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Selecting a Rational Scheme of Delivery by Road Transport: A Case Study of Goods Deliveries from China to Russia through Kazakhstan

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Abstract: Road transport is in most cases the only available transport option in rural regions with undeveloped railway infrastructure. The problem of choosing the structure of the logistics chain is one of the most important ones that forwarding companies must solve when planning freight transportation. Due to political peculiarities, transportation of goods by road through the territory of Kazakhstan must be carried out by national forwarders, which results in centralizing the decision-making process and shifting the tasks of designing the structure of supply chains to the Kazakh forwarding companies. In this paper, we develop a mathematical model to solve the problem of choosing the right structure for a logistics chain. The proposed model considers the existing legal constraints in the region. Based on a simulated demand for cargo deliveries from China to Russia, we use a numerical example to show how to justify the structure of the logistics chain characterized by minimal total costs of the companies involved in the delivery process.

Keywords: road transport deliveries; logistics chain structure; parameters of demand for deliveries; total logistics expenses

1. Introduction

The movement of goods is one of the foundations for the development of commodity–money relations. Freight transport is a complex process that unites numerous governmental and commercial structures, specialists, and transport facilities. International transport is characterized by the fact that the places of origin and destinations are located in different countries. When delivering goods, it may be necessary to cross several borders, which in turn entails the need to obtain appropriate permits and go through numerous formal procedures.

The traditional scheme of truck transportation from China to Russia through Kazakhstan is as follows. The truck enters Kazakh territory and moves to a transport terminal. According to the Kazakh and Chinese agreements, the countries do not need to have entry and exit permits. For this reason, Chinese carriers can only go to certain places on Kazakh territory. The same applies to Kazakh carriers on Chinese territory. Chinese vehicles cross the border without restrictions and arrive at a terminal near the border for transshipment into a vehicle of a Kazakh carrier. China uses all available legal means to prevent the transit

of foreign (including Russian) shipments through Kazakh territory; therefore, goods on the Kazakhstan–Russia route are delivered mainly by Kazakh carriers.

This study aims to propose a methodology that allows practitioners and researchers to choose the most effective logistics chain structure based on basic numerical demand parameters—delivery distance and shipment weight. The substantiation of the most effective structure of the delivery chain for the given consignment allows for reducing the relatively unproductive delivery operations, leading to the decrease in the total distance covered by vehicles and enhancing the quality of services provided by transportation companies. The minimization of the total delivery distance and waiting time during the loads delivery contributes to the sustainable development of the transportation system in the region by fulfilling the key sustainability concept—minimizing the resources used to produce the goods or perform the service.

The novelty of the proposed methodology lies in its approach to defining the efficiency criterion as the total expenses per unit of transportation work completed. Unlike the conventional criterion to evaluate the efficiency of the logistics chain—the total expenses of all the entities involved in the delivery process—the proposed indicator considers the utility of the completed operations per each unit of the provided services. That allows for more precise estimation of the areas of the most efficient use for alternative structures of logistics chains. Additionally, the proposed simulation model considers the set of technological parameters as stochastic variables, which enhances the adequacy of the estimations obtained as the simulation results.

This paper is structured as follows: the introduction is followed by a brief review of recent scientific literature related to the subject of the paper; the third part describes in detail the proposed methodology for estimating the efficiency of a delivery scheme; the fourth section contains the numerical results for two alternative schemes of freight delivery by road transport, using China–Kazakhstan–Russia as an example; and the last part contains brief conclusions and directions for future studies.

2. Review of Recent Literature

Multimodal transport, i.e., the combination of different modes in a transport chain, is a key element of modern logistics systems, especially for long-distance cross-border transport. It can be a cost-efficient and environmentally friendly alternative to unimodal transport [1]. Based on the results of a survey [2], a vehicle cost simulation attributed 7% of transport costs to congestion, which increases the attractiveness of multimodal transport and other solutions. The multimodal model has been used to select alternative routes using various factors such as transportation cost, transfer cost, transit time, transportation distance, document fees, port congestion surcharges, customs fees, and trust index in research [3]. The work in [4] aims to develop a solution framework for large-scale planning problems through a novel multimodal stochastic model to help decision-makers to create a desirable plan for China–Europe routes. The research streams on deterministic and stochastic models for multimodal transportation (including uncertain demand, transportation time, cost, and capacity) are compared in [1]. In [5], a multicriteria framework for multimodal transportation efficiency evaluation is combined with order relation analysis and an entropy-weighted analytical fuzzy hierarchy process method to evaluate route performance under different multimodal transportation systems.

Intermodal medium and long-distance transport has been strongly promoted by the European Commission and national governments as a solution to ensure the sustainability of the freight transport sector. In [6], a modified model of network data envelopment analysis is presented to measure the performance of intermodal freight transport chains and to identify the sources of inefficiencies. In [7], an approach is proposed to estimate changes in the reliability of the transportation time in an intermodal transportation chain due to the changes in the structure of this chain. The authors of [8] present a methodology to evaluate constraints in logistics chains with intermodal transportation. In [9], the functions and the role of intermodal terminals in the delivery of intermodal units along international

transport corridors are discussed. However, so far, it has been shown that intermodal transport can only compete with road transport to a limited extent.

The Belt and Road Initiative (BRI) is defined as a massive and long-term project initiated by the Chinese government with the participation of many other countries to facilitate trade and improve logistics to promote global economic development. The paper [10] highlights the supply chain and logistics innovations associated with the BRI project. These innovations include new routes and modes for global trade, new supply chain design, and reducing cross-border logistical frictions. Container transport has become an important part of global transportation and could [11] gain new potential considering the BRI. It is expected that the development of the BRI will lead to a significant shift of container transport from sea to rail (intermodal). The authors of [12] additionally explore the potential of the Belt and Road economic corridors as alternative trade routes between China and Europe.

