Determination of an Effective Supply Chain: Case Study for Delivering Products from the USA to Ukraine

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Abstract. The solution to finding optimal product delivery variants is always relevant. The best supply chain scheme choice is essential for long-distance transportation of specific cargoes, such as vehicles and spare parts. Therefore, the purpose of the study was to establish the dependence between the cost of delivery of automotive products on the technological and economic parameters of the provision of transport services. This approach made it possible to select the best supply chain option based on the minimum unit cost value during shipping vehicles and spare parts in containers from the USA to Ukraine. Improvement of operations determining the interaction of different kinds of transport, as well as achieving the optimal level of distribution of goods between them, allows the development of timely rational management decisions, significantly increasing the quality and efficiency of the supply chains. The study used mathematical modeling as the primary tool to achieve goals. The designed model includes several cost parameters that characterize specific conditions of certain transportation schemes. Unit cost values were compared to determine the most efficient option from the proposed ones. The most effective option is Supply Chain 3 because it has minimal values of unit costs in most tests of the experiment. The newly developed regression models give a universal mathematical tool by which researchers can choose an effective option of supply chains for delivering vehicles and their repair parts in containers. This approach can assess other distribution channels with the same or analog conceptions of route designing.

Keywords: Sustainable Supply Chain · Containers · Simulation · Regression Analysis

1 Introduction

The goods supply process on world markets is connected with performing a number of works, operations, and services, the complex of which will ensure effective goods distribution. Companies supplying goods from abroad must solve tasks that arise of

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preparing effective supply chains for servicing orders [1] in this situation. It is important for any customer of logistics services with significant demand for quality services at lower prices.

A reliable supply chain organization is formed using existing infrastructure elements of the transport network, considering risks and failures [2]. The resources must use more effectively, and the logistical system must build with the simultaneous use of various supplying sources and with using such delivery principles as “flexibility” and “just-in-time” [3] because this help to reduce failure risks and problems in supply chains.

The development of Ukraine’s economic ties with world trade leaders directly affects the creation of reliable supply chains. The United States is one of the promising markets for economic recovery and a reliable partner of our country. We can say that the United States ranks fifth [4] according to results analyzing importing goods cost by countries. The imports’ percentage from the United States reaches 11% of the total import volume of other countries. The most significant amount of goods are imported from the United States according to the Ukrainian commodity nomenclature of foreign economic activity – mineral fuel, oil, and its distillation products (30.4% of total imports from the United States to Ukraine), and in second place – land transport, except for rail, accounting for 21.5% of the total volume. The volume of vehicle imports increased by 36.4% [4] compared to the last year, 2021. All this suggests that demand will be restored in the post-war period, and this perspective direction for determining options of reliable supply chains will function more efficiently.

The need to develop new reliable systems for goods supply between countries should be based on the principles of Industry 4.0 [5], SMART solutions [6, 7], sustainable development of all kinds of transport [8], as well as on the definition of rational conditions for all participants in the supply chain [9]. Therefore, a promising object of research using mathematical simulation methods is determining an effective supply chain for automotive spare parts in containers from the United States to Ukraine.

The research aim is to determine the effective logistics chain for supplying automobile spare parts and automotive equipment in containers from the USA to Ukraine, considering possible options for organizing work and the advantages of existing routes when using various means of transport. The scientific novelty of the proposed research is concluded in new parameter sets that are used for designing regression models. This aspect allows the creation of more rational routing for delivery vehicles and their repair parts in containers.

2 Literature Review

It is difficult to underestimate the importance of supply chain innovation for effective operational management practices [10]. New supply chains designed using digital technologies give the most outstanding results [11]. Sustainability is fundamental in creating new logistical chains [12]. It creates an opportunity to form effective supply chain options based on a statistical analysis of demand data [13]. An integrated supply chain structure based on the hierarchical clustering triplet is also proposed to achieve sustainability, which is implemented by a leading furniture company [14] and in textile manufacturing [15].

