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Analysis of Cost Allocation Methods in International Sea-Rail Multimodal Freight Transportation

Uluslararası Deniz-Demir Yolu Kombine Yük Taşımacılığında Maliyet Dağıtım Yöntemlerinin Analizi

Yaşanur KAYIKCI, Turkish-German University, Turkey, yasanur@tau.edu.tr
Orcid No: 0000-0003-2406-3164

Abstract: Freight consolidation is often considered in order to enhance the competitive advantage and operational efficiency level of multimodal freight transportation. The transport networks require substantial horizontal collaborations between multiple partners in the multimodal transport chain. In this regard, it raises a question as how the benefits, which will be provided via collaboration, shall be allocated among the participants and beneficiaries. The vast collection of scientific literature has mainly focused on the development of allocation models for unimodal road transport conducted with the collaboration among shippers and carriers, however there is no sufficient research on the allocation of cost and saving which are provided over the multimodal freight transport. Furthermore, since the sea and rail transport providers in multimodal freight transport operate with different size and shape of vessels and rail freight wagons with different price structures, application of allocation mechanisms is more complex than unimodal transport. In this research, cost allocation models are analyzed in multimodal freight transport. In addition to this, three types of cost allocation model, respectively, proportional allocation mechanism, decomposition method and Shapley value for the same freight transport volumes are analyzed with comparison of the situations for coalitions which comprise of the two, three and four partners of sea-rail multimodal transport service providers and it ends with the delivered sustainable results.

Keywords: Freight Coalition, Multimodal Transportation, Consolidation, Cost Allocation, Horizontal Collaboration, Sea-Rail
JEL Classification: L91, R41, R49

Öz: Kombine yük taşımacılığında rekabet üstünlüğünün ve operasyonel verimlilik seviyesinin arttırılabilmesi için yüklerin konsolide edilebilmesine sıklıkla başvurulmaktadır. Kombine yük taşımacılığı zinciri üzerinde bulunan taşıma ağları birden fazla ortak arasında yatay işbirliklerini gerektirmektedir. Bu bağlamda, sağlanacak işbirliği vasıtasıyla elde edilecek faydanın tüm katılımcılar yani paydaşlar arasında adil bir şekilde dağıtımının (tahsis) nasıl yapılması gerektiği ile ilgili soruyla karşılaşılmaktadır. Şu ana kadar yapılan bilimsel çalışmalar, daha ziyade tek türlü kara yolu taşımacılığında nakliyatçılar ve taşıyıcılar arasındaki işbirlikleri üzerinden dağıtım modellerinin geliştirilmesine yoğunlaşmıştır, ancak kombine yük taşımacılığında elde edilen maliyet ya da kazancın dağıtımı ile ilgili yeteri kadar araştırma yapılamamıştır. Bunun yanı sıra kombine yük taşımacılığında deniz ve demir yolu yük taşımacılığı operatörlerinin kullandığı farklı boyut ve ebatta gemi ve tren tiplerinin farklı fiyat yapılarını içermesinden dolayı dağıtım mekanizmalarının uygulanması tek türlü taşımacılığa göre hayli karmaşıktır. Bu çalışmada kombine yük taşımacılığında kullanılan maliyet dağıtım modelleri incelenecektir. Bunun yanı sıra üç çeşit maliyet dağıtım modeli, sırasıyla orantılı tahsis mekanizması, ayrıştırma yöntemi ve Shapley değeri olarak, eşit olan yük gönderimlerine sahip iki, üç ve dört ortak deniz-demir yolu kombine taşımacılık operatöründen oluşan koalisyon yapısına göre birbirleriyle karşılaştırılarak analiz edilecek ve elde edilen sonuçların sürdürülebilirliği gösterilecektir.

Anahtar Sözcükler: Yük Koalisyonu, Kombine Taşımacılık, Konsolidasyon, Maliyet Dağıtımı, Yatay işbirliği, Deniz-Demir Yolu
JEL Sınıflandırması: L91, R41, R49

1. Introduction

The cost of transportation operations constitutes a significant part of the total production costs and this cost has a significant influence on the competitive capability of the companies (Tuzkaya et al., 2014; Verdonck et al. 2015). Besides the large volume and relatively long transportation distances, the rising oil prices and the growing environmental sensitivity lead to the need to improve the load-carrying efficiency. Although there are many transport companies that perform similar operational activities within the same region, examples of the fact that the load flow can be consolidated by horizontal collaboration between two or more companies is not very common (Audy et al., 2011). However, consolidation of these loads increases the level of operational efficiency as well as it provides significant cost savings for the stakeholders (Guajardo and Rönnqvist, 2015). Similarly, using a combination of different types of transport mode for consolidated freight transport will result in greater savings in shipping costs for terminal to terminal freight movements and greater productivity and sustainability gains than using a single mode (Defryn et al., 2013; Lowe, 2005). Nonetheless, consolidation of various transport modes requires more logistics coordination and hands-on involvement.

In the literature, the combination of more than one mode of transportation is represented with different terms like multimodal transport, intermodal transport, combined transport and integrated transport chain. All terms differ from each other with respect to their identities such as contract type/bill of lading, handling of goods and transport provider responsibility/liability of the movement and so on. In this paper, multimodal transport is used to characterize a multi-unit transport chain in which freights are carried by the combination of at least two different transport modes among road, rail, inland waterway, sea and air under a single transport contract or bill of lading from origin to destination (O-D) (Kayikci et al. 2018), whereas intermodal transport comprises several transport modes for the movement of cargo from O-D, where

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a different transport provider with its own independent contract is responsible for each of these modes and each leg of the shipment is be handled by a separate transport carrier. The goods placed in transport units (e.g. trailers, semi-trailers, transferable/cranable containers and similar cases) are taken from a place (origin, departure terminal) in one country in charge by multimodal transport providers (MTPs) in transport means (e.g. RoRo vessel, RoLa train) to a designated place (destination, delivery terminal) for delivery in another country (UBAK, 2014). The organization of transport modes for multimodal transport takes place across different combinations, such as road-rail, inland waterway-road, sea-road, sea-rail, and so on, where transport units cannot be changed and cannot be handled within the transport process (Kayikci, 2014). A transport chain comprises of basically three distinct divisions: pre-haulage, main-haulage and end-haulage (Kayikci and Çatay, 2017). These three divisions are connected to each other by transfer hubs (also named as multimodal hubs, cargo hubs, logistics hubs) that enable changing transport modes. These transfer centers can be a sea transport terminal, railway terminal, hinterland terminal or multimodal terminal.