Nowadays, goods can be transported from China to Russia by any means of transport—ship, plane, train, or car. The problem is to choose an option that stands out for economic feasibility, convenience, or timesaving in transportation.

Sea transport remains the most widely used and most demanded method of transporting goods from China. The reason for that is a large proportion of Celestial Empire manufacturers are concentrated in the eastern and southeastern regions, close to major maritime hubs. In addition, Chinese authorities are paying attention to the development of maritime trade routes. Based on the theory of interacting processes, the authors of [13] examine various options for export–import transportation routes via seaports and land border crossings.

Airfreight shipments from China are used for the fast transportation of goods. Airfreight is critical to the modern supply chain as it enables efficient and timely delivery [14]. The study of [15] discusses the situation of China's air cargo sector in the face of the pandemic COVID-19 and suggests strategies for Chinese air cargo providers to adapt to the pandemic. However, the study in [16] acknowledges that large scale transportation, such as container ships and cargo planes, does not always positively involve the competitiveness of the logistics industry.

Shipping from China to Russia by rail is conducted in containers or wagons. The undoubted advantage of container transport by rail is that no additional reloading operations are required directly for the cargo. The corresponding characteristics of the central and the North Eurasian railway corridor from China to the European Union are estimated in [17].

Two main routes have been developed simultaneously with different intensities:

- Loaded containers are sent to Manchuria along the Harbin railway, through border crossings to Zabaikalsk, and further along the route of the Trans-Siberian Railway to the destination points;
- Delivery of goods from China via Kazakhstan is the alternative to rail freight transport Manchuria–TransSib.

Considering basic economic indicators, the China–Kazakhstan–Russia rail route seems very promising as it is much shorter than the Trans-Siberian Railway. However, due to the underdeveloped infrastructure of Kazakhstan's railways, it is not yet very popular compared to road transport deliveries.

The current state of transport infrastructure and the development of the logistics systems in Kazakhstan are discussed in the following papers: [18–20]. The article [18] deals with the current state of transport infrastructure of the Republic of Kazakhstan and its integration into the international network and refers to the further development of transport and logistics infrastructure as a catalyst for the economy. The study of [19] discusses problems and obstacles to the development of the country's logistics system and ways to solve them, and also conducts an analysis of the country's logistics capacity. In [20], it is noted that despite the rapid process of Kazakhstan's integration into the global logistics system, the stages of ex-post evaluation and mechanisms for optimizing the transport and environmental risks of international corridors have not yet been developed, considering

their impact on the development of regions involved in transit. The authors of [21] deal with the evaluation of the socio-economic impact of transport projects depending on the budget and the economic characteristics of the project. The importance of considering the reliability of infrastructure in the selection of trade routes is highlighted in [12].

Vehicle transit through Kazakhstan seems to be a more attractive delivery alternative. This is not only because the route passing through the territory of the eastern EurAsEC partners is shorter compared to a Trans-Siberian "bypass route"; In addition, the condition of the Trans-Baikal and Siberian transport arteries leaves a lot to be desired. Based on the Box–Cox approach, in the study in [22], several elasticities of freight demand for road, barge, and rail transport about a change in the total cost of transport, transit time, and speed are presented.

The problems of the organization of freight transport processes in the Republic of Kazakhstan (but without the deliveries of goods from China to Russia) were considered and solved by the authors of the following works: [23,24].

The wide range of simulation-based approaches to improve the performance of logistics systems are described in the literature [25–28]. The common method of improving the transportation system's efficiency is to optimize the technological operations in the multimodal transport hubs [28–30], but the approaches to optimizing operations for the whole delivery chain [26,31–34] are also used as the solutions.

The popular methodology for simulating the servicing process within the transport system is the use of Petri nets [29,30,32]; such models allow for the considering of discrete stochastic states of the logistics system and yield resulting indicators that describe distributions for durations of technological operations as stochastic variables. The simulation results obtained with Petri-net-based models can be used for estimating the indicators that characterize the efficiency of a logistics system. A wider range of random parameters can be considered when using tailor-suit simulation models (e.g., the models described in [26] and [28]); these models simulate technological processes with a given level of detail without the necessity of the use of standard logic (as is conditioned by the Petri nets) but provide the implementation of specific processes.

3. Proposed Methodology

We propose to perform the choice of the logistics chain structure out of a set of alternatives by using the decision scheme pictured in Figure 1: for the single run of the simulation model, the logistics chain structure, the demand characteristics, and the numeric parameters of the servicing process are provided as the input parameters, the efficiency criterion characterizing the result of delivery for the given input data is considered as the output of the simulation.
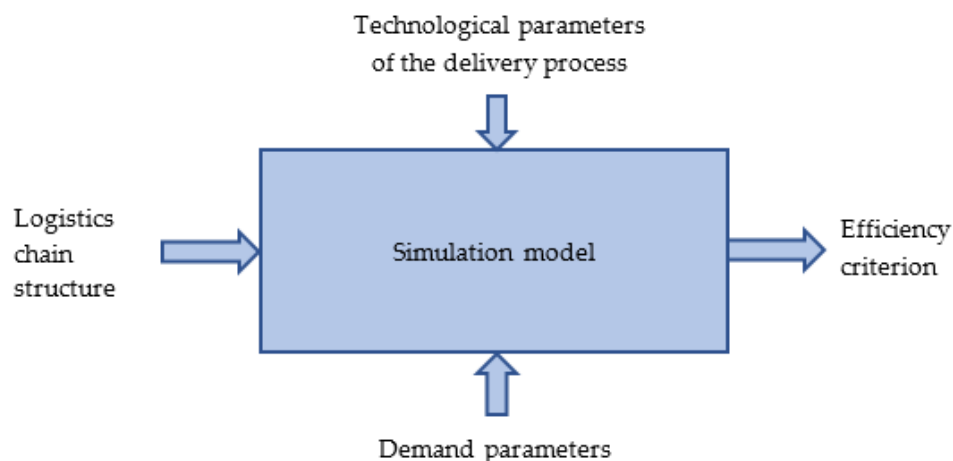

