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SYSTEMATIC ANALYSIS OF FACTORS INFLUENCING THE EFFICIENCY OF MULTIMODAL TRANSPORT

The transport policy of many developed countries is based on the development and implementation of multimodal transport systems. They are an effective means of solving urgent problems of social development, globalisation of internal and external relations between states. The wide coverage of the problems of functioning and developing multimodal transport systems by the world scientific community shows that multimodal transport systems are currently considered as one of the means of solving the most pressing problems of the economy, transport, mobility, etc.

The authors have analysed existing research and found that there are no holistic approaches to analysing, designing, planning and managing different types of multimodal transport systems. The direct application of mathematical methods alone is insufficient and inefficient for such large technical systems as multimodal transport systems (MMTS). The reason for this is the uncertainty of a large number of factors and situations. Therefore, this paper uses the logical foundations of systems analysis. This has allowed the authors to gain a much deeper understanding of the nature of multimodal transport systems, their structure, organisation, tasks, regularities of functioning, optimal ways of development and management methods. The most important factors influencing the efficiency of international multimodal transport were identified using the method of expert evaluation. The content of the most influential factors identified by the experts was systematised. The systematic procedure allowed analysing possible alternative methods and means of achieving the goals, identifying effective solutions for improving the efficiency of MMTS, identifying the largest possible number of organisational and subjective factors affecting the object of study and considering how they affect each other.

Keywords: multimodal transport system, system analysis, influence factors, automation, efficiency.

INTRODUCTION

Multimodal transport systems are integrated systems in which different transport modes work closely together to make moving people and goods convenient and efficient. These systems combine the use of cars, bicycles, pedestrians, public transport and air travel, creating the conditions for the optimisation of traffic flows. The main benefits are improvements in accessibility, reductions in travel time and reductions in carbon dioxide emissions. Multimodality allows travellers to choose the mode of transport that is most appropriate for them.

The terminology of multimodal transport has been laid down in international law. The first document introducing the multimodal concept was the 1980 UN Convention on International Multimodal Freight Transport (Geneva Convention) [1]. In 1995, the United Nations Conference on Trade and Development (UNCTAD) developed a set of rules for multimodal transport. The International Chamber of Commerce (ICC) has made an important contribution to the development of legal regulation of multimodal transport. Under its auspices the “Package of Rules on Multimodal Transport” has been adopted.

In the European Union, multimodal transport systems are regulated by Council Directive 92/106/EEC of 7 December 1992 establishing common rules for certain types of combined transport of goods between Member States, which has to be implemented by all Member States by 2022. This Directive aims to reduce road transport by developing multimodal rail, inland waterway and maritime systems. [2].

Much attention is given to developing and improving multimodal transport in Ukraine, which is served by road, rail, air and water. The country occupies 603,550 sq km. The shape of the country is complex, stretched in the latitudinal direction, the maximum distance from east to west is 1316 km, from north to south – 893 km.

The geographical location of Ukraine allows it to control land and air transport routes between Eastern and Central Europe, sea transport routes in the Black and Azov seas, transport corridors along inland waterways between the Baltic and the Black Sea (Dnipro-Bug channel of the Vistula-Dnipro water system), and pipeline transport of hydrocarbons to European countries from the East (Druzhba, Soyuz, Urengoy-Pomary-Uzhhorod [3]). Rail and waterways played a leading role in multimodal freight transport, which was significantly reduced due to hostilities.

Developing multimodal transport systems (MMTS) is an important process whose successful implementation can solve the country’s security problems and increase investment in its economy.

ANALYSIS OF LITERATURE DATA AND FORMULATION OF THE PROBLEM

The strong interest of the scientific community in the development of this topic confirms the importance of the introduction and development of multimodal transport systems.

The essence of the "multimodal transport" concept, its development prospects and multimodal transport infrastructure are considered in [4-10].

In particular, Petrenko O.I. and Derepovska T.V. [4] substantiated the factors that have a negative impact on the development of multimodal transport in Ukraine; outlined the basic principles of the multimodal system and the main reasons that hinder the development of multimodal transport in Ukraine.