The divisions for pre-haulage and end-haulage show short-distance and transport units are mainly transported by road between customers (producers) and terminals/ports and vice versa (Kayikci and Çatay, 2017). The main-haulage shows long-distance (more than 300 km) mainly pursued by using sea transport and rail transport where transport units are shipped by vessels from one port to another and/or transported by rail from one terminal to another among different countries or even continents (Tavasszy and van Meijeren, 2011; UBAK, 2014; Kayikci and Çatay, 2017). Main-haulage consists of several modal shifts (transshipments) with the combination of sea-rail connections. In the main-haulage, a consortium is established by different MTPs (e.g. liner shipping providers and railway freight providers) where the consortium is responsible for the whole operational performance of haulage contract from O-D serving door to door or terminal to terminal or port to port and also capacity management of transport means, where, under the contract, the cargo in a transport unit is taken from the consignor (shipper)'s door or pick-up terminal and delivered to the consignee (receiver)’s door or delivery terminal (UBAK, 2014; Kayikci, 2014; Kayikci and Çatay, 2017).

Transport networks in the multimodal freight transport chain require horizontal collaborations among multiple partners. Horizontal collaborations are needed in order to ensure operational efficiency and cost optimization among many MTPs, especially those operating in main-haulage (Kayikci, 2014). So that, many railway freight and/or liner shipping/maritime providers operating in the multimodal freight transport chain come together to form coalitions in order to obtain higher benefits (like improving occupancy rate or reducing transport cost) through collaboration. In this context, the question arises as how the benefit of collaboration should be fairly allocated among all participants, in other words, stakeholders of multimodal transport chain? So far, scientific studies have focused on the development of distribution (allocation) models through collaborations between shippers and carriers in unimodal transport (road based), however, no sufficient studies have been done on distribution of costs or profits in multimodal freight transport. In addition, because of the different types and sizes of vessels and train or wagon types used by the sea/inland waterway and rail freight transport operators in the multimodal freight transport, the allocation mechanisms are highly complex than unimodal transport. This study pays particular attention to the main-haulage part of transport chain, especially the cost allocation models used in sea-rail multimodal freight transport, where, the road transport kept out of the scope of this research. In addition, answers to the following questions are sought in this research: How should the possible cost/profit through collaboration be distributed among freight operators? How should a freight coalition be formed with potential operators for horizontal collaboration? The following sections respectively deal with these steps: First, the cost allocation methods used in multimodal freight transport will be examined. Then, a real-life case study will be pursued with three most used cost allocation methods, where proportional allocation mechanism, decomposition method and Shapley value method are applied, and the paper will end with the result section showing the outcomes of the real-life case study.

2. Literature Review: Cost Allocation Methods

The most important aim of the collaboration established on the transport chain is to increase the operational efficiency of the participants. Collaborations often result in additional profit or cost savings (Verdonck, 2015), as the opportunities for transport collaboration represent important savings, in the range 5–15% among the companies in the similar region (Guajardo and Rönnqvist, 2015). Guajardo and Rönnqvist (2016) referred to five main issues of collaboration in the literature review of freight transport by combining cargoes: transportation planning, traveling salesman, vehicle routing, joint distribution, and inventory related issues. In this study, the collaboration problem related to joint distribution is examined and the cost allocation methods used in practice are examined.

There are various cost/profit distribution techniques in the field of collaboration in logistics industry. When these cost/profit allocation methods are analyzed in detail, proportional allocation mechanism is seen as the most commonly used method in practice (Liu et al., 2010). In this method, profit revenues obtained through collaboration are distributed equally on the basis of the volume of transport or individual cost level as a result of the collaboration undertaken between the participants (Liu et al., 2010; Verdonck, 2015). The second method is collaborative game theory (Tijs and Driessen, 1986; Young, 1994; Defryn et al., 2013). Here, participants share and consolidate the payload and pay or receive in return. This collaboration process results in the distribution of the gain or cost that can be considered equivalent to the output of the collaborative game to each participant. One of the known distribution methods in collaborative game theory is the Shapley value concept (Shapley, 1953). In this method, gain or cost is distributed according to the weighted average of the contribution of each participant in the coalition. A more complex distribution mechanism supported by game theory is the concept of the game nucleolus. In this profit or cost sharing procedure developed by Schmeidler (1969), there is a special feature that minimizes the maximum excess of the difference between the total cost of the coalition and the sum of the costs allocated to the coalition partners.

Finally, some researchers develop distinct, more intuitive, open distribution mechanisms, which are based more on an exact specific collaboration feature and partly on hypothesis of game theory (Defryn et al., 2013). Tijs and Driessen (1986) examined three distribution techniques based on the division of the total cost of collaboration within the divisible and inseparable costs. Frisk et al. (2010) and Liu et al. (2010) developed profit-sharing mechanisms with the aim of finding a fixed (stable) distribution technique. This fixed distribution minimizes the maximum relative difference between the cost savings of any two partners. Audy et al. (2011) developed a modified version of equal profit method and alternative cost avoided method for testing with various transport coalitions. Ozener and Ergun (2008), in the event that new partners participate in the coalition, have developed distribution mechanisms that enable existing partners to avoid any savings.

All these evaluations show that there is a wide distribution mechanism. Each method contains some special benefits and drawbacks; however, it remains unclear which method can guarantee stability and operational sustainability within the context of multimodal transport (Saeed, 2012; Lada et al., 2016). In addition to this, in the literature, no cost allocation model for collaboration between MTPs has been studied, but only a few scientific studies have examined the distribution of costs amongst stakeholders equally by using collaborative game theory methods for the companies that carry out terminal operations within the framework of the multimodal transportation project (Soons, 2011; Theys et al., 2008). Therefore, in this research, the most used three different allocation models were analyzed with a real-life case study. These allocation models, respectively, proportional allocation mechanism, decomposition method and Shapley value were analyzed according to the coalition structures in horizontal collaboration with two, three as well as four partners with equal load shipments and compared to each other, then the results obtained are shown.

