most requests among the carriers. This again yields a high error. Similar examples are instance i5, i55, i65, i68, i78 or i80, whereas most of them occur in set I. In those instances where the deviation is moderate or small it just means that the value of the requests bought and sold is similar to what they had in the initial state. In general the mean absolute percentage error lies between 18 and 55%, except an outlier of even 117% in set I, the identical set, which attributes to the already described phenomenon. In set I15 and O15 the error is in general the lowest of all the sets with a highest maximum value of about 90% in I15 and between 65% and 80% in set O15. As this are the sets with the most requests per carrier we are observing the following trend: the more requests the carriers initially have, the higher is the Moriarity value. Similarly, the more requests the carriers have initially, the more trade-off is possible and therefore the BW value is higher. Summing up a high Moriarity value and a high BW value lead to a lower deviation. Observing geographical aspects in those sets with a high number of requests per carrier in the initial state (O10, O15) which refers to a high Moriarity value, the results show: the more overlapping the sets are, the easier is the trade-off (because distances are lower), which leads to a higher BW value. This again means a low deviation. In the sets with a low number of requests in the beginning (set A, O and I), which refers to a low Moriarity value: the more overlapping the sets are, the easier trade can be conducted and the higher the BW value. A low Moriarity value and a higher BW value end up in a high deviation.

Summing up, although the difference between BW and Moriarity is quite high this does not decrease the usefulness and applicability of method BW. A separation from negative shares for the carriers as shown in Moriarity's value is rather a positive aspect than a decrease in plausibility. Nevertheless it is recommended that a real-life experiment is done to substantiate the acceptance of the new created allocation scheme.

5 Strategic behaviour

During the whole thesis it was assumed that the carriers bid their true marginal profit for the requests inside the request candidate set. This section deals with the problem if the carriers do not bid their true values but different ones in order to improve their own profit. In this thesis the author tries to make a first basic approach in direction of strategic behaviour. It is not an exhaustive research but just a first attempt to enlighten the case of carriers behaving unfair.

The first question that arises is, how would the carriers behave and in which way would they change their bids. First it is assumed that just one carrier does not bid his true marginal profit. In a second step all different scenarios if either one or two carriers bid unfair, and all the possible combinations that may occur, are examined.

The first idea was to analyze what happens if one carrier bids higher than his true marginal profit. The author took the values of bidding 10%, 30% or 50% higher, which yields in the factors 1.1, 1.3 and 1.5. At first sight bidding lower seems not to make any sense. The wrong values just come into operation during the bidding process. When it comes to calculating the real profit, the true values have to be taken into account again. The results are further discussed in Section 5.1 and reported in the appendix.

After this first examination it turned out that it should be distinguished between own requests and requests of other carriers. Then a carrier may take advantage even before the profit sharing phase starts, which is explained in detail in this paragraph. Nevertheless this is just an outlook and a suggestion about some future work.

As stated in Chapter 4 profit sharing can be divided into two stages. First each carrier receives his initial profit and second the collaborative gain is split. In the following flowcharts two different situations are shown. Either a carrier bids higher for his own request, or a carrier bids higher for a request of another carrier.

First, the situation if carrier 1 bids higher on the requests of another carrier, e.g. carrier 2 is analyzed. If he does not win the request, because another carrier bids even higher, then neither something positive nor something negative happens to carrier 1, this case is not even shown. But if carrier 1 really wins the request he risks to pay more for the request than it is truly worth to him. This depends on the compensation value he has to give to carrier 2 for buying his request.

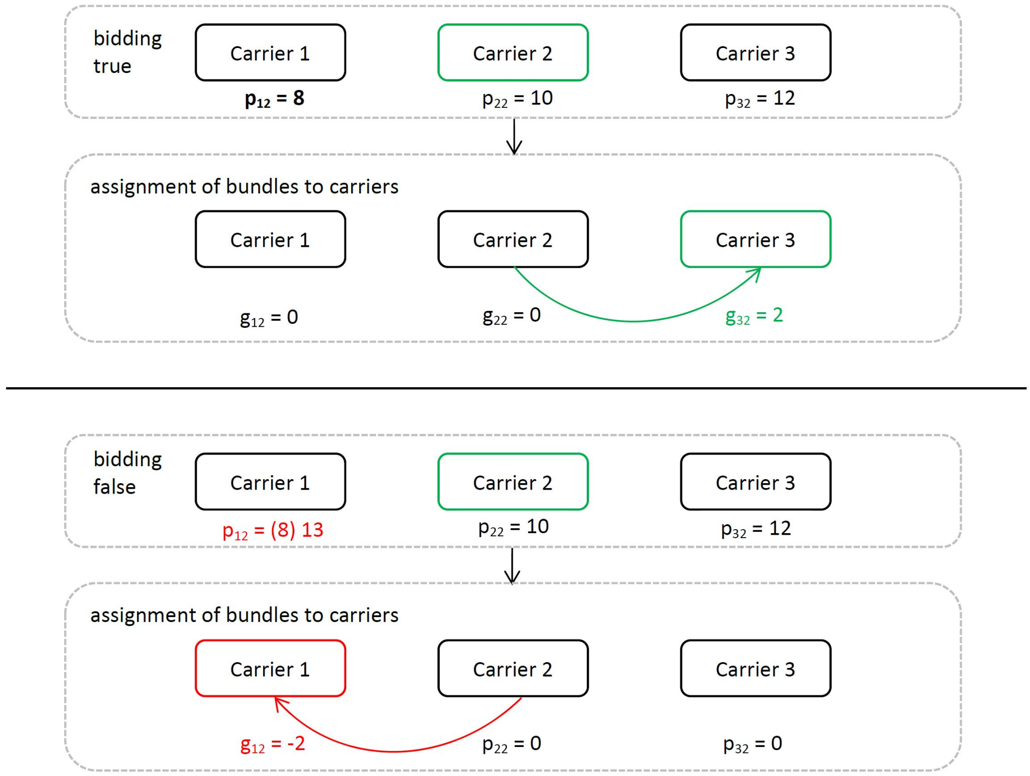

Figure 3: Flowchart bidding higher: scenario 1

Figure 3 shows the following situation. A request of carrier 2 is inside the auction pool and all three carriers set their bids p_{ij} for this request. (To recapture, i are the carriers 1, 2 and 3 and j equals to two, as the request of carrier 2 is under consideration.) The first part shows their true marginal profits of 8, 10 and 12 respectively. If all carriers are bidding truthful, carrier 3 receives the request, because he has the highest marginal profit of 12. He has to compensate the former owner of the request, carrier 2, with 10, which yields a gain of 2. The second part of the figure shows the situation if carrier 1 bids 13 instead of 8 for the request inside the pool. Then carrier 1 wins the request, but as he has to compensate carrier 2 with 10, he even makes a loss, because he pretended to make a profit of 13, but in reality just manages a profit of 8.