The problem of multimodal transport development from the point of view of ensuring its safety and reliability was addressed by Cherednichenko K., Ivankikova V. et al [5]. The authors have proposed a methodology for the evaluation and selection of the optimal safe transport route. The issue of reliability is important for the effective organisation and functioning of multimodal transport systems. This is shown by the analysis of existing studies [5, 6, 11]. According to the authors, the complexity of multimodal transport systems and the involvement of different types of vehicles explain the importance of this criterion for the evaluation of multimodal transport systems. The complexity of ensuring the safety of such integrated transport systems lies in the need for adaptation of their assessment methods and the main criteria that ensure reliability and safety for all modes of transport.

Methodological and methodical support of making management decisions in the system of multimodal freight transport and analysis of ways to improve the economic efficiency of making decisions is the subject of research by many authors [12, 13, 14, 15].

In order to organise the management process, management often uses graph models [12, 13, 14]. In our opinion, these models do not always take into account all the characteristics of a multimodal system in detail, in particular the time spent at freight or passenger transfer points, which does not always correspond to the plan. Researchers are developing modern software products for effective management and management methods which include the use of automated and digital control systems and artificial intelligence [16, 17, 18]. Such a management organisation meets the requirements of universality. It takes into account the multi-criteria choice under conditions of uncertainty from a discrete or continuous set of alternatives.

An analysis of recent research has shown that researchers have been developing new approaches to the solution of multimodal transport problems [19-21].

Zukhruf F., Frazila R. B. and others [19] proposed a comprehensive model for the restoration of a multimodal system destroyed by a natural disaster. The model includes measures to restore the road network and multimodal terminals, and also takes into account the interdependence of infrastructure and equipment in the system for the smooth distribution of humanitarian aid.

In this paper [20], the authors highlight the importance of travel time assessment in a multimodal freight transport network. This parameter is essential for the improvement of supply chain and logistics operations. Accurate travel time prediction is very important for freight transport and allows to improve logistics efficiency and quality. This paper develops a DLTTE-MFTN time estimation method that can be used to reduce dimensionality of multimodal transport data objects, significantly improving travel time prediction. The method has been tested by the authors and shows that using it gives superior performance compared to other models.

In order to justify the modes of transport for Japanese export containers, Dongxu Chen, Sufan Peng and others [21] used actual freight data. They developed a route selection model through data integration. This model is a theoretical basis for Japanese companies which are interested in the use of multimodal transport for the export of various goods to Europe or China. In addition, this approach helps to provide the operators with a more accurate assessment of the potential demand in the market.

Chuanzhong Yin, Ziang Zhang and others [22] have developed a comprehensive model for restoring a multimodal system that has been destroyed by a natural disaster. The model includes measures to restore the road network and multimodal terminals. It takes into account the interdependence of infrastructure and equipment in the system to ensure the smooth distribution of humanitarian aid.

The wide coverage of the functioning and development of multimodal transport systems by the global scientific community shows that the public policies of many countries are currently based on developing them, and MMTS are considered as one of the means to solve the most pressing economic, transport, mobility, etc. problems.

At the same time, an analysis of the literature showed that holistic approaches to the analysis, design, planning and management of different types of multimodal transport systems do not exist. The authors have used various methods of mathematical modelling, structural synthesis, optimal control, optimisation for load studies, description of the conditions for the safe operation of transport, capacity, etc.

The direct application of mathematical methods alone is insufficient and not very effective for such large technical systems as MMTS. The reason for this is the uncertainty of a great number of factors and situations. That is why we will not use mathematical methods, but the logical foundations of systems analysis, which will allow us to understand better the nature of multimodal transport systems, their structure, organisation, tasks, regularities of operation, optimal ways of development and management methods.

PURPOSE AND OBJECTIVES OF THE STUDY.

The purpose of the study is the systematic analysis of the factors which have an impact on the efficiency of multimodal transport. In order to achieve this goal, it was necessary to carry out the following tasks: an expert assessment to identify the most important factors influencing the efficiency of international multimodal transport; systematisation of the content of the most influential factors identified by the experts.

RESEARCH RESULT

Effective use of MMTS requires a systematic and scientific approach to the organisation of multimodal transport. All logistical and technological processes must be taken into account. This is particularly important in the case of international multimodal transport. In contrast to other formalised approaches, systems analysis makes it possible to:

- analyse all possible alternative methods and means of achieving objectives, combining them where necessary to solve the problem identified;
- find non-standard, but effective solutions;
- identify the maximum number of organisational and subjective factors influencing the studied problem and consider how they interact.

