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REGULAR ARTICLE

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Collaborating freight forwarding enterprises

Request allocation and profit sharing

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Abstract The paper presents a model for the collaboration among independent freight forwarding entities. In the modern highly competitive transportation branch freight forwarders reduce their fulfillment costs by exploiting different execution modes (self-fulfillment and subcontraction). For self-fulfillment they use their own vehicles to execute the requests and for subcontracting they forward the orders to external freight carriers. Further enhancement of competitiveness can be achieved if the freight forwarders cooperate in coalitions in order to balance their request portfolios. Participation in such a coalition gains additional profit for the entire coalition and for each participant, therefore reinforcing the market position of the partners. The integrated operational transport problem as well as existing collaboration approaches are introduced. The presented model for collaboration is based on theoretical foundations in the field of combinatorial auctions and operational research game theory. It is applicable for coalitions of freight forwarders, especially for the collaboration of Profit Centres within large freight forwarding companies. The proposed theoretical approach and the presented collaboration model are suitable for a coalition of freight forwarding companies with nearly similar potential on the market.

Keywords Collaboration · Freight forwarder · Profit sharing · Multi-agent auction

1 Introduction

In the ongoing globalization process large international freight forwarding companies are more competitive than small companies due to their wider portfolio of disposable resources and a higher ranking in the market power structure. The remedy for the medium- and small-sized carrier businesses is to establish coalitions

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in order to extend their resource portfolio and reinforce their market position. Moreover, the structure of large freight forwarding companies frequently assumes autonomously operating subsidiaries, that should, however, cooperate in order to maximize the overall business profit.

The purpose of the cooperation of freight forwarding entities is to find an equilibrium between the demanded and the available transport resources within several carrier entities by interchanging customer requests (Kopfer and Pankratz, 1999).

Section 2 presents the request processing at a single freight forwarding entity. Section 3 introduces the theoretical frame for collaboration modelling. Section 4 investigates the existing models of collaboration in the transportation branch. In Section 5 we present and analyse a model for the collaboration among freight forwarding enterprises.

2 Integrated operational freight carrier planning

A great number of enterprises source transportation tasks out by entrusting independent freight forwarding companies with the execution of the necessary transport activities. For each transportation task the forwarding company is allowed to choose the mode of fulfillment, i.e., own vehicles can be used for the execution of the corresponding entrusted tasks (self-fulfillment) or an external freight carrier (subcontractor) receives a fee for the request fulfillment (subcontraction). Independent shipment contracts of different types and specifications are awarded to the subcontractor for completion. The involvement of the subcontractor can occur due to two incentives (Chu, 2005). In reality, freight forwarders face demand fluctuations. When the total demand is greater than the whole capacity of owned trucks, the logistics managers may consider using outside carriers. Furthermore, integrating the choice of fulfillment-mode into transportation planning may bring significant cost savings to the company, because better solutions can be generated in an extended decision space. This extended problem is known as integrated operational freight carrier planning.

A customer request is assumed to be a pick-up and delivery request describing a single transportation demand, which typically results in a transportation process involving a less-than-truckload packet. The location of the pickup and the location of the delivery are specified as well as the quantities to be moved. Time windows for the loading and unloading operations are also declared. In case of relatively short distances, or in case of a small number of loads per truck, direct transportation is preferred to establishing expensive *hub-spoke* systems, involving inventories or at least reload locations. Therefore, the direct transport from locations of loading to locations of unloading is assumed.

A freight forwarding company generates its profit from the difference between the price that the customer is obliged to pay for the request execution and the costs of request fulfillment. These costs result either from the fulfillment by own transportation capacity, or from the external processing of orders in consequence of involving a subcontractor.

In case of self-fulfillment the execution must be planned and the costs can be optimized by routing and scheduling a fleet of homogenous vehicles with a given capacity in accordance with the general *pick-up-and-delivery-problem with time* *windows* (PDPTW). The distance and/or time costs are calculated for the round trips of all vehicles. The marginal costs of a single request execution are determined by the additional costs for the used vehicles for the execution of this request.

In contrast to self-fulfillment, the costs of subcontraction cannot be calculated independently, but depend on the shipment contract with the involved subcontractor. The models of integrated operational freight carrier planning proposed so far incorporate different types of subcontraction. Requests can be forwarded to the subcontractors independent of each other, on equal terms (Schmidt, 1994; Greb, 1998). Hence, the freight cost calculation results from isolated price assessment for each request on the basis of a freight cost function. It is also possible to forward complete tours, relative to the tours constructed for self-fulfillment (Savelsbergh and Sol, 1998; Stumpf, 1998). A traditional method of practical relevance for the subcontraction of less-than-truckload packets, called freight flow consolidation (FOP), can be also used (Kopfer, 1990, 1992; Pankratz, 2002). For flow consolidation a least cost flow through a given transportation network under the assumption of request bundling is sought. The costs are calculated in accordance with a tariff which depends on the distance and/or the loading weight. With regard to the last two methods of cost calculation for subcontractor involvement, the marginal costs of a single request execution refer to the additional transportation costs of the corresponding bundle.

3 Preliminaries for collaboration modelling

Collaboration is a powerful measure to improve the integrated operational freight carrier planning of cooperating partners. Bruner (1991) defines collaboration in the following way:

Collaboration is a process of reaching goals that cannot be achieved acting singly (or, at a minimum, cannot be reached efficiently). Collaboration includes all of the following elements: jointly developing and agreeing to a set of common goals and directions; sharing responsibility for obtaining those goals and working together to achieve those goals, using expertise of each collaborator.