Figure 1. The problem of choosing the structure of a logistics chain.

It should be noted that because the demand parameters and characteristics of the technological process are stochastic, the result of simulations will be random as well. The best structure of the logistics chain that fits the provided variables characterizing the demand parameters should be selected based on the average value of the efficiency criterion. However, to evaluate the mean value of the resulting indicator, a sufficient number of model runs should be performed. For this, the number of observations must be justified for the given level of statistical significance.

As the demand parameters, the following numeric indicators must be considered:

- The consignment weight Q [t];
- The total delivery distance L [km].

As stochastic variables characterizing the servicing process, we propose to consider the following set of technological parameters:

- The durations of searching operations performed to find third-party companies that participate in the delivery process—$\widetilde{t}_{sC}$ for carriers, $\widetilde{t}_{sFT}$ for freight terminals, and $\widetilde{t}_{sFF}$ for other partner forwarders [h];
- The total duration of loading and unloading operations $\widetilde{t}_{sLU}$ [h];
- The durations of loading and unloading operations per 1 t of cargo in a consignment: $\widetilde{t}_t^L$ for loading and $\widetilde{t}_t^U$ for unloading [h/t];
- The time needed to form a transport package $\widetilde{t}_{cont}$ [h/unit];
- The average speed of a vehicle $\widetilde{V}$ [km/h];
- The duration of downtime at a customs point $\widetilde{t}_{cust}$ [h];
- The durations of loading and unloading operations per 1 t of cargo in cases when the freight terminal facilities are used—$\widetilde{t}_t^{TL}$ for loading and $\widetilde{t}_t^{TU}$ for unloading [h/t];
- The per-unit duration of unpacking and packing operations $\widetilde{t}_h^{pack}$ [h/t];
- The time of intermediate storage of cargo at the warehouse of a terminal $\widetilde{t}_{store}$ [h].

As the efficiency criterion for selecting the delivery scheme *LC*, we propose to use the total logistics expenses per ton-kilometer E [KZT/tkm] defined in the following way:

$$E(LC) = \frac{1}{Q \cdot L} \cdot \left(E_{FO} + \sum_{i=1}^{N_{FF}} E_{FF(i)} + \sum_{i=1}^{N_{FT}} E_{FT(i)} + \sum_{i=1}^{N_C} E_{C(i)} \right) \rightarrow \min, \tag{1}$$

where E_{FO} are expenses of a freight owner [KZT],

$E_{FF(i)}$ are expenses of the *i*-th forwarding company participating in the delivery scheme [KZT],

$E_{FT(i)}$ are expenses of the *i*-th cargo terminal used within the delivery [KZT],

$E_{C(i)}$ are expenses of the *i*-th carrier that delivers a consignment [KZT],

N_{FF}, N_{FT}, and N_C are the numbers of freight forwarding companies, freight terminals, and carriers involved in the process of a consignment delivery.

Following the accepted efficiency criterion, its main partials are the expenses of the corresponding subjects involved in the delivery process [34]. It should be noted that the consignment numeric parameters considered in Equation (1) are the basic characteristics of a flow of requests for deliveries [35].

According to the methodology described in [34], possible cost items for a freight forwarder as an organizer of the delivery process are the following:

- Costs of finding a client E_{search}^{FF} [KZT];
- Costs related to the preparation of transport documentation E_{doc}^{FF} [KZT];
- Costs of finding carriers, other partner forwarders (if needed), or outsourcing organizations (if needed) E_{just}^{FF} [KZT];
- Costs of the organization and implementation of loading and unloading operations E_{LU}^{FF} [KZT];
- Costs of the services provided by carriers E_C^{FF} [KZT];

- Expenses for services provided by outsourcing organizations (if such are involved) E_{FT}^{FF} [KZT];
- Customs payments (if applied—in case of international deliveries) E_{cust}^{FF} [KZT].

    A carrier, providing transportation services, has the following costs:

- Direct costs of delivery operations E_{tr}^{C} [KZT];
- Costs of idle time during loading and unloading operations E_{LU}^{C} [KZT];
- Costs of vehicle's idle time in the customs point E_{cust}^{C} [KZT].

    Freight terminals involved in the delivery chain are characterized by the following costs:

- Costs of loading and unloading operations E_{LU}^{FT} [KZT];
- Costs of the formation and disbandment of transport packages (if such services are performed) E_{pack}^{FT} [KZT].
- Costs of storage operations (if performed) E_{store}^{FT} [KZT].

    It should be noted that tax deductions may be applied for the delivery chain entities that provide services—forwarders, carriers, and freight terminals.

