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ASSESSING THE SYNERGETIC EFFECT OF SELECTING THE OPTIMAL STRUCTURE OF A LOGISTICS CHAIN

Summary. This study tackles a critical challenge in logistics optimization: assessing the economic efficiency not only of individual entities within a logistics chain, but also the synergistic benefits that arise from their collaboration. We achieve this by proposing a methodology that evaluates the economic efficiency of interactions between participants in a logistics chain. This methodology goes beyond individual efficiency and delves into how the overall economic benefit is distributed among key stakeholders. These stakeholders include freight owners, who initiate the delivery process, forwarders who manage and optimize deliveries, carriers who physically transport goods, and freight terminals that facilitate cargo handling and storage. To ensure the methodology's relevance to contemporary practices, we begin with a comprehensive review of recent advancements in

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delivery chain optimization research. We propose to measure the synergetic effect by considering delivery demand parameters, such as the weight of the consignment and the distance it needs to travel. To validate our methodology and gain practical insights, we conducted a series of experimental studies specifically tailored to the Kazakhstani transportation market. By analysing the share of the synergistic effect under varying delivery demand parameters, we were able to identify trends and patterns.

Keywords: freight transportation, synergetic effect, requests flow, logistics chain

1. INTRODUCTION

An efficient transportation system serves as the lifeblood of any modern economy. It facilitates the seamless movement of goods and people, fulfilling the critical needs of both consumers and businesses. This paper delves into the intricate world of logistics, exploring the fundamental role of the transportation industry and the challenges inherent in designing and optimizing delivery systems.

Transportation bridges the gap between production and consumption. By efficiently delivering goods, businesses can reach wider markets, fostering economic growth. Reliable and cost-effective transport empowers businesses to access raw materials, distribute finished products, and connect with a wider network of employees and clients. Furthermore, robust transportation systems underpin international trade, enabling the smooth flow of goods across borders and fostering global economic cooperation.

Within the transportation sector, road transport plays a central, yet often underappreciated, role. It serves as the foundation, handling the crucial “first mile” and “last mile” deliveries in most journeys. This ensures seamless movement of goods throughout the entire supply chain, even when other modes of transport, such as airplanes or ships, are involved.

Behind the scenes, logistics companies act as the masterminds, meticulously coordinating the intricate web of activities that form the supply chain. Forwarding companies play a vital role in managing this complex network. The effectiveness of their services directly impacts the efficiency of the entire system. Their primary task is to meticulously plan and organize the transportation process, ensuring goods arrive at their destination on time, within budget, and in good condition. These efforts may be summarized by selecting the proper structure of the logistics chain that ensures the minimum total expenses for all entities participating in the delivery process.

This study aims to develop a methodology for evaluating the economic efficiency of delivery processes within a logistics chain. Furthermore, the methodology will assess how the resulting synergetic effect is distributed among the different entities involved in the delivery process.

The paper is structured as follows. Section 2 provides a concise review of recent research directions in delivery chain optimization. Section 3 details the methodology employed to estimate the synergistic effect for various delivery process participants: freight owners, forwarders, carriers, and freight terminals. Section 4 presents the results of experimental studies conducted to calculate the share of the synergistic effect under varying delivery demand parameters (consignment weight and delivery distance). Finally, Section 5 offers concise conclusions and outlines potential avenues for future research.

2. LITERATURE REVIEW

The field of transportation process optimization is rich with diverse challenges. Researchers grapple with issues like managing fleets, controlling costs, and developing optimal strategies for both customer service and vehicle routing [1-4]. Ensuring quality control throughout the transportation process, understanding market behaviour to predict demand [5-7], and allocating resources efficiently are all crucial aspects [5, 8]. Additionally, mitigating risks associated with transportation decisions and maximizing supply chain reliability are key areas of research [9, 10]. This complex field draws on a multitude of academic disciplines. Operations research, economics, and engineering all contribute valuable approaches to finding optimal solutions, as evidenced by the variety of models and algorithms developed. Notably, a recent area of focus involves optimizing supply chains while considering factors like risk, uncertainty, and sustainability [11].

The ever-changing technological landscape constantly presents new research opportunities. Studies like [12] highlight how the evolving business environment challenges the effectiveness of current optimization methods. This research also identifies key trends and knowledge gaps relevant to both practitioners and academics, exploring future directions for optimization research in emerging markets and evolving freight transport organizations [12]. Similarly, Köhler and Brauer delve into the transformation of freight transport, outlining new analytical needs and potential modelling approaches for the future [13].

The transportation and logistics industry is undergoing a digital revolution fuelled by the Internet of Things and Big Data. The COVID-19 pandemic and the shift to remote work further accelerated this trend, pushing major players like Maersk, MSC, and Hapag-Lloyd to embrace online platforms. This digital shift has a ripple effect, forcing even smaller transport companies to adapt. Research by [14] explores the impact of online freight platforms (OFPs) on traditional logistics service providers (TLSPs). The authors found that OFPs don’t necessarily threaten TLSPs, but rather offer manufacturers new options for outsourcing deliveries. Similarly, authors of [15] examine the interaction between information systems and the performance of international freight forwarders. Looking ahead, digitalization and automation are expected to continue shaping the industry with advancements in artificial intelligence and blockchain technology, as evidenced by works like [16] and [17]. These developments hold promise for real-time shipment tracking and increased supply chain transparency.

Sustainability is emerging as a second major trend within the transportation and logistics industry. Sustainable practices act as a crucial bridge between modernization and responsible industry functioning. Research by [18] exemplifies this by developing a model that integrates resilience and agility into designing sustainable agri-food supply chains. This model considers uncertainties in the environment. The ultimate goal of sustainability efforts in freight transport is to minimize overall costs while reducing negative environmental and social impacts. To achieve this, research by Pamucar et al. [19] recommends maximizing the potential of alternative transportation modes, like rail, to lessen the negative consequences of road freight transport such as emissions, noise, and congestion. The authors propose a transportation planning strategy for freight companies based on fuzzy sets to rank these alternative modes effectively. Similar studies in [20] further explore ways to encourage a shift towards rail and other alternatives to road transport. Focusing on eco-friendly solutions, [21] proposes an effective algorithm for routing vehicles specifically within the context of sustainable transport. This algorithm, based on restrictive inheritance, helps determine environmentally friendly routes. By implementing such solutions, the transportation industry can contribute to sustainable development by minimizing the environmental and social impact of transport.