For the purpose of formalized collaboration modelling, we introduce some aspects of cooperative game theory. In Operational Research Games, apart from inherent optimisation problems, there arises the natural question of how to allocate the joint cost/benefit among the individual decision-makers (Fernandez et al., 2004). Cooperative games address building coalitions as a crucial aspect. The general problem consists in the analysis of the benefits the players can achieve creating coalitions, in looking for winning coalition and for allocation of benefits which could be accepted by the players (Krus and Brunisz, 2000).

A *cooperative game with transferable utility* (*TU game*) is described (Slikker et al., 2005) by a pair (N,v), where N=*1,2,...,n* denotes a set of players and $v : 2^N \longrightarrow \Re$ is the characteristic function, assigning to every coalition $S \subset N$ of players a value $v(S)$, representing the maximal total monetary reward the members of this group can obtain when they cooperate. Let v denote the payoff vector $v = (v_i)_{i \in N} \in \Re^n$, specifying for each player $i \in N$ the benefit v_i that this player can expect if he does not cooperate and x the payoff vector $x = (x_i)_{i \in N} \in \Re^n$, specifying for each player the benefit x_i that the player can expect if he cooperates with the other players (Hinojosa et al., 2005). An allocation is called efficient if the payoffs to the various players add up to exactly $v(N)$. $v_0(N)$ denotes the value of the characteristic function if there is no collaboration at all, i.e., $v_0(N) = \sum_{i=1}^{n} v_i$. $I(v)$ is defined as the set of individually rational allocations of the characteristic function v (Borm et al., 2001):

$$I(v) = \{x \in \Re^n \mid \sum_{i \in N} x_i = v(N),\ \forall i \in N : x_i \geq v_i\}.$$

The set $I(v)$ consists of all the payoff vectors with the conditions that the total reward of all players is equal to the monetary reward of the maximal coalition N and that the reward of each player is at least as high as it is without collaboration.

Two desirable properties of a game are superadditivity and monotonicity (Slikker et al., 2005). Superadditivity assures that for any two disjoint coalitions S and T of players $v(S) + v(T) \leq v(S \cup T)$. An important consequence of a superadditive characteristic function is that it is always attractive for two disjoint coalitions to form one big coalition rather than to operate separately. A game is monotonic if the addition of more players will increase the value obtainable, it means $v(S) \leq v(T), \quad \forall S \subseteq T$.

As the players are not primarily interested in the benefits of a coalition, but in the individual benefits, the allocation of the additional profit is of main importance. An efficient allocation $x \in \Re^n$ with the property that $x_i \geq v_i$ for all $i \in N$ is individually rational, i.e., $x \in I(v)$. A coalitional game is convex if a player's marginal contribution increases if he joins a larger coalition: $v(S \cup i) - v(S) \leq v(T \cup i) - v(T)$, $\forall S \subseteq T$.

Next, we give a brief introduction to combinatorial auctions. Auctions characterise a general form of multilateral negotiations, where participants interact on the basis of bids (Peters, 2000). Due to complementarities or substitution effects between different assets, the bidders have preferences not just for particular items but for sets or bundles of items. For this reason, economic efficiency is enhanced if participants are allowed to bid on combinations of different assets. The most obvious problem that bids on combinations of items impose consists of selecting the set of winning bids. The problem is called the *Combinatorial Auction Problem* and can be formulated as an Integer Program (de Vries and Vohra, 2003):

Let N be a set of bidders, M a set of m distinct objects. For every subset S of M let $b^j(S)$ be the bid that auction participant $j \in N$ has announced he is willing to pay for S. For all $j \in N$ $b^j(S)$ is superadditive, which corresponds to the idea that the goods complement each other. Let $b(S) = max_{j \in N} b^j(S)$, $x_S : 2^M \to \{0, 1\}$ and $S_i = \{S \subset M \mid i \in S\}$. $x_S = 1$ is interpreted to mean that the highest bid on the set S is to be accepted, whereas $x_S = 0$ means that no bid on the set S is accepted. In order to determine an optimal set of winning bids we consider the following optimisation model

$$max \sum_{S \subset M} b(S) x_S \qquad (1)$$

subject to

$$\sum_{t \in S_i} x_t \leq 1 \, \forall i \in M, \, \forall S \subset M \tag{2}$$

The constraint Eq. 2 ensures that no object in M is assigned to more than one bidder.

The seller is interested in choosing an auction design that will do three things (de Vries and Vohra, 2003):

1. induce bidders to create bids on the basis of their actual evaluations (incentive compatibility)
2. no bidder is worse off (in expectation) by participating in the auction
3. subject to the two above-mentioned conditions the seller maximizes the expected revenue.

Auction designs that satisfy these conditions are called optimal.

Gomber et al. (1997) distinguish between four types of auctions:

1. *English auction*: bids increase until only one bidder is willing to accept the price, he gets the offered good at the price of the last quote.
2. *Dutch auction*: the price decreases until the first bidder accepts the price, he gets the offered good at the current price.
3. *First price sealed bid auction*: the bidders offer their price separately and then the best offer is chosen and the corresponding participant gets the good at the offered price.
4. *Second price sealed bid auction* (*Vickerey auction*): it corresponds to the *First price sealed bid auction*, but the bidder with the best offer gets the good at the price of the second best offer.