Multimodal international transport can be seen as a process based on the integration of production and transport that can lead to improvements in transport quality and reductions in resource costs. Transport efficiency is influenced by many factors, both internal and external. However, it should be understood that external factors are virtually impossible to change. However, on the basis of a systematic analysis they can be taken into account, predicted and controlled, which will allow timely adjustment of internal factors.

The first phase of the research was an expert assessment of the key factors that influence the efficiency of international multimodal transport.

According to the recommendations of [23], an expert group was formed. It consisted of 12 experts: 3 teachers, 6 representatives of transport companies (4 of them were specialised in international transport), 3 representatives of the Ukrzaliznytsia.

Several stages were involved in the technology of expert evaluation: Stage I – formulating the purpose of the expert analysis; Stage II – forming an expert group; Stage III – developing procedures and expert assessment; Stage IV – obtaining results; Stage V – processing the results and analysing the data obtained; Stage VI – determining the degree of achievement of the purpose of the expert assessment.

The experts were asked to analyse the following factors: automation of control systems, technical support, introduction of information technologies, meteorological conditions, availability of means of transport, social conditions, spatial planning and organisation of transport.

Generalised information about the object under investigation and the decision was obtained on the basis of the experts’ assessments. A variety of quantitative and qualitative methods are available for the processing of individual expert opinions. The choice of the method depends on the complexity of the problem to be solved and on the form and the purpose of the expert opinion.

The experts used the ranking method. This is the arrangement of objects in ascending or descending order of some inherent characteristic. The ranking method makes it possible to select the most important of the set of factors or parameters that have been studied. The resulting ranked list is called the Ranked List. The rank of the most important indicator equals 1 and the rank of the least important indicator equals the number n. The advantage of the method is its simplicity. The responses of the experts are averaged to obtain a generalised assessment of a group of experts. Averages are most often used for this.

The arithmetic mean of the rankings assigned to the objects:

$$\bar{x} = \frac{\sum_{j=1}^{m} x_j}{m}, \tag{1}$$

where $\bar{x}$ is the arithmetic mean of the expert group scores;

x_j is the score of the j expert.

The accuracy of the experts' ratings was determined by the degree of concordance between the opinions of the experts. The coefficient of concordance was calculated by the formula

$$W = \frac{12S}{n^2(m^3-m)},\qquad (2)$$

where S is the sum of the squared deviations of the number of rankings or preferences of each factor from the mean; n is the number of experts; m is the number of factors to score.

Sum of the squares of the deviations from the arithmetic mean (P_{cep})

$$S = \sum_{i=1}^{n}\left(\sum_{j=1}^{m} x_{i,j} - \bar{x}\right)^2,\qquad (3)$$

where $x_{i,j}$ is the number of ranks assigned by the *j* expert to the *i* factor;

$\bar{x}$ is the arithmetic mean of the rankings.

The results of the expert ranking are presented below.

The expert evaluation method showed that the main factors influencing transport are automation of control systems, introduction of information technologies, availability of modes and infrastructure (Table 1).

Table 1 – Results of the experts' assessment of the importance of the influencing factors

The factors	Scores of the experts												Sum of rankings	Deviation square $\Delta^2 = (x_j - \bar{x})^2$
	1	2	3	4	5	6	7	8	9	10	11	12		
the meteorological conditions	1	1	2	3	1	1	1	2	3	1	1	1	18	1296
the availability of transport and infrastructure	6	5	6	5	5	5	6	6	6	3	5	2	60	36
the social conditions	2	2	1	1	2	3	2	1	1	2	3	3	23	961
the automation of the control systems	8	7	8	8	8	6	8	7	7	8	7	8	90	1296
the technical support	5	4	5	4	6	7	5	3	5	4	6	4	58	16
the implementation of information technology	7	6	7	6	7	8	7	8	8	7	8	7	86	1024
spatial planning	3	3	4	7	4	2	3	4	2	5	2	6	45	81
the organisation of the transport operations	4	8	3	2	3	4	4	5	4	6	4	5	52	4
-	-	-	-	-	-	-	-	-	-	-	-	-	$\bar{x} = 54$	$\sum 56856$

The coefficient of concordance is the result of the formula (2): $W = 0{,}78$. The value of the concordance coefficient is close to 1, which indicates the consistency of the experts' opinions.