Another key direction for the transportation and logistics industry involves integrating passenger and freight movement within cities, often referred to as “urban co-modality”. Research by Ma et al. [22] explores the potential benefits of such integration by modelling a public transport system that accommodates both passengers and goods. Their study examines how this co-modality can impact existing forwarding, trucking, and passenger services across the urban transport system. Notably, the authors identify scenarios where co-modality can improve profits for forwarders, carriers, and transit operators, while also increasing consumer surplus for both freight customers and passengers compared to traditional separated systems. Beyond modelling, the paper [23] presents a practical framework for developing and evaluating an innovative service called Integrated Demand-Responsive Transport (I-DRT). This service combines passenger and freight transportation with a demand-responsive approach, meaning it adapts to real-time needs. The study utilizes Osterwalder’s business model canvas to outline the infrastructure, vehicles, personnel, costs, revenue streams, and partnerships required for I-DRT implementation. A pilot project in Misano Adriatico, Italy, demonstrated the service’s potential. The results suggest that addressing challenges related to legislation, policy, and stakeholder participation is crucial for achieving more robust and sustainable long-term outcomes. Further supporting this trend, a comprehensive review by [24] explores existing practices and approaches used to integrate passenger and freight transport in urban areas. This review highlights the numerous positive impacts of integration, including reduced traffic congestion, improved resource utilization, and increased overall sustainability within cities.

The transportation and logistics industries are navigating a turbulent economic landscape shaped by geopolitical tensions and global downturns. These disruptions necessitate that transport companies re-evaluate their operational practices. To thrive in this environment, effectively combining traditional approaches with modern modelling and analysis techniques is crucial. This allows for the development of efficient strategies for managing and optimizing transportation processes. The paper [25] exemplifies this by exploring the synergy between business analytics and modelling in freight transport. The study establishes updated criteria for evaluating business intelligence in this context and applies the IF-AHP method to assess the implementation of data analytics and modelling in logistics. Additionally, the research [26] provides an empirical analysis of factors contributing to volatility in the freight transportation market. Technological advancements also play a key role. For instance, the study [27] proposes an architecture for telematics tools along with a methodology that merges delivery planning with transportation demand modelling. This allows for calculating performance indicators used in the preliminary assessment of delivery scenarios. Understanding shipper decision-making is another crucial aspect. The research [28] utilizes latent class modelling to analyse the heterogeneity of freight shippers’ preferences when choosing transportation modes. This research sheds light on the thought processes behind shipper and agent choices. Optimization remains a critical focus. The paper [29] proposes a mathematical algorithm for route construction, leveraging real-world data and demonstrating its effectiveness in solving large-scale instances. Similarly, the authors of the study [30] aim to create a tool that generates cargo loading plans and route sequences for efficient pallet distribution, tackling a combined vehicle routing, and loading problem. Furthermore, the paper [31] proposes a two-stage model to optimize procurement of road-rail transshipment and truck routing, fostering synergies between these transportation modes. By embracing these advancements and fostering a data-driven approach, the transportation and logistics industries can navigate economic challenges and develop more efficient and resilient operations.

The research presented utilizes a diverse range of methodologies to tackle various challenges in transportation and logistics. Optimization problems are frequently addressed through mixed integer linear programming [2, 4] and hybrid approaches combining goal programming with genetic algorithms [4]. Additionally, game theory proves valuable in analysing strategic interactions between different players within the transportation ecosystem [3, 14, 31, 32]. For modelling and analysis, researchers leverage techniques like discrete event modelling [5] to simulate real-world scenarios and functional analysis [6] to understand complex relationships. Cluster modelling [6, 28] helps identify groups with similar characteristics, while fuzzy logic approaches and fuzzy stochastic programming [8, 18] allow for incorporating uncertainty into decision-making. Statistical methods, including structural equation modelling [10, 15] and regression analysis [15], are employed to identify relationships between variables. Furthermore, cluster, variance, and a posteriori analyses [15] provide deeper insights into data. Decision-making support tools are explored as well, with research by Pamucar et al. [19] utilizing an order priority approach based on fuzzy sets of images. Qualitative methods also play a role. Studies based on in-depth interviews [20] offer valuable insights from industry professionals, while SWOT analysis [21] provides a framework for strategic planning. Looking towards the future, research by [25] highlights the potential of the intuitionistic fuzzy analytical hierarchy process for decision-making. Additionally, empirical analysis and panel regressions used in [26, 33] offer valuable insights into market trends. Finally, research by [29, 30] demonstrates the effectiveness of operational research techniques for solving complex optimization problems related to vehicle routing and cargo loading. This rich tapestry of methodologies ensures a comprehensive understanding of the transportation and logistics landscape, allowing researchers to develop effective solutions for the challenges faced by the industry.

The presented literature review emphasizes that efficient transportation systems require strong interaction between all participants in the transport market. This collaboration allows for considering the inherent randomness of demand and technological processes. Additionally, it helps eliminate roadblocks caused by poorly defined goals at the tactical planning stage.

3. THE PROPOSED APPROACH TO ESTIMATE THE SYNERGETIC EFFECT

Our proposed methodology builds upon the research presented in [34] on optimal delivery chain structure selection. While we demonstrate the approach for calculating the synergistic effect for each participant type within the context of four basic logistics chain structures, the methodology itself is inherently scalable. The framework can be readily extended to accommodate a wider range of alternative structures or additional delivery process participant types without requiring any fundamental modifications.

3.1. Alternative structures of a logistic chain

Within a logistics system, individual supply chains involve a set of potential structures for delivering goods. These structures can be analysed by considering the key players involved in the flow of materials. The starting point of any supply chain, acting as the source of the material flow, is the freight owner, also known as the consignor. The destination point is another cargo owner, the consignee. Therefore, both the beginning and end points of the delivery chain involve freight owners. Physically, the movement of materials (the material flow processing) is handled by a carrier company. The organization and planning of this flow are often managed by a freight forwarder, who may utilize resources such as freight terminals when necessary.