4 Existing collaboration models in transport logistics

Kopfer and Pankratz (1999) define a *groupage system* as a logistic interorganisational system which exchanges information and manages capacity balancing by using the cooperation between several independent carriers. Groupage systems enable a request interchange between several forwarding companies to achieve an equilibrium between demanded and available transport resources. The increased number of disposable requests for each individual freight forwarder results in economies of scale. Economies of scope are created due to better capacity utilisation. An additional advantage results from the considerably lower costs of arrangement as in case of external processing of orders. A quasi-merger of freight forwarders to a super-carrier with a central managing entity is not of practical relevance, thus, the decentralization of the collaboration process is recommended (Kopfer and Pankratz, 1999). At the first stage each freight forwarder plans the requests by incorporating self-fulfillment or subcontraction. Only now is the exchange of requests among collaborating forwarders possible.

A model for freight carriers' collaboration was proposed by (Schönberger, 2005). Requests are negotiated among freight forwarding entities. In case of fulfillment of a request by a collaborating forwarder and according to the approach of Schönberger, the entire corresponding revenues are simultaneously shifted to the serving collaboration participant. For the requests that remain unserved an external carrier service is engaged, i.e., the requests are subcontracted at the spot market. The main assumption of Schönberger is that the carrier service incorporation on the spot market is unprofitable, because the charge for each request is higher than the revenues associated with the request. The sum of the external carrier costs is distributed uniformly among the participants of the cooperation. Within the usage of a memetic algorithm, which combines the exploring genetic search and exploiting local search procedures (hill climbers)(Schönberger, 2005), it is proved that the cooperation is able to incorporate significantly more requests, contributing to an increase in the overall profit. The model does not fully support the assumption that each participant should benefit from this cooperation by enlarging its efficiency. Instead, as the preservation of the interests of certain carriers cannot be guaranteed, a 2-step approach is suggested. First, each forwarding entity selects the requests from their own portfolio as well as from portfolios of the other participants, leading to maximal profit contributions. Typically, a single request cannot be served in a profitable way. For this reason, the carrier composes several requests into routes in order to achieve positive profit contributions. The carriers do not only specify single requests but bundles of requests that they can serve in a profitable way. Such a bundle consists of the requests served within one route (Schönberger, 2005). Thus, not the single requests but the subsets resulting from bundling of requests are subject to negotiation. The desired subsets of each forwarder are released. Usually, the most attractive requests are contained in a few subsets. As only one of conflicting subsets can be executed, an independent mediator is introduced. Bundle assignment by the mediator is based on the principles of combinatorial auction. The decision is made with the goal of minimizing the negative sum of avoided carrier costs. The subset of one freight forwarder is accepted and all the other subsets including the request are turned down.

Gomber et al. 1997 present a model of collaboration for transport planning suitable for a freight forwarder agency with several Profit Centres. Profit Centres should be autonomous in request acquisition and negotiations of the price for the request execution with customers. Profit Centres can either fulfill requests with their own vehicle fleet or forward it to the other Profit Centres on the basis of a cooperation structure. The coordination mechanisms for collaboration should meet the following conditions (Gomber et al. 1997):

1. an efficient allocation of requests among Profit Centres
2. no strategic planning, i.e., for each Profit Centre it is profitable to announce the true assessments
3. the requests generating losses should also be dispatched optimally
4. the costs of communication should be acceptable.

In (Gomber et al., 1997) several models for collaboration based on the multi-agent-auction-theory are proposed. The types of cooperation models vary depending on the features of the requests. If the single request forwarding is concerned, the *Vickerey auction* is proposed as the dominant strategy. In order to maximize the probability of getting the request, each participant quotes the maximal price for the request, yet providing profit. In case that a request generates losses, it is assumed that the participants can offer negative bids. *Vickerey auction* functions for negative prices in the same manner as for the positive prices. The bidder is paid for the acceptance of the request the amount of the second "best" bidder price, hence, generating profit. The payment comes from the offering participant who has acquired the request. The mechanism of combinatorial auction, called *Matrix auction*, is proposed for bundles of requests. In principle, it is also based on *Vickerey auction*. Each of the m participants offer the (positive or negative) prices for all $2^n - 1$ combinations of n requests. In order to find the optimal allocation of the requests, a matrix with $2^n - 1$ columns and m rows is constructed. Only one matrix-element can be chosen from each column. Referring to rows, the chosen bundles cannot contain common requests.

5 Proposed model of collaboration

5.1 Description of the collaboration process

Now the profit optimisation and profit sharing of the collaboration among several freight forwarding entities is considered. Each entity operates autonomously. It can quote the price for request execution and decide the method of request fulfillment independently, i.e., each request can be executed by self-fulfillment or by subcontraction. With regard to each request, irrespective of the mode of fulfillment, profit or loss can be generated. It results from the difference between the freight charge received from the customer and the costs of request execution. These costs correspond to the additional travel costs of the vehicle used in case of self-fulfillment, or to the payment for subcontracting. Furthermore, it is assumed that each entity is able to fulfill all the acquired requests within the usage of own disposable resources: own vehicle fleet or subcontractors.

