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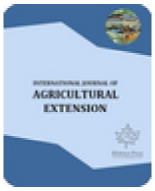

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IMPROVING THE TECHNOLOGY OF PRODUCT SUPPLY CHAIN MANAGEMENT IN THE CONTEXT OF THE DEVELOPMENT OF MULTIMODAL TRANSPORTATION SYSTEMS IN THE EUROPEAN UNION COUNTRIES

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ABSTRACT

The relevance of the study is caused by the growing role of multimodal transportation in Ukraine and the European Union, ensures the optimization of the goods supply chain management to the consignee, and an important element of this development is the significant role of rail transport in the multimodal transportation, which is relevant towards minimization of costs and preserving the environment. The purpose of the article is to develop measures to improve the designing processes of the multimodal route parts for grain supply chains through the using of network systems and minimizing the total transportation cost. Taking into account the specifics of the functioning and management of multimodal transportation, an approach to the integrated assessment of the effect from the transport enterprises activities in multimodal transportation based on the building of network models of each part of the multimodal route is offered. The article presents the results of the analysis and theoretical generalization of approaches to formalizing the process of functioning the multimodal transportation systems for goods supply chains with rail and road modes of transport. The materials of the article are of practical value for vocational and industrial training of logistics operators, transport companies' staff, and scientific and pedagogical personnel in order to improve their professional competencies.

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INTRODUCTION

In modern conditions for the development of production processes in Ukraine and the world, a special place is occupied by the functioning of multimodal transportation systems. The effectiveness of multimodal transportation is due to the availability of methods for organizing cargo delivery processes based on modern logistics principles with the involvement of various types of transport (Lavrukhin *et al.*, 2017). The existing efficiency, range, and quality of transport services for users of the multimodal transportation system in Ukraine does not meet modern world requirements. There are no methods for working out the multimodal development projects of infrastructure and rolling stock, determination of the investment resources for the development of competitive infrastructure, methods of interaction between the public and private sectors (Sergeieva *et al.,* 2021). For the development and implementation of these projects in multimodal transportation systems, it is necessary to accumulate and analyze practical experience in the implementation of similar logistics schemes.

JSC "Ukrzaliznytsia" draws attention to the essence of its vision of the company's development towards successful management of multimodal transportation with the countries of the European Union, pays attention to the transportation management issues in order to increase their efficiency both financially and organizational, technological and informational terms (Krasheninin and Shapatina, 2016). Globalization processes, changes in traditional world economic relations set for Ukraine a task of rational use the potential of its economic and geographical location, the effective implementation of which will permit not only to get an economic effect from participation in international transportation but also to create new economic instruments to influence on world economic processes.

Multimodal transportation is a strategic direction for the agriculture industry development in Ukraine and in the world and, accordingly, requires the use of new approaches to its development. Such approaches can be the development of a sustainable scientific and practical basis for the logistics of multimodal transportation, and the studying on its basis management process of product supply chains. The science of supply chain management (Primachenko and Maslinkov, 2018) is now perceived as a concept for optimizing the added value of services in supply chains and is being actively implemented in the economies of industrialized countries. Most transport enterprises have departments for managing the product supply chain. Therefore, this study is a topical subject.

It is not enough to do the job well, but it is also necessary to manage the product supply chains with high quality, ensuring the criteria: cheap, on time, and on term (Butko *et al*., 2019). Under market fluctuations, it is necessary to modernize elements of services rapidly along the entire length of their supply chain. The main task of railway transport is to balance the unpredictability of the market with the necessity to obtain constant and, preferably, growing profits by offering new and better services to customers (Dei *et al.,* 2019a). The main barrier to this goal is the segmented product supply chain. Supply chain management can be optimized in six steps: individual control, creating strategic understanding, alignment, and integration, repurposing orders, global thinking, customer perspective (Atajanov and Solayev, 2020).

Theoretical overview

Individual control over the product supply chain should be carried out from the highest level and define clear parameters and areas of responsibility for each link. In large companies, the only strategy can get lost somewhere. To prevent it it is necessary to define the requirements for the service in the context of the supply chain operation - including such indicators as speed, flexibility, and reliability - regardless of the difference in markets, as well as the relationship between new and older products. It is recommended to originate the scheme that clearly states which results should serve as criteria for the effectiveness of the supply chain. The aim of each step in the supply chain needs to be clear and aligned with the specific requirements of any given market.

The product supply chain in multimodal transportation is, first of all, whole organizations: suppliers of everything necessary for transportation, consumers of services and intermediaries, interconnected by a technological chain (Jha, 2008).

It is advisable to classify the supply chain according to the following criteria:

1. By the number of levels of suppliers and consumers, the supply chain can be direct, extended, or maximum. A direct supply chain consists of a service "producer", which, as a rule, becomes a focus company (the central company of the supply chain around which the supply chain is built), a supplier, and the first level consumer who directly interact with the focus company in moving commodity, information, and financial flows. The number of suppliers and customers in the supply chain can vary. The maximum supply chain consists of the focus company and all of its counterparties and the service distribution network. At its core, the maximum supply chain is an extensive network of suppliers and consumers of services at various levels, as well as intermediaries with whom participants in the supply chain interact at different stages.