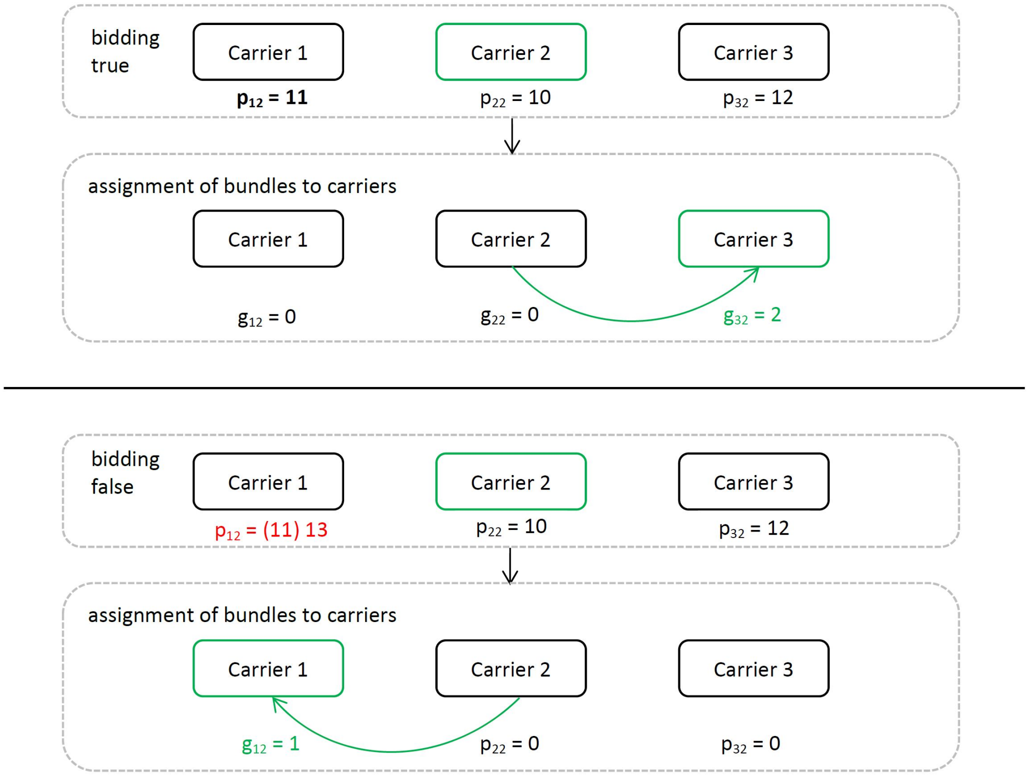

Figure 4: Flowchart bidding higher: scenario 2

Figure 4 shows a similar situation, but we assume that carrier 1 has a true marginal profit of 11 for the request inside the auction pool. If he then states an untrue bid of 13 he again wins the request, but now he can create a gain of 1, after compensating carrier 2 with 10.

To sum up, in some cases it may turn out to be profitable to bid higher for the request of carrier 2, namely if the true marginal profit of carrier 1 is higher then the compensation price he has to give to carrier 2. And in those cases where the compensation price is higher then his true marginal profit it has a negative impact to bid higher.

In Figure 5 the situation of bidding higher for an own request is shown.

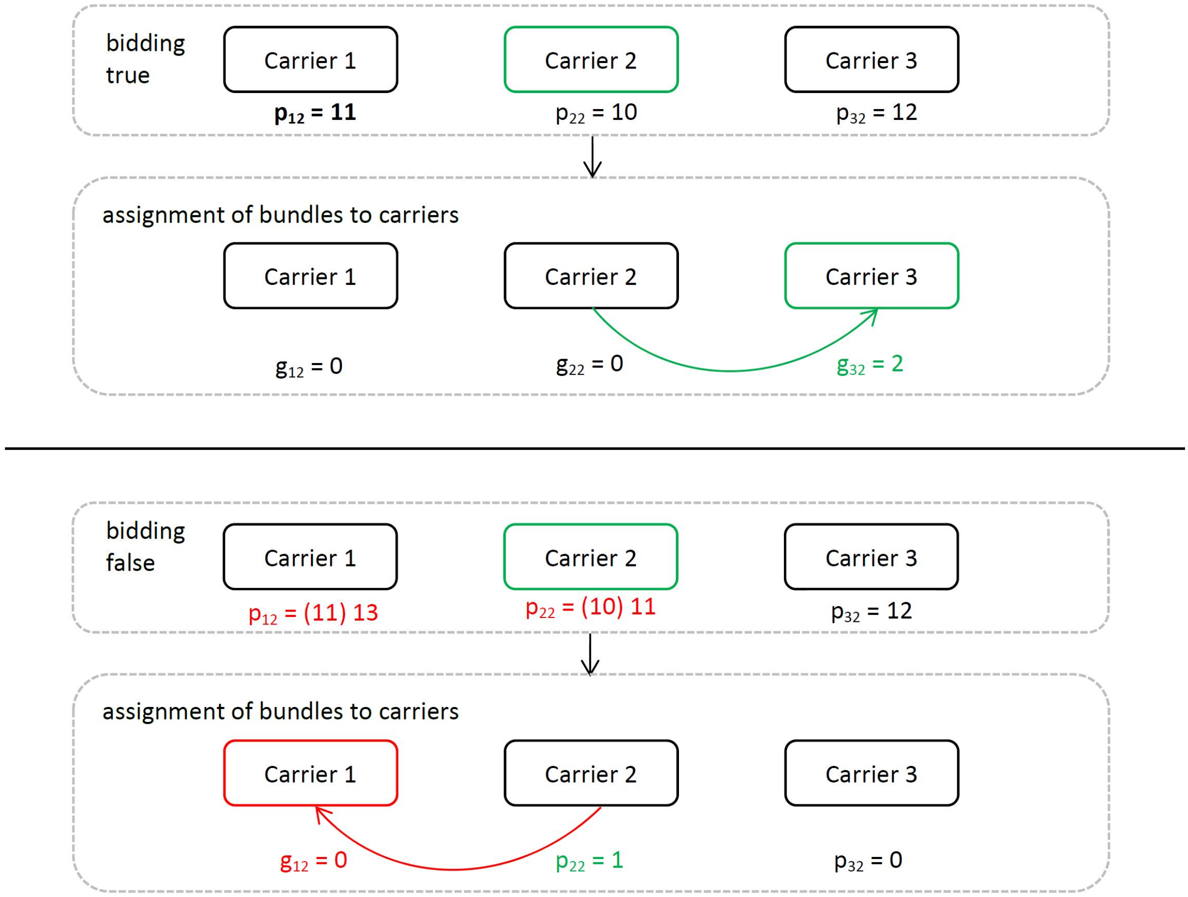

Figure 5: Flowchart bidding higher: scenario 3

If carrier 2 pretends to have a higher marginal profit for his own request and additionally this request is bought by another carrier he can generate some additional profit. In Figure 5 it is assumed that carrier 2 bids 11 instead of 10 for this own request. Also carrier 1 is bidding higher than his true marginal profit, he is setting 13 instead of 11. This means that carrier 1 wins the request, but he has to compensate carrier 2 by his pretended 11 instead of 10. Which means that the additional gain of 1 for carrier 1 diminishes to zero. But for carrier 2 this transaction was profitable. He has made a profit even before the allocation of the collaboration gain starts. So if a carrier bids higher on his own requests he can take advantage out of this, but only if another carrier still bids higher and buys the request. By doing so the carrier risks to get his own request back and no advantage was created.

If carrier 2 would bid lower than his true marginal profit for his own request then again the following two cases are distinguished. If carrier 1 buys the request then he has to compensate carrier 2, but this compensation value is lower than the true marginal profit of carrier 2, so it is definitively disadvantageous for him. In case the carrier stays with his own request, although he has bidden lower, it will not yield any additional profit, too. The same goes for bidding lower for a foreign request. In both cases, winning the request or not, it has no positive impact for the carrier. This is the reason for not examining the case of bidding lower.

Summing up distinguishing between own and foreign requests is an interesting question that should be examined and tested in some future work.

5.1 Computational study

As discussed in Section 5 it is tested what happens if a carrier does not bid his marginal profit, but pretends a higher value. The same test instances as explained in Section 4.5.1 are used for the computational study of strategic behaviour.

5.1.1 Computational results

First the situation, if just one carrier does not bid his true marginal profit, is analyzed. Table 5 represents the mean percentage deviation of the share of gain that the carrier, that solely bids higher, receives if bidding higher instead of bidding truly.