Each freight forwarding entity defines that subset of requests from the self-acquired requests that it does not want to offer to collaborating partners. Those requests are fulfilled within the usage of the own disposable resources: they are planned in the schedule of the own vehicle fleet or forwarded to subcontractors while minimizing the resulting freight costs. All the other requests are included in the collaboration process.

In the collaboration process requests are interchanged among the cooperating freight forwarders. The costs of communication among partners are not considered. Furthermore, it is assumed that each collaboration participant announces their true assessments. There exist incentives for the partners to reveal their true assessments. On one hand, the collaborating entity aims to receive the bundle it is interested in. In order to remain competitive, it quotes the minimal possible costs of bundle execution. On the other hand, it wants to generate profit (or, more precisely, not to generate losses). Thus, the real costs are revealed. In practice, the partners are often interconnected to each other by the formalised market structures, e.g. the partners represent the Profit Centres of one company or holding. In this case, the access to the real costs and profit of the partner is seldom denied.

The collaboration process consists of three phases: preprocessing, profit optimisation and profit sharing.

In the preprocessing phase each partner specifies the lowest costs of fulfillment for each acquired request that they offer to the collaboration partners. These costs are assessed for request execution within the usage of own disposable resources, without participating in the collaboration. It means, the costs of subcontracting and, if it is possible, the costs of self-fulfillment are calculated and the lower amount is chosen. This amount is called potential self-fulfillment costs of the request.

In line with the definition, the main assumption for the collaboration of the freight forwarders is that requests acquired by one partner are allowed to be fulfilled by another cooperating partner if the collective revenues increase. In the profit optimisation phase it is aimed to generate a mapping of requests to collaborating partners. This mapping represents the assignment of requests to the available partners, such that the profit of the entire coalition is maximized. Hence, as the price paid by the customers remains constant, the minimal execution costs for the fulfillment of the offered requests are claimed.

No collaborating participant, except the acquiring enterprise, has to serve requests that it does not want to fulfill. Partners who intend to take over some requests bid on these requests or on a set of requests. Thus, each partner defines bundles of requests it would be able to and wishes to fulfill. For all desired bundles the enterprise evaluates its costs for the fulfillment of the bundle of requests. These costs are called the potential fulfillment costs. Moreover, the potential fulfillment costs have to be specified for each request included in the desired bundles of a particular enterprise as if it were assigned to it separately. Hence, the potential fulfillment costs should be obligatorily specified for all the one-element-bundles of requests for those requests which belong to many-element-bundles considered by a particular collaboration participant. Furthermore, the potential self-fulfillment costs of each request are regarded as a bid on a one-element-bundle that is offered by the acquiring partner itself. The assessments are then revealed and are subject to an optimisation process.

The set of bundles that assures the lowest serving costs for the entire set of requests offered by collaborating partners is determined by solving the Integer Program of the Combinatorial Auction Problem (models 1–2). This set of bundles

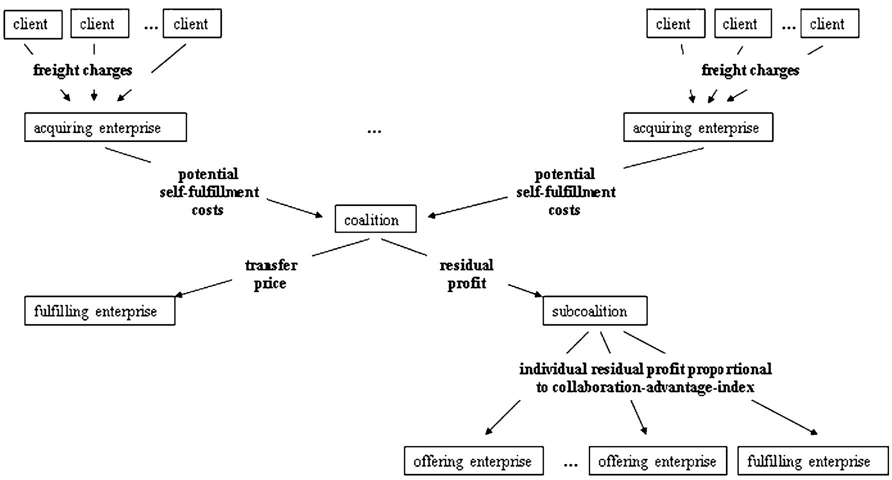

Fig. 1 Payment flows for a single request bundle

assigns all the requests offered by collaborating participants uniquely to one of the bundles. Provided that a one-element-bundle constructed on the basis of potential self-fulfillment costs is included in this set, the request is executed by the offering entity itself. Otherwise, the requests are shifted between partners for execution.

Cooperation is favourable, because the maximal joint profit is always at least as high as the sum of the profits of the players separately. Now the question arises how to allocate the joint benefit among the individual partners in a fair way. The definition of collaboration determines that all freight forwarders should reach at least such a profit as in the case without collaboration, otherwise they should be compensated. Thus, the incentives for each enterprise to participate in collaboration are that they can make additional profit as well as the certainty that their profit in case of operating autonomously is not higher (alternatively loss is not lower) than the one resulting from the collaboration process. In the profit sharing phase the profit resulting from fulfillment of each request is divided among the coalition members. Figure 1 shows the flow of payments for one bundle of requests.

