

Dynamic Multimodal Transport Systems with The Participation of Railway Transport: Work Management Technology

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Abstract: The purpose of the article is to analyze the technical implementation tools of integrated development of rail and sea transport systems in multimodal transportation in their modern conception. The authors of this article analyzed studies and practical approaches in the field of multimodal transportation with the participation of rail and other modes of transport. The authors suggested improving the organization of the movement of material flows in a multimodal transport system by developing models for organizing multimodal transportation based on the theory of inventory management, probabilities, and mass service. The article presents the results of the analysis and theoretical generalization of approaches to the formalization of the operation process of the dynamic multimodal transport systems with the participation of rail and sea transport.

Keywords: Multimodal transport systems, railway transport, multimodal transportation, sea transport, storage capacities

1. Introduction

In modern conditions of the development in manufacturing and industrial sector the organization of multimodal transport systems occupies a special place. The effectiveness of their work is due to the analysis of the methods for organizing the movement of material flows in the delivery of products in a multimodal connection and the functioning of logistics projects involving different modes of transport. The interaction of rail and sea transport modes as the primary carriers of mass consignments

and their interaction with road transport upon consignment delivery by door-to-door technology plays a leading role in the development of multimodal transport systems. As known, the market economy is characterized by the ability to develop industries through investment projects, and the development of multimodality in transport is characterized by investment projects of the interaction development between different modes of transport.

The existing levels of efficiency, range, and quality of transport services in the organization of multimodal transport do not meet modern international requirements. There are no methods of developing multimodal projects for infrastructure and vehicles growth, because a very acute issue is the competitiveness of each mode of transport separately, and not their synergy. To promote and implement such projects, it is necessary to analyze the similar experiences of other countries and similar pilot projects in order to gain experience in the formation of multimodal logistics schemes for cargo delivery. Of course, Ukraine's transport system is interested in increasing the flow of goods through and on its territory, and, as known, exporting, transiting and importing goods are foreign economic material flows that are highly profitable for any country. Mixed freight technologies are often used in the organization of multimodal transport systems, but it is not a modern approach.

2. Methods

The problem of the efficiency of multimodal transport systems is the most present in the interaction of railway and water transport. Within the framework of the complex theory of transport, the necessity for interaction between different types of transport was substantiated [1]. The basics of routing the railway-water communication were developed based on the designed contact schedules; the principles for coordinating the work of railway, water, and road transport were developed [2,3]. It became clear that it makes no sense to link the technological processes of the activities of railway stations and ports at cargo transshipment points, because these points are an important element of the transport process, but do not affect the process of multimodal transportation. Due to the fact that the elements of the transport process are not covered by the agreed technology, there are situations in which it is the port that experiences the uneven transport load. Trains and vessels arrive at the port without an agreed order, there is usually not enough empty rolling stock, warehouses are overcrowded, and there are downtimes and railway cars and vessels.

The general coordination of the transportation process is not carried out from the port and, accordingly, the port's activity is not able to influence the organization of the transportation process on the approach to it, and along the entire route of the cargo. The cargo flow enters the port by rail and water transport and is processed here, but the flows arrive without any signs of organization. Therefore, violations of technological norms for railway and water transport are often observed. As a result, the interaction of rail and water transport in large transport hubs began to get more and more

attention in scientific studies. Theoretical issues of organizing freight transportation in the areas of interaction between rail, sea, river and road transport have been studied [4]. Continuous combined schedules for the movement of trains of different types of transport, and so-called unified technological processes for the operation of railway-water and railway-road cargo transshipment points have been developed on the basis of mutual coordination of technological standards of work.

Then more attention began to be paid to the study of the transportation process as a stochastic whole, while human activity has minimal impact. The combination of probabilistic and deterministic approaches gave the best practical result. As a result of modeling, the entire transportation process is a set of tasks, the solution of which provides the optimal multimodal route with minimal costs. The quality of the transportation process is assessed by the need for a certain cargo at the destination. Therefore, to achieve the goal it is necessary to provide a certain number of transportation processes. The quality of railway transport can be determined by the scoring system [5]. Out of 100 points of the total factor of transport service quality, 20 points are estimated for the delivery service using door-to-door technology, which is possible for transportation by rail only if the consignor and consignee have approach lines.

3. Results

The high efficiency of intermodal transportation in the transport complex and the developed theoretical base for the operation of transport hubs using combined work schedules made it possible to conduct a production experiment in the Odesa seaport in Ukraine. The following were chosen as the main principles of cooperation between transport companies: 1) to ensure the supply of vessels, cars and vehicles according to the agreed continuous plan-schedule of the transport hub; 2) comprehensive informatization of all participants in the transportation process about working with vehicles; 3) collaborate planning of freight operation with the maximum possible double operations and direct transshipment options, wide use of containers, packages and pallets; 4) introduction of uniform changes for port employees, adjacent railway stations, motor transport enterprises and approach lines; 5) performance of freight operation by enlarged crews; 6) a clear specialization of berths, railway stations and loading and unloading points by type of cargo.