The novelty and contribution of these mentioned distribution models can be possible in three ways: (1) Methods can provide a stable cost distribution, when combined with the main concept. (2) A distribution can be made by taking into consideration the request and service request of each operator. (3) These three methods offer more options for operators to choose the cost/profit allocation mechanism in collaboration.

3. Methodology

The system elements used in this study are shown in Table 1. While the grand coalition N includes all the participant MTPs (i, j), coalition $S, \forall\, S \subseteq G,$ refers to the sub-coalitions established for each multimodal freight transport route. If the sub-coalition S cooperates, a coalition cost with function $c(S)$ is generated. Similarly, a profit or cost savings indicated by $v(S)$ is obtained through the coalition. This unit is also equal to the result of $\sum_{i \in s} c(i) - c(S)$. Each considered distribution method is assigned a cost (c_i) or a saving (y_i) amount for the coalition partner (i).

Table 1. System Elements

Elements	*Explanation*
i, j	Coalition partner
G	Grand coalition
S	Sub-coalition
$c(G), c(S)$	Cost of coalition
$c(i)$	Independent cost of ith partner
$v(G), v(S)$	Savings of coalition
$\|S\|$	Number of partners in the coalition
c_i	Allocated cost of ith partner
y_i	Allocated savings of ith partner
z_i	Transport volume of ith partner
w_i	The weight of gain of ith partner

Figure 1 depicts a hypothetical example of coalition structures in a transport network. The whole transport network consists of one grand coalition (G) with different maritime and rail operators and three different size sub-coalitions (S1, S2 and S3). Each leg (l) is operated by one transport provider and there is a single contract for each sub-coalition. Some legs can be operated by the same transport providers. S1 shows two partners coalition on contract A for legs $l1$ and $l3$, S2 depicts the three partners coalitions on contract B for legs $l2, l3$and $l4$, whereas S3 denotes the four partners coalitions on contract C for legs $l1, l3, l5$ and $l6$.

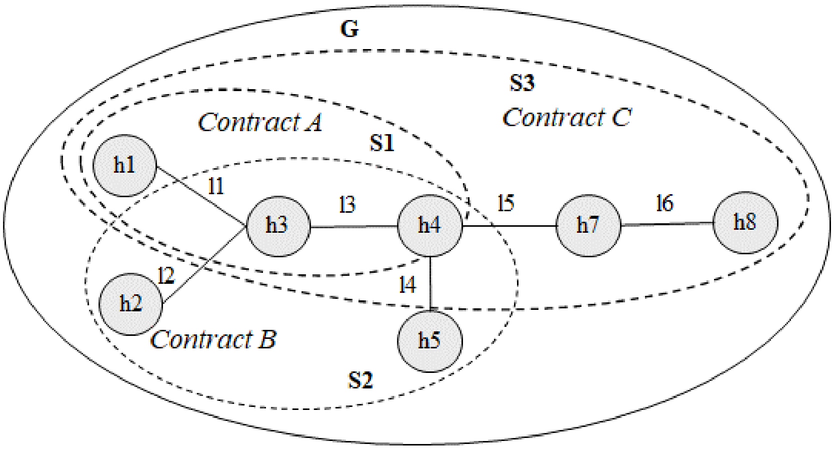

Figure 1. Forming coalitions in a transport network

There are more than forty different allocation methods in the literature on collaborative transportation (Guajardo and Rönnqvist, 2016). But in this study, three different most commonly used cost allocation models in freight transport were selected to analyze. These are: proportional allocation mechanism, decomposition method and Shapley value method. A description of these methods is provided as follows:

3.1. Proportional Allocation Mechanism

The proportional allocation mechanism is the most commonly used profit or cost allocation mechanism in practice (Liu et al., 2010). The profit obtained as a result of collaboration is distributed equally to all coalition partners on the basis of the independent cost or transport volume (z_i) corresponding to the participation of the partner in the coalition. The biggest reason why this method is used so widely is that it is easy to understand, calculated and applicable. However, this method does not guarantee a long-lasting stable collaboration between partners, as any partner in the coalition at any time can leave the partnership in order to earn more individually (Liu et al., 2010; Audy et al., 2012).

Proportional allocation was calculated by considering the transport volume in the case study. This volume is expressed by the annual load dispatch needed by each partner on the same route. So that a weight of ith partner (w_i) is found out. The overall cooperation profit is weighted at the rate of each participant's transport volume as shown in Equation (1).

$$y_i = w_i * v(G), \forall i \in G \tag{1}$$

Here, $w_i = \frac{z_i}{\sum_{i\in G} z_i}$

3.2. Decomposition Method

The second gain distribution mechanism is based on the method of decomposing the total route distance in the participants' common connections. This method is particularly suitable for combined cargo transportation (Boyd et al., 2007; Saeed, 2012). The delivery volume-based proportional distribution is then applied separately to each connection. For example, in a transport collaboration with three MTPs, the transport chain is divided into two parts. In the first part, two MTPs that provide the same type of service combine their operations and in the second part, the load is consolidated among all participants. Proportional distribution method shares the profit of collaboration between the MTPs operating in the first section on the basis of number of shipments. On the second connection, the savings provided by the coalition with respect to the total number of shipments of the participants are proportionally distributed.

