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Cooperation between Sea Ports and Carriers in the Logistics Chain

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Abstract: In a modern economy, international trade is an important factor in the development of various regions. Shipping is one of the most important elements of the global supply chain. However, after the economic crisis of 2008, global shipping revenues plummeted. One way to restore profitability is the consolidation of shipping routes and the globalization of shipping lines. As container transport lines move to larger ships, the structure of the delivery route becomes a structure with intermediate points. This trend put forward higher demands on the port infrastructure, which aggravated the competition between regional ports, as well as ports that could degrade into a large cargo consolidation port. The economic advantage is enhanced by cooperation between shipping lines and ports. Thus, ports and shipping lines in the same supply chain can be mutually beneficial partners. The study analyses the effectiveness of horizontal and vertical cooperation between ports and carriers. As a source of information, a review of the literature on this issue, expert opinions, and statistical data is taken. Next, a mathematical model is built on the basis of cooperative game theory, and numerical analysis is carried out. The results show that the strategy of cooperation of shipping lines strongly depends on the situation with the supply and demand of vessels. A port that interacts with shipping lines will significantly reduce port charges, which creates the advantage of receiving more port requests. However, cooperation may lead to losses for the port, so a redistribution of profits is necessary to maintain the coalition.

Keywords: cooperative game theory; supply chain management; supply disruption

1. Introduction

With the development of the world economy, international trade has become an important factor in the economic development of different regions. As a key element of the global trade chain, the shipping industry covers more than 80 percent of the world trade. However, after the global financial crisis of 2008, the shipping industry faced problems of overcapacity. According to various data, by 2008 about 35–40% of container capacity was already excessive [1–3]. To restore profitability, it has become common practice to consolidate sea routes and globalize shipping lanes. For example, [3] discusses the cooperation of European seaports: the advantages, limitations, and development prospects. In [4], the activities of the largest alliances of sea carriers are analyzed, and the profitability of creating such alliances is shown.

Shipping companies have taken steps to unite their fleet in a coalition. The coalition of carriers can receive lower prices for the port service, and use the vessels more economically, fully loading them, rather than using partially loaded ones. In [5], the game theory approach is applied, showing the profitability of the sea carriers' merger, the problems of the stability of alliances, and the distribution of the total profit between the participants. A significant advantage of cooperation between participants in the supply chain is the ability to reduce losses in case of accidental interruptions in supplies, which can occur for various reasons (e.g., a fully loaded port cannot accept cargo for processing, equipment failure may occur, weather conditions are unfavorable, etc.). In [3], a theoretical model

of the supply chain is proposed, and the role of the port as a participant in this chain is discussed. In [6], the efficiency of supply chain management is discussed. In [7,8], models are considered which show the importance of coordinating the work of all participants in chain.

Consolidation of shipping lanes led to significant changes in the shipping industry. Cooperation agreements between ports and carriers have led to changes in the role of the ports. Larger ports stood out as hubs dealing with the largest ships. Smaller ports began to serve hub ports, "collecting" cargo from land transport lines. In modern conditions, peripheral ports lose in competition with hub ports. However, the cooperation of sea routes and ports, uniting peripheral ports and hubs in a single coalition, gives ports an opportunity to increase the level of loading and unloading services, and allows sea routes to receive a stable income from the port's operation. It also protects peripheral ports from closure, saving jobs.

The goal of this study is to analyze the possibilities of various participant cooperation in the logistics chain in order to increase profits and reduce costs. This article discusses a logistic chain that includes a hub port, peripheral ports, and land carriers. It is shown that the cooperative work of the participants in the chain brings significant savings in logistics costs.

2. Theoretical Background

Global changes in the carrier market are of great interest. In [3], a theoretical model of the supply chain is proposed and the role of the port as a participant in this chain is discussed. Effective supply chain management methods are discussed in [6]. Paying close attention to this topic helps to avoid the problems of shortages or surpluses of goods, as well as mitigate problems in case of possible supply disruptions.