As a result, new schemes for interaction of modes of transport and automated systems for managing material, information and financial flows at such interaction were developed. However, problematic issues were also identified, namely: 1) coordination of technological interaction between different modes of transport does not significantly accelerate the transportation of goods and reduce costs without ensuring coordination of economic, legal and administrative decisions; 2) the problem of technical interaction between different modes of transport is not nodal, but a network, because nodes cannot determine the control of vehicle flows throughout the network, but only process the

incoming cargo flows; 3) the most important shortcoming is the lack of coordinated work of railway and water transport.

The experience of the Odesa seaport has shown that the use of technology of a single technological process for organizing traffic in the operation of a multimodal transport system leads to the improved operation of the transport hub as a whole, but does not provide qualitative changes in different modes of transport. Thus, the transport node handles cargo flows coming from different departure points. Without some experience in their organization, there are situations of prolonged downtime of railway cars and vessels, that lead to traffic disruption in neighboring regions. Therefore, the organization of multimodal transport cannot be limited by activities only in transport hubs. A network-wide statement of the problem is required that will completely cover the organization of the transportation process based on the integrated use of different modes of transport.

In the 1980s, when organizing the transportation of goods by different modes of transport on one route, the concept of multimodal transportation was used. Operational regulation is the basis for managing any type of transportation today, but previously there was no responsible party for operational regulation and the transportation process was divided into several parts. For example, the railway part from the departure station to the destination station, and the water part from the departure port to the destination port. This has led to significant time and financial costs for the transportation process as a whole. There was a question of improving the process of freight transportation by several modes of transport on one route.

In the activities of modern transport companies operating in the market of transport services, more and more attention is paid to marketing. This process is natural, because in the Soviet economy, the initial information for the planning of freight traffic was directive instructions on the distribution of the volume of freight traffic between modes of transport. Currently, the volume of transportation work is determined by the forecasts for the development of the transport services market in relation to the mode of transport and the competitive environment.

However, despite the large number of publications devoted to marketing, the attitude of transport employees to this area of knowledge has not been quite formed. There are a number of objective reasons for this. Firstly, it is the ambiguity of interpretations of the subject and methods of marketing, and as a result, its non-recognition by many as a scientific discipline. There are about 2000 definitions of the essence of marketing [6].

According to Kotler's classical definition, marketing is “a type of human activity aimed at meeting needs in the form of exchange” [7]. The definition of the London Institute of Marketing reads as follows: “Marketing is a systematic process aimed at identifying, forecasting and meeting customer needs, and is profit-oriented”. In addition to the above, there are others: marketing is often introduced as a philosophy, concept or complex system of management and organization of production and

product distribution, that proclaims the orientation of meeting the needs of specific consumers [8]. Such an abundance of definitions and interpretations can not but lead to differences in the functions, objectives and subject of marketing. At the same time, the general provisions in these definitions for customers are “satisfaction of needs”, and for producers, and service providers “making a profit” [9]. In numerous publications on marketing, the following three definitions are very common: marketing is a “concept ...” [10]; • marketing is a “process ...” [11]; •marketing is a “system ...” [12].

The concept of marketing is a scientifically grounded idea for organizing the activities of the company, based on the guiding idea, effective operational and strategic tools that ensure the implementation of plans, as well as improving the quality of life. Today, the exact sciences are being replaced by sciences that have formed at the junction of several others. Entrepreneurs often perceive marketing as a tool for market research and neglect all the features of this industry [13]. Also, of course, the definition of marketing is interpreted as a system, and in the transport industry, as a comprehensive system for organizing of the transportation process and performing transportation [14].

Marketing research is relevant in order to identify new segments in the multimodal transportation market, namely, the competitiveness of each company in the transport market, the presence of enterprises in demand for multimodal transportation of their products, the assessment of options for land, water and air transportation of freight, the assessment of product transshipment points, assessments of the logistics issues complex, maintenance of current traffic volumes, assessment of the customer base of multimodal transportation, and the creation of a new product for the transport company, that is, the multimodal transportation of goods [15]. Such a service can be offered to cargo owners and can be developed specifically for their requests and requirements. The costs for the implementation of the multimodal transportation service will include cost components for each mode of transport involved in the multimodal service, the cost of transshipment points, and here the use of marketing tools is relevant and necessary [16]. The transport service is intangible, so the definitions of "marketing of products" or "sales of products" are not entirely relevant, because for the transport company and its products transportation of goods is an integral part of the transshipment process and the movement process itself. Thus, marketing for a transport company is a complex system of organizing transportation and providing services, which will be focused on the most complete satisfaction of variable demand for multimodal transportation and maximizing sustainable profits and competitive advantages [17,18].