3.3. Shapley Value Method

As a third method, Shapley value is chosen as allocation mechanism. This method is a cost allocation method based on highly complex game theory compared to other methods (Shapley, 1953). The Shapley value distributes the weighted average of each participant operator in all sub-coalitions to the coalition. The cost of the Shapley distributed to the ith partner is calculated mathematically as shown in Equation (2) below:

$$c_i = \sum_{S\subseteq N\setminus\{i\}} \frac{(|S|-1)!(|N|-|S|)!}{|N|!}[c(S\cup i) - c(S)] \tag{2}$$

The number of all participants in the sub-coalitions considered with $|.|$ in the equation is shown. The Shapley value method is derived from the axioms of efficiency, symmetry, dummy player axiom and additivity (Dai and Chen, 2012), thus providing a special distribution and is highly profitable in the context of transport collaboration and multimodal transport. However, this method does not guarantee long-term cooperation between partners (Liu et al., 2010; Frisk et al., 2010; Dai and Chen, 2012; Vanovermeire et al., 2014).

4. Real-Life Case

A real-life case was used to examine the applicability of cost allocation methods. A grand coalition was established by various rail freight and maritime transport operators based on horizontal collaboration for the main haulage route operations and sub-coalitions consisted of two, three and four different MTPs. The main haulage connections between O-D were integrated with both sea and rail transport - road transport was not considered in this study. The grand coalition consists of one maritime operator and four different rail operators, and this coalition serves for various main-haulage routes through sea-rail freight transport with thirteen established sub-coalitions. The list of these sub-coalitions is shown in Table 2. The formed coalitions determine the division of the set of stakeholders. Each freight coalition is designed with a number of sea-rail transport legs. Table shows multimodal freight transport route for each sub-coalition, number of operators, weekly shipment frequency between O-D, total transport time as a day, transshipment numbers, unit cost of a semi-trailer. The unit cost includes only transportation costs between hubs, the other costs like the cost of departure and arrival terminals and transfer terminals, BAF etc. are excluded. In addition, the tariffs per sea-rail route are given in the Appendix.

The sea-rail multimodal transport routes, in which the sub-coalitions used for this case study operate, are shown on a map as shown in Figure 2. Five multimodal transport routes have been identified including two exit terminals (origin) from Istanbul (Ambarli and Pendik ports) and five arrival terminals (destination) to Dourges, Duisburg, Ludwigshafen, Paris and Rotterdam. In this study, thirteen sub-coalitions with different number of MTPs showing collaborative activities on the mentioned routes were examined. These thirteen sub-coalitions are the combination of total five different MTPs, one of them is the maritime operator (UN-RORO) and four of the rail operators (Alpe Adria, HUPAC, Kombiverkehr and Novatrans). The grand coalition (N) consists of these five different MTPs. The sub-coalitions are formed by two, three or four different operators. The multimodal freight transport routes which are used in this study are taken from the webpage of https://intermodallinks.com/. Depending on whether the transport unit is a wheeled cargo (semi-trailer, full-trailer, flatbed trailer, lowbed trailer) or a container (20' - 30', 40' - 45' HC - Box – Swapbody) and whether it is empty or full, different fare tariffs for the vessel ticket and train ticket are offered to the shippers for the transport mean. In this study, only semi-trailer is considered as transport unit due to simplification of calculation.

Table 2. The Sub-Coalitions List in Sea-Rail Horizontal Collaboration

Si	*Origin-Destination (O-D)*	*Multimodal freight transport route from terminal to terminal*	*Multimodal Transport Providers*	*Number of Operators*	*Frequency (weekly)*	*Transport time (days)*	*Transshipments*	*Unit cost, € (semi-trailer)*
S1	Ambarli-Dourges	Ambarli + S + Trieste + R + Novara + R + Rotterdam + R + Dourges	UN-RORO, Alpe Adria, HUPAC, Novatrans	4	2	8	3	1790
S2	Pendik-Dourges	Pendik + S + Toulon + R + Dourges	UN-RORO, Novatrans	2	5	8	1	1657
S3	Ambarli-Paris	Ambarli + S + Trieste + R + Novara + R + Paris	UN-RORO, Alpe Adria, Novatrans	3	3	6	2	1490
S4	Pendik- Paris	Pendik + S + Toulon + R + Paris	UN-RORO, Novatrans	2	5	7	1	1524
S5	Ambarli-Paris	Ambarli + S + Trieste + R + Ludwigshafen + R + Novara + R + Paris	UN-RORO, Kombiverkehr, HUPAC, Novatrans	4	2	9	3	2210
S6	Pendik-Duisburg	Pendik + S + Trieste + R + Duisburg	UN-RORO, Novatrans	2	3	5	1	1830
S7	Ambarli-Duisburg	Ambarli + S + Trieste + R + Wels + R + Duisburg	UN-RORO, Alpe Adria, Kombiverkehr	3	3	6	2	1760
S8	Ambarli-Rotterdam	Ambarli + S + Trieste + R + Novara + R + Rotterdam	UN-RORO, Alpe Adria, HUPAC	3	3	6	2	1590
S9	Ambarli-Rotterdam	Ambarli + S + Trieste + R + Ludwigshafen + R + Rotterdam	UN-RORO, Kombiverkehr, HUPAC	3	2	7	2	1940

S10	Ambarli-Ludwigshafen	Ambarli + S + Trieste + R + Novara + R + Ludwigshafen	UN-RORO, Alpe Adria, HUPAC	3	3	6	2	1460
S11	Ambarli-Ludwigshafen	Ambarli + S + Trieste + R + Munich + R + Ludwigshafen	UN-RORO, Alpe Adria, Kombiverkehr	3	3	6	2	1740
S12	Ambarli-Ludwigshafen	Ambarli + S + Trieste + R + Wels + R + Ludwigshafen	UN-RORO, Alpe Adria, Kombiverkehr	3	3	6	2	1710
S13	Ambarli-Ludwigshafen	Pendik + S + Trieste + R + Ludwigshafen	UN-RORO, Kombiverkehr	2	2	5	1	1640

S: Sea Route, R: Railway

All of the thirteen sub-coalitions examined in this study are transported from the exit terminal to the arrival terminal by sea and rail connections. For example, the sub-coalition number 1 (S1) consists of four transport legs including one sea route (UNRORO) and three railway (Alpe Adria, HUPAC, Novatrans) freight forwarding operators and operates through three transfer centers (Trieste, Novara, Rotterdam) between Istanbul Ambarli and Dourges. In addition, the coalition number 3 consists of three transport legs including one sea route (UNRORO) and two railway (Alpe Adria, Novatrans) freight forwarding operators and operates from two transfer centers (Trieste, Novara) between Istanbul Ambarli and Paris. As a maritime transport mean (transport vehicle) for sea transport, RoRo (Roll-on/roll-off) and/or container vessels with various sizes are used, whereas as a rail transport mean for rail way transport, RoLa (Roll-Landstraße - Rail-road), ISU-system (Innovativer Sattelauflieger Umschlag - innovative trailer loading-unloading system) and/or container trains are used. The transport units for vessel and train obtain certain transport capacity. The maximum capacities of vessel and train are 240 slots/vessel and 32 slots/train per service. In this case study, semi-trailers which provide the same operational capacity as a transport unit were selected and moreover, a single train type and vessel model used by the sea and railway MTPs are determined as transport means.