The complete shipping chain in the general case is as follows (Figure 1):
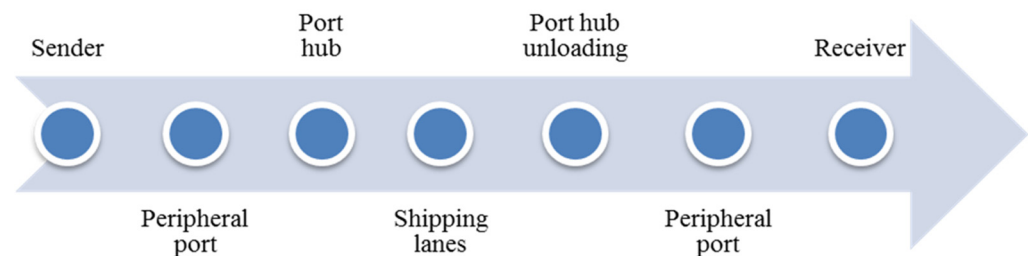
Figure 1. The scheme of shipping supply chain.

At each stage, horizontal cooperation of several participants is possible. One might also consider vertical cooperation, which brings together participants from different parts of the logistics chain.

2.1. Customer Cooperation at the Stage of Placing an Order

Cost reduction in this type of cooperation is achieved through the formation of bigger quantities of goods, which allows the use of larger vessels and, as a result, reduces the cost of delivery. Water shipment is more profitable than land transportation, provided that the consignment of goods is large enough. Therefore, ports often act as cargo aggregators, collecting several orders for a large vessel. In addition, at the stage of consignment formation, one can use the optimization model of the delivery scheme. Individual customers cannot always form batches that are optimal in terms of the economic order quantity (EOQ), as they are bound by standard container sizes. Joint orders allow more flexibility to determine the frequency and size of orders. In detail the task of forming the optimal size of the order is considered in [9].

2.2. Port Cooperation and Competition

Let us assume that the economical region under consideration has a main port that handles large vessels. In addition, there are several peripheral ports. When creating an order, a consumer may be guided by various reasons when choosing a port: contracts, service convenience, special offers, etc. In addition, ports have different capabilities for processing orders. Queues and delays are possible for this reason. The benefits of combining are due to more coordinated cargo handling.

Such cooperation is a method used by market players in an attempt to reduce a high level of competitiveness [10]. Horizontal integration between ports can lead to lower freight rates and more efficient logistic control, thus increasing the demand for port services. Some authors suggest that cooperation between ports can have a positive impact on the overall competitiveness of ports in the region, leading to overall market growth in the region.

Ports compete with one another for customers. In [10], the authors discuss the advantages of cooperation over competition. The main indicators of the port functioning are the number of sites for unloading, the speed of cargo handling, and the cost of service. Competition among the ports leads to the situation in which the main flow of goods in the region goes through the "winning" port. To survive, small ports switch to peripheral shipments. At the same time, it is beneficial to enter into a peripheral port–port hub coalition. The coalition is beneficial to both parties, as both types of ports are loaded with work.

Port competition is more complex than it seems to be. Not all ports have the necessary capacity to ensure the loading and unloading of modern large vessels. At the same time, already allocated hubs that have intercepted the main flow of goods make competition very difficult, leaving the rest of competitors few opportunities for development.

What are the options for alliances around the hub? The first option is a contract between a peripheral port and a hub port. As a result, the hub receives the flow of goods, while the peripheral port gains a possible reduction in tariffs for service and priority service. However, if the port hub has limited capacity to handle cargo, holdups may occur, and the competition between the ports will escalate. The cause of such congestion may be an insufficient number of unloading sites, especially for large vessels, slow service, etc. In this case, the ports compete with one another. Customers are attracted by higher levels of service or lower prices. Price competition in this case is well described in terms of Bertrand oligopoly.