Within the logistics chain, freight forwarders act as organizers of technological processes. They play a crucial role by concentrating information flows and ensuring smooth communication between all parties involved in moving goods. When a cargo owner needs to deliver goods, it typically contacts a freight forwarder who then coordinates the entire delivery process. This is known as the 1F-structure [34], where one forwarder and one carrier are involved. Notably, cargo terminals are not utilized in this specific scenario. The process starts with the shipper informing the freight forwarder about the need for delivery. The forwarder then identifies a suitable carrier capable of transporting the shipment to the consignee (receiver). Bilateral agreements are then established: one between the forwarder and the shipper, and another between the forwarder and the carrier. The shipper pays the forwarder for their services, and the forwarder uses these funds to pay the carrier. Depending on the specific arrangement, the carrier might be responsible for delivering the shipment from the shipper to the border, and then from customs to the destination. This type of logistics chain is commonly used for road transportation when the shipment weight matches the capacity of a single vehicle.

The 2F-structure represents a more complex variant within the logistics chain where two freight forwarders are involved [34]. Upon receiving a shipment request from a shipper, the initial freight forwarder locates a carrier to deliver the goods to the border. They then send the request to a partner forwarder, who arranges onward delivery to the consignee using a regional carrier in their area. This structure necessitates four bilateral agreements: shipper and initial freight forwarder, initial freight forwarder and carrier delivering to the border, the two freight forwarding companies, partner forwarder, and regional carrier completing the final leg of the delivery. The financial flow involves the shipper paying the initial forwarder. From this payment, the initial forwarder then compensates both the regional carrier and the partner forwarder for their respective services. The partner forwarder, in turn, uses their received payment to cover the costs of the regional carrier they utilize.

The cargo terminal plays a central role in the logistics chain with the 1T-structure [34]. Upon receiving a request from a shipper, the freight forwarder assesses the economic feasibility of using the cargo terminal. If this option proves cost-effective, the forwarder then identifies carriers for two legs of the journey: one to deliver the cargo to the terminal and another for international export to the destination. This process involves establishing four bilateral agreements: between the forwarder and the shipper, between the forwarder and the regional carrier delivering to the terminal, between the forwarder and the cargo terminal, and between the forwarder and the international carrier for export. The freight forwarder utilizes funds received from the shipper to pay for the services of both carriers and the cargo terminal itself. The 1T-structure is particularly suited for situations where initial cargo deliveries occur by road, followed by consolidation based on the destination at the terminal, and finally, onward shipment using a main transport mode like rail. In some cases, the cargo terminal may even handle the export of the consolidated shipment, offering comprehensive logistics services.

The 2T-structure is a common option for deliveries involving long distances and the use of a main transport mode [34]. In this scenario, the freight owner initiates the process by contacting a freight forwarder. The freight forwarder, after evaluating various logistics chain options, selects the 2T structure as the most efficient solution. The forwarder then takes charge of coordinating the entire process. They first arrange for a regional carrier to transport the goods from the shipper's location to a nearby cargo terminal. Agreements are then established with the terminal, the main carrier (e.g., shipping line or railway company), and a partner forwarder in the recipient's region. The partner forwarder mirrors these actions in their region, arranging for a regional carrier to deliver the goods from the receiving terminal to the destination. Contracts are also established with the terminal and the regional carrier. Additionally, a separate agreement exists between the two forwarders. Financially, the freight forwarder in the sender's region uses the payment received from the freight owner to cover the costs of all involved parties: regional and international carriers, the local terminal, and the partner forwarder's services. The recipient region's forwarder, in turn, uses the funds received from the first forwarder to pay for the local terminal and carrier services. There can be variations in this payment structure. Sometimes, the sender's terminal might directly pay the regional carrier there, while the recipient's terminal handles the final delivery costs.

3.2. The method to calculate the synergistic effect

The use of the most effective structures of cargo delivery chains is possible through the interaction of transport market entities within a single system. Therefore, the effect of choosing the optimal supply chain options is a synergistic effect.

The effect of a management decision on choosing a delivery chain structure is assessed relative to other alternative options. For a given request for transport services, the effect $\varepsilon_{req}^{(i)}$ relative to the i-th option is determined as follows:

$$\varepsilon_{req}^{(i)} = E_{req}^{(i)} - E_{req}^{opt}, \tag{1}$$

where $E_{req}^{(i)}$ is total costs of delivery process participants for i-th structure, [EUR/request]; E_{req}^{opt} is total costs of delivery process participants for the optimal structure, [EUR/request].

For a set of alternative structures, the effect of choosing the optimal option can be assessed as an arithmetic mean, but it is more correct to estimate the average considering the weight of each of the alternative options, assessed by the corresponding value of the total costs:

$$\varepsilon_{req} = \frac{\sum_{i\in \mathrm{L}} \varepsilon_{req}^{(i)} \cdot E_{req}^{(i)}}{\sum_{i\in \mathrm{L}} E_{req}^{(i)}}, \tag{2}$$

where ε_{req} is the effect of choosing the optimal structure for a given request for transport services, [EUR/request]; L is the set of alternative structures, $\mathrm{L} = \{1F,\ 2F,\ 1T,\ 2T\}$.

Using the models developed in [34] to calculate the costs of the subjects of the delivery process, the total costs of servicing one request for the i-th type of a logistics chain can be estimated based on the average number of requests received over a given period:

$$E_{req}^{(i)} = E^{(i)} \cdot \frac{\mu_I}{T_m}, \tag{3}$$

where $E^{(i)}$ is the total costs of delivery process subjects for the i-th structure of a logistics chain, [EUR]; μ_I is the expected value of the time interval between requests in a flow [hours/request]; T_m is the duration of the period during which the process of receiving requests for transport services is considered, [hours].

Then formula (2) can be written as:

$$\varepsilon_{req} = \frac{\mu_I}{T_m} \cdot \frac{\sum_{i\in \mathrm{L}} \left(E^{(i)} - E^{(opt)}\right) \cdot E^{(i)}}{\sum_{i\in \mathrm{L}} E^{(i)}}, \tag{4}$$

where $E^{(opt)}$ is the total costs of subjects of the delivery process during the simulated period for the optimal structure of a delivery chain, [EUR].