2. By the type of service produced - a supply chain of the particular product. Service is the result of labor activity, in process of which "a new, previously non-existent material product is not created, but the quality of an existing, created product changes. In other words, it is a good that is provided not in material form, but in the form of activity. That is, it is the provision of services

creates the desired result". The services include the following activities: transportation, insurance, services for processing shipping documents, etc.

3. By the nationality, that is, depending on whether the supply chain is limited by the territory of one state or not, there are national and international supply chains. National supply chains are limited by the territory of one state, all links of such a supply chain are within one country, including suppliers and consumers. It means that goods or services produced by counterparties in the national supply chain are made from raw materials and materials obtained on the territory of this country. All consumers including final consumers, are also located in this country (Dei *et al.,* 2019b).

At the same time, the problem of forming models and methods for managing resource flows is of particular interest. The research has shown that on the one hand, it is possible to use the developed and tested analytical apparatus of models and methods of material flow management, in particular, the available solutions to such problems as (Porter, 1998):

- selection of logistics intermediaries;
- forecasting (indicators, cargo flows, etc.);
- "to make or to buy" (decision-making models);
- definition of nomenclature groups (ABC analysis for high-speed transport services, etc.)
- additive time models ("just in time");
- choice of transport modes and transportation methods (transport tasks, network methods, etc.)
- multicriteria optimization under conditions of risk and uncertainty;
- synthesis models (design) of logistics systems with "minimizing total costs" or "economic compromises", etc.

On the other hand, the specificity of resource flows, due to the intellectual component, possess such qualities as self-regulation, self-learning, self-organization and self-improvement, requires the development of new analytical tools based on situational analysis, social psychology (search for compromises in conflict situations), game theory, Markov random processes, queuing theory, decision making under conditions of risk and uncertainty, and others (Marinov, 2009). A feature of this class of models and methods is the reflection of the expectable behavior of the "active element", in particular, in a competitive environment (Pedersen *et al*., 2010).

However, studying logistics systems it is necessary to strive for them to ensure organical integration into the natural practical activities of the enterprise and ultimately become their integral part and a means of solving strategic problems. Thus, internal and interfirm logistic interaction in activities is as following:

- allows to minimize the total costs of organizing service flows within the enterprises themselves and outside them, thereby increasing the competitiveness of this economic structure;
- helps to improve the quality of total performed operations, it is important from the point of view of relationships with the consumer and the satisfaction of their requirements in a competitive environment;
- helps to optimize the enterprise management system, that increases the competitiveness and economic stability, reliability of both individual enterprises and their multitude within the framework of strategic alliances;
- widely determines the development trends of integration processes between commercial organizations, municipal and state structures within the regions and at the state level of management;
- has a positive impact on the formation, development of logistics infrastructure and innovative processes in various business structures, companies and in the process of their interaction in supply chains.

From this definition we can see that the main flows: material and (or) service (service flows); accompanying flows - information, financial, service; in addition, for the main service flow, financial flows are concomitant. At the same time, an analysis of studies has shown that there are works over the past decade in which personnel (labor, human), passenger (transport), tourist and other flows are considered from a logistic point of view. Generalization of the above is the following: on the one hand, logistics objects are material flows, work in progress, finished products; information flows (messages in language, documentary (paper and / or electronic) and other forms) financial flows (funds in cash or non-cash form); service flows (a set of objects in the form of a certain set of intangible values (services)) (Dei *et al.,* 2021b). On the other hand, there are actually existing flows of human resources, which fully correspond to the general definition of a logistic flow, namely: "total number of objects (variety) united on a specific basis that move in space and time and are adapted to quantitative and qualitative transformations in accordance with the influence of the logistics system management subject".

The logistic approach stipulates the introduction of an integrated management system. The main feature of the logistically oriented approach is to construct an integrated management system in which the movement of material and related flows and operations is not divided into several disparately functioning management subsystems, but are considered and managed as a single whole. There are several reasons that make it necessary to develop cooperation, interaction within the supply of the services carrying out chain to high-speed trains passengers:

- the participants in the supply chain recognize the existence of common interests in the development, implementation of innovations and the creation of a service that has value for the consumer;
- railway and other transport companies cannot always afford to invest resources in the innovations they need, therefore, attracting investment funds is practiced;
- risks can be shared among several organizations;
- the ability to occupy new shares of the transport market;
- cooperation with other companies located in another country or region can reduce the level of political risks, and therefore help to avoid additional costs.

One of the most important categories in logistics is logistics expenses, the optimization of which makes it possible to assess the feasibility of transforming the logistics system. In this case, we are talking about "total costs" for carrying out certain selected processes within the performing a specific business process. The concept of "total costs" means that the system should not aspire to minimize costs at all stages of the process. Moreover, lowering of costs in one area can lead to increased costs in another area of activity. It is completely unimportant, for example, that transportation costs structure will be, if the enterprise as a whole fulfills the assigned tasks with minimal total costs, as in the market system "the price of a service and its quality" is not always the same.

METHODOLOGICAL FRAMEWORK

One of the methods for increasing efficiency of logistics management processes in railway transport in Ukraine today is using technology "just in time" (JIT). JIT is a technology for building a logistics system or organizing logistics processes in a separate functional area, which ensures the delivery of material resources, work in progress, finished products in the required quantity, at a specified time and designated place. JIT appeared due to the changing situation in the Japanese market. The situation led to the fact that the course to increase output cut off the former effect. It led to the intensification of the competition for markets and to the search for new methods of production management aimed at increasing profits. The goal of JIT is continuous production or batch services with zero-waste. The main philosophical line is constant development and improvement. In general, using JIT, for example, to carry out the process of delivering cargo to customers just in time, allows on average to halve the lead time, approximately 50% reduce the level of stocks and reduce by 50-70% the duration of order fulfillment at the enterprise that manufactures products. It is important enough for consumers as they believe it is better to complete an order in 10 days than the cycle time will range from 3 to 30 days.