The second type of possible cooperation between the ports is the creation of coalitions of equal ports. This can lead to better integration in the supply chain, lower costs, and the elimination of redundant links, as well as more flexible route planning conditions.

In addition to reducing costs, port cooperation helps reduce the impact of possible supply disruptions. The recent increase in the number of natural disasters, as well as terrorist attacks, has drawn much attention to the vulnerability of supply chains. Having passed through many links of the logistics chain that cover continents and organizations, the reliability and timeliness of cargo delivery is becoming increasingly difficult to assess. In particular, in seaports that are an indispensable hub in global supply chains and where complex sea and land interfaces take effect, the role of ports in disrupting marine supply chains needs to be explored. Loh, H. and Vinh, T. are examining the changing functions of the ports and supply chain helps determine the consequences and develop strategies to mitigate the effects of such disruptions [11].

The cooperation of carriers also helps in case of possible problems. The most frequently discussed operational risks of the port are port accidents [12,13], port equipment failures [13], improper handling of dangerous goods [14], port congestion [15], low qualification of personnel [16], safety violations [13], and strikes. In addition, human factors that impede communication (cultural differences, political problems, and conflicts between staff) may increase the scope of problems [17].

One of the main ways to quickly respond to the resulting failure is to change the logistics chain. Well-established schemes of vertical and horizontal cooperation of chain

participants can help minimize the consequences: redirect goods to another node of the chain (another port) or change the type of transport.

Of course, one of the main issues is the sustainability of such coalitions. It, in turn, depends on the profitability of the participation of ports in the union. Here, the important role is played by the principle on which the profit of the coalition members is distributed.

At the modern market of sea shipping, there are several port alliances [3]. Examples include the following alliances:

1. Ports of Elba. In 2009, the ports of Cuxhaven, Brunsbüttel, Glückstadt, Stade, and Hamburg merged. The seaports of the three different federal states of Germany collaborate in the areas of marketing, customer analysis, and infrastructure planning and management;
2. Ports of the Rhine. The cross-border cooperation "RheinPorts" between the inner ports of the Rhine Basel in Switzerland, Mulhouse in France, and Weil am Rhein in Germany, began in 2007. The main joint tasks of neighboring ports in the three countries include service marketing and exchange of information, as well as handling of goods, customs, and container repair services. Since 2016, a joint logistics flow management system has been in use. The information system provides detailed information on the arrival of ships and connects various port participants, such as terminal operators, gateways, and transport companies;
3. Malmö–Copenhagen. In 2001, the ports of Malmö, Sweden and Copenhagen, Denmark agreed on the maximum possible form of cooperation—a joint venture responsible for cargo handling and storage. The ports are located in geographical proximity and benefit from direct and joint navigational access to the Oresund region. A joint venture called "Copenhagen Malmö Port CMP" is registered in Sweden. The company acts as a port and terminal operator in both cities. The objectives of cooperation are to focus on the various transport segments and to manage traffic at close range. The port of Copenhagen concentrates on imports and cruise shipments. The port of Malmö mostly serves as a transit cargo center.

2.3. Cooperation of Shipping Lines and Ports

The shipping line and the port are two different elements of the logistics chain and there is no direct competition between them. These conditions make the coalition easier and more profitable. Vertical integration of the shipping line and the port can effectively satisfy maritime logistics and increase the level of service. Shipping lines choose landing terminals for their ships; therefore, it becomes increasingly important for the port to cooperate with one or several shipping lines in order to ensure long-term prosperity. Shipping lines take a series of measures to increase efficiency and reduce costs. Global strategic alliances of sea carriers using large ships have appeared [18]. Cooperation with a large shipping line can guarantee port loading for a considerably long period of time.

The advantage of creating these kind of coalitions can be obtained in various ways. First, the shipping line may receive either a reduction in tariffs for cargo service, or a dedicated site where the shipping company is to be serviced without delay. In turn, shipping companies invest in the development of the port. In some cases, shipping companies have a share in the port.