The offering partner holds the payment of the customer freight charge as the reward for request acquisition. Instead, if the request is shifted to another enterprise, the offering partner pays for the request execution the amount of the potential self-fulfillment costs to the coalition. Thus, its financial situation is not worsened in comparison with the situation without collaboration. The amount of profit or loss is maintained.

The transfer price is the payment that the serving enterprise receives from the coalition for bundle fulfillment. In order to set this price, the minimal fulfillment costs for each single request in the bundle are determined. For each request this corresponds to the lowest potential fulfillment costs that have been specified by any partner for the one-element-bundle that contains the considered request. The fulfilling enterprise is awarded the sum of the minimal fulfillment costs for all the requests included in the bundle it should execute. As for the fulfilling entity, the costs for the execution of that bundle can only be equal to or lower than the sum of the minimal fulfillment costs, the participation in the collaboration can exclusively be profitable for the fulfilling entity. The total profit amounts to the difference between the payment the customers offer to the acquiring enterprises and the payment for the fulfilling of bundles by the serving enterprise. The overall residual profit that has not yet been absorbed by the offering and serving partners should be divided among the partners. For one bundle the residual profit consists of the difference between the potential self-fulfillment costs of the requests in the bundle and the transfer price of the bundle. The division corresponds to the benefit that each participant offers to the collaboration and its calculation is based on collaboration advantage indexes. For offering partners the part of the residual profit they receive is calculated for each request they have offered and depends on the benefit of exchanging this request. The collaboration-advantage-index for the offering entity amounts to the difference between the potential self-fulfillment costs and the minimal fulfillment costs. For serving partners their part of the residual profit is determined for the bundle they serve and it depends on the cost reduction that can be achieved by bundling the proper requests. The collaboration-advantage-index for the fulfilling enterprise is equal to the difference between the sum of all potential self-fulfillment costs for the requests in the bundle and the transfer price paid to the serving partner. The residual profit of each bundle is divided among offering and fulfilling coalition members proportional to the collaboration-advantage-indexes.

The formal model of the collaboration process and the proof of satisfying the main assumptions of the collaboration are presented in the subsequent section.

5.2 Formal statement of the collaboration process

Assume a coalition of m independent freight forwarders $P = \{P_1, ..., P_m\}$. Each partner P_k has acquired the set of N_k requests $R^k = \{r_1^k, ..., r_{N_k}^k\}$. First, each participant defines the maximal obtainable profit while only using own disposable resources. Let $F(r_i^k)$ be the freight charge paid by the customer to the acquiring enterprise for the fulfillment of the request r_i^k . The request portfolio of each freight forwarder $R^k = (R_v^{k+}, R_{sc}^{k+}, R^{k-})$ is partitioned into three disjoint sets R_v^{k+} , R_{sc}^{k+} and R^{k-} . Requests from the set R_v^{k+} are executed by the own vehicle fleet. The set R_v^{k+} is dispatched according to the routing plan denoted as $\pi(R_v^{k+})$. Requests from the set R_{sc}^{k+} are forwarded to a subcontractor. The costs of execution of the vehicle scheduling plan refer to $C(\pi(R_v^{k+}))$ and the execution costs of all requests shifted to a subcontractor amount to $C(R_{sc}^{k+})$. R^{k+} denotes $R_v^{k+} \cup R_{sc}^{k+}$ and contains all requests that the freight forwarder does not want to offer to other coalition members. R^{k-} incorporates all the requests that are offered to the collaboration partners.

Preprocessing phase For each request r_i^k from the set R^{k-} the enterprise P_k defines the potential self-fulfillment costs $C(r_i^k)$ as the minimal costs of execution by the usage of own disposable resources (self-fulfillment or subcontraction). The potential profit/loss PR_i^k resulting from the execution of a single request $r_i^k \in R^{k-}$ without collaboration would amount to

$$PR_i^k = F(r_i^k) - C(r_i^k) \tag{3}$$

Hence, the set of requests R^{k-} of the single non-collaborating freight forwarding entity P_k generates the profit of

$$PR^k = F(R^{k-}) - C(R^{k-}) \tag{4}$$

with $F(R^{k-}) = \sum_{r_i^k \in R^{k-}} F(r_i^k)$ and $C(R^{k-}) = \sum_{r_i^k \in R^{k-}} C(r_i^k)$. The overall profit for all members of the coalition P without collaboration refers to the value v_0 of the characteristic function v

$$v_0(P) = \sum_{k=1}^{m} (PR^k) \tag{5}$$

Coalition profit optimisation phase In the profit optimisation phase all the enterprises offer the requests from their sets R^{k-} to the coalition. The requests are then subject to a transfer process between the coalition members, which causes an updating of the request portfolio of each partner in the coalition. Let the set R_i^{kj} , $k \neq j$ denote the transfer of r_i^k from P_k to P_j , i.e., $R_i^{kj} = \{r_i^k\}$ if r_i^k is transferred from P_k to P_j and $R_i^{kj} = \oslash$ else. The updated portfolio of requests $\overline{R}^k$ for P_k should refer to (Schönberger, 2005)

$$\overline{R}^k = R^{k+} \cup \left(\bigcup_{i=1}^{N_j} \bigcup_{\substack{j=1 \\ j \neq k}}^{m} R_i^{jk}\right) \setminus \left(\bigcup_{i=1}^{N_k} \bigcup_{\substack{j=1 \\ j \neq k}}^{m} R_i^{kj}\right) \tag{6}$$

It is assumed that only disposable requests are transferred: $R_i^{kj} \subseteq R^{k-}$ and that the transfer is unique: $R_i^{kj} \cap R_i^{kl} = \oslash$, $\forall j \neq l$.