Flexibility, resilience, and reliability as supply chain trends have become relevant strategies to address the current challenges of the digital world [16]. However, digitizing or adopting digital technologies in supply chain operations poses significant challenges such as coordination, tracking, and flexibility. On the other hand, initiatives such as Industry 4.0 are becoming industry-level trends, improving supply chain operations through high levels of transparency, control, dynamic network reconfiguration, and modernization provided by intelligent technology integration [17].

The actual supply chain management tasks are very complex, so the procedure for optimizing them requires significant computational resources due to the extensive size and uncertainty of their critical variables [18]. Simulation optimization is widely used to determine optimal variables because the problem is too complex [19, 20]. It is also worth considering the reliability of optimal solutions due to the uncertainty of real systems. The prediction characteristics of artificial neural networks compare with different structural settings in the article [21], and the authors propose to select the most appropriate networks for obtaining reliable solutions.

Designing a reliable multimodal supply network for products with various uncertainty sources is important while minimizing costs and risks [22]. The main aspect is achieving contradictory costs and risk estimates of significance for all supply chain participants. It is often necessary to create a system for product supply with numerous participants and constantly improve management [23, 24]. The flexibility of designed supply chains is highlighted by database preparation of the whole system for possible risk situations.

Planning the efficiency of container use has become more complicated due to the rapid development of the container transportation market in the world. It is particularly evident with an increase in the number of mega-container carriers operated by major container operators [25]. The authors of this article developed a model of a container transportation network that covers both the main route and a segment of coaster shipping, considering the sea container port as a hub. Ports have a crucial role in the container transportation system, especially in the main hubs of the continents – Asia (ports of China), North America (ports of the USA), and Europe (ports of the Netherlands and Germany) [26].

3 Research Methodology

The current, reliable conditions for functioning the supply system, which Ukraine seeks, require more attention to logistics, fast growth, and improvement. The efficiency and quality of supply chains significantly depend on actions optimization to coordinate the functioning of different kinds of transport, the optimal distribution of consignment sizes between them, and the timely formation of rational management decisions. Particular attention should be paid first to the two most important indicators of the transport process – the transportation cost and the timing of order implementation for the cargo delivery.

The United States ranks second in the world after China in terms of seaport quantity and first in terms of the total length of highways and railways. At the same time, real assets are not considered an advantage. Exclusive importance is attached to the management of information flows because industry leaders' efforts are concentrated on the technology of organizing collections, analysis, and decision-making. That's why it gives good results. For example, Baltimore receives almost one and a half million containers yearly as the most efficient US port. The port handles ships of 14,000 containers (TEUs) and up to 9,000 trucks [27].

Some essential features of the American transportation market should be considered when planning and organizing the delivery of containers from the United States to Ukraine because ignorance of them can lead to curious but expensive situations. There are, for example, other norms of lengths, weights, and another norm of load on the axis (all about 20% more than in Ukraine or Europe) in the USA. There are also no height restrictions on the railway and, basically, "53 ft" containers for transporting goods are used, and not the usual "20 ft" and "40 ft" (through the use of powerful diesel traction on railways, which allows you to transport "53 ft" containers in 2 rows).

The port of New York and the port of Houston are the main ports for designing supply chains of cargo in containers, including automobiles, from the United States. Ports of destination are in Ukraine - the port of Odesa, and in the European Union - the port of Klaipeda (Lithuania) (Fig. 1). Thus, interaction schemes of participants in the cargo delivery process in containers are formed based on existing lines of maritime transport (Table 1).