2.4. Coalition of Shipping Lines

There is a large amount of research examining coalition of maritime carriers. For carriers, it is more advantageous to use large vessels. Therefore, they may combine to ensure full loading. At present, the largest alliances of maritime carriers have been formed in the world trade.

Various forms of cooperation help shipping lines expand their business, streamline their services, and reduce their costs in varying degrees [19]. The most demonstrative examples in history are price agreements between shipping lines [20]. There is also an agreement on the fleet and route sharing [21].

Currently, there are several major alliances of shipping companies: A.P. Molle–Maersk Group, Mediterranean Shipping Company S. A., CMA CGM Group, China Ocean Shipping Company (COSCO), Evergreen Marine, etc. Today, a more comprehensive and flexible form of cooperation has emerged, namely the global strategic alliance [19]. Panayides and Wiedmer in [22] explore the motivation to cooperate, naming among them the opportunity to share risks, eliminate duplicate routes, and use super-large vessels.

Shipping lines cooperation can be divided into a strategic or global alliance, an agreement on the ships sharing, and slot charters [22]. By sharing risks as well as improving customer service, product quality and market accessibility, partners in a global alliance gain a number of competitive advantages over others, thus increasing profitability [19].

2.5. Cooperation and Coopetition

Researchers also point out a new form of interaction between companies—coopetition. This is both cooperation and competition at the same time. Agreeing to cooperate on one issue, companies continue to compete in other areas. Dung-Ying Lin [23] offers a theoretical framework for characterizing cooperation and competition in international maritime shipping, and explores how carriers can manage their business models. In [24], various forms of cooperation and competition in the field of linear transportation, industrial and economic reasons for cooperation, and consequences for port competition in Europe are considered.

3. Model Conceptualization

The goal of this study is to analyze the profitability of the ports and land carriers' cooperation. Let us consider a large port hub (Seagate) and i peripheral ports, $i = 1, \ldots, n$. They serve the area with j customers, $j = 1, \ldots, m$. In this case, upon receiving an order, its delivery can be carried out in two ways. Cargo can be delivered by land immediately to the port hub (Figure 2).
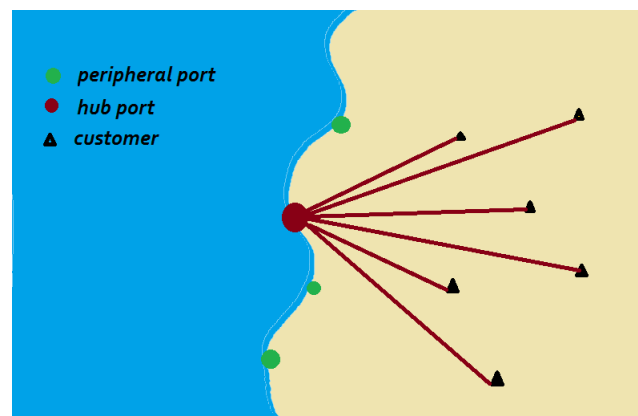

Figure 2. Ports network without cooperation.

It can also be delivered by land to the nearest peripheral port, and then by water to the hub. Further, the following notation is introduced:

q_j is the number of containers in the order from j. To simplify the model, tt is assumed that the cargo consists of standard containers;

p_i is the price assigned by port I for handling one container;

l_j^i is the overland distance between customer j and peripheral port i;

l_i^h is the distance from a peripheral port i to the hub port;

p_j^h is the overland distance from customer j to the hub;

$c(q_j, l_j^i)$ is the cost of shipping q_j containers over a distance of l_j^i by land;

$s(q_j, l_i^h)$ is the cost of shipping q_j containers over a distance of l_i^h by water;

V_i is the capacity of the port i (in containers);

V_i^*—currently available capacity of the i-th port;

m_j—customer losses in case of container demurrage (per day) or additional time of cargo handling in the peripheral port. In some cases, this value can be neglected. For example, when shipping goods over long distances, one or two additional days do not play a major role;

t_i—for a fixed time moment under consideration, the amount of time remaining until the peripheral port is ready to accept cargo for handling.