First of all, it is necessary to identify sections of the multimodal route of the cargo supply chain that are on a "critical path" (the duration of which takes a significant period of time, which can be reduced) and identify the allowable time. One of the effective methods in this direction is network planning and management (NPM) (Kniazieva *et al.*, 2019). Using NPM methods, it is possible to present the technological process in graphical form, clearly establish the sequence and logical relationships of individual works and sections of the route that make up the process, identify the defining ("critical") work and focus on them. Mathematical formalization of the process allows the use of computers to calculate the duration of the cargo under technological operations, which opens up ample opportunities for multivariate analysis of complex processes. In addition, the methods of NPM allow the most efficient use of resources, which minimizes the execution time of the whole process. At the stage of scientific analysis, the network schedule is optimized, there is an order of all works that will ensure the minimum costs associated with technological operations (cost optimization) and the minimum time for their implementation (time optimization) (Dei *et al.,* 2021a). NPM methods alone do not provide the optimal solution, they are only a tool with which to obtain an effective solution, but the degree of effectiveness is assessed subjectively by the graphic designer.

Consider the basic technological operations and the sequence of their implementation for an arbitrary multimodal route of the supply chain. To calculate the duration of delays in the execution of the route it is necessary to build a diagram of the technological section of the route in the form of a network schedule. In this case, the network schedule will mean a graphical representation of a certain set of technological works on sections of the route, which reflects their logical sequence, relationship, and duration. A graph is a model of a process in which you can perform experiments and find out what changes in the resulting indicator will lead to one or another change in the input parameters of the model. The network schedule consists of segments (sections of the route) and circles (points of the route).

After calculating the original network schedule, a very important stage of its improvement (optimization) and bringing the parameters in line with these conditions and restrictions (in terms of the implementation of a set of works, resources, etc.) begins. The success of complex operations depends, first of all, on the clear coordination of work overtime, as well as on how correctly and rationally distributed the necessary material, labor, and financial resources to achieve this goal. Therefore, the optimization of the network schedule means the consistent improvement of the network in order to achieve a minimum (directive) time of the complex or the allocation of all types of resources, taking into account the existing limitations. First, we optimize the network schedule on the parameter "time", without restrictions, and after reaching the deadline, we begin to adjust the allocation of resources (time - labor resources; time - material and territorial resources; time - money costs). Optimization of the network schedule over time involves reducing the total duration of the complex to the minimum value, or to the value of the relevant directive deadline. Since the total duration of the complex is determined by the length of the "critical path", the optimization over time involves, above all, reducing the duration of critical work.

RESULTS

Under such conditions, it is advisable to introduce technologies that have been widely developed in the countries of the European Union, namely, multimodal transportation of grain (Lavrukhin *et al.*, 2017). Multimodal transportation effectively combines several types of transport, while transportation is carried out according to a single transport document and under the control of a single operator at all stages of transportation (Congli and Yixiang, 2016). It gives an impulse that attracts new customers for this type of transportation, which is especially important for the railway industry in Ukraine and for the international transportation (Islam, 2014). Thus, in performing multimodal transportation, the main attention is paid to such indicators as speed, reliability, and cost of cargo delivery (costs of organizing the product supply chain) (Panchenko *et al.*, 2017). The main indicator carrying out multimodal transportation is the total cost of services, which is provided in the form of an objective cost function:

$$C(x) = C^1 + n \cdot (l_{x_i} \cdot C^2_{x_i} + C^3_{x_i}) + \Theta z_{x_i} \cdot (C^4_{x_i} + C^5_{x_i} \cdot t), \qquad (1)$$

where x– the factor, corresponds to the multimodal route of the grain supply chain;

C^1 - the expenses for registration shipping documents (including customs duty for international transportation within Ukraine and the countries of the European Union);

n - the volume of the consignment;

l_{x_i} - the length of the route section, corresponds to the i - element of the factor x;

$C^2_{x_i}$ - the costs of organizing the goods supply chain in the section corresponding to the arc x_i;

$C^3_{x_i}$ - extra costs for operations with the load on the arc x_i;

Θ - Heaviside function;

z_{x_i} - changing the type of transport on the arc x_i;

$C^4_{x_i}$ - costs for the fulfillment of loading/unloading cargo operations;

$C^5_{x_i}$ - costs for the storage of goods in the depot (including goods protection);

t - time delays for the storage of goods in the depot, the fulfillment of cargo operations, etc., that depend on the starting moment of the route.

To obtain an adequate solution, certain restrictions are imposed on the control variables of the model:

$$\begin{cases} t^1 \le t \le t^2, \\ n \le N(t), \end{cases} \qquad (2)$$

where t^1 and t^2 – the boundaries of the interval of the beginning of the implementation of the multimodal route, determined by the shipper;

$N(t)$ – the number of free seats at the time of the beginning of the movement of cargo in an arc x_i depending on the moment of the beginning of realization of a multimodal route t.