Fig. 1 Container supply chain options from the USA to Ukraine

Unit costs to unit cargo weekly delivery is proposed as a selection parameter of the effective supply chain of the n-th type – C_u^n, which is influenced by: automobile orders intensity – I_{or}; cargo supply time – T_d; cargo order volume – Q_{or}; transportation distance in a certain section of the corresponding kind of transport – L_{sh}; the cost of a particular service – S_c.

$$C_u^n = f(I_{or}, T_d, Q_{or}, L_{sh}, S_c), n = 1, ..., N \quad (1)$$

The mathematical model for determining the effective supply chain has been formed to achieve the goal set in the article

$$C_u^n = \frac{\sum_{i\in K} C_{l(ul)i}^{cont} + \sum_{j=1}^{J}(C_{i(ul)j}^{car} + C_{shj} + C_{\exp j}^{sh}) + C_{doc}^{\inf}}{I_{or}\cdot T_w} \quad (2)$$

Table 1 Supply Chain Designation

Supply chain type	Departure area	Dispatching port	Destination port	Railway	Road carrier	Recipients' area
"Supply Chain 1"	northern part of the United States	the port of New York (USA)	the port of Klaipeda (Lithuania)	the railway station of Klaipeda (Lithuania)-the railway station of Odesa (Ukraine)	the carrier by road in Kharkiv (Ukraine)	the company's warehouse in Kharkiv (Ukraine)
"Supply Chain 2"	northern part of the United States	the port of New York (USA)	the port of Klaipeda (Lithuania)	-	the carrier by road in Kharkiv (Ukraine)	the company's warehouse in Kharkiv (Ukraine)
"Supply Chain 3"	northern part of the United States	the port of New York (USA)	the port of Odesa (Ukraine)	-	the carrier by road in Kharkiv (Ukraine)	the company's warehouse in Kharkiv (Ukraine)
"Supply chain 4"	southern part of the USA	the port of Houston (USA)	the port of Odesa (Ukraine)	-	the carrier by road in Kharkiv (Ukraine)	the company's warehouse in Kharkiv (Ukraine)
"Supply Chain 5"	southern part of the USA	the port of Houston (USA)	the port of Odesa (Ukraine)	the railway station of Odesa - the railway station of Kharkiv		the company's warehouse in Kharkiv (Ukraine)

This model takes into account the next factors such as are: the costs of loading (unloading) the container with the i-th cargo type; costs for loading (unloading) of the container on the vehicle (truck, railway wagon, ship) of the j-type of transport ($C^{cont}_{l(ul)i}$); container transportation costs by a vehicle (truck, railway wagon, ship) of j-th kind transport ($C^{car}_{i(ul)j}$); costs of container waiting to be sent by j-th kind transport ($C^{sh}_{\exp j}$); cost of documentation and information support ($C^{\inf}_{doc}$).

The cost components take into account the cost of performing the relevant types of work, the time of their execution, the risk components (idle time, service waiting, failures), work scopes (transportation distances, loading and unloading time, storage, etc.) at all logistics areas of the container supply chain.

4 Results and Discussion

Statistical assessment of experimental study data results is necessary to solve problems according to the proposed method. Experimental studies were conducted according to the data of 10 companies operating in the Kharkiv market (Ukraine). Order flows in 2021 will be used as input. Flow characteristics include cargo order volume, vehicle order intensity, and delivery time. The value was obtained by analyzing orders for the delivery of vehicles and spare parts of automobiles from the United States to Ukraine. The total number of orders (observations) is one hundred.

The required number of observations is determined (Table 2) to obtain the most reliable data on the value changes in the technological process for container delivery by certain supply chains.

Table 2 Results of sample size calculations for specific parameters

Indicators	Cargo order volume (t)	Delivery time (days)	Vehicle order intensity (unit/time)
Expected value	10.05	31.5	6.5
Standard deviation	35.28	35.72	26.10
Measurement error	0.50	1.58	0.33
Sample size	59	65	80

The Chi-square or Pearson square test was used to test correlation significances between two variables. Using Statistica, calculations were made to identify the distribution laws of specific parameters of incoming order flows. It was found that the values of cargo order volumes, vehicle order intensities, and cargo delivery time are distributed according to normal distribution laws of random variables. It is confirmed by the appropriate level of confidence (more than 5%).