It is assumed that the hub port has a large capacity, and it is always available (waiting time is less than one day). Shipping costs when using the peripheral port are as follows:

$$TS_i^p = c(q_j, l_j^i) + s(q_j, l_i^h) + q_j p_i. \tag{1}$$

Costs in case of shipping directly to the hub:

$$TS^h = c(q_j, p_j^h). \tag{2}$$

Experience shows that in the process of delivery and handling of goods, disruptions are possible, leading to delays in the delivery of goods. These can be short delays associated with heavy traffic. Long delays are also possible, due to equipment breakdown, unfavorable weather conditions, etc. The cost of the delay includes the cost of lost profits for the transport company, the cost of waiting (idle time) at the peripheral port and the hub port, the cost of re-forming the cargo handling queue in ports, the cost of the route delay. The cost of delay per unit of time depends on many factors appropriate to a particular situation. Its assessment requires the work of experts. The duration of the delay is also an important factor. The probable duration of disruption is estimated on the basis of historical data by experts. Estimating the cost of delay is beyond the scope of this study. It is also necessary to take into account the additional time for handling cargo at the peripheral port. If necessary, one can also consider the possibility of marine shipping taking longer than overland delivery. This can be important, for example, in case of delivering perishable goods. This time difference can be accounted for in the t_i. variable.

Let us introduce the following notation:

t_{dis}—possible duration of the disruption;

t_{ex}—possible duration of the cargo processing in the peripheral port i.

Then, Formula (1) for the shipping cost is estimated as follows:

$$\begin{aligned} TS_i^p &= c(q_j, l_j^i) + s(q_j, l_i^h) + q_j p_i + \alpha_i t_{dis} m_j + \beta_i t_{ex} \\ TS^h &= c(q_j, p_j^h) + \alpha_h t_{dis} m_j. \end{aligned} \tag{3}$$

Variables α_h, α_i, and β_i indicate whether there is a problem on path i or h:

$$\alpha_i = \begin{cases} 1, & \text{if there is a problem} \\ 0, & \text{if there is no problem} \end{cases} \tag{4}$$

$$\alpha_h = \begin{cases} 1, & \text{if there is a problem on the way to the hub} \\ 0, & \text{if there is no problem} \end{cases}$$
$$\beta_i = \begin{cases} 1, & \text{if there is a problem on the way} \\ 0, & \text{if there is no problem} \end{cases} \tag{5}$$

Let us propose the following algorithm for finding the optimal delivery method (optimal delivery route). The proposed algorithm takes into account, not only the distances between customers and ports, but also the feasibility of using an intermediate peripheral port, as in this case the goods go through additional processing, which requires additional expenditures. The algorithm also takes into account the current situation on the roads and in ports. If obstacles arise on a certain route, the feasibility of switching to another route is assessed. To do this, the losses from waiting for the restoration of the original supply chain

and the possible additional costs when changing the route (i.e., the cost of handling cargo at an intermediate port or an increased distance) are compared.

The purpose of the algorithm is to find the optimal (minimum cost) cargo delivery route. For this, the cost of delivery only by land transport directly to the hub is compared with the cost of a route that includes sea transportation with the participation of one of the intermediate ports. Of course, it is necessary to take into account the additional costs of handling cargo at the intermediate port. However, shipping by sea is several times cheaper, which will save on costs.

The following Algorithm 1 of decision making is proposed:

Algorithm 1 An optimal route search algorithm.