At the same time, the first restriction ensures the search for such a solution when the time of starting the multimodal route is within a certain time interval that corresponds to the conditions of the shipper (Islam, 2015).

The second restriction ensures the selection of the multimodal route parts that quarantee the availability of a sufficient number of vacant places to arrange the possibility of moving the consignment in full along all segments of the route (Kawa *et al.*, 2010). Thus, the cost of cargo delivery largely depends on the choice of the optimal parts of the multimodal route in the cargo supply chain. Thus, one of the tasks to determin the cost indicator for multimodal transportation is to substantiate the optimal transportation route.

In this formulation, the problem of choosing the optimal transportation route is solved by the dynamic programming method (Tanaino *et al.,* 2019). In dynamic programming problems the decision-making process can be divided into separate stages (Huang *et al.,* 2021). Setting of the problem is reduced to finding on the road network the most economically profitable route for the goods transportation from the initial point to the final one (Di Ludovico *et al.,* 2021). Thus, the solution is reduced to a network problem. Suppose that the first mode of transport on a multimodal route is rail, then on a given road network there are several routes for cargo delivery from point 1 to point 15 by rail (Fig. 1). The concept of dynamic programming method is to provide a step-by-step optimization process (Bogachev *et al.,* 2020). The transportation route is divided into seven steps, that is shown in Figure 2.

Note down the objective functions of the tasks:

k=1 – planning the first stage, which includes two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 2}\end{Bmatrix} = min_{U_1^1:\text{i}=1}\begin{Bmatrix}\text{route to}\\ \text{the point 2}\end{Bmatrix} = 202, U_1^1\text{:1-2;}\ldots\ldots\ldots\ldots(3)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 3}\end{Bmatrix} = min_{U_1^2:\text{i}=1}\begin{Bmatrix}\text{route to}\\ \text{the point 3}\end{Bmatrix} = 148, U_1^2\text{:1-3;}\ldots\ldots\ldots\ldots(4)$$

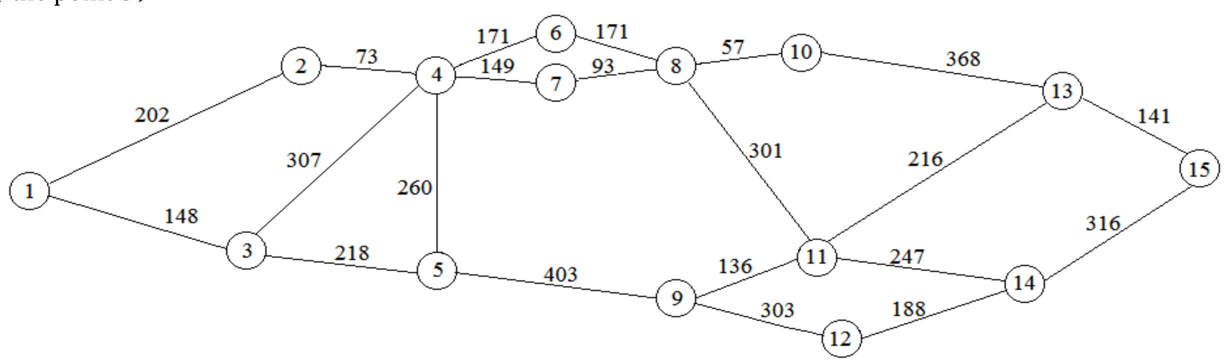

Figure 1. Any polygon of the multimodal route of grain supply chain from point 1 to point 15 by rail.

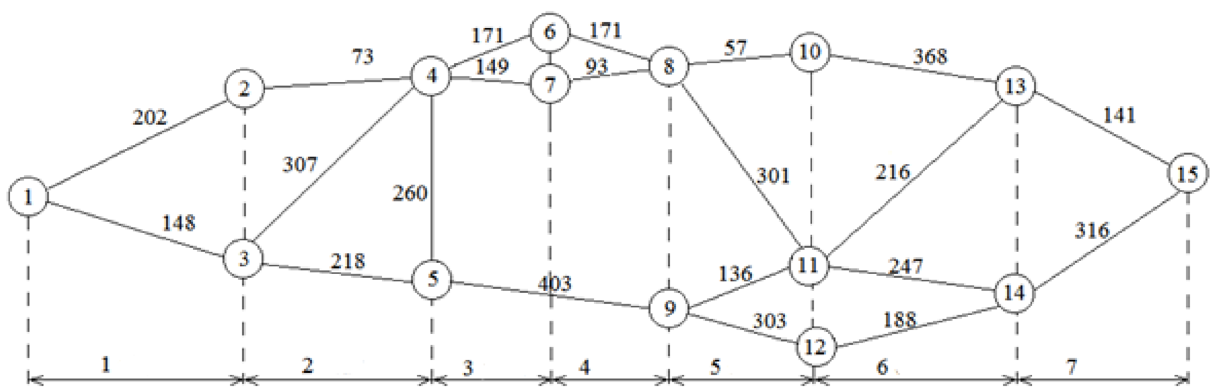

Figure 2. Step-by-step splitting the part of the multimodal route of grain supply chain by rail.