Let us consider expression (4) for the case when the 1F structure is the optimal one for a given request:

$$\varepsilon_{req}(1F) = \frac{\mu_I}{T_m} \cdot \frac{\left(E^{2F}-E^{1F}\right)\cdot E^{2F}+\left(E^{1T}-E^{1F}\right)\cdot E^{1T}+\left(E^{2T}-E^{1F}\right)\cdot E^{2T}}{E^{1F}+E^{2F}+E^{1T}+E^{2T}}, \tag{5}$$

$$\varepsilon_{req}(1F) = \frac{\mu_I}{T_m} \cdot \frac{\left(E^{1F}\right)^2+\left(E^{2F}\right)^2+\left(E^{1T}\right)^2+\left(E^{2T}\right)^2-E^{1F}\cdot\left(E^{1F}+E^{2F}+E^{1T}+E^{2T}\right)}{E^{1F}+E^{2F}+E^{1T}+E^{2T}}, \tag{6}$$

Finally, from (6) we obtain:

$$\varepsilon_{req}(1F) = \frac{\mu_I}{T_m} \cdot \left[\frac{\left(E^{1F}\right)^2+\left(E^{2F}\right)^2+\left(E^{1T}\right)^2+\left(E^{2T}\right)^2}{E^{1F}+E^{2F}+E^{1T}+E^{2T}} - E^{1F}\right] = \frac{\mu_I}{T_m} \cdot \left[\frac{\sum_{i\in \mathrm{L}}\left(E^{(i)}\right)^2}{\sum_{i\in \mathrm{L}} E^{(i)}} - E^{1F}\right]. \tag{7}$$

Generalizing (7) for the case where the k-th logistics chain structure is optimal ($k \in \mathrm{L}$), we obtain the following relationship for determining the synergistic effect per request:

$$\varepsilon_{req}(k) = \frac{\mu_I}{T_m} \cdot \left[\frac{\sum_{i\in \mathrm{L}}\left(E^{(i)}\right)^2}{\sum_{i\in \mathrm{L}} E^{(i)}} - E^{(k)}\right]. \tag{8}$$

The synergistic effect for the entire logistics system servicing a flow of requests for deliveries, that arises due to the justification by a freight forwarder of the most effective logistic chain structures, can be determined as the sum of effects obtained for the requests in the flow.

3.3. Estimating a part of the synergetic effect for the participants

The share of the synergistic effect attributable to a specific participant in the delivery process is assessed based on the effect per request using the following formula:

$$\delta^{(j)} = \frac{\varepsilon_{req}^{(j)}}{\varepsilon_{req}}, \ \forall j \in \mathrm{P}, \tag{9}$$

where $\delta^{(j)}$ is the share of the synergistic effect attributable to the j-th entity of the delivery chain; $\varepsilon_{req}^{(j)}$ is the synergistic effect from servicing a request attributable to the j-th participant, [EUR/request]; P is the set of the delivery process participants, $\mathrm{P} = \{FO,\ FF,\ C,\ FT\}$: FO – freight owner, FF – freight forwarder, C – carrier, FT – freight terminal.

The synergistic effect of the j-th participant is estimated as the weighted average value of the difference in expenses according to the total expenses of all entities that participate in the delivery process similarly to (4):

$$\varepsilon_{req}^{(j)} = \frac{\mu_I}{T_m} \cdot \frac{\sum_{i\in \mathrm{L}}\left(E_j^{(i)}-E_j^{(opt)}\right)\cdot E^{(i)}}{\sum_{i\in \mathrm{L}} E^{(i)}}, \tag{10}$$

where $E_j^{(i)}$ is the expenses of the j-th participant in the delivery process during the simulated period when the i-th structure of the logistics chain is used, [EUR/request]; $E_j^{(opt)}$ is the expenses of the j-th participant for the optimal structure of the delivery chain, [EUR/request].

Let us consider expression (10) for freight owner for the case when the 1F-structure is optimal for the given demand parameters:

$$\varepsilon_{req}^{FO} = \frac{\mu_I}{T_m} \cdot \frac{\left(E_{FO}^{2F} - E_{FO}^{1F}\right) \cdot E^{2F} + \left(E_{FO}^{1T} - E_{FO}^{1F}\right) \cdot E^{1T} + \left(E_{FO}^{2T} - E_{FO}^{1F}\right) \cdot E^{2T}}{\sum_{i \in \mathrm{L}} E^{(i)}}, \tag{11}$$

where ε_{req}^{FO} is the synergistic effect obtained by cargo owners, [EUR/request]; E_{FO}^{1F}, E_{FO}^{2F}, E_{FO}^{1T}, and E_{FO}^{2T} are expenses of freight owners during the simulated period when 1F-, 2F-, 1T- and 2T-structures of delivery chain used, [EUR/request].

Summing up the synergistic effect of all participants in the delivery process, we obtain the following expression:

$$\begin{gathered}
\frac{T_m \cdot \sum_{i \in \mathrm{L}} E^{(i)}}{\mu_I} \cdot \left[\varepsilon_{req}^{FO} + \varepsilon_{req}^{FF} + \varepsilon_{req}^{C} + \varepsilon_{req}^{FT}\right] = \\
= \left(E_{FO}^{2F} - E_{FO}^{1F}\right) \cdot E^{2F} + \left(E_{FO}^{1T} - E_{FO}^{1F}\right) \cdot E^{1T} + \left(E_{FO}^{2T} - E_{FO}^{1F}\right) \cdot E^{2T} + \\
+ \left(E_{FF}^{2F} - E_{FF}^{1F}\right) \cdot E^{2F} + \left(E_{FF}^{1T} - E_{FF}^{1F}\right) \cdot E^{1T} + \left(E_{FF}^{2T} - E_{FF}^{1F}\right) \cdot E^{2T} + \\
+ \left(E_{C}^{2F} - E_{C}^{1F}\right) \cdot E^{2F} + \left(E_{C}^{1T} - E_{C}^{1F}\right) \cdot E^{1T} + \left(E_{C}^{2T} - E_{C}^{1F}\right) \cdot E^{2T} + \\
+ \left(E_{FT}^{2F} - E_{FT}^{1F}\right) \cdot E^{2F} + \left(E_{FT}^{1T} - E_{FT}^{1F}\right) \cdot E^{1T} + \left(E_{FT}^{2T} - E_{FT}^{1F}\right) \cdot E^{2T},
\end{gathered} \tag{12}$$