    The basic types of delivery-associated costs for freight owners are:

- Cost of the preparation of a transportation unit E_{pack}^{FO} [KZT];
- Losses due to withdrawal of funds that present the value of goods to be delivered E_{loss}^{FO} [KZT];
- Expenses of the forwarders' services E_{FF}^{FO} [KZT].

    Below, we define the methodology of calculating the costs of entities involved in the process of a consignment delivery.

    Costs of finding a customer, E_{search}^{FF}, can be defined as the forwarding company's expenses for completing the searching procedures by dispatchers:

$$E_{search}^{FF} = s_h^{FF} \cdot t_{search} \cdot N_d^{FF}, \tag{2}$$

where s_h^{FF} is the cost of an hour of a dispatcher's operation [KZT/h],

t_{search} is the mean time spent by a dispatcher while searching for a customer [h/dispatcher],

N_d^{FF} is the total number of dispatchers providing the servicing process [dispatchers].

    The cost of a dispatcher's operation can be estimated based on the total monthly costs, defined as the sum of office rental costs, communal payments, expenses for communication services (services of Internet providers, telephony, services of logistics portals, etc.), costs of banking services, depreciation for office equipment, and the gross salary of a dispatcher.

    The costs, E_{doc}^{FF}, of a forwarder for preparation of documents associated with the consignment delivery process can be determined similarly to the approach presented in Equation (2):

$$E_{doc}^{FF} = s_h^{FF} \cdot t_{doc}, \tag{3}$$

where t_{doc} is the average time spent by a dispatcher while preparing accompanying documentation [h].

    The costs, E_{just}^{FF}, of substantiating the expedient delivery scheme structure and searching for contractors can be defined based on the cost of an hour of a dispatcher's operation and the duration of searching operations:

$$E_{just}^{FF} = s_h^{FF} \cdot \left(t_{just} + \tilde{t}_{sC} + \tilde{t}_{sFT} + \tilde{t}_{sFF} \right), \tag{4}$$

where t_{just} is the average time needed for the substantiation of the decision regarding the structure of the delivery scheme [h].

    The costs, E_{LU}^{FF}, of the organization by a forwarder of loading and unloading operations can be defined as follows:

$$E_{LU}^{FF} = s_h^{FF} \cdot \tilde{t}_{sLU} + P_{LU}, \tag{5}$$

where P_{LU} is the costs of services provided by contractors for loading and unloading operations [KZT]:

$$P_{LU} = Q \cdot \sum_{i=1}^{N_{LU}} T_{t\,i}^{LU}, \tag{6}$$

N_{LU} is the number of completed loading and unloading operations [operations],

$T_{t\,i}^{LU}$ is the average tariff for the *i*-th operation [KZT/t].

If the weighted average tariff per ton-kilometer for carriers' services, $\overline{T}_{tkm}^{C}$, is used, the costs, E_{C}^{FF}, of carrier services can be determined in the following way:

$$E_{C}^{FF} = Q \cdot L \cdot \overline{T}_{tkm}^{C}. \tag{7}$$

The costs, E_{FT}^{FF}, of freight terminal services are determined based on tariffs for a consignment servicing:

$$E_{FT}^{FF} = Q \cdot \sum_{i=1}^{N_{FT}} \sum_{j=1}^{N_{ser}^{FT_i}} T_{ser\,j}^{FT_i}, \tag{8}$$

where $N_{ser}^{FT_i}$ is the number of types of services that are provided by the *i*-th terminal [services],

$T_{ser\,j}^{FT_i}$ is the tariff for the *j*-th type of service provided by the *i*-th terminal [KZT/t].

The amount, E_{cust}^{FF}, of customs payments, made by a forwarder on behalf and at the expense of a freight owner, is determined based on the consignment value:

$$E_{cust}^{FF} = 0,01 \cdot Q \cdot c_t \cdot \left(\delta_{cust} + \delta_{imp} \right), \tag{9}$$

where c_t is the value per 1 t of goods [KZT/t],

δ_{cust} and δ_{imp} are the rates of customs and import duties [%].

The costs, E_{pack}^{FO}, of forming a transport package include the cost of maintaining the means of packaging (pallets, containers), labor costs for personnel involved in the preparation of transport packages, and the cost of packaging materials (packing tape, cellophane, etc.):

$$E_{pack}^{FO} = \left\rceil \frac{Q}{q_{cont}} \right\lceil \cdot \left(\tilde{t}_{cont} \cdot s_h^{FO} + c_{pack} + k_{turn} \cdot c_{cont} \right), \tag{10}$$

where q_{cont} is the nominal carrying capacity of a shipping container [t],

s_h^{FO} is cost of 1 h of work of an employee who forms transport packages (including the cost of work of special mechanisms, if such are used) [KZT/h],

c_{pack} is the cost of packaging materials [KZT/unit],

c_{cont} is the cost of the shipping container [KZT/unit],

k_{turn} is the coefficient that considers the turnover of shipping containers (see the detailed interpretation in [34]).

The costs, E_{FF}^{FO}, of a freight owner's payment for the services of a freight forwarding company are the costs of contractor services paid by the freight forwarder on behalf of the freight owner, as well as the costs of directly paid-for forwarding services:

$$E_{FF}^{FO} = P_{LU} + E_{C}^{FF} + E_{FT}^{FF} + E_{cust}^{FF} + P_{FF}, \tag{11}$$

where P_{FF} is the cost of freight forwarding services [KZT]:

$$P_{FF} = \left(E_{search}^{FF} + E_{doc}^{FF} + E_{just}^{FF} + E_{LU}^{FF} - P_{LU} \right) \cdot (1 + R_{FF}), \tag{12}$$

R_{FF} is the profitability level of a freight forwarder.