DISCUSSION OF THE RESULTS OF THE STUDY

Problem solving is the process of exploring different ways of finding an answer to a problem. The essence of problem solving is the presentation of the collected and processed information material in the form of a coherent, consistent and reasoned justification for the achievement of the objectives. Much time is often lost in finding the most effective way to achieve the end goal because of incomplete or inadequate information. It is at this level that information needs are most active. Satisfying them can lead to significant savings in human, material and financial resources.

The expert analysis carried out by the authors of the article made it possible to identify the main factors influencing the transport process. This is the basis for finding ways to improve the efficiency of multimodal transport, including in Ukraine.

We want to systematise the content of the first three factors identified by experts as having the greatest impact on the efficiency of multimodal transport.

1. The automation of the control systems.

The infrastructure and management of transport systems are complex and require the implementation of automated systems at the current stage of development. The processes of traffic tracking and operational management of transport systems are greatly facilitated by automated systems. It is possible to react quickly to emerging dangerous situations through the use of automated systems. This can be achieved through automated tools that support the exchange of data between vehicles and systems, and between vehicles and infrastructure. At present, it is known that automated systems are built into the design of vehicles to ensure the safety of the driver: ABS (Anti-Lock Braking System); ESC (Electronic Stability Control); DBC (Dynamic Brake Control); TCS (Traction Control System); EBD (Electronic Brake Distribution); BAS (Brake Assist Systems); AEBS (Automatic Emergency Braking Systems); LDWS (Lane Departure Warning Systems); FCWS (Frontal Collision Warning Systems), etc. These functions are implemented using ultrasonic sensors, infrared sensors, radar and artificial vision.

The safety of road traffic is not only influenced by the reliability of the vehicle itself and its equipment, but also by the automation of road traffic equipment. In particular, automated meteorological systems based on using high-precision sensors to measure temperature, wind speed, direction, precipitation, etc. Detectors for the monitoring of traffic are a set of sensors placed under the surface of the road. Various sensors transmit information to control panels. The information is processed immediately.

Rail transport is an important component of the multimodal transport system of Ukraine. Mainly due to its ability to carry the majority of bulk freight over long distances throughout the year, rail is the backbone of the country's transport system. The loss of sea freight has also contributed to the growing importance of this mode of transport. Automation equipment has become a vital part of the railway's technical armoury, helping it to reliably perform its transport tasks, increase its capacity, ensure the safe movement of trains and provide seamless communication between all rail transport equipment.

Automation equipment includes: automation equipment that regulates the movement of trains on the tracks (semi-automatic and automatic blocking); control equipment for switches and signals in the station; door position sensors; automated systems for control of power supply to power equipment and their operation. The reliable operation of automated systems ensures the safety of people, goods and rolling stock, the speed of transport and the comfort of passengers and staff. Automated systems perform tasks of optimal process control, collection and processing of information, planning and prediction of technological processes and the state of equipment.

2. The implementation of information technology.

We now turn to the second influencing factor, namely the importance of information technology for the efficient organisation of multimodal transport. The concept of information is important for the systems and for the analysis of them. Therefore, there will be a formalisation of this concept. To organise the process of efficient information use for multimodal transport, high-bandwidth electromagnetic and optical channels are used. In particular, fibre optic information transmission networks are widely used in Ukraine. They enable information exchange, video surveillance and free access to Internet resources. Information systems make it possible to process information concerning the location, safety and environmental situation of transport. Railway transport uses fibre optic networks. Road transport uses wireless technologies such as GSM and DSRC. The monitoring and management of logistics processes is being improved by artificial intelligence and other technologies.

The number of devices that use GPS and GSM-R has now grown considerably and is continuing to develop in all modes of transport. This provides detailed information on passenger and freight movements to transport infrastructure operators.

The use of information technology enables rail and road companies to have access to each other's information and to communicate with customers.