	1,1	1,3	1,5
set_a	0,18	-1,50	-1,50
set_o	18,16	30,91	33,23
set_i	18,34	56,72	67,42
91-100	15,08	24,97	49,53
101-110	3,35	30,01	43,98
O10_150	0,00	3,25	2,28
O10_200	4,48	6,10	2,66
O10_300	-4,15	-3,39	-6,85
O15_150	2,27	1,35	-1,51
O15_200	-3,01	-7,56	-10,45
O15_300	-2,47	-6,82	-8,65

Table 5: Mean percentage change in share of gain of a carrier that solely bids higher

In the adjacent area bidding higher is not promising, because it makes the carrier that bids higher, winning requests that are costly, because of the longer distances. In the sets with more competition, as set O, set I and set I9 the situation changes. The share that the carrier that bids higher receives, is between 18% and even 67% higher than if he would bid his true marginal profit. One reason is, that in many instances the carrier owns in the end much more requests than the others. This bulking of requests is profitable, because if a carrier has already many requests and therefore a longer tour, it is always easier to add further requests. But in the adjacent area the bulking effect does not work out, because the distances are too long.

In some instances the reason is not bulking of requests, but the execution of more auction rounds. If there are more rounds conducted, the values of requests bought or sold are higher. Both effects get stronger the higher the carrier bids: the higher the carrier deviates from his true value, the higher is the gain. But this gain is diminishing – whereas the difference between using factor 1,1 and 1,3 is quite high, the gain of bidding 1,5 times higher instead of 1,3 is much lower.

Comparing set I and set I9 (i91-i100), where the difference is the initial number of requests (3 versus 9), it can be seen that the gain decreases slightly. Whereas the gain in the share for the carrier that bids higher is between 18 and 67% in set I, that in set I9 is just between 15 and 50%, whereby the range refers to the bidding-factors from 1,1 to 1,5. This decrease continues in set I15 (i101-i110) where the carriers own 15 request initially. Here the gain ranges from only 3 to 44%. Noticeable is, that here the carrier that solely bids higher does often not reach to have the largest number of requests, as it was the case in set O, set I and set I9, and is therefore in many instances not better-off. If the bulking of many requests does not work out, then the few requests that the carriers still has won are not profitable, because the advantage of a long tour can not be taken. But capacity restriction are not the reason for this, which will be explained later. Here the previously explained effects occur exactly the other way round. Firstly if a carrier bids unfair he often owns in the end less requests than he would own if he would bid truly this is a hint for a deviation from the true value which is too low. And secondly there are often less auction rounds conducted, if a carrier bids unfair, which decreases the values for the requests bought and sold. This means that false bidding often ends up in a strange situation, where no further auction rounds are possible. A remarkable example is instance i104 where normally 9 auction rounds are done, but because carrier c0 bids higher just 2 auction rounds come up, which enormously decreases the share for the carriers. But again the capacity restrictions are no reason for this development. These phenomena are especially present when using the factor 1,1 and explains the change of only 3,3% in set I15. This leads to the following advice: in identical regions with a high number of requests per carrier it does not make sense to deviate just a little bit from the true marginal profit, but it is recommended to deviate stronger.

In the sets O10 and O15 this trend is even intensified. Here the carrier that bids a wrong value is often even worse off (between -1,5 and -10%) than if bidding truly. In set O10_150 and a factor of 1,1 nothing is happening at all. When using the factor 1,3 in some instances the bulking-effect occurs but in most of the instances the carrier that bids unfair just wins one request more which makes him worse-off than if he would have bid truly, and again often less auctions rounds are done. Also increasing the factor up to 1,5 still shows the same situation or even worse. The higher the factor the higher the loss. The bulking effect does not really come out on top. This means the carrier should deviate even more from his true value, which would reflect a situation that would not be believable in reality anymore.

Summing up, if every carrier owns initially a large number of requests, it is easier for everyone to integrate further requests into the existing tour. Therefore the bidding-higher factor hast to be chosen higher as well. Therefore the instance sets taken from Berger and Bierwirth (2010) and those of Gansterer and Hartl (2015) show quite different results. Whereas for example the results of set O lead to favour bidding higher, those from set O10 and O15 rather advise to bid the true marginal profits in order to avoid loss.

The already mentioned bulking-effect is shown in the following table. Table 6 shows the average percentage of requests that the carrier that solely bids higher owns in the end of all auction rounds.

	1,1	**1,3**	**1,5**
set_a	33,58	33,83	33,83
set_o	37,28	41,98	43,95
set_i	41,73	54,81	60,86
91-100	38,15	45,80	50,49
101-110	39,93	50,22	55,78
O10_150	33,33	33,56	33,72
O10_200	33,72	34,39	34,83
O10_300	34,67	37,06	37,94
O15_150	33,59	33,93	34,04
O15_200	33,63	34,26	34,70
O15_300	35,67	37,00	39,19

Table 6: Mean percentage of requests that a carrier that solely bids higher possesses

The result is split in two parts the one for the sets A, O, I, I9 and I15, and the other part for the sets O10 and O15. This goes along with the former presented mean percentage change in share of the gain. In the adjacent area the number of requests of the carrier that solely bids higher is about 33% and no sign of bulking of requests can be found, no matter which bidding-higher factor was chosen. In the overlapping and identical sets the bulking-effect which was already shown in Table 5 is also present here. The carrier that bids higher owns much more requests than the other carriers. The higher the carrier deviates from his true marginal value, the more requests he owns in the end. The highest values occur when using factor 1,5 in the sets I, I9 and I15, with 50 to 60%.

In the sets O10 and O15 the value lies between 33 and 34%, just in set O10_300 and O15_300 a value of 37 and 39% comes up. So we see that there is no bulking effect in the overlapping sets with a higher number of requests in the beginning. This was again already reflected in the share that the carrier receives.

But not in all instances it has an effect at all, if a carrier deviates from this true marginal profit. As shown in Table 7 there are many instances where no change happens at all.

	1,1	**1,3**	**1,5**
set_a	1,1	3,3	3,3
set_o	17,8	37,8	45,6
set_i	40,0	75,6	83,3
91-100	73,3	96,7	96,7
101-110	80,0	100,0	100,0
O10_150	0,0	5,0	8,3
O10_200	15,0	28,3	40,0
O10_300	25,0	55,0	60,0
O15_150	6,7	16,7	20,0
O15_200	11,7	28,3	36,7
O15_300	45,0	58,3	85,0

Table 7: Mean percentage of instances where false bidding causes an effect at all

A very low percentage between 0 and 20% can be seen in set A, set O10_150 and O15_150, because of the low competition. The value climbs up between 15 and 45% in the further overlapping sets and finally in the identical sets in up to every instances an effect of the false bidding is caused. Of course, the more similar the geographical regions are, the more likely it is to pocket requests from other carriers. And again the higher the bidding-false factor the more changes happen - no matter if the effect is positive or negative.

Looking at the situation for the whole network, cheating mostly has a negative impact on the overall network gain, as presented in Table 8.

	1,1	1,3	1,5
set_a	-0,09	-2,21	-2,21
set_o	1,51	-2,86	-4,61
set_i	-0,33	-4,00	-8,51
91-100	-1,25	-8,13	-2,89
101-110	-6,34	10,39	13,62
O10_150	0,00	-6,18	-7,79
O10_200	1,31	2,71	-1,31
O10_300	-3,99	-1,87	-4,75
O15_150	2,35	2,42	-0,71
O15_200	-1,85	-4,74	-7,72
O15_300	-1,40	-4,25	-5,13

Table 8: Mean percentage change in the overall collaborative gain if one carrier solely bids higher

The overall impression that Table 8 shows is that bidding higher is disadvantageous for the overall network gain. Mostly, the higher the carrier deviates from his true value, the higher the loss will be. The highest loss of up to 8,5% happens in set I. Remarkably and contradictory is, that in set I15, in the instances i101 - i110 in setting 1,3 and 1,5 a quite high gain up to 13% is achieved. A closer examination of the underlying instances shows that on the one hand the carrier that bids not truly achieves an enormous gain, and on the other hand, those carriers that stick to their true marginal profits also observe a small gain. In some instances the false bidding of the other carriers still leads to a loss for the truly bidding carriers, but in those cases this loss is very small and therefore abolishes when we look at the result for the whole network. This phenomenon just appears in the identical area with a high number of requests per carrier and a high deviation from the true marginal profit. Here the analysis shows a clear support for bidding untrue.