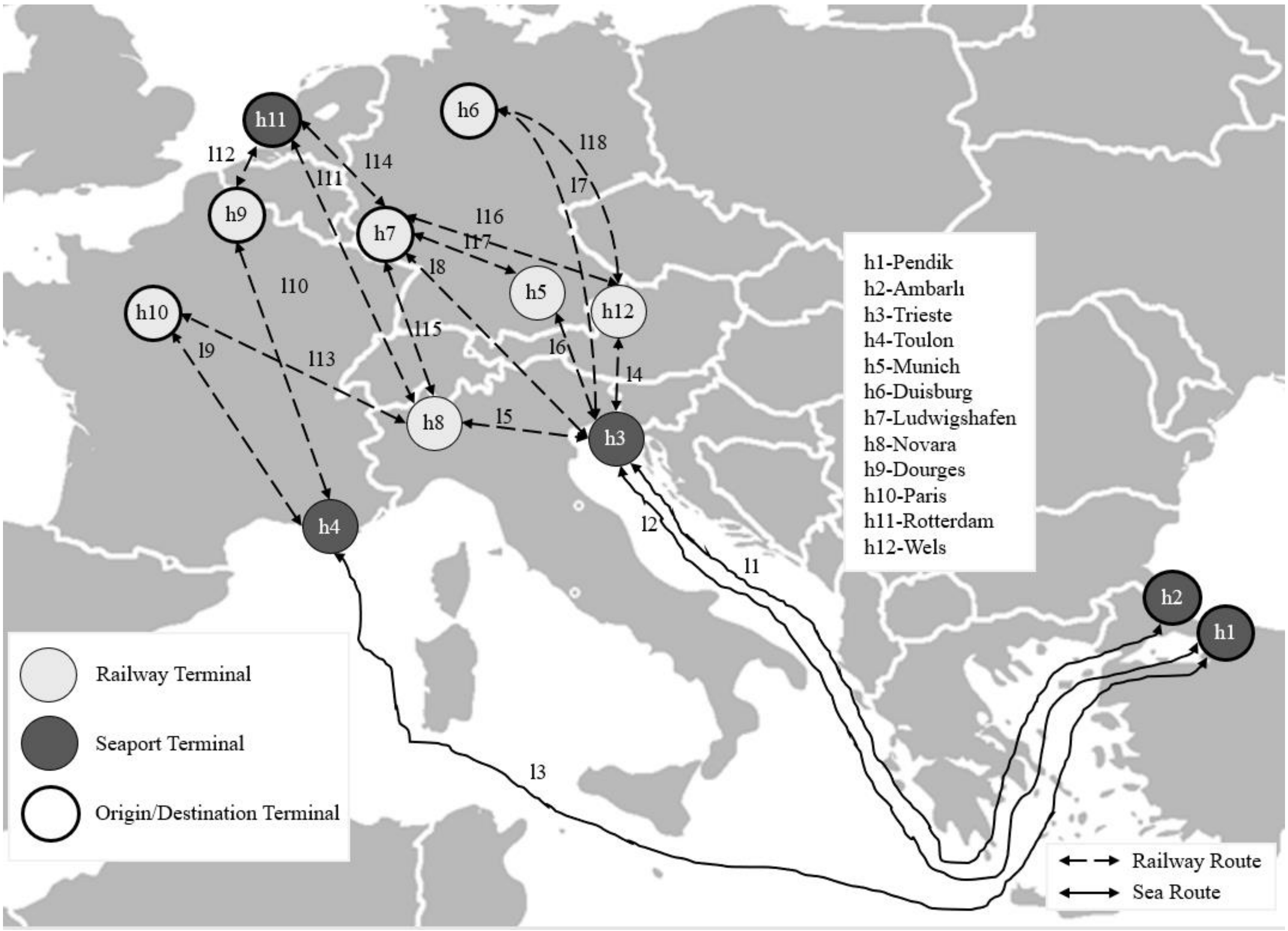

Figure 2. Sea-Rail Multimodal Freight Transport Routes

5. Evaluations

According to the selected three allocation methods, the case study is run with the given tariff costs and weekly frequency in Appendix 1. The calculation of these three methods are explained briefly as follows:

(i) Proportional allocation mechanism: This approach was explained with a sample Ambarli-Dourges route for sub-coalition (S1) which composes four legs with one sea and three rail transport, namely first leg: Ambarli-Trieste, second leg: Trieste-Novara, third leg: Novara-Rotterdam, fourth leg: Rotterdam-Dourges. In order to calculate the weight of gain (w_i) for ith partner for ith leg, first of all, yearly transport volume (z_i) of ith partner is found. For that; maximum capacities of train or vessel, weekly frequency and total number of weeks in a year are multiplied. The total number of weeks in a year was assumed as 52 weeks whereas maximum transport capacity for train is 32 slot per leg and for vessel is 240 slot per leg. For Ambarli-Dourges, the total slots for legs are calculated as follows: $z_1 = 240\ x\ 3\ x\ 52 = 37440;$ $z_2 = 32\ x\ 3\ x\ 52 = 4992;$ $z_3 = 32\ x\ 6\ x\ 52 = 9984;$ $z_4 = 32\ x\ 2\ x\ 52 = 3328$. The transport volumes for all routes are similarly calculated then the total transport volume for all routes is obtained as $\sum_{i \in G} z_i = 678080$ slot per year. Afterwards, the weight of gain (w_i) is calculated: $w_1 = \frac{37440}{678080} = 5{,}52\%;$ $w_2 = 0{,}74\%;$ $w_3 = 1{,}47\%;$ $w_4 = 0{,}49\%$, then this weight is multiplied with unit cost of each leg and the allocated saving (y_i) of ith partner is found: $y_1 = 890\ x\ 5{,}52\% = 49{,}14;$ $y_2 = 300\ x\ 0{,}74\% = 2{,}21$; $y_3 = 400\ x\ 1{,}47\% = 5{,}89;$ $y_4 = 200\ x\ 0{,}49\% = 0{,}98.$ The total saving is $\sum y_i = 49{,}14 + 2{,}21 + 5{,}89 + 0{,}98 = 58{,}221.$ The proportional cost allocation is calculated: $1790 - 58{,}221 = 1731{,}78$. The other routes are calculated similarly. The result of proportional allocation mechanism is shown in Appendix 2.

(ii) Decomposition method: This approach was explained with a sample Ambarli-Dourges route, which composes four legs. The total cost of each route is shared according to number of legs equally to each operator. The average cost per leg in each sub-coalition is calculated as $\frac{\text{unit cost}}{\text{total operators per route}} = \frac{1790}{4} = 448$. The weight of gain (w_i) is calculated as $w_1 = \frac{\text{unit cost}}{\text{total unit cost}} = \frac{1790}{22341} = 8\%$. The allocated saving (y_i) of ith partner is found: $y_1 = 448\ x\ 8\% = 35{,}85;$ $y_2 = 35{,}85;$ $y_3 = 35{,}85;$ $y_4 = 35{,}85$ that means the total saving is $\sum y_i = average\ cost\ per\ operators * weight\ of\ gain * number\ of\ operators\ per\ route = 448 * 8\% * 4 = 143{,}42$. The decompositional cost allocation is calculated: $1790 - 143{,}42 = 1646{,}58$. The other routes are calculated similarly. The result of decomposition method is depicted in Appendix 3.

(iii) Shapley value method: This approach was explained with a sample Ambarli-Dourges route. The weight of gain (w_i) is calculated with applying this formulation: $\frac{(|S|-1)!(|N|-|S|)!}{|N|!} = \frac{(3*2*1)*(1)}{5*4*3*2*1} = 0{,}05$, where total number of operators (N) in the grand coalition is 5 and the number of operators (S) is 4. The formulation of Equation (2) is applied to find the allocated saving (y_i) of ith partner: total savings: $y_1 = (1790 - 890) * 0.05 = 45;$ $y_2 = (1790 - 300) * 0.05 = 74{,}50;$ $y_3 = (1790 - 400) * 0.05 = 69{,}50;$ $y_4 = (1790 - 200) * 0.05 = 79{,}50$. The total saving is $\sum y_i = 45 + 74{,}50 + 69{,}50 + 79{,}50 = 268{,}50$. The Shapley cost allocation is calculated: $1790 - 268{,}50 = 1521{,}50$. The other routes are calculated similarly. The result of Shapley method is displayed in Appendix 4.

Table 3. Cost Allocation Result (in Euro)

Si	*Origin-Destination (O-D)*	*Number of Operators*	*Frequency (weekly)*	*Transshipment (days)*	*Independent (No Collaboration)*	*Proportional Allocation Mechanism*	*Decomposition Method*	*Shapley Value Method*
S1	Ambarli-Dourges	4	2	8	1790	1731,49	1646,58	1521,50
S2	Pendik-Dourges	2	5	8	1657	1594,99	1534,10	1574,15
S3	Ambarli-Paris	3	3	6	1490	1433,22	1390,63	1390,67
S4	Pendik- Paris	2	5	7	1524	1462,64	1420,04	1447,80
S5	Ambarli-Paris	4	2	9	2210	2149,08	1991,38	1878,50
S6	Pendik-Duisburg	2	3	5	1830	1757,20	1680,10	1738,50
S7	Ambarli-Duisburg	3	3	6	1760	1701,69	1621,35	1642,67
S8	Ambarli-Rotterdam	3	3	6	1590	1532,48	1476,84	1484,00
S9	Ambarli-Rotterdam	3	2	7	1940	1880,26	1771,54	1810,67
S10	Ambarli-Ludwigshafen	3	3	6	1460	1405,07	1364,59	1362,67

S11	Ambarli-Ludwigshafen	3	3	6	1740	1680,14	1604,48	1624,00
S12	Ambarli-Ludwigshafen	3	3	6	1710	1651,07	1579,12	1596,00
S13	Ambarli-Ludwigshafen	2	2	5	1640	1570,46	1519,61	1558,00
Total Cost of Grand Coalition					22341	21553,66	20600,36	20629,12

All calculations for aforementioned three cost allocation methods are obtained, then the result is summed up in Table 3. The table shows the total cost allocation for the coalition partners for each coalition according to the amount of cargo carried per unit. When the MTPs operate independently, they might face higher unit cost than in a collaboration. It is observed that transport costs in a coalition can decrease considerably, if they take part in a coalition which is formed as a result of transport collaboration. In particular, the cost savings achieved through collaboration with the Shapley value from the game theory are allocated by far the best among the participants as the highest savings (S1 and S5) was obtained through this methodology.

Proportional allocation mechanism as well as decomposition method provides also significant savings for coalition partners. Table 3 also shows the most appropriate number of MTPs for transport coalition. According to the results of this study, the ideal number of operators in a coalition should be four for the best cost or profit allocation obtained as a result of the transport collaboration. The Figure 3 shows the total savings for each sub-coalition according to three allocation methods. The graphic shows that the higher the number of participants in the sub-coalition, the higher the savings per partner and therefore, the total cost savings might be sufficient enough to sustain the partnership. However, the different allocation methods give different result about the optimal number of operators in a coalition. The highest savings for three methods: according to proportional method, the two partners coalition (S13) can obtain almost 4,2% cost savings, whereas decomposition method shows that four partners coalition (S5) can achieve almost 9,9% cost savings and finally, Shapley value method displays that four partners coalitions (S1 and S5) can extract 15% cost savings. The total cost of grant coalition is also reduced almost %7,7 by Shapley value method, similarly reduced 7,8% by decomposition and 3,5% by applying proportional method.