The transfer of electronic texts between computers in management and transport eliminates the need for paper documentation. It greatly simplifies the management and planning of multimodal transport and reduces the time required for its implementation. In addition, according to UNECE experts [24], the development of electronic information systems saves on average 7-8% of the value of goods in international trade.

3. Accessibility of transport infrastructure.

Transport infrastructure is the fixed structures, facilities and networks that enable people and goods to move. Urban transport infrastructure is divided into five broad groups: roads, bridges and tunnels, rail and tram, water, and cycling and walking [25]. Underdeveloped transport infrastructure has a direct impact on the speed, safety and reliability of transport, including an insufficient number of vehicles, both road and rail.

For the creation of an efficient infrastructure for both domestic and international transport, it is necessary to develop the construction of logistics terminals that enable the interaction of different modes of transport, which in turn creates favourable conditions for the organisation of multimodal transport and integration into the international logistics system.

We are going to analyse how the infrastructure affects the efficiency of the MSEs. First of all, the basis for reducing negative environmental impacts is to solve the problem of organising modern high-tech infrastructure. Particularly in Ukraine, in view of the reduction in the number of waterways, it is advisable to build and technically develop existing railway lines and equip them with modern logistics centres. As a result, carbon dioxide emissions will be significantly lower in comparison with road transport.

Given the strategic importance of rail transport for the country, a major problem in developing it as a component of the multimodal transport system is the low level of organisation of high-speed rail transport. The solution to this problem will require a whole range of systemic research, which will result in a programme of scientific, technical and technological solutions.

The development of the transport infrastructure in Ukraine also requires the creation of multimodal transport and logistics hubs in the country. The current multimodal transport system in Ukraine, as revealed by the system analysis, requires the relocation of freight terminals from the eastern and southern parts of the country to the western part. An example of this is the organisation of a logistics centre in the Rivne region. This centre is used for both export and import of goods. Most of the staff are employees of sea freight terminals who have experience in the construction and maintenance of such terminals. The terminal offers cargo owners handling and storing, customs clearance, packing, insurance, etc.

An analysis of the organisation of production processes within the terminal allowed the authors to identify the main factors preventing the terminal from becoming more dynamic. The first is the increase in the cost of transporting goods due to the need to replace wagons, which is caused by the difference in track gauge between Ukraine and the EU. In addition, the MMTS of the partner countries does not have enough rolling stock, which hinders the growth of freight traffic from Ukraine.

SUMMARY

The study has carried out a systematic analysis of the problem of organising multimodal transport and of the factors that influence its efficiency.

The results of the study led to the following conclusions:

1. The scientific community pays considerable attention to the study of modern principles of operation of certain types of transport and multimodal transport. Researchers' attention is mainly focused on improving a particular mode of transport, certain stages of multimodal transport or solving problems in a particular geographical region. This approach does not meet the current development trends and problems of multimodal transport and innovative technologies.

2. Using expert assessment, the authors have established the main factors affecting the efficiency of multimodal transport systems, that is, determining the specifics of the multimodal freight transport system: automation of control systems, introduction of information technologies, availability of transport modes and infrastructure.

3. A systematic analysis of the content of the factors that primarily affect the efficiency of multimodal transport allows to identify the main unresolved problems of organising MMTS.

Regarding Ukraine, these are:

- low development of transport infrastructure, including insufficient number of vehicles, in particular in the field of rail transport, which directly affects the speed, cost, and reliability of transportation;

- poor development of innovative technologies.

4. In order to achieve significant progress in the field of multimodal transport system of Ukraine, a number of strategic tasks must be solved:

- to intensify the construction of logistics terminals that enable broad interaction between different modes of transport and create favourable conditions for organising multimodal transport, increase the efficiency of logistics processes and create conditions for successful integration into the international logistics system;

- to introduce transport innovations, including the digitalisation of the transport industry;
- to apply electronic document management, electronic data exchange, technologies and standards of EDIFACT, EDI and others.

In order to increase the efficiency of MMTS, the research should be continued in the following directions:

- development and implementation of adaptive systems for controlling motion parameters, including software and hardware solutions using artificial intelligence elements;
- development of a model for managing transport routes using information technologies, taking into account the peculiarities of the economic, social and political situation in Ukraine.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

Data will be made available on request.

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