4. Discussion

Consider the mathematical modeling of multimodal transport systems. The efficiency of multimodal transportation is determined by the level of coordination of different modes of transport and

transshipment points. Since chaotic development can lead to unreasonable costs for a particular industry, there must be a balance in the development of each mode of transport and transshipment points in the field of multimodal transportation in order to meet customer needs [19].

It is necessary to consider the impact of storage capacity reserves on the downtime of vehicles, for example, in the port, where two types of traffic flows arrive in the form of railway cars and vessels. There may be a lack of storage capacity, when either rail cars or vessels will be unused, when there are not enough cargo or free berths in the development of the average specified freight flow [20]. At the same time, operational regulation allows to align the oncoming traffic flows and to eliminate the concept of development of a given freight flow. Then the vessels on arrival at the berths are immediately loaded with cargo, if it is in sufficient quantity. Railway cars arriving at the port are immediately delivered for unloading, if there is sufficient storage capacity. If not, the cars are waiting in line for unloading. The flow of ships usually conforms to Poisson. The flow of railway cars is uniform and regular with constant intensity.

With this statement of the problem, it is possible to determine how the average waiting time of ships and wagons in the queue depends on the value of the cargo capacity of port depots and the initial technological stock of cargo in the port. There are some limitations to the set task, namely the lack of operational regulation, which reduces downtime of vessels waiting for cargo and free berth and downtime of rail cars with cargo waiting for unloading, which depends on the storage capacity of the port. At the same time, the capacity of railway tracks should provide a high intensity of arriving railway cars in comparison with the intensity of arrival of vessels [21]. The capacity of loading and unloading mechanisms in the port is not limited.

The carrying capacity of one vessel is denoted in units of capacity of trains as v , the intensity of the flow of vessels arriving at the port per day as w , as l – the intensity of the flow of railway trains, as T – port operating time, days, k - the number of vessels handled during T , s – free storage capacities in the port in units of carrying capacity of vessels, z – initial stock of cargo in the port warehouses in units of carrying capacity of railway cars. By consignment we mean the number of railway cars with a carrying capacity equal to the carrying capacity of the vessel. t_i^j is denoted as waiting time by j car from i party for the moment of unloading, as t_n waiting time by n vessel for the time of complete loading, as $t_{cep}(s, k)$ the average waiting time in days of j car that arrived at the port in the interval of $(0, T)$ of the beginning of its unloading:

$$t_{mid}(s, k) = \frac{1}{w \cdot v \cdot T} \sum_{i=s+1}^{wT} \sum_{j=1}^v M(t_i^j), \quad [s] \quad (1)$$

as $t_{mid}(z, k)$ the average waiting time in days by one vessel that arrived at the port in the interval $(0, T)$, the moment of completion of its loading:

$$t_{mid}(z, k) = \frac{1}{w \cdot T} \sum_{i=z+1}^{wT} M(t_n), \quad [s] \quad (2)$$

where: $M(t_i^j)$, $M(t_n)$ - mathematical expectation of random variables t_i^j and t_n .

The intensity of the arrival of vessels at the port will be $w = \frac{k}{T}$. And for the development of a given freight turnover, the average intensity of arrival of railway cars with cargo will be equal to $l = w \cdot v$. Cars arrive at the port regularly at regular intervals [22]. Next, the values of the average waiting time for the beginning of each car unloading and the average waiting time for the end of loading of one vessel, which arrived at the port in the time interval $(0, T)$. When using this model, the result is the average downtime of the vessel while waiting for loading and cars while waiting for free storage capacities and the available amount of cargo in the warehouse.

Consider the work of the freight transport hub with an annual turnover of 15 million tons. During the year it handles $k = 1500$ vessels with a capacity of 10 thousand tons. The intensity of the approach of vessels to the port is $w = 5$ per day. At first, we determine the influence of the port operation time on the average waiting time for one vessel arriving at the port and the end of its loading, and on the average waiting time for one railway car arriving at the port and the moment of its unloading. For this purpose, the parameters of the port operation time for 10 days at the cargo turnover $k = w \cdot T = 50$ of vessels were set. The results of the dependence of the average waiting time for cars to start unloading on the free initial capacity of port warehouses and the time of port operation are presented as an asymptotic dependence:

$$t_{mid}(s, k) = T \cdot \frac{2}{3 \cdot \sqrt{2\pi k}} \left(1 - \frac{3\pi(s-1)}{2 \cdot \sqrt{2\pi k}}\right), \quad [s] \quad (3)$$

Figure 1 shows the obtained dependences $t_{mid}(s, k)$ on s and T .