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1. An order arrives from the customer j;
2. All sections of the route and ports are checked. If there is a disruption on some section of the route or in the peripheral port, then for this section the cost of delivery is estimated using Formulas (1).
3. For all i, the following values are calculated:
4. TS_i^p, TS^h
5. $TS^{\min} = \min\limits_i \left(TS_i^p, TS^h \right)$
6. If $TS^{\min} = TS^h$, then the cargo is shipped by land directly to the port hub.
7. If $TS^{\min} = TS_i^p$ for some i, then it is checked that this port is currently available: $q_j < V_i^*$.
8. If the condition $q_j < V_i^*$ is not satisfied, then for the obtained i the following value is defined:
9. $TS_i^p = c(q_j, l_j^i) + s(q_j, l_i^h) + q_j p_i + m_j t_i.$

The algorithm runs again from the second step. The algorithm stop criterion is selected by the algorithm running time or by the number of iterations.

Cooperative Game

With each order, a path is determined that minimizes the total costs of the coalition of carriers and customers and, therefore, increases profits. The next problem is how to divide the total profit between the members of the alliance. The costs of each individual carrier are allocated according to the Shapley vector. The Shapley vector was chosen based on its properties. As E. Moulin notes, Shapley's vector is based on sequential accounting of additional income from joining a fixed participant to each coalition [25]. This property is important, as the members of such a coalition are "unequal", and a large port hub contributes a significant part of the coalition's profit. For example, let us consider the alliance of three ports. Consider a cooperative game $\Gamma(N, v)$ with three players. Here, $N = \{1, 2, 3\}$, where {1} is a hub port, and {2} and {3} are peripheral ports. Grand coalition is {1,2,3}. The characteristic function describing the profit of the grand coalition is denoted by $v(\{1, 2, 3\})$. Characteristic functions $v(\{1, 2\})$, $v(\{1, 3\})$ are also specified. As the main goal is to deliver the cargo to the hub, coalitions without a hub have no profit:

$$v(\{2\}) = v(\{3\}) = v(\{2, 3\}) = 0 \tag{6}$$

The alliance members divide the received profit in accordance with the Shapley vector, where φ_i is the profit (gain) of the i-th player.

For the game with three ports the following profits are obtained:

$$\begin{aligned} \varphi_2 &= \tfrac{1}{3}(v(1,2,3) - v(2,3)) + \tfrac{1}{6}(v(1,2) - v(2)) + \tfrac{1}{6}(v(1,3) - v(3)) \\ \varphi_1 &= \tfrac{1}{3}(v(1,2,3) - v(1,3)) + \tfrac{1}{6}(v(1,2) - v(1)) + \tfrac{1}{6}(v(2,3) - v(3)) \\ \varphi_3 &= \tfrac{1}{3}(v(1,2,3) - v(1,2)) + \tfrac{1}{6}(v(1,3) - v(1)) + \tfrac{1}{6}(v(2,3) - v(2)) \end{aligned} \tag{7}$$

4. Results and Discussion

Numerical experiments were carried out to demonstrate the performance of the algorithm. As an example, the region with one main and three peripheral ports was considered (see Figure 3). Ports receive delivery orders. Port #1 is the main port, and all shipments go through it. Possible delivery options are either by land transport directly to port #1, or through a peripheral port. In the latter case, a part of the way is provided by land transport to the peripheral port, and then by water transport to port #1. The parameters of the demand function were varied, and the equilibrium competition and cooperation levels were estimated. For numerical simulation, the parameters were varied in the following intervals: $q_j = [20, 150]$, $p_i^h = [20; 100]$, $c = [1.5; 3]$, $s = [0.3; 1]$, $l_i^h = [50; 500]$, $p_i = [150; 350]$, $t_i = [1; 3]$, and $m_j = 500$. The algorithm was implemented in MATLAB.
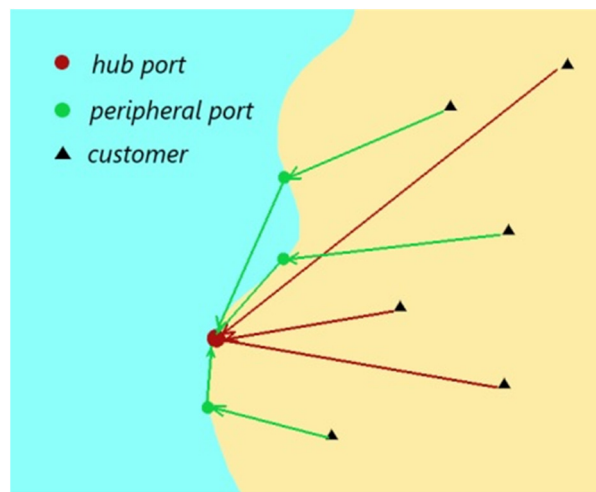