$$\begin{gathered}
\frac{T_m \cdot \sum_{i \in \mathrm{L}} E^{(i)}}{\mu_I} \cdot \left[\varepsilon_{req}^{FO} + \varepsilon_{req}^{FF} + \varepsilon_{req}^{C} + \varepsilon_{req}^{FT}\right] = \\
= \left(E_{FO}^{2F} - E_{FO}^{1F} + E_{FF}^{2F} - E_{FF}^{1F} + E_{C}^{2F} - E_{C}^{1F} + E_{FT}^{2F} - E_{FT}^{1F}\right) \cdot E^{(2F)} + \\
+ \left(E_{FO}^{1T} - E_{FO}^{1F} + E_{FF}^{1T} - E_{FF}^{1F} + E_{C}^{1T} - E_{C}^{1F} + E_{FT}^{1T} - E_{FT}^{1F}\right) \cdot E^{(1T)} + \\
+ \left(E_{FO}^{2T} - E_{FO}^{1F} + E_{FF}^{2T} - E_{FF}^{1F} + E_{C}^{2T} - E_{C}^{1F} + E_{FT}^{2T} - E_{FT}^{1F}\right) \cdot E^{(2T)}.
\end{gathered} \tag{13}$$

The following equalities are true by definition:

$$E^{(i)} = E_{FO}^{(i)} + E_{FF}^{(i)} + E_{C}^{(i)} + E_{FT}^{(i)}, \ \forall i \in \mathrm{L}. \tag{14}$$

Substituting (14) into (13), we obtain the following:

$$\begin{gathered}
\frac{T_m \cdot \sum_{i \in \mathrm{L}} E^{(i)}}{\mu_I} \cdot \left[\varepsilon_{req}^{FO} + \varepsilon_{req}^{FF} + \varepsilon_{req}^{C} + \varepsilon_{req}^{FT}\right] = \\
= \left(E^{2F} - E^{1F}\right) \cdot E^{2F} + \left(E^{1T} - E^{1F}\right) \cdot E^{1T} + \left(E^{2T} - E^{1F}\right) \cdot E^{2T}.
\end{gathered} \tag{15}$$

Or, similar to the transformations in (5), equality (15) can be shown in the following form:

$$\varepsilon_{req}^{FO} + \varepsilon_{req}^{FF} + \varepsilon_{req}^{C} + \varepsilon_{req}^{FT} = \frac{\mu_I}{T_m} \cdot \left[\frac{\sum_{i \in \mathrm{L}} \left(E^{(i)}\right)^2}{\sum_{i \in \mathrm{L}} E^{(i)}} - E^{1F}\right] \tag{16}$$

Since the expression on the right side of equation (16) in accordance with (8) is the synergistic effect in the logistics chain from using the 1F-structure as the optimal one, it can be argued that the sum of the synergistic effects of the delivery chain entities when choosing the optimal 1F-structure is equal to the synergistic effect for the entire chain.

It is easy to verify that equality (16) is satisfied for cases when the 2F-, 1T-, and 2T-structures of the delivery chain are optimal.

Thus, the sum of the effects of the delivery process participants is equal to the synergistic effect of choosing the optimal delivery option for the logistics chain as a whole:

$$\varepsilon_{req}^{FO} + \varepsilon_{req}^{FF} + \varepsilon_{req}^{C} + \varepsilon_{req}^{FT} = \varepsilon_{req}. \tag{17}$$

The described approach allows us to calculate the share of synergetic effect for each type of the delivery participants, such that the sum of shares equal to 1.

4. RESULTS OF EXPERIMENTAL STUDIES AND DISCUSSION

To evaluate the synergistic effect for each participant within a given logistics chain structure, a simulation model was developed based on the proposed methodology for calculating this effect. This model determines the corresponding share of the synergistic effect for each participant. Implemented in the C# programming language, the simulation model leverages a library available from a publicly accessible repository [35].

The simulation experiment incorporated numerical parameters reflecting the Kazakhstani cargo transportation market. These parameters included fuel costs, operator wages, tariffs for storage and transportation services, etc. The results of this experiment, investigating the impact of request flow parameters on the distribution of the synergistic effect among delivery process participants, are presented in Fig. 1-4.

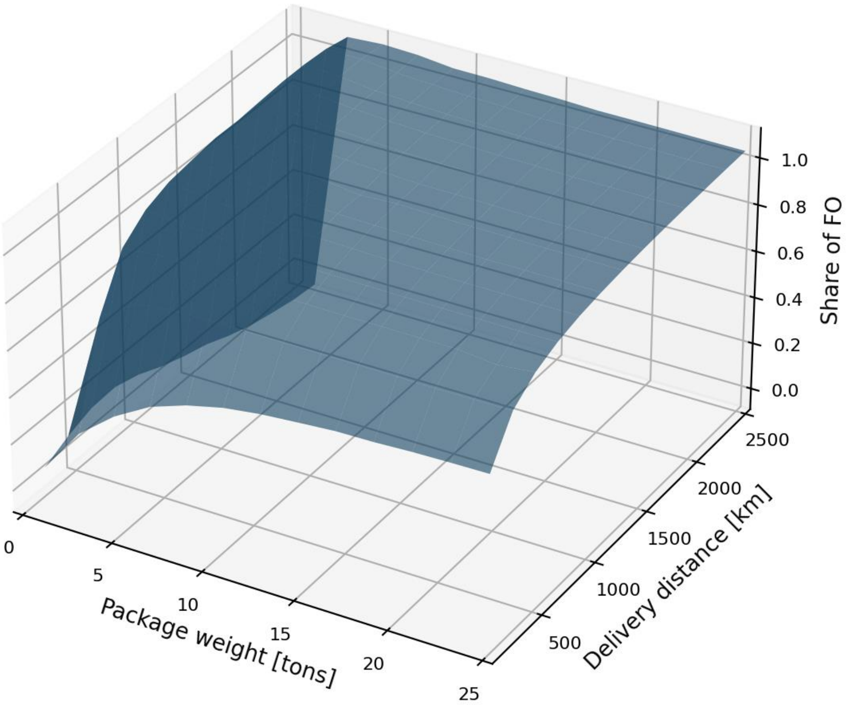

Fig. 1. Dependence of freight owners’ share in the synergistic effect on demand parameters