2. k=2 – planning the first two stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 4}\end{Bmatrix} = min_{U_2^1:\text{i}=2,3}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix}+\begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point 4}\end{pmatrix}\right\} = min_{U_2^1:\text{i}=2,3}\begin{Bmatrix}202+73\\ 148+307\end{Bmatrix} = 275; U_2^1\text{:1-2-4;}\ldots\ldots(5)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 5}\end{Bmatrix} = min_{U_2^2:\text{i}=3,4}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix}+\begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point5}\end{pmatrix}\right\} = min_{U_2^2:\text{i}=3,4}\begin{Bmatrix}275+260\\ 148+218\end{Bmatrix} = 366; U_2^2\text{:1-3-5;}\ldots\ldots(6)$$

3. k=3 – planning three stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 6}\end{Bmatrix} = min_{U_3^1:\text{i}=4}\begin{Bmatrix}\text{route to}\\ \text{the point 6}\end{Bmatrix} = 446, U_3^1\text{:1-2-4-6;}\ldots\ldots(7)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point7}\end{Bmatrix} = min_{U_3^2:\text{i}=4}\begin{Bmatrix}\text{route to}\\ \text{the point7}\end{Bmatrix} = 424, U_3^2\text{:1-2-4-7;}\ldots\ldots(8)$$

4. k=4 – planning four stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point8}\end{Bmatrix} = min_{U_4^1:\text{i}=6,7}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix}+\begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point8}\end{pmatrix}\right\} = min_{U_4^1:\text{i}=6,7}\begin{Bmatrix}446+171\\ 424+93\end{Bmatrix} =$$

$517; U_4^1$:1-2-4-7-8;……………………(9)

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 9}\end{Bmatrix} = min_{U_4^2:\text{i}=5}\begin{Bmatrix}\text{route to}\\ \text{the point9}\end{Bmatrix} = 769, U_4^2\text{:1-3-5-9;}\ldots\ldots(10)$$

5. k=5 – planning five stages, including three objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 10}\end{Bmatrix} = min_{U_5^1:\text{i}=8}\begin{Bmatrix}\text{route to}\\ \text{the point10}\end{Bmatrix} = 574, U_5^1\text{:1-2-4-7-8-10;}\ldots\ldots(11)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point11}\end{Bmatrix} = min_{U_5^2:\text{i}=8,9}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix}+\begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point11}\end{pmatrix}\right\} = min_{U_5^2:\text{i}=8,9}\begin{Bmatrix}517+301\\ 769+136\end{Bmatrix}$$

$$= 818; U_5^2\text{:1-2-4-7-8-11;}\ldots\ldots(12)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 12}\end{Bmatrix} = min_{U_5^3:\text{i}=9}\begin{Bmatrix}\text{route to}\\ \text{the point12}\end{Bmatrix} = 1072, U_5^3\text{:1-3-5-9-12;}\ldots\ldots(13)$$

6. k=6 – planning six stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 13}\end{Bmatrix} = min_{U_6^1:\text{i}=10,11}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction }i\end{pmatrix}+\begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point13}\end{pmatrix}\right\} = min_{U_6^1:\text{i}=10,11}\begin{Bmatrix}574+368\\ 818+216\end{Bmatrix}$$

$$= 942; U_6^1\text{:1-2-4-7-8-10-13;}\ldots\ldots(14$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point14}\end{Bmatrix} = min_{U_6^2:\text{i}=11,12}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix}+\begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point14}\end{pmatrix}\right\} = min_{U_6^2:\text{i}=11,12}\begin{Bmatrix}818+247\\ 1072+188\end{Bmatrix} =$$

$1065; U_6^2$:1-2-4-7-8-11-14;………………………………………(15)

7. k=7 – planning of all seven stages:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point15}\end{Bmatrix} = min_{U_7:\text{i}=13,14}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix}+\begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point15}\end{pmatrix}\right\} = min_{U_7:\text{i}=13,14}\begin{Bmatrix}942+141\\ 1065+316\end{Bmatrix} =$$

$1083; U_7$:1-2-4-7-8-10-13-15…………………………….(16)

So, the shortest route from point 1 to point 15 is $f1083$ км,$_{min}$ that is achieved by such an optimal task management strategy U_{onm}:1-2-4-7-8-10-13-15, as shown in Fig. 3.

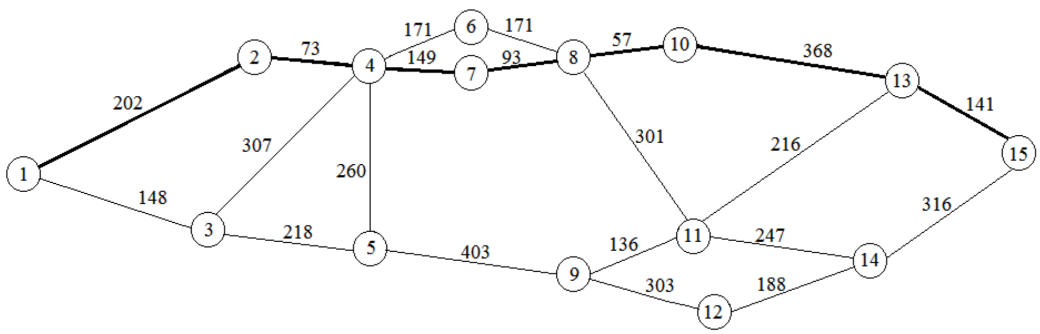

Figure 3. The optimal part of the multimodal route of grain supply chain from point 1 to point 15 by rail.