Let T be the set of all requests offered to the coalition. The total number of requests involved into the collaboration process amounts to $|T| = \sum_{k=1}^{m} |R^{k-}|$. Let $B_L, L \in \{1, ..., 2^{|T|} - 1\}$, be a bundle of offered requests. The set of all possible bundles is denoted as B . For each bundle B_L the parameter $x_L(r)$ is defined, such that:

$$x_L(r) = \begin{cases} 1 & \textit{if bundle } B_L \textit{ contains request } r \\ 0 & \textit{else} \end{cases} \tag{7}$$

The set of all possible bundles illustrates a pure academic approach. In practice it is impossible to enumerate all bundles, because for a realistic number of offered requests, e.g. 100, there exists an astronomic number of $2^{100} = 1,27 * 10^{30}$ bundles. Therefore, to simplify the combinatorial complexity, only some bundles are specified by the participants.

Each partner P_k defines its potential fulfillment costs $C_k(B_L)$ for each bundle B_L of requests he wants to fulfill and for all one-element-bundles of requests included in the many-element bundles he has defined. For bundles that P_k does not want to fulfill $+\infty$ is assigned to $C_k(B_L)$. All potential self-fulfillment costs $C(r_i^k)$ are regarded as potential fulfillment costs $C_k(\{r_i^k\})$ for one-element-bundles $\{r_i^k\}$ offered by P_k .

A modified *Matrix auction* based on a *first price sealed bid auction* is used to identify the most profitable bundle combination for the coalition and to assign the bundles to coalition partners. Assume the binary variable

$$y_k(B_L) = \begin{cases} 1 & \textit{if bundle } B_L \textit{ is selected to be executed by } P_k \\ 0 & \textit{else} \end{cases} \tag{8}$$

Let $\overline{B}$ be the set of optimal request bundles. Then

$$C(\overline{B}) = \min\left(\sum_{k=1}^{m} \sum_{B_L \in B} C_k(B_L) * y_k(B_L)\right) \tag{9}$$

s.t.

$$\sum_{k=1}^{m} \sum_{B_L \in B} x_L(r_i^j) * y_k(B_L) = 1, \quad \forall r_i^j \in T \tag{10}$$

are the minimal total costs the coalition can obtain using the collaboration process. Hence, in accordance with the *Matrix auction*, such a set of request bundles $\overline{B}$ is found that each request is assigned to exactly one partner for execution. This is guaranteed by constraint Eq. 10. As the prequoted payment from the customer for each request is constant and cannot be influenced, the minimization of the potential fulfillment costs for the entire coalition *P*, which is targeted in Eq. 9, concurrently guarantees profit maximization for the coalition. Thus, for the characteristic function *v* of the TU game between the collaborating partners

$$v(P) = \sum_{r_i^k \in T} F(r_i^k) - C(\overline{B}) \tag{11}$$

represents the maximal total monetary reward the members of the coalition can obtain when they cooperate. In particular $v_0(P) \leq v(P)$. $v_0(P) = v(P)$ corresponds to the situation when each coalition member should execute all his acquired requests on his own. A transfer of requests is reasonable only if it improves the total profit of the coalition.

Profit sharing phase In the profit sharing phase it must be assured that the generated solution is acceptable for the partners. Superadditivity is one main prerequisite to guarantee that in the collaboration process no worsening of the financial situation for any participant takes place. The overall new profit NPR^k is the profit that the partner P_k achieves by means of the collaboration. Let NPR_i^{k-} denote the new profit for P_k resulting from offering the request $r_i^k \in T$ to the coalition. NPR_L^{k+} denotes the new profit of P_k for the fulfillment of bundle B_L in result of collaboration. Individually rational allocations of $v(P)$ are defined as:

$$\begin{aligned} I(v) = \{(NPR^k), k = 1, \ldots, m \mid \\ \sum_{k=1}^{m} NPR^k = v(P), (a) \\ NPR^k \geq PR^k, \forall P_k \in P\}(b) \end{aligned} \tag{12}$$

Assume that $R_i^{kj} \neq \emptyset,\ k \neq j$. Each offering enterprise P_k holds the payment from its customer. If it forwards the request to the coalition, it pays the self-defined potential self-fulfillment costs for the request execution and gets additionally some part of the residual profit (RPR_L^k). Hence, the profit increases, respectively, loss decreases for the offering entity, $NPR_i^{k-} = F(r_i^k) - C(r_i^k) + RPR_L^k$, i.e., no worsening of its situation is guaranteed: $NPR_i^{k-} \geq PR_i^k, \forall r_i^k \in R^{k-}$.