In the further analysis the values shown in Table 9 and 10 are always aggregated over all possible scenarios, where either just one carrier or two carriers bid higher. There are 6 in sum, neglecting the combination that all carriers bid higher (hnn, nhn, nnh, hnh, hhn, nhh). In Table 9 the situation without capacity constraints is additionally shown. The first two rows show the mean percentage change of the collaboration gain of the whole network, when comparing the setting where carriers bid false to the setting where all carriers bid true. The next two rows represent the average percentage change of the share of gain of those carriers who bid higher. The last two rows show the average percentage change of the share of gain of those carriers who bid normal. In the columns the three different deviation parameters 1.1, 1.3, and 1.5 for all the different sets are shown.

		set_a			set_o			set_i			91-100			101-110		
		1,1	1,3	1,5	1,1	1,3	1,5	1,1	1,3	1,5	1,1	1,3	1,5	1,1	1,3	1,5
avg. perc. change of collaboration gain	w/ cap	-0,1	-2,2	-2,2	1,3	-2,5	-4,4	0,0	-2,9	-7,6	0,9	-5,7	-4,4	-6,8	11,5	14,5
	w/o cap	46,5	33,9	32,0	14,8	7,9	1,1	2,9	-3,2	-8,6	0,9	-6,2	-4,5	-6,8	11,5	15,3
avg. perc. change of share of gain of those carriers who bid higher	w/ cap	0,1	-0,7	-0,7	11,6	17,7	18,7	13,1	31,5	35,2	13,2	22,1	29,3	-0,7	24,1	34,1
	w/o cap	57,8	50,8	50,0	30,5	40,0	37,1	22,5	41,4	43,8	13,2	21,6	29,2	-0,7	24,0	35,8
aveg. perc. change of share of gain of those carriers who bid normal	w/ cap	-0,6	-4,2	-4,2	-9,1	-22,6	-27,4	-12,9	-37,2	-50,5	-10,3	-32,3	-36,7	-13,1	-1,1	-5,3
	w/o cap	55,0	35,9	31,4	-0,9	-24,2	-34,8	-16,7	-48,2	-61,5	-10,3	-32,8	-36,7	-13,1	-1,1	-5,4

Table 9: Mean percentage change of: collaboration gain / share of those who bid higher / share of those who bid normal

	O10_150			O10_200			O10_300			O15_150			O15_200			O15_300		
	1,1	1,3	1,5	1,1	1,3	1,5	1,1	1,3	1,5	1,1	1,3	1,5	1,1	1,3	1,5	1,1	1,3	1,5
avg perc. change of collaboration gain	0,0	-6,2	-7,8	0,7	3,4	-0,7	-4,2	-2,3	-4,5	2,4	2,6	0,6	-1,6	-4,0	-7,0	-2,0	-3,3	-4,1
avg. perc. change of share of gain of those carriers who bid higher	0,0	-2,1	-3,3	1,8	4,7	1,2	-4,2	-1,3	-3,6	2,0	2,3	0,5	-2,5	-5,4	-8,3	-2,6	-4,1	-4,6
avg. perc. change of share of gain of those carriers who bid normal	0,0	-8,3	-10,4	-0,1	2,3	-2,5	-4,3	-3,7	-5,7	2,7	3,0	0,6	-0,7	-2,7	-5,7	-1,4	-2,4	-3,7

Table 10: Mean percentage change of: collaboration gain / share of those who bid higher / share of those who bid normal

The statements in the already shown tables continue also in the aggregated case. Those carriers bidding higher make a gain (up to 35%), whereas the overall network gain is harmed (up to -8%). Those carriers bidding lower receive up to 51% less than if nobody would bid unfair.

In detail the situation looks as follows. In the adjacent area bidding false has a negative impact for all the carriers. This is the same situation as when looking at just one carrier that bids false. the reason is that the distances are too long, because of the adjacent setting. But if we ignore capacity restrictions the situation changes. Then all the carriers would make a remarkable gain if some carriers bid false instead of bidding truly. The overall network gain would then be between 32 and 47% higher than if everyone bids his true marginal profit. 47% refer to a deviation factor of 1.1

and the 32% refer to a factor of 1.5. This shows that the higher the deviation from the true marginal profit, the more the gain is diminishing. The reason behind is clear, if the carriers can accumulate as much requests as they want, and their tour length is not restricted, then the reassignment of the requests during the auction has a remarkable positive impact. The carriers bidding higher accumulate many requests and draw advantage out of bulking requests and the other carriers make profit, because they sell requests that are quite far away - so both parties benefit.

In set O and set I, the ones that bid higher benefit (11 to 35%), and the ones that bid truly are penalized (-9 to -51%). The change in the overall network gain is between -8 and 1.3%. The higher the deviation factor, the higher the loss/gain. The reason is the bulking of requests, which is even intensified if capacity restrictions are ignored: here carriers bidding higher make even more gain and the carriers bidding truly receive even less. In the overlapping set the overall network gain even increases without capacity restrictions, but in the identical set the loss of the carriers bidding truly is so high, that the overall network gain is again negative. The difference between using capacity restrictions or omitting them is getting lower, the higher the deviation factor is chosen. The same goes for the geographical setting: the more overlapping/identical the regions are, the less difference occurs between using capacity restrictions or not. This is due to the shorter distances in the competitive settings.

In the identical sets I9 (i91 - i100) and I15 (i101 - i110) there is almost no difference between setting capacity restrictions or not, again because of the identical region and therefore shorter distances, but also because the initial tour length is longer because of a higher number of requests in the beginning.

Whereas in set I9 we see the same picture as before: positive change for those who bid higher, negative change for those who bid normal and a negative change of the overall network gain (except a slightly positive change when using the factor 1.1), the situation in set I15 changes. When using a factor of 1.1 all the carriers are worse off if someone bids false instead of bidding truly. As in Table 8 deviating higher from the true marginal profit has a very positive impact in the setting with a high number of requests and identical regions. Those carriers bidding higher observe a change of 24 to 34% and the overall network gain is changed by 11 to 15%. Those carriers bidding normal still observe a negative change between -1 and -5%, but this is comparably low.

The sets of Gansterer and Hartl (2015) show interesting results. In set O10_150, O10_300, O15_200 and O15_300 each carrier is worse off, no matter if he has bid normal or higher, and of course also the overall network gain is lower than in the case that everyone bids his true marginal profit. Set O15_150 shows a completely contradictory result, with a positive gain for those who bid higher as well as for those who bid normal and summing up, also a positive value for the overall collaboration gain. A similar effect can be obtained in set O10_200. But nevertheless those positive values are with a range between 0.6 and 4.7% rather low.

These quite different results call for some further examinations, which are left over for some future work. Suggestions to start with are firstly the differentiation between own and foreign requests, such that the bidding-higher factor can be different. And secondly the difference between the instance sets from Berger and Bierwirth (2010) and Gansterer and Hartl (2015) should be examined to find out more about the reason for the varying results.

6 Conclusion and future work

This thesis deals with collaborative transportation and examines a framework based on an auction-process. The goal of the auction is to maximize the overall network profit. The last phase of the auction process is the profit sharing that uses a method to allocate the generated collaboration gain fair among all participants. The aim was to find a profit sharing method that takes into account the specific facts of incomplete information in the underlying framework. This lack of information does not allow to use any of the multitude of existing, well-known and often-applied profit or cost allocation methods. Therefore the author tried to adapt an existing method and created a new profit allocation scheme. The author found a method that uses the marginal profit of the requests bought and sold separated, which fulfills all the requirements. Firstly, the resulting allocation is individually rational, as each carrier receives his standalone profit and additionally a share of the collaborative gain which is greater or equal to zero. Secondly, the collaborative gain is fully split among the carriers, which satisfies group rationality. And thirdly the method induces that it is always more profitable or at least equal profitable when two coalitions join. Nevertheless an experiment would be useful to test the acceptance of the new created method in real-life. To quantify the plausibility of the new method it was compared to Moriarity's method, a simple and well-known allocation method. The author found that the allocation differs quite a lot from Moriarity, but as Moriarity would misleadingly allocate negative values in some instances, it is rather positive that the new created method differs from Moriarity. Therefore the deviation is not a decrease in plausibility. Nevertheless a real life experiment could be done to substantiate the acceptance of the new created allocation scheme. Maybe also some additional methods, respecting the absence of full information, could be found, which means that some further research should be done in this regard.