Figure 3. Ports network example.

Sample results of the numerical simulations are presented in Table 1.

Table 1. Sample results of the numerical simulations.

Port # That Received the Order	Port # That Handled the Order	Costs without Cooperation	Costs with Cooperation	Disruption	Savings%
1	1	11,624	11,624	no	0.00%
1	1	23,008	23,008	no	0.00%
1	4	12,000	11,548	yes	3.77%
3	4	17,968	16,843	yes	6.26%
1	2	9600	8800	no	8.33%
4	3	28,000	25,000	no	10.71%
2	2	13,654	13,654	no	0.00%
3	4	28,345	27,567	no	2.74%
4	3	23,780	22,445	yes	5.61%
3	1	21,658	19,567	no	9.65%
3	3	7846	7846	no	0.00%
2	1	6810	6654	yes	2.29%
3	1	22,365	20,248	no	9.47%
2	2	13,568	13,568	no	0.00%

The data in Table 1 contain information about the port that received the order, the port to which the cargo was redirected after determining the optimal route, the initial cost of delivery of the cargo, and the cost after determining the optimal route, taking into account possible disruptions. The main idea in selected examples was to observe the percentage of successful and unsuccessful coalitions. Numerical experiments showed that linking ports

in order to reduce transport costs and losses in the event of network outages helped to reduce costs by an average of 5%. This study does not take into account the situation where different ports and land carriers belong to different alliances. Our goal is to demonstrate the benefits of cooperation and highlight the value of peripheral ports, many of which are on the verge of closure.

5. Conclusions

In response to strong competition in the container shipping markets, collaboration became a major focus of this era. Consolidation of sea routes, globalization of shipping lines, and cooperation of port operators emerged. The presented study uses a game-theoretic approach to model port consolidation, and describes a multi-port game scenario. The presented model assumes horizontal cooperation of ports. Restrictions on alliances were not introduced deliberately, and cooperation between alliances was considered. The cooperation of terminal operators, located in close proximity to one another, improves the quality of services for the main customers—liner carriers—and helps to reduce transport costs. Among the expected positive effects of the considered cooperation are more efficient use of existing port infrastructures through equipment sharing, and flexible workforce distribution, as well as better rationalization of traffic peaks.

The study demonstrated the effectiveness of cooperation between ports and land carriers in reducing the effects of disruptions as well as reducing overall logistics costs. Numerical experiments have shown that the efficiency of such cooperation is 5% on average. In some cases, the savings are more than 10%.

Cooperation of sea carriers, land carriers, and ports, uniting peripheral ports and hubs in a single coalition, gives such alliances the opportunity to increase the level of loading and unloading services, and allows sea routes to receive a stable income from the port operation. It also protects peripheral ports from closure, saving jobs and financial revenues to economic regions. Of course, such a tactic is not a panacea, and there are cases when the savings from such cooperation cover the losses for unclaimed peripheral ports.

An important issue is the stability of such coalitions. The creation of such alliances involves formal negotiations, signing agreements, and can be quite costly. The issue of coalition stability may be a topic for future research.

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