Next, the payment received by the enterprise P_k for the fulfillment of bundle B_L, called transfer price TP_L^k , is determined. In order to define the transfer price the Matrix auction based on the *first price sealed bid auction* is performed, but now only one-element-bundles, that include only single requests $B_L^* \in B$ are subject to consideration. The solution of the models 13–14, that assures the minimal fulfillment costs of each request r_i^j, should be found.

$$min \sum_{k=1}^{m} \sum_{B_L^* \in B} C_k(B_L^*) * y_k(B_L^*) \tag{13}$$

s.t.

$$\sum_{k=1}^{m} \sum_{B_L^* \in B} x_L(r_i^j) * y_k(B_L^*) = 1, \quad \forall r_i^j \in T \tag{14}$$

The minimal fulfillment costs of each one-element-bundle B_L^* can easily be determined by

$$C^*(r_i^j) = \min_{\{k=1,\ldots,m\}} C_k(B_L^*) \tag{15}$$

The minimal fulfillment costs $C^*(r_i^j)$ of a particular request correspond to the potential self-fulfillment costs $C(r_i^k)$ of the offering enterprise, if no other coalition member is able to execute this single request at a lower price than the offering partner.

Bundles specified in $\overline{B}$ can include requests offered by different participants. Assume that the bundle B_L consists of L_n requests offered by L_m different participants. One bidder P_k is chosen to serve the bundle. P_k is granted the transfer price of

$$TP_L^k = \sum_{r_i^j \in B_L} C^*(r_i^j) \tag{16}$$

for bundle fulfillment.

The models 13–14 conforms to the models 9–10 with the only exception that models 13–14 are limited to one-element-bundles. In models 9–10 a bundle B_L is assigned to a coalition partner P_k for fulfillment only if its potential fulfillment costs $C_k(B_L)$ are not higher than the sum of minimal fulfillment costs of all one-element-bundles belonging to the assigned bundle B_L. Thus, all the bundles $B_L \in \overline{B}$ satisfy the assumption Eq. 17.

$$C_k(B_L) \leq TP_L^k \tag{17}$$

The new profit for P_k for the fulfillment of B_L amounts to

$$NPR_L^{k+} = TP_L^k - C_k(B_L) \tag{18}$$

which is always positive. Hence, collaboration cannot be unfavourable for any fulfilling enterprise.

The residual overall profit of the entire coalition amounts to

$$RPR = \sum_{B_L \in \overline{B}} \sum_{r_i^j \in B_L} [C(r_i^j) - C^*(r_i^j)] \tag{19}$$

For each bundle $B_L \in \overline{B}$ assume the subcoalition P_L that consists of coalition members offering requests included in the bundle and the coalition member executing this bundle. The residual profit RPR_L, resulting from the collaborative fulfillment of the bundle B_L amounts to

$$RPR_L = \sum_{r_i^j \in B_L} [C(r_i^j) - C^*(r_i^j)] \tag{20}$$

RPR_L is divided among members of the subcoalition P_L. The collaboration-advantage-index CAI_k is calculated for each $P_k \in P_L$ in the following way.

If P_k offers requests to bundle B_L, then its collaboration-advantage-index is defined as the sum of the differences between the potential self-fulfillment costs and minimal execution costs for all requests offered by P_k:

$$CAI_k^- = \sum_{r_i^k \in B_L} [C(r_i^k) - C^*(r_i^k)] \tag{21}$$

The collaboration-advantage-index for the fulfilling entity P_k is defined as the difference between the sum of all potential self-fulfillment costs of the requests in the bundle and the transfer price:

$$CAI_k^+ = \sum_{r_i^j \in B_L} C(r_i^j) - TP_L^k \tag{22}$$

Each subcoalition member $P_k \in P_L$ that participates in the collaborative execution of the bundle B_L holds the individual residual profit that refers to

$$RPR_L^k = \frac{CAI_k * RPR_L}{\sum_{j=1}^{|P_L|} CAI_j} \tag{23}$$

$CAI_k \geq 0,\ \forall P_k \in P_L$. Hence, the individual residual profit $RPR_L^k \geq 0,\ \forall P_k \in P_L$. $NPR^k = \sum_{B_L \in B} RPR_L^k + \sum_{r_i^k \in R^{k-}} NPR_i^{k-} + \sum_{B_L \in B} NPR_L^{k+} \geq PK^k,\quad \forall P_k \in P$ and assumption (12b) is completed for each coalition member. The entire profit of the coalition, $v(P)$, is divided among collaboration partners, satisfying assumption (12a). The assumption (12) is maintained, all the partners have incentives to participate in the coalition.

5.3 Example

Asume a coalition of three freight forwarding entities. In the preprocessing phase the freight forwarders specify the potential self-fulfillment costs. The following requests are offered to the collaboration participants:

P_1 offers portfolio $R^{1-} = \{R_1^1(F = 20, C = 30), R_2^1(F = 30, C = 15)\}$
P_2 offers portfolio $R^{2-} = \{R_1^2(F = 27, C = 22)\}$
P_3 offers portfolio $R^{3-} = \{R_1^3(F = 22, C = 20), R_2^3(F = 17, C = 16)\}$

The request R_1^1 generates losses, while all the other requests are profitable for the acquiring freight forwarders. The overall costs of the coalition partners without collaboration amount to 103 monetary units. The profit from the request execution without collaboration is equal to 13 units.

In the profit optimisation phase the freight forwarders specify the potential fulfillment costs for request execution of the bundles they are interested in. They specify also the potential fulfillment costs for the particular requests from the bundles they would like to serve. The costs of $+\infty$ are assigned to all the other combinations. Table 1 presents the specifications of the example.