The second issue that was discussed is strategic behaviour. This thesis just takes the first step to open this broad topic. This study does not claim for completeness, but just touches the behaviour of the carriers and start the discussion and hopefully some future research towards examining strategically behaving participants. In this first study it was examined what happens if a carrier does not bid his true marginal profit, as it would be claimed by the underlying framework, in order to make himself better off. Bidding lower than the true marginal profit seems not to yield any positive effect, thus the focus was directed on bidding higher. By varying the deviation from the true marginal profit the impact on the profit of the single carrier that bids higher, as well as on the overall network gain, was examined. The higher the deviation, the greater the impact, regardless of whether the effect is positive or negative. It was found that bidding higher not always makes the carrier that bids higher better off, especially in the settings with adjacent or overlapping areas. Thus in the identical sets with a high number of requests and a high deviation from the true marginal profit, a remarkable gain can be obtained. The overall network gain is mostly harmed if one ore more carriers are bidding not truly. To give more precise statements a further analysis has to be done. Distinguishing between own and foreign request would be a first suggestion. This may help to analyze the not yet substantiated results.

Appendix

set_a	coll_gain	gain_c0	gain_c1	gain_c2
i1	0,000	0,000	0,000	0,000
i2	0,000	0,000	0,000	0,000
i3	0,000	0,000	0,000	0,000
i4	0,000	0,000	0,000	0,000
i5	37,698	-2,911	40,609	0,000
i6	2,337	-16,218	18,555	0,000
i7	0,000	0,000	0,000	0,000
i8	0,000	0,000	0,000	0,000
i9	15,560	-4,731	20,291	0,000
i10	0,000	0,000	0,000	0,000
i11	0,000	0,000	0,000	0,000
i12	0,000	0,000	0,000	0,000
i13	0,000	0,000	0,000	0,000
i14	0,000	0,000	0,000	0,000
i15	0,000	0,000	0,000	0,000
i16	0,000	0,000	0,000	0,000
i17	0,000	0,000	0,000	0,000
i18	0,000	0,000	0,000	0,000
i19	11,919	-1,640	13,558	0,000
i20	0,000	0,000	0,000	0,000
i21	0,000	0,000	0,000	0,000
i22	0,000	0,000	0,000	0,000
i23	0,000	0,000	0,000	0,000
i24	6,843	-1,568	8,411	0,000
i25	0,000	0,000	0,000	0,000
i26	0,000	0,000	0,000	0,000
i27	3,896	24,129	-20,233	0,000
i28	0,000	0,000	0,000	0,000
i29	0,000	0,000	0,000	0,000
i30	0,000	0,000	0,000	0,000

Table 11: Collaborative and individual gain in set A (after all auction rounds are done, before profit sharing starts)

set_o	coll_gain	gain_c0	gain_c1	gain_c2
i31	0,000	0,000	0,000	0,000
i32	73,856	34,689	107,359	-68,193
i33	75,233	47,208	9,351	18,673
i34	98,408	152,772	-6,084	-48,279
i35	57,103	1,151	42,833	13,118
i36	17,703	0,000	75,196	-57,494
i37	50,572	-7,474	58,046	0,000
i38	18,682	-7,111	25,792	0,000
i39	73,175	5,578	-32,114	99,712
i40	48,075	68,233	0,000	-20,158
i41	3,277	20,974	0,000	-17,698
i42	28,726	37,875	-9,148	0,000
i43	19,510	0,000	-10,096	29,605
i44	56,117	-46,835	-22,826	125,778
i45	19,283	24,710	0,000	-5,428
i46	49,269	-12,989	62,259	0,000
i47	63,525	36,682	-22,491	49,334
i48	12,107	2,264	0,000	9,843
i49	25,760	-14,428	40,188	0,000
i50	0,877	0,000	-25,684	26,561
i51	91,203	84,420	30,878	-24,095
i52	6,530	42,890	-36,359	0,000
i53	25,429	19,446	0,000	5,983
i54	101,798	46,461	82,201	-26,864
i55	50,278	142,919	-27,561	-65,080
i56	49,921	-44,689	20,030	74,580
i57	45,378	-103,731	0,000	149,109
i58	21,955	26,234	-4,279	0,000
i59	17,193	0,000	94,046	-76,853
i60	62,063	161,833	-26,309	-73,460

Table 12: Collaborative and individual gain in set O (after all auction rounds are done, before profit sharing starts)

set_i	coll_gain	gain_c0	gain_c1	gain_c2
i61	77,001	9,757	7,550	59,695
i62	154,014	156,334	-50,318	47,998
i63	61,079	31,253	-45,527	75,353
i64	120,598	11,596	116,403	-7,401
i65	81,494	-14,707	81,900	14,300
i66	178,934	-75,780	-36,837	291,551
i67	35,905	-73,901	-71,491	181,297
i68	117,644	37,912	121,145	-41,413
i69	39,883	0,483	1,926	37,474
i70	102,330	99,997	-33,935	36,269
i71	184,508	1,151	283,682	-100,325
i72	186,257	118,324	110,203	-42,270
i73	111,018	269,654	-65,076	-93,559
i74	131,813	-50,629	275,851	-93,408
i75	224,920	341,412	33,663	-150,156
i76	97,773	-74,953	89,472	83,255
i77	77,547	95,674	-60,189	42,062
i78	113,981	95,921	-27,248	45,308
i79	105,970	-47,112	-8,113	161,194
i80	111,379	171,923	0,150	-60,694
i81	122,426	3,677	1,071	117,678
i82	206,306	131,979	22,300	52,027
i83	157,978	73,125	106,248	-21,396
i84	155,613	-16,162	220,754	-48,979
i85	150,799	-39,252	146,899	43,153
i86	86,093	24,569	-110,722	172,246
i87	92,486	4,002	-52,524	141,008
i88	67,153	226,109	-59,218	-99,738
i89	40,882	106,718	-116,814	50,979
i90	123,678	-39,369	7,588	155,459

Table 13: Collaborative and individual gain in set I (after all auction rounds are done, before profit sharing starts)

	coll_gain	gain_c0	gain_c1	gain_c2
i91	87,195	-112,236	142,692	56,740
i92	202,937	121,184	-69,110	150,863
i93	105,668	132,669	-114,407	87,405
i94	51,959	47,301	-33,000	37,659
i95	156,582	227,308	28,356	-99,081
i96	147,426	16,932	254,293	-123,799
i97	114,096	-85,831	155,920	44,007
i98	99,863	-96,202	20,971	175,094
i99	100,427	-66,249	98,809	67,866
i100	89,906	66,331	-119,467	143,042

Table 14: Collaborative and individual gain in set I9 (after all auction rounds are done, before profit sharing starts)

	coll_gain	gain_c0	gain_c1	gain_c2
i101	113,248	-6,586	135,756	-15,922
i102	139,254	23,209	-92,888	208,933
i103	140,016	-89,507	142,218	87,305
i104	127,194	-349,539	169,110	307,623
i105	72,232	79,525	35,278	-42,571
i106	153,544	214,901	-124,226	62,869
i107	37,225	41,803	-4,070	-0,508
i108	241,570	-26,325	-46,661	314,556
i109	144,550	29,323	-169,626	284,853
i110	225,888	258,017	-375,343	343,213

Table 15: Collaborative and individual gain in set I15 (after all auction rounds are done, before profit sharing starts)