The financial loss, E_{loss}^{FO}, of a freight owner due to the freeze of funds constituting the value of goods in a consignment can be estimated as follows:

$$E_{loss}^{FO} = \frac{Q \cdot c_t \cdot \alpha \cdot t_d}{365 \cdot 24 \cdot 100}, \tag{13}$$

where t_d is the total time of a consignment delivery [h],

α is the coefficient considering losses due to freezing of funds during the delivery of a shipment [%/year].

The carrier's costs, E_{tr}^{C}, of consignment's transport are usually defined based on constant and variable components of costs. If the travel time is determined based on the average speed of a vehicle, the transportation costs may be presented as follows:

$$E_{tr}^{C} = L \cdot \left(\frac{s_h^C}{\tilde{V}} + s_{km}^C \right), \tag{14}$$

where s_h^C and s_{km}^C are constant and variable components of transportation costs, [KZT/h] and [KZT/km].

The costs E_{LU}^{C} of a carrier for the vehicle downtime during loading operations are determined based on the constant component of transportation costs:

$$E_{LU}^{C} = s_h^C \cdot Q \cdot \left(\tilde{t}_t^L + \tilde{t}_t^U \right). \tag{15}$$

The costs, E_{cust}^{C}, for downtime at a customs point can be estimated in a similar way:

$$E_{cust}^{C} = s_h^C \cdot \tilde{t}_{cust}. \tag{16}$$

The terminal's costs, E_{LU}^{FT}, associated with the consignment transshipment can be determined by using the formula:

$$E_{LU}^{FT} = s_{h(LU)}^{FT} \cdot Q \cdot \left(\tilde{t}_t^{TL} + \tilde{t}_t^{TU} \right), \tag{17}$$

where $s_{h(LU)}^{FT}$ is the cost of 1 h of technological operations associated with the shipment of consignments [KZT/h].

The expenses, E_{pack}^{FT}, of a freight terminal associated with the packaging operations can be defined as follows:

$$E_{pack}^{FT} = Q \cdot s_{h(pack)}^{FT} \cdot \tilde{t}_h^{pack}, \tag{18}$$

where $s_{h(pack)}^{FT}$ is the cost of 1 h of packaging operations [KZT/h].

The costs, E_{store}^{FT}, of a terminal for intermediate storage can be presented based on the unit cost of 1 h of storage per 1 t of cargo to store:

$$E_{store}^{FT} = Q \cdot s_{th}^{FT} \cdot \tilde{t}_{store}, \tag{19}$$

where s_{th}^{FT} is the cost of 1 h of storage per 1 t of loads [KZT/(t·h)].

Tax deductions for entities participating in the delivery chain should be calculated for two basic types of taxes—value-added tax and income tax.

The amount of value-added tax is estimated considering costs of services provided by third-party enterprises:

$$VAT = \frac{\delta_{VAT}}{100 + \delta_{VAT}} \cdot \left(IC - E_{paid} \right), \tag{20}$$

where δ_{VAT} is the rate of the value-added tax [%],

IC is the income of the delivery chain entity [KZT],

E_{paid} is the cost of services and goods purchased by the enterprise from third-party entities and included in its operating costs [KZT].

The income tax amount is determined based on the positive value of the company's net profit and income tax rate:

$$PT = 0.01 \cdot \delta_{PT} \cdot NP, \tag{21}$$

where δ_{PT} is the rate of an income tax [%],

NP is the net profit obtained as a result of servicing the delivery request [KZT]:

$$NP = IC - E_{total} - VAT + \frac{\delta_{VAT}}{100 + \delta_{VAT}} \cdot E_{paid}, \tag{22}$$

E_{total} is the total operating costs of an enterprise [KZT].

The income of a forwarding company is the amount paid by the freight owner as a reward for the forwarding services: $IC_{FF} = P_{FF}$. Revenues of terminals and carriers are the corresponding amounts paid to them as to contractors by the freight forwarder: $IC_{FT} = E_{FT}^{FF}$, $IC_C = E_C^{FF}$.

When delivering the goods, a carrier pays the costs of fuel and lubricants, as well as the costs of maintenance and repair of vehicles; these expenses already include value-added tax. Thus, these cost items represent a variable component of the transportation costs, so the costs of third-party services, E_{paid}^C, paid by a carrier can be defined as:

$$E_{paid}^C = s_{km}^C \cdot L. \tag{23}$$

The costs of third-party services are included in the forwarder operation costs. These services include office rent expenses, E_{rent}^{FF}; costs of utilities, E_{cs}^{FF}; and banking services, E_b^{FF}; as well as communication services' costs, E_{com}^{FF}. Thus, the cost component $s_{h(paid)}^{FF}$ can be calculated as follows:

$$s_{h(paid)}^{FF} = \frac{1}{T_{month}} \cdot \left(E_{rent}^{FF} + E_{com}^{FF} + E_{cs}^{FF} + E_b^{FF} \right). \tag{24}$$

Then the amount, E_{paid}^{FF}, paid by a forwarding company to third-party organizations can be calculated as the average interval between requests in a flow:

$$E_{paid}^{FF} = s_{h(paid)}^{FF} \cdot I, \tag{25}$$

where I is the mean time interval between consecutive requests for deliveries [h].