The second part of the multimodal route of the goods supply chain by road from point 1 (equal to point 15 for the first part of the multimodal route "Figure 3") point 15 (destination of the cargo) is shown in Figure 4-5.

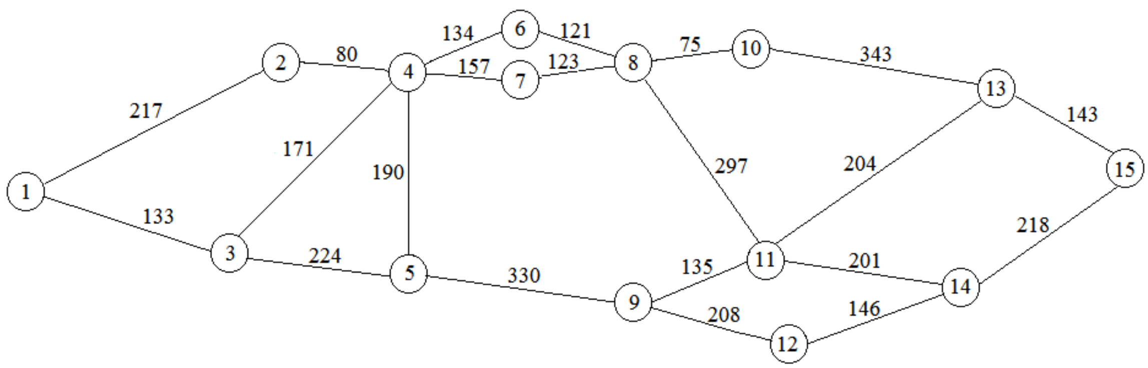

Figure 4. Any polygon the second part of the multimodal route of grain supply chain from point 1 to point 15 by road.

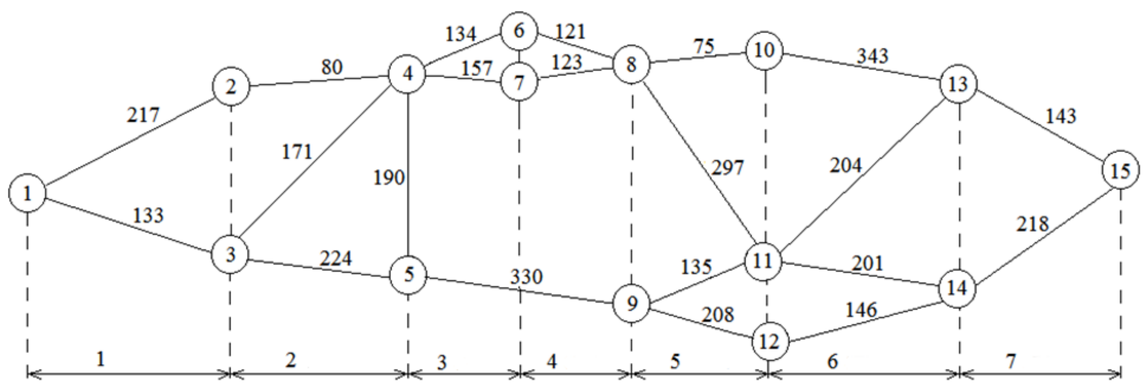

Figure 5. Step-by-step splitting of the second part of the multimodal route of grain supply chain from point 1 to point 15 by road.

Note down the objective functions of the tasks in stages:
k=1 – planning the first stage, which includes two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point2}\end{Bmatrix} = min_{U_1^1:\text{i=1}}\begin{Bmatrix}\text{route to}\\ \text{the point 2}\end{Bmatrix} = 217, U_1^1\text{:1-2;}\ldots\ldots\ldots\ldots\ldots\ldots\text{(17)}$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point3}\end{Bmatrix} = min_{U_1^2:\text{i}=1}\begin{Bmatrix}\text{route to}\\ \text{the point3}\end{Bmatrix} = 133, U_1^2\text{:1-3;}\ldots\ldots\ldots\ldots\ldots(18)$$

2. *k*=2 – planning the first two stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point4}\end{Bmatrix} = min_{U_2^1:\text{i}=2,3}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix} + \begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point4}\end{pmatrix}\right\} = min_{U_2^1:\text{i}=2,3}\begin{Bmatrix}217+80\\ 133+171\end{Bmatrix} =$$
$$297; U_2^1\text{:1-2-4;}\ldots\ldots\ldots\ldots(19)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point 5}\end{Bmatrix} = min_{U_2^2:\text{i}=3,4}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction } i\end{pmatrix} + \begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point 5}\end{pmatrix}\right\} = min_{U_2^2:\text{i}=3,4}\begin{Bmatrix}133+224\\ 297+190\end{Bmatrix} =$$
$$357; U_2^2\text{:1-3-5;}\ldots\ldots\ldots\ldots\ldots(20)$$

3. *k*=3 – planning three stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point6}\end{Bmatrix} = min_{U_3^1:\text{i}=4}\begin{Bmatrix}\text{route to}\\ \text{the point6}\end{Bmatrix} = 431, U_3^1\text{:1-2-4-6;}\ldots\ldots\ldots\ldots\ldots(21)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point7}\end{Bmatrix} = min_{U_3^2:\text{i}=4}\begin{Bmatrix}\text{route to}\\ \text{the point7}\end{Bmatrix} = 454, U_3^2\text{:1-2-4-7;}\ldots\ldots\ldots\ldots\ldots(22)$$