Three factors were found using the model data (2) affecting the estimated indicator, and minimum and maximum values were determined - by evaluating selected values of three parameters (Table 3). An experimental plan was designed according to the previously described data set. The results of the obtained data are presented in Table 4.

Table 3 Exposure factor variation levels

Value level	Cargo order volume (t)	Delivery time (days)	Vehicle order intensity (unit/time)
Minimum	0.1	25	1
Maximum	20	38	12

Regression analysis was performed by functions of two types: linear and power functions. The experiment used MS Excel, particularly the Data Analysis -Regression

Table 4 Experiment plan

Observation series	Variation levels		
	Cargo order volume (t)	Delivery time (days)	Vehicle order intensity (unit/time)
Test 1	0.1	1	25
Test 2	0.1	1	38
Test 3	0.1	12	25
Test 4	20	1	25
Test 5	20	1	38
Test 6	20	12	25
Test 7	0.1	12	38
Test 8	20	12	38

function packages. This software helps to find values of such parameters as equation coefficients under variables, variance, and regression statistics. The power function model was found to be most adequate since the value of the "R-square" index is close to one and is 0.96. The values of the regression model coefficients were also checked, which are adequate only for vehicle order intensities according to the values of standard error, "t-statistics," "P-values," and minimal and maximal values. The regression models were designed for five supply chain options of vehicles in containers from the USA to Ukraine (Table 5).

Table 5 Regression models for relevant supply chain options

Supply chain options	Regression model
"Supply chain 1"	$C_u^n = e^{9.38} \cdot I_{or}^{-0.42}$
"Supply chain 2"	$C_u^n = e^{9.39} \cdot I_{or}^{-0.419}$
"Supply chain 3"	$C_u^n = e^{9.19} \cdot I_{or}^{-0.39}$
"Supply chain 4"	$C_u^n = e^{9.63} \cdot I_{or}^{-0.46}$
"Supply chain 5"	$C_u^n = e^{9.6} \cdot I_{or}^{-0.45}$

The parameter was calculated based on obtained regression models to find an effective option. The parameter values are accepted as vehicle order intensity from minimum to maximum rates $\{1.12\}$. Based on the modeling results, the designed graphs show the dependences of container unit cargo delivery costs from the change in vehicle order intensities (Fig. 2).

The plot curves show that Supply Chain 3 is less costly. At the same time, unit costs have minimum values when ordering volumes reach twelve vehicles per week. The most expensive are Supply Chain 4 and Supply Chain 5 since the distance of transportation

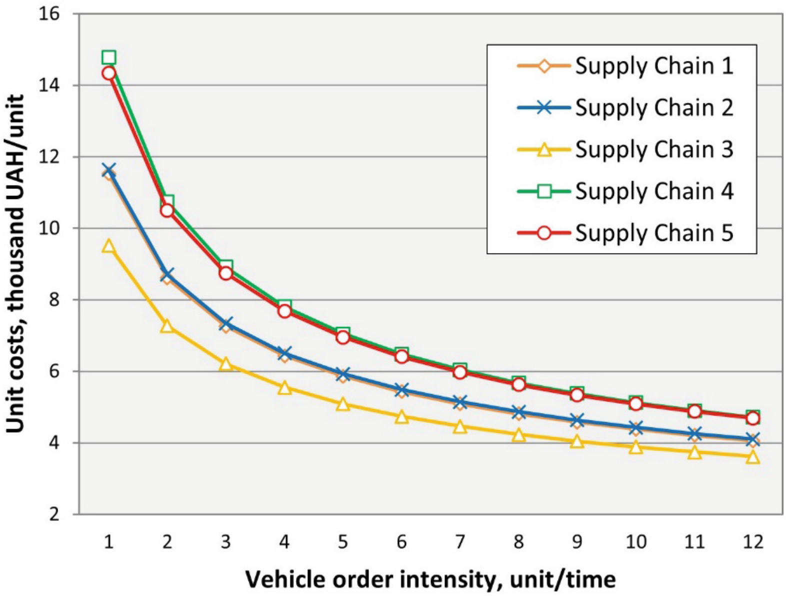

Fig. 2 Dependence plot of unit costs for goods delivery in containers from values changes of vehicle orders intensity

by sea between the port of Houston and the port of Odesa is much longer than the first three options.