Next, the optimal combination for the entire coalition is found on the basis of the *Matrix auction*. Optimal bundles are:

$$\overline{B_1} = \{R_1^1\} \rightarrow P_1$$

$$\overline{B_2} = \{R_2^1, R_1^2, R_1^3\} \rightarrow P_3$$

$$\overline{B_3} = \{R_2^3\} \rightarrow P_1$$

The costs of request execution in case of collaboration amount to 99 monetary units. The total additional profit from the cooperation is then equal to four monetary units.

In the profit sharing phase this profit should be divided among the cooperating freight forwarders. First, the minimal fulfillment costs of each request from one-element-bundles are specified:

$C_1^*(R_1^1) = 30$, $C_1^*(R_2^1) = 15$, $C_1^*(R_1^2) = 20$, $C_2^*(R_1^3) = 20$, $C_1^*(R_2^3) = 15$

The transfer prices for such bundle execution are as follows:

$TP_1^1 = 30$, $TP_2^3 = 15 + 20 + 20 = 55$, $TP_3^1 = 15$

The profit for the fulfilling freight forwarder amounts to:

$NPR_1^{1+} = 0$, $NPR_2^{3+} = 55 - 54 = 1$, $NPR_3^{1+} = 0$

Table 1 Potential (self-)fulfillment costs

bundle	P_1	P_2	P_3
$\{R_1^1\}$	30	33	$+\infty$
$\{R_2^1\}$	15	$+\infty$	25
$\{R_1^2\}$	20	22	21
$\{R_1^3\}$	20	20	20
$\{R_2^3\}$	15	$+\infty$	16
$\{R_1^1,R_1^3\}$	$+\infty$	52	$+\infty$
$\{R_1^2,R_2^3\}$	35	$+\infty$	$+\infty$
$\{R_1^3,R_2^3\}$	$+\infty$	48	$+\infty$
$\{R_2^1,R_1^2,R_1^3\}$	$+\infty$	$+\infty$	54
$\{R_1^2,R_1^3,R_2^3\}$	58	$+\infty$	$+\infty$
$\{R_2^1,R_1^2,R_1^3,R_2^3\}$	$+\infty$	$+\infty$	70

The overall residual profit of the coalition is equal to three monetary units. It is split among the bundles as follows:

$RPR_1 = 0$, $RPR_2 = 2$, $RPR_3 = 1$

Next, the specification how it is divided among the freight forwarders takes place.

The collaboration-advantage-index for $\overline{B_2}$ is equal to:

$CAI_1^- = 0$, $CAI_2^- = 15 + 22 + 20 - 15 - 20 - 20 = 2$, $CAI_3^- = 0$, $CAI_3^+ = 2$

Then, each participating coalition member holds the singular residual profit that refers to:

$RPR_2^1 = 0$, $RPR_2^2 = \frac{2*2}{2+2} = 1$, $RPR_2^3 = 1$

In case of $\overline{B_3}$ the residual profit is shared as follows:

$CAI_1^- = 1$, $CAI_3^+ = 1$, $RPR_3^1 = \frac{1}{2}$, $RPR_3^3 = \frac{1}{2}$

Concluding, the overall profit from the collaboration is shared among the participants: P_1 , P_2 and P_3 are awarded $\frac{1}{2}$ monetary unit, one monetary unit and $2\frac{1}{2}$ monetary units.

The profit from the request execution has risen to 17 monetary units. No freight forwarder has generated a loss in result of collaboration, the sum of generated profit/loss is either maintained, or the financial situation improves.

6 Conclusions and future work

The collaborative freight carrier planning is of high practical importance in the modern transportation branch. However, there hardly exist any theoretical frames for the market actors in the literature. As far as we are aware there is no approach in the literature for the collaboration of freight forwarders including the choice of fulfillment mode for each forwarder and the exchange of orders among independent cooperating partners. The model we propose is based on the combinatorial auction theory as well as on the operations research game theory. Its main strength is that each participant generates no losses in consequence of the collaboration and has a realistic chance to increase its profit by participating in the coalition. The collaboration-advantage-indexes have been chosen in a way that all participating coalition members can expect positive payoff-vectors. Therefore each partner has strong incentives to join and to maintain the coalition they belong to.

The presented collaboration model forms the theoretical frame for request exchange, profit optimisation and profit sharing for a coalition of freight forwarding entities. It is assumed that the market forces of all the coalition members are equal or strongly similar. Therefore, in order to receive empirical results, it would be recommendable to apply the cooperation mechanism to a forwarding company with several autonomous nearly similar Profit Centers. In a practical case study of cooperating Profit Centres we will analyse and investigate whether the collaboration profit resulting from such a mechanism is high enough to create an incentive for establishing a coalition. Secondly, the question arises, whether the potential self-fulfillment costs are easy to assess for the offering partners and whether the other Profit Centres are willing to execute the requests at lower costs than the subcontractors from the spot market.

In additional future work the model could be adapted for collaboration scenarios where not all partners have similar potential on the market. In general, the residual profit can be divided among the partners on the basis of different mechanisms, the proposed collaboration-advantage-indexes can be adapted to different situations. Especially in the case that the requests offered to the coalition are most unfavourable for all the partners, it could be possible to increase the reward for the fulfilling partner while decreasing that of the offering partners. If transaction costs should be taken into account, some part of the reward should be transferred to the coalition itself. Anyhow, the proposed model is a useful basis for developing application-specific profit-sharing mechanisms.

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