Similarly, the costs of services provided by a freight terminal include the cost of purchased services and goods, which may contain fuels and lubricants, utilities, communication services, etc. We may assume that the share, δ_{paid}^{FT}, of these components in the self-cost value is constant. Based on this assumption, the costs, E_{paid}^{FT}, of services paid to third-party organizations can be assessed in the following way:

$$E_{paid}^{FT} = Q \cdot \delta_{paid}^{FT} \cdot \left[s_{h(LU)}^{FT} \cdot \left(\tilde{t}_t^{TL} + \tilde{t}_t^{TU} \right) + s_{h(pack)}^{FT} \cdot \tilde{t}_h^{pack} + s_{th}^{FT} \cdot \tilde{t}_{store} \right]. \tag{26}$$

The total operating costs, E_{FF}, of a freight forwarder include the cost of finding a client, justifying the delivery scheme structure and finding its participants, preparing customs and transport documentation, and organizing loading and unloading operations:

$$E_{FF} = E_{search}^{FF} + E_{just}^{FF} + E_{doc}^{FF} + E_{LU}^{FF} - P_{LU}. \tag{27}$$

The operating costs, E_{FT}, of a terminal include the costs of the consignment transshipment and the formation and dismantling of transport packages, as well as the consignment intermediate storage:

$$E_{FT} = E_{LU}^{FT} + E_{pack}^{FT} + E_{store}^{FT}. \tag{28}$$

Accordingly, for the carrier, the total operating costs, E_C, include the costs of movement operations, as well as expenses for downtime of vehicles during loading and unloading operations and at the customs point:

$$E_C = E_{tr}^C + E_{LU}^C + E_{cust}^C. \tag{29}$$

As far as the presented methodology refers to a set of stochastic variables representing technological operations (such as the vehicle speed and durations of operations), its use in real-world conditions is possible only if it is implemented as dedicated software. The corresponding program code was implemented in C# programming language; the source code can be forked from the repository at https://github.com/naumovvs/delivery-chain-simulation (accessed on 15 April 2022).

4. Case Study and Discussion

To illustrate the developed methodology of choosing the efficient delivery scheme, we consider two alternative structures described in [34]—a 1T structure and 2T structure (see Figures 2 and 3).
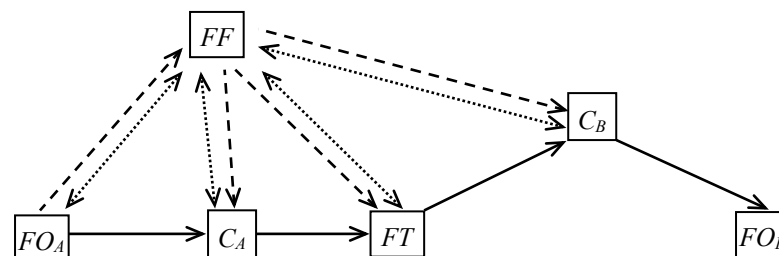

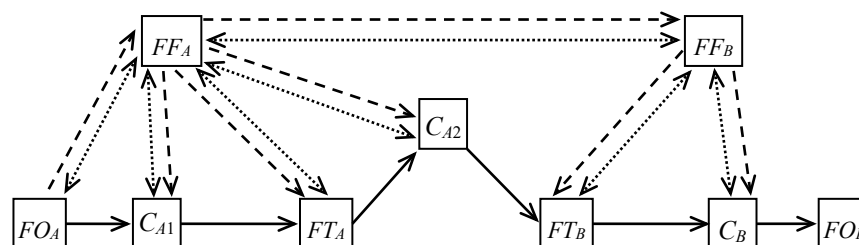**Figure 2.** Structure of the 1T delivery scheme.

Figure 3. Structure of the 2T delivery scheme.

The interactions of the companies within the 1T supply chain are as follows. A freight forwarder, FF, receives the delivery order from the freight owner, FO_A, and assesses the desirability of shipping via the freight terminal, FT. If this option is economically feasible, the forwarder searches for carriers, C_A and C_B, to provide delivery to the terminal and then to the end customer, FO_B. After the forwarder has determined the appropriate delivery scheme, bilateral agreements should be signed between the companies involved in the delivery process. The forwarding company pays for the services of the outsourcing companies, the forwarders and the freight terminal.

In the case of the 2T delivery scheme, the cargo owner, FO_A, notifies the freight forwarder of his need for the delivery of cargo. Upon receipt of the request, the freight forwarder, FF_A, examines the expediency of applying the 2T delivery scheme. If the result of the check is positive, the forwarder selects the carrier C_{A1} for delivery of the shipment to the freight terminal, FT_A, makes an agreement with the main carrier C_{A2}, and sends the request to a partner freight forwarder, FF_B. The partner freight forwarder arranges delivery of the shipment from the terminal, FT_B, located in its region to the end customer, FO_B. For this purpose, the forwarder, FF_B, finds the carrier C_B. The forwarder who arranged the delivery pays for the services of carriers C_{A1} and C_{A2}, covers the costs of the freight

terminal, FT_A, and pays the forwarder, FF_B. The freight forwarder, FF_B, in turn covers the costs of the services of the terminal, FT_B, and the carrier C_B.

For the purposes of the simulation experiment, the described delivery schemes were considered the basic alternative structures of the logistic chains in cases of road transport deliveries between China and Russia through the territory of Kazakhstan.

The average market values (at the time of December 2021) were accepted for the price indicators, and the tax rates that are in force in the territory of the Kazakh Republic were applied to evaluate the efficiency criterion. For all the random variables (both groups of the demand parameters and the technological characteristics) normal distribution was used to generate the corresponding values.