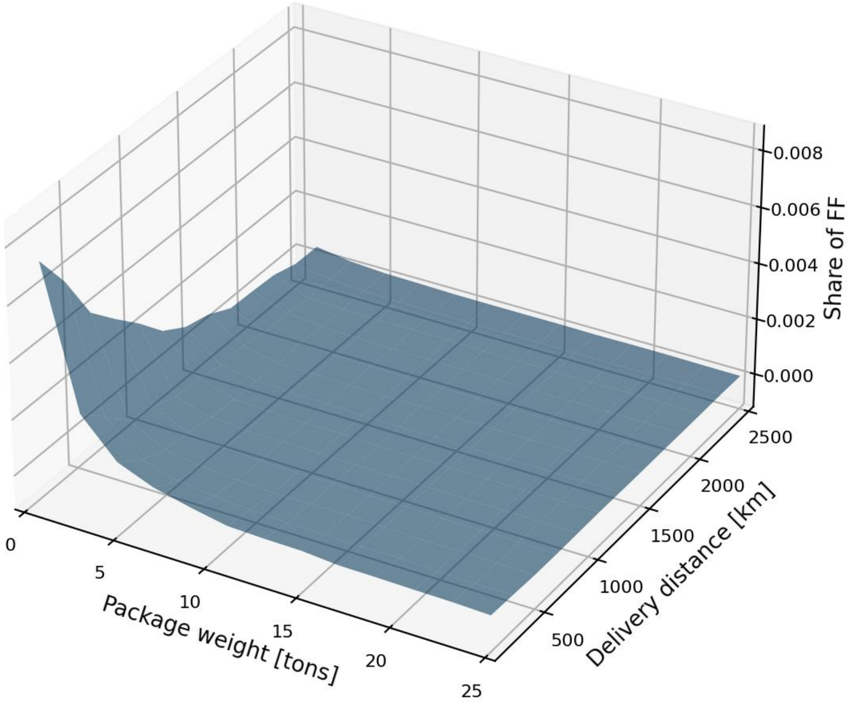

Fig. 2. Dependence of a freight forwarder's share in the synergetic effect from demand parameters

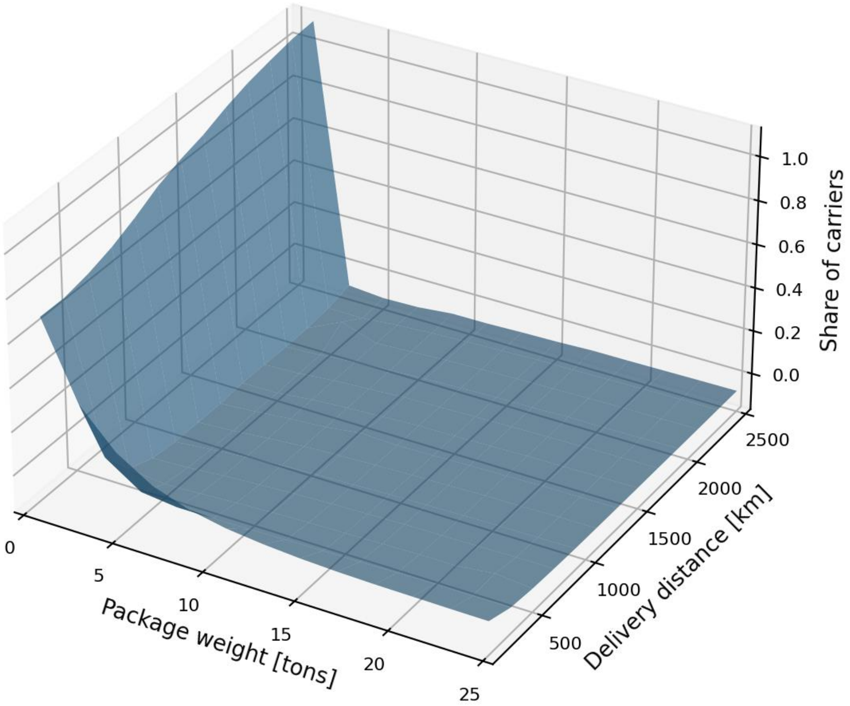

Fig. 3. Dependence of a carrier's share in the synergetic effect from demand parameters

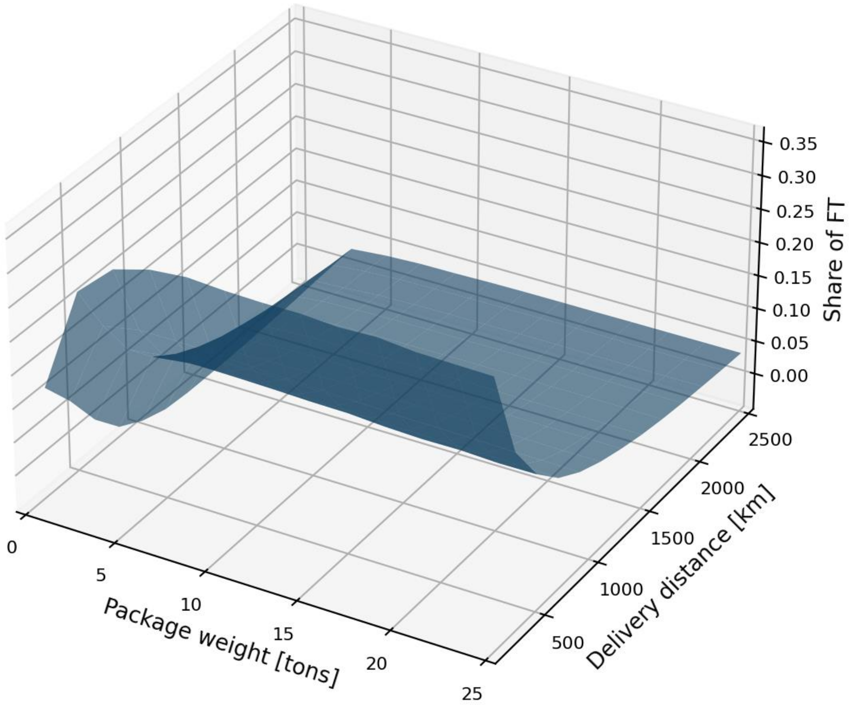

Fig. 4. Dependence of a freight terminal’s share in the synergistic effect from demand parameters