4. *k*=4 – planning four stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point8}\end{Bmatrix} = min_{U_4^1:\text{i}=6,7}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix} + \begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point8}\end{pmatrix}\right\} = min_{U_4^1:\text{i}=6,7}\begin{Bmatrix}431+121\\ 454+123\end{Bmatrix} =$$
$$552; U_4^1\text{:1-2-4-6-8}\ldots\ldots\ldots\ldots\ldots(23)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point9}\end{Bmatrix} = min_{U_4^2:\text{i}=5}\begin{Bmatrix}\text{route to}\\ \text{the point9}\end{Bmatrix} = 687, U_4^2\text{:1-3-5-9;}\ldots\ldots\ldots\ldots\ldots(24)$$

5. *k*=5 – planning five stages, including three objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point10}\end{Bmatrix} = min_{U_5^1:\text{i}=8}\begin{Bmatrix}\text{route to}\\ \text{the point10}\end{Bmatrix} = 627, U_5^1\text{:1-2-4-6-8-10;}\ldots\ldots\ldots\ldots\ldots(25)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point11}\end{Bmatrix} = min_{U_5^2:\text{i}=8,9}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix} + \begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point11}\end{pmatrix}\right\} = min_{U_5^2:\text{i}=8,9}\begin{Bmatrix}552+297\\ 687+135\end{Bmatrix}$$
$$= 822; U_5^2\text{:1-3-5-9-11;}\ldots\ldots\ldots\ldots\ldots(26)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point12}\end{Bmatrix} = min_{U_5^3:\text{i}=9}\begin{Bmatrix}\text{route to}\\ \text{the point12}\end{Bmatrix} = 895, U_5^3\text{:1-3-5-9-12;}\ldots\ldots\ldots\ldots\ldots(27)$$

6. *k*=6 – planning six stages, including two objective functions:

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point13}\end{Bmatrix} = min_{U_6^1:\text{i}=10,11}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix} + \begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point13}\end{pmatrix}\right\} = min_{U_6^1:\text{i}=10,11}\begin{Bmatrix}627+343\\ 822+204\end{Bmatrix} =$$
$$970; U_6^1\text{:1-2-4-6-8-10-13;}\ldots\ldots\ldots\ldots\ldots(28)$$

$$\begin{Bmatrix}\text{the shortest}\\ \text{route to}\\ \text{the point14}\end{Bmatrix} = min_{U_6^2:\text{i}=11,12}\left\{\begin{pmatrix}\text{the shortest}\\ \text{route to}\\ \text{the junction}i\end{pmatrix} + \begin{pmatrix}\text{distance to the}\\ \text{junction}i\\ \text{to the point14}\end{pmatrix}\right\} = min_{U_6^2:\text{i}=11,12}\begin{Bmatrix}822+201\\ 895+146\end{Bmatrix}$$
$$= 1023; U_6^2\text{:1-3-5-9-11-14;}\ldots\ldots\ldots\ldots\ldots(29)$$

7. k=7 – planning of all seven stages:

$$\begin{Bmatrix}\text{the shortest} \\ \text{route to} \\ \text{the point15}\end{Bmatrix} = min_{U_7:\text{i}=13,14}\left\{\begin{pmatrix}\text{the shortest} \\ \text{route to} \\ \text{the junction}i\end{pmatrix} + \begin{pmatrix}\text{distance to the} \\ \text{junction}i \\ \text{to the point15}\end{pmatrix}\right\} = min_{U_7:\text{i}=13,14}\begin{Bmatrix}970+143 \\ 1023+218\end{Bmatrix} =$$

1113; U_7:1-2-4-6-8-10-13-15……………………………………….(30)

The shortest route for the second part of the multimodal route from point 1 to 15 by road $f1113$ км$,_{min}$ was found, that is achieved by such an optimal task control strategy U_{onm}:1-2-4-6-8-10-13-15 (Figure 6).

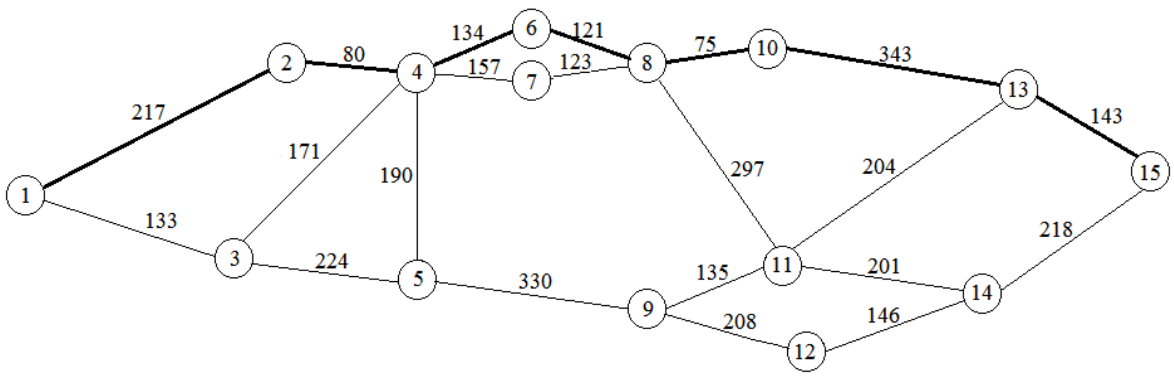

Figure 6. The optimal route for the second part of the multimodal route of grain supply chain from point 1 to point 15 by road.