O10_150	coll_gain	gain_c0	gain_c1	gain_c2
0	20,404	-25,178	45,582	0,000
1	0,000	0,000	0,000	0,000
2	0,000	0,000	0,000	0,000
3	0,000	0,000	0,000	0,000
4	0,000	0,000	0,000	0,000
5	40,530	0,000	-136,747	177,277
6	70,493	0,000	-46,785	117,278
7	0,000	0,000	0,000	0,000
8	15,987	0,000	12,613	3,374
9	184,387	40,878	143,509	0,000
10	40,970	-13,695	54,665	0,000
11	15,787	-30,671	0,000	46,458
12	0,000	0,000	0,000	0,000
13	0,000	0,000	0,000	0,000
14	0,000	0,000	0,000	0,000
15	0,000	0,000	0,000	0,000
16	0,000	0,000	0,000	0,000
17	0,000	0,000	0,000	0,000
18	187,241	0,000	-87,699	274,940
19	19,613	0,000	-63,727	83,340

Table 16: Collaborative and individual gain in set O10_150 (after all auction rounds are done, before profit sharing starts)

O10_200	coll_gain	gain_c0	gain_c1	gain_c2
0	165,244	-229,362	394,606	0,000
1	199,384	80,394	118,990	0,000
2	230,044	8,714	221,330	0,000
3	0,000	0,000	0,000	0,000
4	41,226	136,867	-95,641	0,000
5	115,625	0,000	-145,598	261,223
6	212,313	29,237	183,076	0,000
7	179,070	-285,576	225,080	239,567
8	109,075	4,818	64,396	39,860
9	0,000	0,000	0,000	0,000
10	0,000	0,000	0,000	0,000
11	413,262	554,727	55,639	-197,105
12	70,482	224,181	-158,371	4,672
13	127,763	0,000	-21,022	148,785
14	90,391	-7,942	0,000	98,333
15	163,040	-326,218	363,894	125,364
16	272,959	168,443	265,974	-161,458
17	379,914	67,474	78,500	233,940
18	192,209	113,776	0,000	78,433
19	58,521	14,619	172,535	-128,633

Table 17: Collaborative and individual gain in set O10_200 (after all auction rounds are done, before profit sharing starts)

O10_300	coll_gain	gain_c0	gain_c1	gain_c2
0	905,498	384,889	782,445	-261,835
1	537,235	646,338	-291,272	182,169
2	288,387	483,273	68,225	-263,110
3	579,389	270,082	262,814	46,493
4	573,218	166,771	440,035	-33,588
5	536,892	-183,398	-8,910	729,200
6	150,747	461,659	-35,778	-275,134
7	470,361	216,637	-198,571	452,294
8	654,989	181,422	-80,782	554,349
9	202,695	290,111	131,682	-219,097
10	437,248	0,000	671,786	-234,537
11	687,936	380,118	-44,683	352,501
12	482,782	-76,704	596,525	-37,038
13	349,761	274,560	70,231	4,970
14	0,000	0,000	0,000	0,000
15	281,098	18,476	262,622	0,000
16	397,148	309,464	48,193	39,490
17	153,532	-233,082	435,467	-48,853
18	369,977	-844,047	656,560	557,463
19	599,178	-415,688	1.389,224	-374,358

Table 18: Collaborative and individual gain in set O10_300 (after all auction rounds, before profit sharing)

O15_150	coll_gain	gain_c0	gain_c1	gain_c2
0	110,424	-76,778	187,202	0,000
1	0,000	0,000	0,000	0,000
2	154,741	112,587	42,154	0,000
3	0,000	0,000	0,000	0,000
4	32,822	0,000	72,155	-39,332
5	59,192	0,000	34,378	24,813
6	79,933	129,629	0,000	-49,696
7	64,969	0,000	49,003	15,966
8	24,976	-70,279	95,255	0,000
9	39,192	0,000	31,493	7,699
10	0,000	0,000	0,000	0,000
11	1,759	65,972	-64,213	0,000
12	137,122	51,156	163,106	-77,139
13	43,812	0,000	93,852	-50,040
14	76,756	9,740	66,717	0,298
15	62,282	0,000	68,964	-6,682
16	87,268	60,832	0,000	26,437
17	17,305	-62,612	79,917	0,000
18	17,439	-61,753	0,000	79,193
19	28,135	-28,984	0,000	57,119

Table 19: Collaborative and individual gain in set O15_150 (after all auction rounds are done, before profit sharing starts)

O15_200	coll_gain	gain_c0	gain_c1	gain_c2
0	184,315	154,586	-7,503	37,232
1	73,126	-57,625	93,193	37,557
2	0,000	0,000	0,000	0,000
3	365,512	187,501	-191,267	369,278
4	0,000	0,000	0,000	0,000
5	17,176	91,651	0,000	-74,475
6	76,573	-24,497	163,259	-62,190
7	256,306	417,730	-371,531	210,107
8	313,519	-203,045	393,674	122,891
9	126,845	9,591	117,254	0,000
10	332,258	-92,510	196,554	228,214
11	168,881	23,619	145,262	0,000
12	576,559	-0,294	-227,828	804,681
13	307,446	220,029	-19,510	106,928
14	152,441	81,073	-14,276	85,645
15	248,495	188,824	0,000	59,671
16	42,421	101,481	-59,061	0,000
17	216,505	10,964	164,769	40,772
18	594,768	51,338	404,209	139,220
19	311,984	336,043	-49,520	25,461

Table 20: Collaborative and individual gain in set O15_200 (after all auction rounds are done, before profit sharing starts)

O15_300	coll_gain	gain_c0	gain_c1	gain_c2
0	720,477	-17,843	366,492	371,828
1	646,855	442,925	584,387	-380,457
2	92,620	381,081	-61,460	-227,001
3	421,284	24,994	501,293	-105,004
4	1.005,698	-119,670	249,187	876,181
5	732,700	-94,628	1.230,563	-403,234
6	405,604	97,926	97,343	210,335
7	640,581	315,282	99,184	226,115
8	506,942	225,324	0,000	281,618
9	507,882	368,261	58,645	80,976
10	510,389	231,023	64,008	215,358
11	645,373	891,866	-38,849	-207,644
12	1.079,189	521,461	-32,182	589,909
13	307,192	-24,114	-438,345	769,652
14	582,912	-217,116	147,638	652,390
15	687,071	423,134	-126,878	390,815
16	789,025	652,444	115,516	21,065
17	787,732	-137,263	79,830	845,165
18	398,092	-76,161	128,584	345,669
19	458,317	8,289	716,057	-266,029

Table 21: Collaborative and individual gain in set O15_300 (after all auction rounds are done, before profit sharing starts)

set_a	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
i5	37,698	3,966	24,180	9,552	111,01	297,84
i6	2,337	1,145	0,249	0,944	69,09	166,21
i9	15,560	4,342	5,873	5,345	67,97	154,07
i19	11,919	3,817	3,850	4,252	14,83	26,31
i24	6,843	1,123	2,271	3,449	41,49	104,67
i27	3,896	1,011	1,294	1,591	24,57	50,14