Analysis of the results of a simulation experiment conducted for the expected values of the consignment weight in the range from 1 ton to 25 tons, as well as the values of the average delivery distance in the range from 100 km to 2500 km, allows us to draw the following conclusions:

- across a considered range of request flow parameters, freight owners generally experience the largest share of the synergistic effect (Fig. 1);
- forwarders see the smallest share of the synergetic effect; within the considered parameters’ range, their maximum share remains low at around 0.7% (Fig. 2);
- the distribution of the synergistic effect is not linear; it exhibits a non-linear relationship with the parameters characterizing the request flow for forwarding services;
- for specific combinations of request flow parameters, some participants, including freight owners, might even experience a negative share of the synergistic effect; this can be attributed to negative individual effects for a specific participant when servicing a request within the overall optimal chain structure for the entire delivery system;
- the share of the synergistic effect captured by freight owners is minimized when request flow parameters approach the lower limit of the considered range; conversely, as average delivery distance and average consignment weight increase, the freight owners’ share also increases;
- for forwarders, the share of the synergistic effect is maximum when servicing requests that are characterized by the delivery of small weights over short distances; with the increase in expected values of the consignment weight and the delivery distance, the share of the synergistic effect of forwarders decreases;
- the share of the synergistic effect attributable to freight terminals is maximum when servicing the flow of requests, which is characterized by delivery distances close to the lower limit of the considered range;

- for carriers, the share of the synergistic effect from the interaction of the delivery process entities is maximum if the flow of requests with small expected values of the consignment weight is serviced.

Fig. 5-7 present diagrams illustrating the distribution of the synergistic effect across participants in the delivery process. These diagrams are generated for various combinations of the expected values of delivery distance and average consignment weight.

Examining Fig. 5, we observe the distribution of the synergistic effect for a consignment weight of 1 ton. Carriers capture the greatest share of this effect, with this share reaching a maximum at the highest considered average delivery distances. In contrast, freight owners experience a peak share for delivery distances around 600-700 km. Interestingly, freight terminals achieve their maximum portion of the synergistic effect at the expected value of a delivery distance of 100 km.

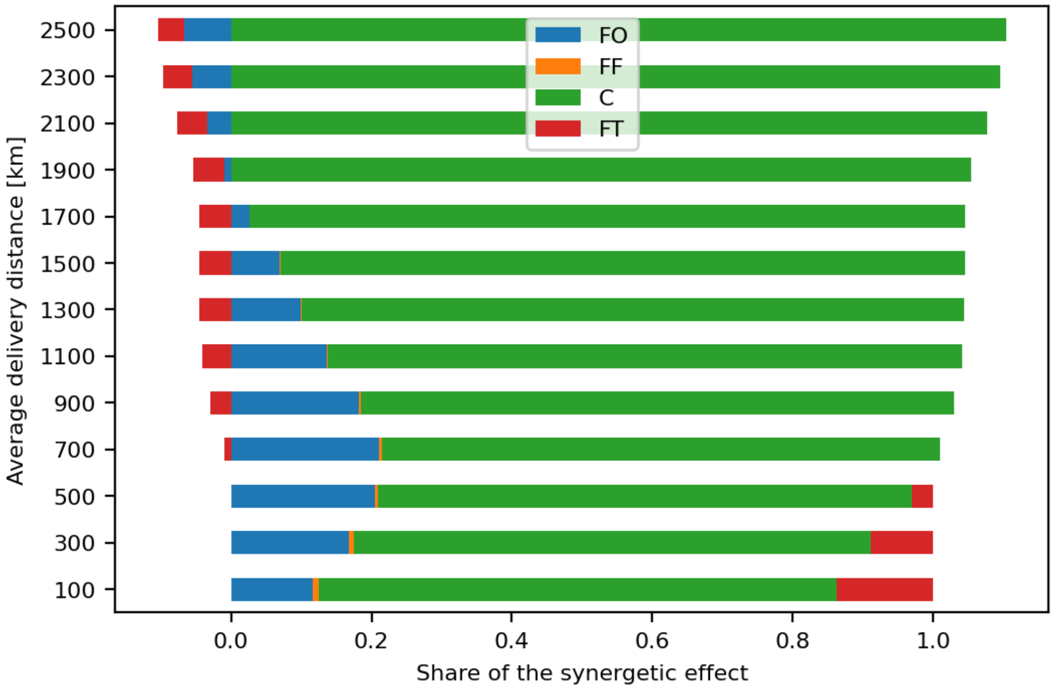

Fig. 5. Distribution of the synergistic effect between entities of the delivery process for an average parcel weight of 1 ton

The diagram in Fig. 6 shows an average cargo volume of 7 tons. In this case, the carrier's contribution to the overall synergistic effect is reduced compared to the scenario shown in Fig. 5. With an average of 7 tons, the carrier only benefits when the average delivery distance is 100 km or more. In this scenario, most of the synergistic effect goes to cargo owners. This synergistic effect for freight owners increases as the average delivery distance gets longer. Conversely, cargo terminals see a decrease in their share of the synergistic effect as the average delivery distance rises.