In this study, collaborative MTPs have used transport means with similar scale in order to make the results simpler and more understandable. The result of this study shows also that allocating the coalition costs or gains impartially presents a key point, since the proposed allocation method should convince coalition partners to act according to the collaborative goal and may improve collaboration stability. The fact that the cost allocation methods used in this study are used within the coalition structure support the MTPs, which serve on various transport modes, in order to improve their operational efficiency by acting together especially on new coalition and collaboration, temporal route planning and fleet management. However, as mentioned earlier, this does not guarantee establishing a long-lasting and stable collaboration among the coalition partners.

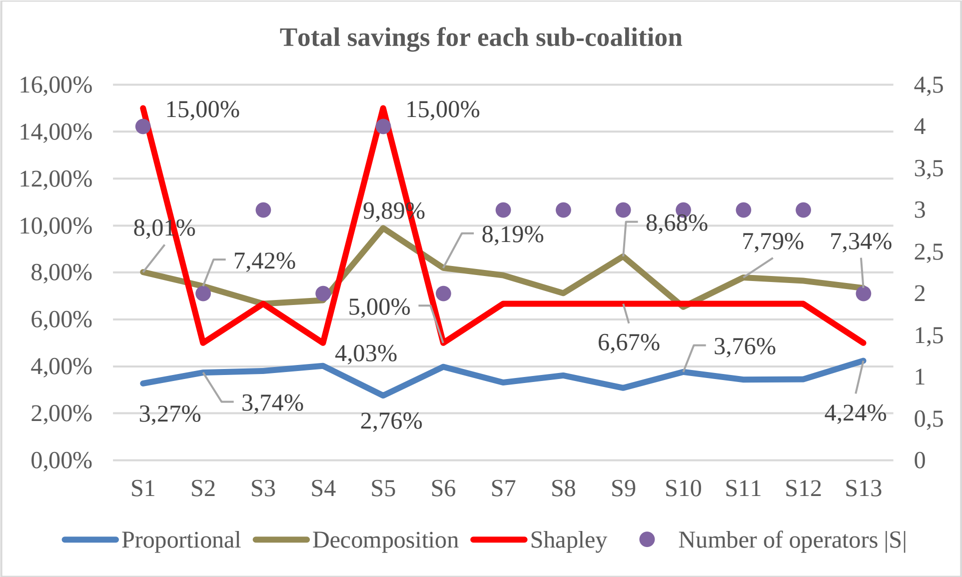

Figure 3 Total savings for each sub-coalition according to three allocation methods

6. Conclusion and Future Work

The policy makers of European Union promote the multimodal transportation for not only reducing carbon emissions but also eliminating other inefficiencies resulted from congested highways, transportation time uncertainty, longer dwell times and so on. The commission set a target of shifting as much as 30 % of road freight being transported further than 300 km to other modes of transport such as rail or sea/waterborne transport by 2030, and more than 50 % by 2050 (EU, 2016). In order to improve the competitive position and efficiency level of multimodal transportation, combining the freight flows by using different transport modes in a transport network are often suggested. Bundling transport network requires horizontal collaboration between multiple partners. Generally, multimodal transport providers run alone among certain terminals without seeking any partnerships from same or different transport modes. This would often result with operational losses and risk. Hence, establishing horizontal collaboration with competing operators in multimodal transport chain might bring more benefits (i.e. cost saving, efficiency/productivity increases) for the MTPs than operating independently.

In this study, three cost allocations methods, respectively, proportional allocation mechanism, decomposition method and Shapley value method are examined and compared with independent (no collaboration) form in order to prove that horizontal collaboration can achieve more cost savings for the participating organizations. The study focuses only on sea and rail transport in multimodal freight transportation, whereas road transport is kept out of the scope, as this study promotes horizontal collaboration between liner shipping/maritime and rail providers. The result of the study shows that applying Shapley value method for combined freight transport provide higher cost savings for all participants. Also, the result of study shows that the transport coalitions with four partners is more beneficial to achieve at most cost savings than the other methods. It needs to be also highlighted that using different types of transport means (vessel and rail) as well as different transport units (trailer, container) in a transport coalition can result with different performance capabilities for the cost function simplification. This research has limitation that only semi-trailer as transport unit is used for simplification of calculation and partners have equal load shipments. The main contribution of this research is to provide a first insight in the complexity of the cost sharing in a transport coalition and also to proof the usability of cost allocation techniques to reduce the total cost per freight route in a horizontal collaboration.

This research might have a great potential to promote horizontal collaboration among sea-rail multimodal transport providers. There is also evidence that different freight allocation methods can result with different cost saving potentials. Therefore, research might lead to the conclusion that collaboration brings more benefits for stakeholders (coalition partners) with greater success than acting alone. The research has future implications to answer how and with how many partners an efficient transport coalition can be established for multimodal transport providers and how coalition partners share cost/profit in a certain multimodal freight network.