Unit cost values were compared (Table 6) to determine the most efficient option from the proposed ones.

The most effective option is Supply Chain 3: unit costs are less by an average of 820 UAH compared to Supply Chain 1, and an average of 890 UAH also reduces expenses compared to Supply Chain 2. Comparing Supply Chain 1 and Supply Chain 2 results in an average cost savings of 69 UAH using Supply Chain 1. Comparing Supply Chain 4 and Supply Chain 5 shows that unit costs give an average savings of 115 UAH using the first option.

Using the developed methodology, an economical or more practical option for product delivery can be chosen under specific conditions. This aspect is important in such studies [28] because here, not only choice issues solving, but also focusing on participant satisfaction.

Table 6 Results of comparative effect determination

Measure values	Effect (UAH/unit)			
	Supply Chain Comparison 1 and 2	Supply Chain Comparison 1 and 3	Supply Chain Comparison 2 and 3	Supply Chain Comparison 4 and 5
1	-115.37	1986.99	2102.36	435.32
2	-92.26	1335.49	1427.75	243.97
3	-80.79	1051.33	1132.11	167.07
4	-73.46	883.99	957.45	124.29
5	-68.21	770.97	839.19	96.67
6	-64.19	688.3	752.48	77.23
7	-60.95	624.57	685.52	62.74
8	-58.28	573.58	631.86	51.5
9	-56.01	531.63	587.64	42.5
10	-54.06	496.37	550.42	35.14
11	-52.34	466.21	518.55	28.99
12	-50.82	440.06	490.88	23.77

5 Conclusions

This paper presents the conditions determining which researcher can choose an effective option for the supply chain of automotive equipment in containers from the United States to Ukraine. The current methodology developed to do this included the following elements: development of alternative supply chain options; defining of parameters for choice evaluating of effective options; designing a mathematical model for determining values of estimated parameters; modeling and evaluation of results.

It was proposed to consider this process through five options for their organization with the participation of automobile, railway, and maritime transport to determine an effective supply chain for cars in containers from the United States to Ukraine. The data of ten companies that organize the delivery of containers (cars and spare parts) from the United States through New York and Houston ports were used to form these schemes. The recipients' main ports are Odesa (Ukraine) and Klaipeda (Lithuania). The designed options consider the possibility of using them in Ukraine to transport containers for automobile and railway transport.

Mathematical modeling is the most promising for describing the process of moving loads in containers according to the options for use. This approach reduces the number of difficulties, the main reason for which is the complication of cause-and-effect relations in complex interacting components. The unit delivery costs are selected as the selection parameter for effective supply chains of vehicles in containers considering the restriction system.

A full-factor experiment plan was developed for three parameters, consisting of eight series of tests. The various combinations of external impact parameters were simultaneously used with varying intervals of cargo order volumes, intensities of truck orders, and cargo delivery times. Regression analysis was performed by functions of two types: linear and power functions. The power function model was found to be most adequate since the value of the “R-square” parameter is close to 1 and is 0.96.

The corresponding regression models were designed for five options of vehicle supply chains in containers from the USA to Ukraine. The final effect showed that the minimum values were obtained for “Supply Chain 3” by the entire range of the values change for vehicle order intensities. But the largest value of the effect was 2102.36 UAH when using “Supply Chain 3” - organizing the delivery of cars from the sender, who is located in the northern part of the United States, to the port of New York (USA), then by sea to the port in the city of Odesa. Then the carrier delivers by road to Kharkiv and the recipient.

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