Table 22: Allocation of the collaborative gain in set A according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to those of Moriarity's method in set A

set_o	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
i32	73,856	3,110	52,389	18,356	60,93	110,09
i33	75,233	33,085	29,837	12,311	46,40	110,17
i34	98,408	66,783	22,358	9,267	68,05	80,72
i35	57,103	0,082	33,028	23,993	47,90	96,06
i36	17,703	5,317	10,900	1,486	54,30	75,80
i37	50,572	3,404	19,595	27,573	19,72	32,94
i38	18,682	7,863	8,976	1,843	19,18	32,18
i39	73,175	1,929	11,104	60,143	108,87	202,40
i40	48,075	21,628	20,837	5,610	12,35	19,46
i41	3,277	2,143	0,574	0,560	10,43	16,87
i42	28,726	7,726	5,794	15,206	11,17	15,79
i43	19,510	7,809	4,499	7,201	4,45	6,64
i44	56,117	13,184	13,007	29,925	41,91	64,48
i45	19,283	4,514	12,939	1,830	16,24	20,42
i46	49,269	17,959	13,097	18,213	17,67	30,49
i47	63,525	32,390	11,103	20,033	39,81	60,71
i48	12,107	5,149	4,435	2,523	5,86	9,27
i49	25,760	5,143	14,609	6,008	14,58	23,33
i50	0,877	0,371	0,098	0,408	14,13	18,30
i51	91,203	30,968	34,152	26,082	46,50	54,26
i52	6,530	2,764	1,273	2,494	22,26	35,73
i53	25,429	5,558	14,623	5,248	30,15	75,53
i54	101,798	41,558	56,692	3,548	72,02	124,97
i55	50,278	32,676	13,091	4,511	165,52	380,48
i56	49,921	3,023	17,495	29,402	59,38	94,74
i57	45,378	3,651	20,264	21,463	58,69	78,13
i58	21,955	10,206	0,117	11,632	50,48	81,84
i59	17,193	2,988	9,864	4,341	27,82	40,66
i60	62,063	46,705	8,124	7,234	46,054	59,069

Table 23: Allocation of the collaborative gain in set O according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set O

set_i	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
i61	77,001	0,851	39,028	37,122	53,639	114,029
i62	154,014	74,492	18,929	60,593	722,997	2.087,942
i63	61,079	18,120	3,513	39,446	56,148	80,310
i64	120,598	23,697	95,499	1,402	90,242	133,516
i65	81,494	1,993	61,499	18,001	320,824	865,237
i66	178,934	40,030	6,344	132,561	180,344	393,431
i67	35,905	10,444	5,516	19,945	36,961	49,126
i68	117,644	70,150	43,696	3,798	154,727	363,324
i69	39,883	16,502	0,104	23,277	40,795	103,868
i70	102,330	45,167	3,295	53,868	42,120	84,052
i71	184,508	0,218	119,961	64,328	68,069	101,538
i72	186,257	119,871	51,298	15,089	155,306	361,270
i73	111,018	61,824	33,622	15,572	83,918	174,897
i74	131,813	4,365	104,852	22,596	71,888	83,366
i75	224,920	124,620	7,556	92,744	149,833	270,197
i76	97,773	4,069	45,434	48,270	46,015	83,205
i77	77,547	48,255	4,316	24,976	49,593	82,017
i78	113,981	62,285	29,681	22,015	175,134	474,022
i79	105,970	18,499	30,289	57,182	70,547	161,287
i80	111,379	39,777	53,591	18,011	327,572	898,190
i81	122,426	6,308	39,706	76,411	57,625	106,842
i82	206,306	110,259	14,298	81,749	54,853	119,121
i83	157,978	70,407	85,247	2,324	38,027	86,955
i84	155,613	2,100	122,718	30,795	91,526	216,483
i85	150,799	4,372	94,541	51,886	47,241	85,782
i86	86,093	35,830	6,676	43,587	116,058	254,294
i87	92,486	8,161	8,675	75,649	30,472	46,903
i88	67,153	45,127	17,542	4,484	80,694	129,488
i89	40,882	21,823	2,972	16,087	53,067	78,112
i90	123,678	4,073	50,153	69,453	36,968	78,905

Table 24: Allocation of the collaborative gain in set I according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set I

I9	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
i91	87,195	13,020	45,663	28,513	38,988	58,169
i92	202,937	87,794	41,324	73,820	30,689	49,153
i93	105,668	59,181	13,778	32,709	42,950	65,684
i94	51,959	16,085	11,266	24,608	73,382	105,719
i95	156,582	50,654	78,753	27,175	30,293	47,090
i96	147,426	59,685	65,527	22,214	30,024	48,908
i97	114,096	26,148	42,308	45,640	26,217	45,037
i98	99,863	46,830	22,700	30,333	25,245	35,594
i99	100,427	42,228	28,795	29,404	22,276	27,361
i100	89,906	27,759	23,855	38,292	17,750	24,497

Table 25: Allocation of the collaborative gain in set I9 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set I9

I15	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
i101	113,248	44,469	30,367	38,413	32,263	58,150
i102	139,254	47,737	34,879	56,639	18,656	27,439
i103	140,016	52,379	40,658	46,979	6,206	9,396
i104	127,194	45,030	19,568	62,596	58,250	89,998
i105	72,232	26,219	25,291	20,721	13,101	18,705
i106	153,544	57,908	45,682	49,954	16,267	24,310
i107	37,225	11,373	12,338	13,514	11,834	17,632
i108	241,570	83,998	80,367	77,205	4,977	6,809
i109	144,550	45,595	42,581	56,373	9,447	14,642
i110	225,888	54,377	99,118	72,393	9,378	13,226

Table 26: Allocation of the collaborative gain in set I15 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set I15

O10_150	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
0	20,404	1,683	7,164	11,556	38,482	68,790
5	40,530	16,899	16,558	7,074	27,135	41,285
6	70,493	19,484	33,633	17,376	29,313	36,400
8	15,987	8,523	5,538	1,926	50,929	78,428
9	184,387	50,706	129,393	4,288	57,172	90,027
10	40,970	12,877	17,099	10,993	15,565	23,299
11	15,787	10,187	2,081	3,519	80,003	136,082
18	187,241	42,984	75,561	68,696	15,662	24,133
19	19,613	2,673	7,493	9,447	38,803	57,626

Table 27: Allocation of the collaborative gain in set O10_150 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set O10_150

O10_200	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
0	165,244	85,320	54,531	25,393	38,880	56,852
1	199,384	16,879	78,496	104,009	45,869	72,824
2	230,044	96,868	76,082	57,094	17,389	26,306
4	41,226	16,022	10,728	14,476	4,031	5,567
5	115,625	39,468	47,596	28,561	2,063	3,638
6	212,313	62,183	49,649	100,481	18,402	26,722
7	179,070	61,373	82,344	35,354	11,848	17,713
8	109,075	46,270	54,656	8,150	82,293	144,899
11	413,262	112,432	63,270	237,559	46,873	68,235
12	70,482	27,506	23,630	19,346	11,793	18,093
13	127,763	19,334	41,757	66,673	37,401	55,948
14	90,391	14,214	40,421	35,756	36,080	52,421
15	163,040	79,423	63,805	19,811	38,479	57,980
16	272,959	101,859	34,265	136,835	32,041	43,068
17	379,914	204,971	34,968	139,975	61,001	77,582
18	192,209	76,473	76,637	39,099	23,238	35,596
19	58,521	10,835	19,550	28,136	19,962	45,189

Table 28: Allocation of the collaborative gain in set O10_200 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set O10_200

O10_300	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
0	905,498	291,905	197,233	416,359	34,305	47,538
1	537,235	270,233	142,784	124,218	16,260	23,132
2	288,387	106,486	58,047	123,854	19,257	31,327
3	579,389	214,687	161,104	203,599	8,465	15,223
4	573,218	178,501	206,848	187,869	3,369	5,039
5	536,892	221,432	60,552	254,908	43,188	63,201
6	150,747	77,182	39,341	34,224	28,150	39,195
7	470,361	122,704	274,117	73,540	49,534	63,485
8	654,989	262,527	194,703	197,760	2,952	3,644
9	202,695	21,931	98,766	81,998	18,418	35,694
10	437,248	126,728	134,175	176,345	31,342	59,489
11	687,936	214,252	208,638	265,046	7,629	10,349
12	482,782	196,946	129,862	155,975	13,033	19,823
13	349,761	110,930	144,211	94,620	23,328	30,998
15	281,098	99,364	99,063	82,671	9,368	14,777
16	397,148	154,552	96,235	146,361	9,739	15,912
17	153,532	48,032	15,622	89,878	48,721	65,796
18	369,977	148,656	104,585	116,735	9,919	15,550
19	599,178	186,518	211,186	201,474	13,029	21,479