For each series of the simulation experiment, 100 runs of the model were performed with the constant values of the averages for demand parameters—the consignment weight and the delivery distance. The mean values of the consignment weight were considered in the range between 30 and 100 t with the step of 10 t, and the average delivery distance was in the range from 300 to 1900 km with the step of 200 km. As a result, 72 series were performed within the simulation experiment for each of the considered structures of a logistics chain. The simulation time for each of the series was in the range between 2.3 and 2.5 s for the 1T structure and in the range between 2.4 and 2.8 s for the 2T structure of a delivery chain at the computer with an Intel Core i7 processor and 16 Gb of random-access memory.

The normal distribution of the efficiency criterion was confirmed in each of the experiment series by using the Kolmogorov–Smirnov test: the hypotheses about the normal distribution were not rejected in any of the series for the significance level of 5%. Because the resulting indicator is normally distributed, the statistically significant number of observations was estimated in each of the experiment series to prove the significance of the obtained results. The number of the simulation model runs that ensure the significance level of 5% were observed in the range between 12 and 25 observations, which is less than the number of the completed 100 runs per series. That allows us to state that the experiment results are statistically significant with the probability of confidence equaling 95%.

The analysis of the functional dependencies between the mean values of the efficiency criterion and average values of the demand parameters has shown that the areas of efficient use of the delivery scheme structures may be distinguished. For the datasets of the experiment results, shown in Figures 4 and 5, at a certain point the preference in choosing the delivery scheme changes: for the consignment weight in Figure 4, the 1T scheme is cheaper when the demand parameter is under 42.78 t, and for the delivery distance in Figure 5, the 1T scheme is a preferable option in cases of deliveries on distances shorter than 801 km.
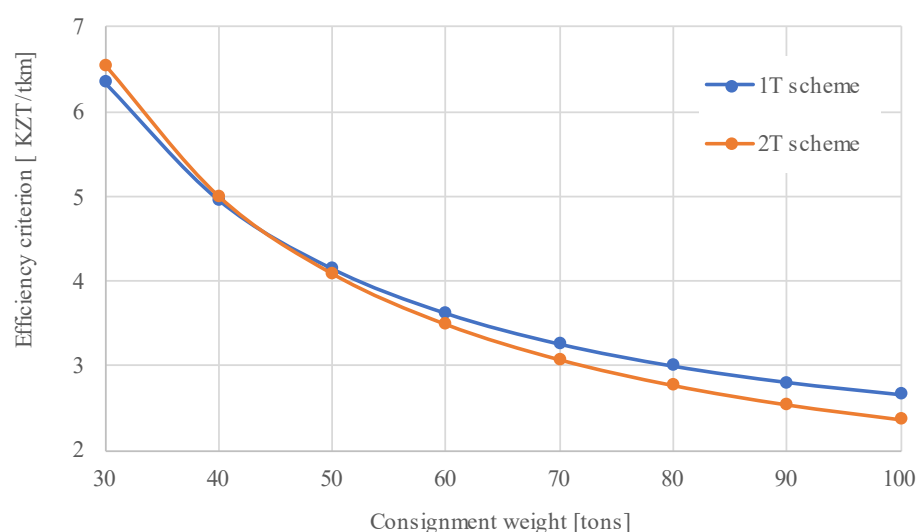

Figure 4. Dependence of the efficiency criterion on the average consignment weight (the mean delivery distance is 700 km).
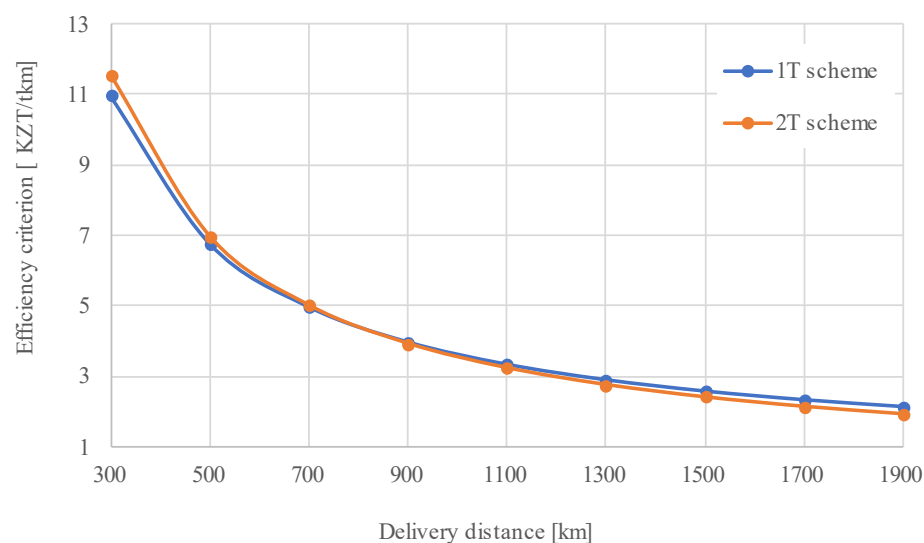
Figure 5. Dependence of the efficiency criterion on the average delivery distance (the mean consignment weight is 40 t).

We have compared the obtained results for the areas of the most efficient (preferable) use of the delivery chain structures with the common approach to evaluating the logistics chain efficiency based on the total expenses of all the participants (e.g., the approach that was described in [36]).