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APPENDIX

Appendix 1. Tariffs per sea-rail route (in Euro) for semi-trailer

Si	*Origin-Destination (O-D)*	*Multimodal freight transport route from terminal to terminal*	*Total legs*	*1st leg*		*2nd leg*		*3rd leg*		*4th leg*		*Total Unit cost*
				Unit cost	*F. (w)*	*Unit cost*	*F. (w)*	*Unit cost*	*F. (w)*	*Unit cost*	*F. (w)*	
S1	Ambarli-Dourges	Ambarli + S + Trieste + R + Novara + R + Rotterdam + R + Dourges	4	890	3	300	3	400	6	200	2	1790
S2	Pendik-Dourges	Pendik + S + Toulon + R + Dourges	2	1065	3	592	2					1657
S3	Ambarli-Paris	Ambarli + S + Trieste + R + Novara + R + Paris	3	890	3	300	3	300	7			1490
S4	Pendik- Paris	Pendik + S + Toulon + R + Paris	2	1065	3	459	2					1524
S5	Ambarli-Paris	Ambarli + S + Trieste + R + Ludwigshafen + R + Novara + R + Paris	4	890	3	750	2	270	4	300	7	2210
S6	Pendik-Duisburg	Pendik + S + Trieste + R + Duisburg	2	890	4	940	3					1830
S7	Ambarli-Duisburg	Ambarli + S + Trieste + R + Wels + R + Duisburg	3	890	3	470	6	400	2			1760
S8	Ambarli-Rotterdam	Ambarli + S + Trieste + R + Novara + R + Rotterdam	3	890	3	300	3	400	6			1590
S9	Ambarli-Rotterdam	Ambarli + S + Trieste + R + Ludwigshafen + R + Rotterdam	3	890	3	750	2	300	9			1940
S10	Ambarli-Ludwigshafen	Ambarli + S + Trieste + R + Novara + R + Ludwigshafen	3	890	3	300	3	270	5			1460
S11	Ambarli-Ludwigshafen	Ambarli + S + Trieste + R + Munich + R + Ludwigshafen	3	890	3	550	5	300	5			1740
S12	Ambarli-Ludwigshafen	Ambarli + S + Trieste + R + Wels + R + Ludwigshafen	3	890	3	470	6	350	3			1710
S13	Ambarli-Ludwigshafen	Pendik + S + Trieste + R + Ludwigshafen	2	890	4	750	2		2			1640

S: Sea Route, R: Railway, F.(w): weekly frequency
The tariffs and weekly frequency are taken from the webpage of https://intermodallinks.com/

Appendix 2. Calculation of the Proportional Allocation Mechanism

Si	*Unit cost*	*Frequency of legs*				w_1	w_2	w_3	w_4	$\sum y_i$	Savings	*Proportional Allocation Mechanism*
		1	2	3	4							
S1	1790	3	3	6	2	5,52%	0,74%	1,47%	0,49%	58,22	3,3%	1731,49
S2	1657	3	2			5,52%	0,49%			61,71	3,7%	1594,99
S3	1490	3	3	7		5,52%	0,74%	1,72%		56,50	3,8%	1433,22
S4	1524	3	2			5,52%	0,49%			61,06	4,0%	1462,64
S5	2210	3	2	4	7	5,52%	0,49%	0,98%	1,72%	60,63	2,7%	2149,08
S6	1830	4	3			7,36%	0,74%			72,44	4,0%	1757,20
S7	1760	3	6	2		5,52%	1,47%	0,49%		58,02	3,3%	1701,69
S8	1590	3	3	6		5,52%	0,74%	1,47%		57,24	3,6%	1532,48
S9	1940	3	2	9		5,52%	0,49%	2,21%		59,45	3,1%	1880,26
S10	1460	3	3	5		5,52%	0,74%	1,23%		54,66	3,7%	1405,07
S11	1740	3	5	5		5,52%	1,23%	1,23%		59,57	3,4%	1680,14
S12	1710	3	6	3		5,52%	1,47%	0,74%		58,64	3,4%	1651,07
S13	1640	4	2	2		7,36%	0,49%			69,20	4,2%	1570,46

Σ	22341					75,83%	10,36%	11,59%	2,22%	787,34	3,5%	21549,77

Appendix 3. Calculation of the Decomposition Method

Si	*Unit cost*	*Number of operators for each route from terminal to terminal*	*Average cost per operator in each sub-coalition*	*The weight of gain (w_i) per operator in a grand coalition*	$\sum y_i$	*Savings*	*Decomposition Method*
S1	1790	4	448	8,0%	143,42	8,0%	1646,58
S2	1657	2	829	7,4%	122,90	7,4%	1534,10
S3	1490	3	497	6,7%	99,37	6,7%	1390,63
S4	1524	2	762	6,8%	103,96	6,8%	1420,04
S5	2210	4	553	9,9%	218,62	9,9%	1991,38
S6	1830	2	915	8,2%	149,90	8,2%	1680,10
S7	1760	3	587	7,9%	138,65	7,9%	1621,35
S8	1590	3	530	7,1%	113,16	7,1%	1476,84
S9	1940	3	647	8,7%	168,46	8,7%	1771,54
S10	1460	3	487	6,5%	95,41	6,5%	1364,59
S11	1740	3	580	7,8%	135,52	7,8%	1604,48
S12	1710	3	570	7,7%	130,88	7,7%	1579,12
S13	1640	2	820	7,3%	120,39	7,3%	1519,61
Σ	22341			100%	1740,64	7,8%	20600,36

Appendix 4. Calculation of the Shapley Value Method

Si	*Unit cost*	*Number of operators $\|S\|$ for each route from terminal to terminal*	*Total number of operators $\|N\|$ in grand coalition*	$\frac{(\|S\|-1)!\,(\|N\|-\|S\|)!}{\|N\|!}$	$\sum y_i$	*Savings*	*Shapley Method*
S1	1790	4	5	0,05	268,50	15,0%	1521,50
S2	1657	2	5	0,05	82,85	5,0%	1574,15
S3	1490	3	5	0,03	99,33	6,7%	1390,67
S4	1524	2	5	0,05	76,20	5,0%	1447,80
S5	2210	4	5	0,05	331,50	15,0%	1878,50
S6	1830	2	5	0,05	91,50	5,0%	1738,50
S7	1760	3	5	0,03	117,33	6,7%	1642,67
S8	1590	3	5	0,03	106,00	6,7%	1484,00
S9	1940	3	5	0,03	129,33	6,7%	1810,67
S10	1460	3	5	0,03	97,33	6,7%	1362,67
S11	1740	3	5	0,03	116,00	6,7%	1624,00
S12	1710	3	5	0,03	114,00	6,7%	1596,00
S13	1640	2	5	0,05	82,00	5,0%	1558,00
Σ	22341				1711,88	7,7%	20629,12