DISCUSSION

Based on the selected optimal multimodal route of grain supply chain, cost calculations are performed for various cargo delivery technologies that depend not only on the route, but also on the quantity and class of cargo (Krasheninin and Shapatina, 2016). At the same time, the weight limits for highways in most countries of the European Union should not exceed 20-40 tons. Therefore, one carriage transportation by weight is equal to three cars and gives cost savings by 2.5-3 times when transporting by rail (Dărăban *et al*., 2012). Whereas in multimodal transportation, the cost calculation is done taking into account the delivery by the whole train that gives a cost reduction of up to 60% and becomes especially profitable for the transportation of bulk cargo (Butko *et al*., 2019).

It is the combination of the two modes of transport in the form of mixed transportation that will ensure an appropriate level of delivery quality and safety of goods, provide cost savings and increase the competitiveness of rail transport. Supply chain management (SCM) is a natural continuation and development of the integrated logistics concept in the cross-functional and inter-organizational logistics coordination (Andrzejewski *et al*., 2012). Today, SCM software products are available only in the most developed integrated corporate management systems, the presence of which is more likely to ensure the delivery of the necessary goods and services to the right place on time and with optimal logistics costs.

In the changing operating environment, transport companies have to go over traditional cost-service paradigm (directly proportion) to a new one, where the service profile improves along with decreasing service costs (Butko *et al*., 2020). Leading transport companies are able to coordinate their activities with consumer behavior to afford this new paradigm. In addition, today in most countries, including Ukraine, there is a change-over and active implementation of the so-called electronic economy (electronic economy is a form of economic relations in the production, distribution, exchange and consumption of goods, works and services provided in electronic form with information and communication technologies) (Congli and Yixiang 2016). Accordingly, the value chain is evolving. The dynamics promote the value chain evolution, namely, the product life cycle is shortened; the variety of types of products and services is growing, and there is a massive customization of standard alternatives in the supply chain (Fechner and Szyszka, 2012). When forming a new service supply chain or improving an existing transport company, it is necessary to form the supply chain assignments or the so-called "vision" of further work in the chosen direction, which is unique for the enterprise. The basic principles for the functioning of dynamic service supply chains, which are goods supply chains (Golinska and Hajdul, 2011):

1 - focus on key competencies;

2 - a clear algorithm for the formation of added value;

3 - the supply chain performs the functions of a value-added system;

4 - developing the supply chain should be focused on the relevant market segments;

5 - optimization of the global operating model towards the scale, flexibility and risk prevention;

6 - stimulating the high culture development of operational processes which ensure high productivity;

7 - introduction the information system that submits analysis, adaptability and flexibility;

8 - sets of business processes used in dynamic supply chain management.

Management and optimization tools for service supply chains (Golinska and Hajdul, 2012):

1 - reduction the uncertainty of demand (shortening the order cycle, shifting the point of "detection (forthcoming) of demand" as high as possible along the service supply chain;

2 - transferring the point of "final service supply" down the supply chain;

3 - focus on key competencies;

4 - transformation of supply chains in the value added chain;

5 - combination of dynamic passenger service supply chains with production concepts: Just-in-Time, etc.

Interaction of participants in the services supply chains of goods transportation

1 - uniting the supply chain participants into a partner network based on the principles of balance of interests, transparency of relationships and a high degree of business processes coordination (like orchestra)

2 - open and complete exchange of information using an appropriate IT system;

3 - a higher level of communication.

Operational offers for improving the existing service supply chains:

1 - segmentation of service chains;

2 - organizing a virtual model of service supply chain management;

3 - developing of a highly efficient service supply chain management system;

4 - coordination of logistics and marketing activities at various stages of the service life cycle;

5 - monitoring and reducing transport and transaction expenses;

6 - optimizing supply chains and attracting 3PL / 4PL - logistics operators for supplying services in accordance with foreign experience;

7 - formation of a system for risk management and prevention;

8 - attracting qualified personnel oriented towards results and speed of decision-making.

CONCLUSIONS

Thus, the offered approach to formalizing the process of the products supply chains management in the context of the development of multimodal transport systems in the countries of the European Union makes it possible to obtain a systematic results assessment of its activities. In addition, the use of the principles of network analysis in the process of modeling parts of a multimodal route makes it possible to take into account the emergence of the system in its research and designing as a whole, to reveal the patterns of its behavior, functioning and developing in order to optimize the economic effect. In particular, the essence of economic efficiency lies in saving costs when designing multimodal routes for goods supply chains carried out continuously and jointly by various modes of transport, due to the reduction of time throughout the logistics network of goods supply with the lowest costs and high quality of services performed for consumers.

The competitive advantage of the principle of transport multimodality is the services that cover several stages of delivery "from door to door" are provided by only one carrier and usually become less costly and more efficient compared to the situation when each of them tries to maximize its profit on the own separate area of the logistics product supply chain. In addition, network methods reduce time of delivery and are characterized by the expected benefits for manufacturers and participants in cargo deliverying due to the savings of time. In this case, the effect of multimodality is formed as a result of certain indicators. The effect consists of saving of time for cargo delivery from production to the consumer, reducing stocks, the ability to establish competitive prices for products, reducing logistics risks, and the like.

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