Table 29: Allocation of the collaborative gain in set O10_300 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set O10_300

O15_150	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
0	110,424	34,005	58,266	18,153	41,927	63,302
2	154,741	23,893	60,211	70,637	24,195	41,827
4	32,822	11,130	15,126	6,566	20,005	33,041
5	59,192	42,733	12,544	3,915	57,864	73,997
6	79,933	33,425	14,146	32,362	25,421	41,022
7	64,969	41,888	15,733	7,348	39,023	64,766
8	24,976	9,251	7,431	8,294	5,359	8,021
9	39,192	8,491	19,076	11,625	27,921	38,816
11	1,759	0,110	1,007	0,642	52,195	80,808
12	137,122	29,245	46,279	61,599	29,333	41,290
13	43,812	16,809	8,246	18,758	18,917	32,185
14	76,756	4,097	26,489	46,170	44,928	78,960
15	62,282	10,439	32,570	19,273	24,421	40,259
16	87,268	33,988	15,085	38,196	28,616	43,952
17	17,305	8,962	3,391	4,952	48,665	80,317
18	17,439	4,754	6,885	5,800	18,430	29,450
19	28,135	13,124	2,932	12,079	44,694	68,108

Table 30: Allocation of the collaborative gain in set O15_150 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set O15_150

O15_200	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
0	184,315	84,544	61,190	38,581	28,990	43,998
1	73,126	23,584	11,332	38,209	49,142	79,534
3	365,512	132,930	141,783	90,798	12,649	19,233
5	17,176	7,941	6,170	3,066	18,646	31,064
6	76,573	36,507	12,023	28,043	40,906	64,433
7	256,306	98,456	88,515	69,334	7,289	10,295
8	313,519	131,351	59,661	122,508	19,261	32,391
9	126,845	33,186	70,535	23,125	29,995	38,337
10	332,258	165,779	97,582	68,897	25,648	34,975
11	168,881	70,450	26,660	71,771	41,578	57,345
12	576,559	126,605	250,508	199,446	28,773	40,252
13	307,446	128,611	82,870	95,965	15,545	22,924
14	152,441	37,974	37,021	77,446	40,322	63,883
15	248,495	39,680	77,107	131,707	35,385	50,103
16	42,421	3,369	19,520	19,532	51,089	76,120
17	216,505	20,178	115,362	80,966	52,447	73,986
18	594,768	216,581	232,538	145,649	16,876	27,197
19	311,984	84,548	149,146	78,291	27,407	39,517

Table 31: Allocation of the collaborative gain in set O15_200 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set O15_200

O15_300	coll_gain	share_c0	share_c1	share_c2	mean_abs_ percent_error	max_abs_ percent_error
0	720,477	171,081	467,014	82,382	43,036	52,625
1	646,855	225,214	113,130	308,510	35,741	54,422
2	92,620	25,757	35,391	31,471	6,201	11,257
3	421,284	162,800	135,856	122,628	21,141	35,431
4	1.005,698	229,997	406,772	368,929	11,339	19,080
5	732,700	175,413	336,881	220,406	34,622	56,418
6	405,604	81,595	181,576	142,432	21,113	29,204
7	640,581	247,446	279,404	113,731	26,116	41,537
8	506,942	148,535	162,444	195,963	20,854	34,978
9	507,882	240,460	58,981	208,441	43,716	65,396
10	510,389	183,071	169,126	158,192	10,695	18,793
11	645,373	235,600	280,375	129,398	16,622	22,600
12	1.079,189	533,023	78,618	467,547	33,452	64,606
13	307,192	106,608	102,642	97,942	7,520	10,670
14	582,912	198,235	172,645	212,033	3,672	5,279
15	687,071	188,424	172,888	325,760	15,520	23,438
16	789,025	466,800	92,918	229,308	38,110	58,357
17	787,732	254,385	235,041	298,305	21,730	39,663
18	398,092	145,640	54,815	197,638	45,761	62,331
19	458,317	171,897	143,296	143,123	8,429	12,723

Table 32: Allocation of the collaborative gain in set O15_300 according to method BW & Mean and maximum absolute percentage error of the carriers' shares of method BW compared to Moriarity's method in set O15_300

List of Abbreviations

ACA	Alternative cost avoided method
BRRA	Bundle request reassignment
BW	The author's profit sharing method
CA	Cost allocation
CCN	Collaborative carrier network
CGM	Cost gap allocation method
E	Egalitarian repartition of the total gain
EC	Equal charge method
EPM	Equal profit method
LTL	Less-than-truckload
M	Moriarity's method
PC	Proportional repartition of non separable costs
SCRB	Cost remaining benefits method
SRRA	Single request reassignment
WRSM	Weighted relative savings method

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Abstract

This study examines collaborative transportation based on an auction-process. Several carriers exchange transportation requests during a combinatorial auction in order to reach a better composition of requests, by avoiding empty trucks and making use of synergies or back-hauls. The goal of the auction is to generate additional profit for the whole network while providing as little private information as possible to the other carriers. The first research question is how to split the additional profit fair among all participants. To answer this the author uses cooperative game theory, and examines existing cost allocation methods that are adapted for profit sharing. As none of the existing methods is applicable - because of incomplete information - the author was forced to find some new methods. In a first approach the Shapley method was adapted which does not lead to a satisfying result. But in a second approach a new method was found, that fulfills all requirements. The second research question deals with strategic behaviour. It examines the situation if a carrier does not bid his true value for the bids but tries to make himself better off by cheating. This study just tries to make a first approach in discussing strategic behaviour and gives the direction for some possible future research.

Deutsche Zusammenfassung

Diese Masterarbeit behandelt kollaborative Speditionsnetzwerke in denen konkurrierende Speditionen auf Basis einer Auktion zusammenarbeiten. In dem Auktionsprozess werden Transportaufträge ausgetauscht um so Synergien und Kapazitäten besser zu nutzen, Leerfahrten zu vermeiden und insgesamt die Routen zu optimieren. Um das Modell so realistisch wie möglich zu halten, werden während des gesamten Prosesses so wenig Information wie möglich zwischen den Speditionen ausgetauscht. Ziel der Auktion ist es, zusätzlichen Gewinn für das gesamte Netzwerk zu generieren. Die erste Frage die diese Arbeit zu beantworten versucht ist, wie der zusätzliche Gewinn fair auf alle Teilnehmer aufgeteilt werden soll. Dazu werden existierende Kosten- oder Gewinnaufteilungsmethoden herangezogen und auf Anwendbarkeit in dem zugrundeliegenden Modell geprüft. Da aufgrund mangelnder Informationen, die die Speditionen preisgeben, weder die in der Literatur existierenden Methoden angewendet noch angepasst werden können, wurde eine neue Methode kreiert. Diese wurde nach den Anforderungen der kooperativen Spieltheorie überprüft und liefert ein plausibles Ergebnis. Die zweite Frage beschäftigt sich mit strategischem Verhalten der Speditionen. Konkret bedeutet das, dass Speditionen in dem zugrundeliegenden Modell dazu angestiftet oder verleitet werden, falsche Angaben bei den Geboten zu machen, um sich selbst einen Vorteil zu verschaffen. Diese Arbeit liefert einen ersten Ansatz um das Thema strategisches Verhalten zu erklären und gibt mit ersten Erkenntnissen die Richtung für mögliche weitere Forschungen vor.

Lebenslauf

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Fortbildung	
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Sprachen	1-semestriger Berlitz-Sprachkurs (Russisch, Französisch), Wien 2009
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EDV-Kenntnisse	
Betriebssysteme	Microsoft Windows: XP, Vista, 7 (sehr gut)
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Anwendungssoftware	MS Office: Word, Excel, Access, PowerPoint, Outlook (sehr gut)
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	SAP SD, WM, MM, PP, APO, CO (Grundkenntnisse)
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Programmiersprachen	Java, C++ (gut)
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