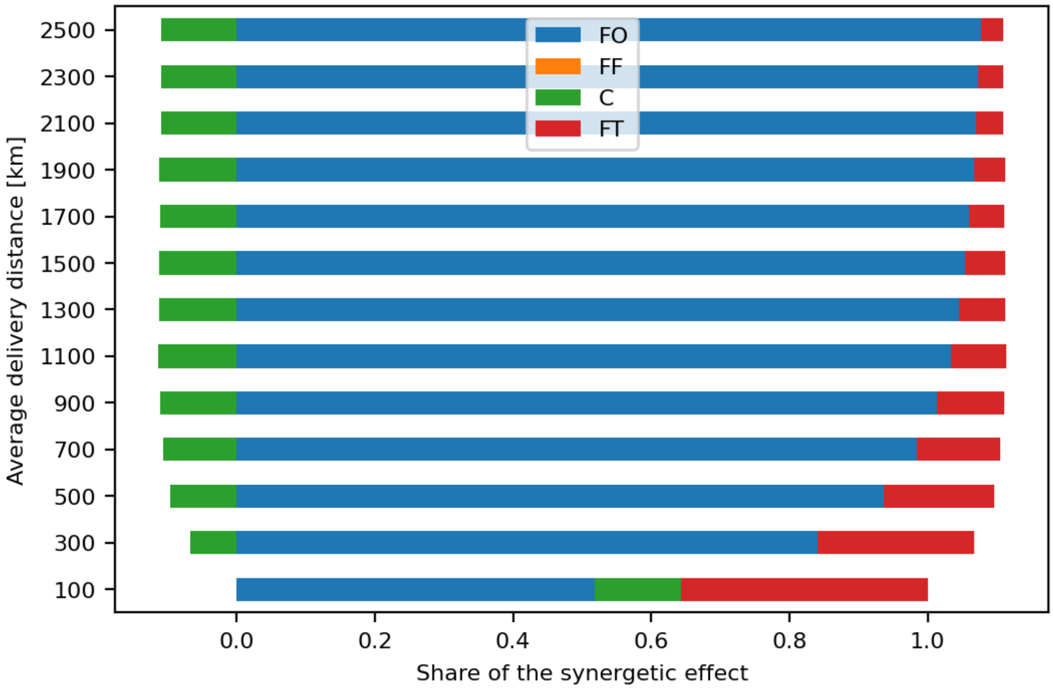

Fig. 6. Distribution of the synergistic effect between entities of the delivery process for an average parcel weight of 7 tons

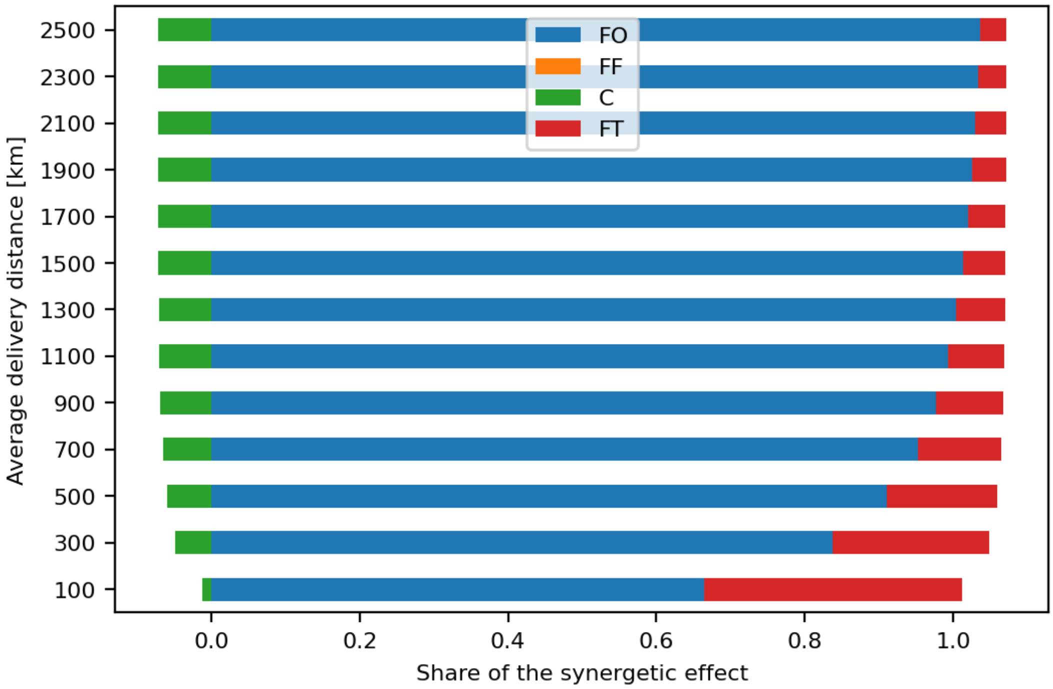

Fig. 7. Distribution of the synergistic effect between entities of the delivery process for an average parcel weight of 25 tons

Analysis of Fig. 7 reveals that increasing the expected value of the consignment weight does not alter the observed distribution of the synergistic effect among delivery participants. Cargo owners continue to capture the largest share, while freight terminals receive a negligible contribution. Notably, the share for carriers remains negative. Furthermore, the trend of increasing cargo owners’ share and decreasing freight terminal share persists with rising average delivery distance.

5. CONCLUSIONS

Recent research has focused on optimizing supply chains while considering risk, uncertainty, and sustainability. As technology evolves and the industry changes, scholars continue to develop innovative solutions for a more efficient and sustainable transportation system. The proposed methodology enables researchers to evaluate the effect of selecting the proper structure of a delivery chain for all participants of the delivery process.

The results of the conducted experimental studies allowed us to state that the combined effects experienced by individual participants in the delivery process are equivalent to the synergistic effect achieved by selecting the optimal logistics chain structure for the entire system. Analysis of the simulation experiment reveals that cargo owners exhibit limited values for their share of the synergistic effect, while forwarders capture the smallest portion. Interestingly, certain request flow parameter combinations can lead to negative shares of the synergistic effect for one or more participants. This phenomenon can be attributed to situations where a specific participant experiences negative effects when servicing a request that is deemed optimal for the entire delivery chain.

The findings of our research offer valuable guidance for optimizing logistics chains within the Kazakhstani market, and potentially other markets with similar characteristics. Ultimately, the results of this study go beyond the Kazakhstani context. They offer a broader contribution by demonstrating how to maximize economic efficiency within logistics chains through a focus on collaboration and the equitable distribution of synergistic benefits. This knowledge can empower stakeholders across the logistics industry to make informed decisions when configuring their supply chains.

Future research efforts can be directed towards a more comprehensive understanding of the factors influencing the distribution of the synergistic effect. This could involve investigating the impact of additional demand parameters beyond those explored in this study. For instance, factors such as order frequency, delivery time windows, and shipment urgency could be examined to determine their influence on the share of the synergistic effect for each participant type. Additionally, expanding the scope of the analysis to encompass a broader range of alternative logistics chain structures would be valuable. This could be achieved by incorporating a more detailed consideration of the technological processes performed by various entities within the chain. By analysing how these processes interact and contribute to the overall efficiency, researchers could gain deeper insights into how different chain structures influence the generation and distribution of the synergistic effect.

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