If the total expenses are used as the efficiency criterion for the data generated within the completed simulation experiment, the bounds for the areas of the preferable use are close to the values obtained for the proposed efficiency criterion. However, a difference may be observed: Figures 6 and 7 show the dependencies between the total expenses and the average values of the demand parameters calculated for the same datasets of input parameters that were used to present the dependencies in Figures 4 and 5. The lines in Figure 6 intersect when the average consignment weight equals 44.09 t, whereas the intersection point in Figure 7 corresponds to the average distance of 789 km.
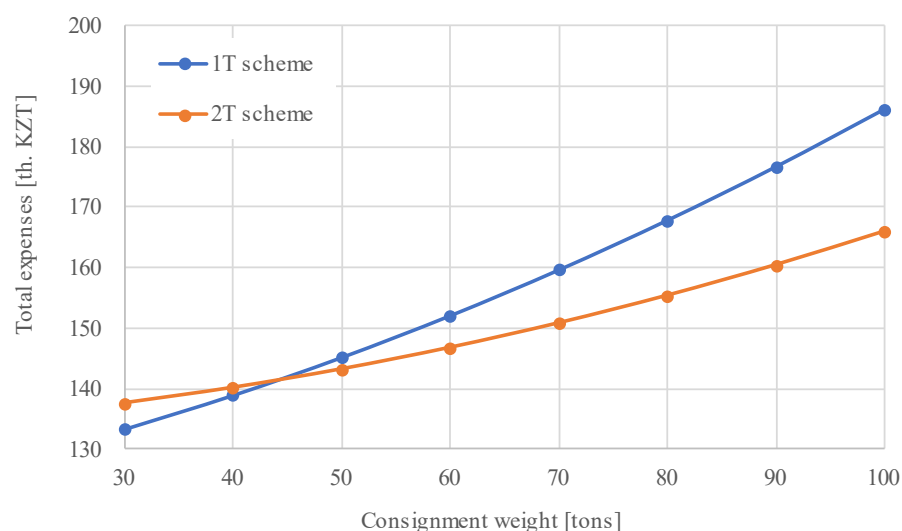

Figure 6. Dependence of the total expenses on the average consignment weight (the mean delivery distance is 700 km).
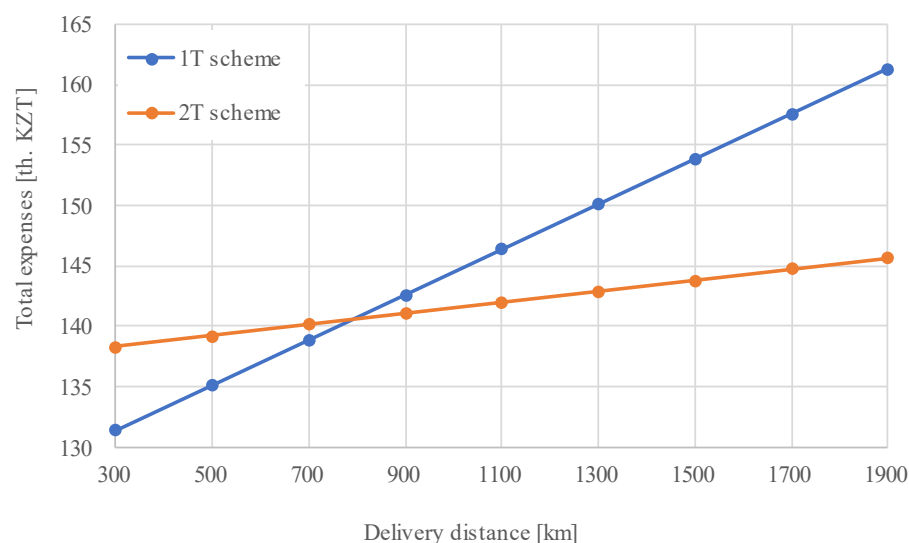
Figure 7. Dependence of the total expenses on the average delivery distance (the mean consignment weight is 40 t).

The observed differences in the areas of the preferable use of the logistics chain structures may provide evidence that the use of the proposed efficiency criterion allows researchers and practitioners a more precise estimation of the bounds for the use of alternative delivery schemes in terms of demand parameters. The difference in values of the area bound may be insignificant if compared with the parameter value; however, the costs savings obtained as a result of the proper scheme selection could be notable.

5. Conclusions

The selection of the optimal variant for the delivery of goods by road should be based on the minimum total cost of the parties involved in the delivery process—cargo owners, carriers, freight forwarders, and freight terminals. The total cost of the parties involved in the delivery process is functionally determined by the structure of the chain, the parameters of demand for transport services, and the parameters describing the impact of the chosen option on the external environment. The use of the efficiency criterion, which represents the logistics costs per unit of the completed transportation work, allows better precision in estimating the best logistics chain structure when the set of alterative structures is known.

Numerical results of the application of the proposed methodology to the conditions of freight deliveries by road transport have shown that the choice of a better delivery scheme depends on the parameters of a transport request: the shipment weight and the delivery distance. The performed simulation experiment has shown that the bound of the area of the preferable use for the 1T and 2T delivery schemes will be shifted when the proposed criterion is used to estimate the efficiency of the logistics chain: the bound for the consignment weight is shifted 1.31 t to the right, whereas the bound for the delivery distance is shifted 13 km the left. The use of the proposed methodology for evaluating the efficiency of the alternative logistics chain structure allows freight forwarders to save costs when choosing the delivery scheme for the given consignment characteristics in situations when the demand parameters are close to the equilibrium point.

As for directions of future research on this subject, the formation of a wider set of alternative delivery chain structures and justification of the areas of their effective use should be mentioned. The presented numerical results are case-dependent and refer to freight deliveries by road between China and Russia through the territory of Kazakhstan, so additional experimental studies are required to confirm the obtained regularities.

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