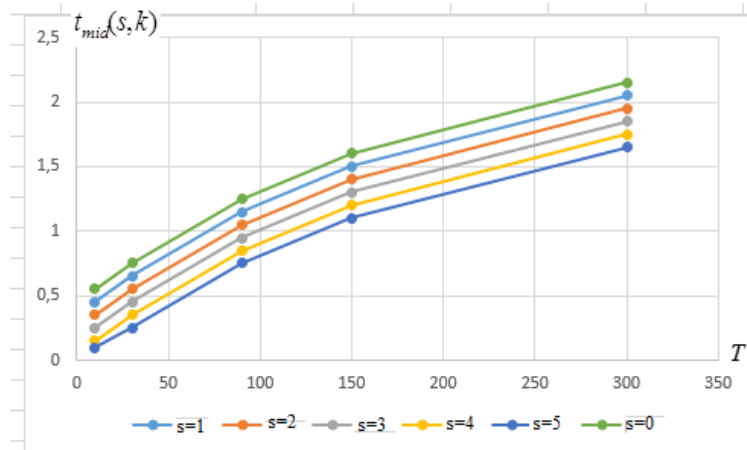


Fig. 1 Dependence $t_{mid}(s, k)$ on s and T . Source: authors

Next, the dependence of the average waiting time for the vessel to start loading on the value of the initial technological stock of cargo in the port warehouses and the time of the port's operation is considered and presented as an asymptotic dependence:

$$t_{mid}(z, k) = T \cdot \frac{2}{3 \cdot \sqrt{2\pi k}} \left(1 - \frac{3\pi \cdot z}{2 \cdot \sqrt{2\pi k}}\right), \text{ [s]} \quad (4)$$

Figure 2 shows the obtained dependences $t_{mid}(z, k)$ on z and T .

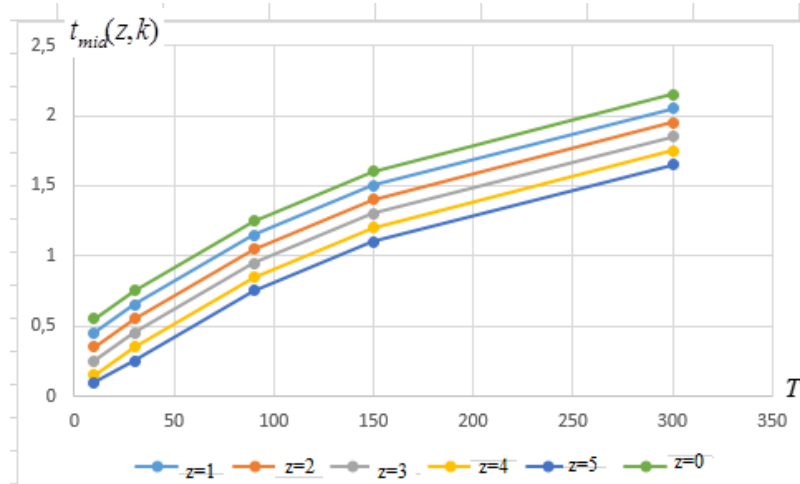


Fig. 2 Dependences $t_{mid}(z, k)$ on z and T . Source: authors

As a result of the analysis of the obtained results the following conclusions are made:

First, the average downtime of vessels while waiting for loading and cars while waiting for unloading in the port increases with the increasing the time of the port operation, during which operational regulation is absent; Second, the average downtime of vessels while waiting for loading and wagons while waiting for unloading in the port decreases with the increase of the initial technological stock at the port's storage facilities and free initial storage capacities; Third, the obtained graphical dependencies in Figure 1 and Figure 2 make it possible to estimate the costs arising from vehicle downtime, the limited storage capacity of the port, and insufficient initial stocks of cargo in the port in the absence of operational regulation.

Now consider the model of the same process, but with the introduction of full operational regulation. It is shown above that the planned freight turnover is not fully mastered, but at the average level, that leads to significant costs associated with the downtime of vehicles involved in multimodal transportation [23]. In the current task, the statement of the previous one is preserved, but with full operational regulation, it is possible to achieve a greater level of consistency in the supply of vehicles for loading and unloading, respectively, which will master the entire cargo turnover [24]. Thus, the coefficient of regulation of cargo flows in a certain time interval will be as follows:

$$\eta(T) = \frac{V(t)}{W(t)} = 1, \text{ [-]} \quad (5)$$

where: $V(t)$ is the amount of cargo arriving at the port in the time interval $(0, t)$, and $W(t)$ is the amount of cargo sent from the port in the time interval $(0, t)$.

In real conditions, the regulation coefficient $\eta(T)$ is a random variable, but if the dispersion of this value has a very small numerical value, then the actual operation of the port in the selected time interval can be described using this model. Other limitations correspond to the limitations of the previous model. Then:

$$t_{mid}(s, k) = TD(s, k) \cdot \frac{2}{3 \cdot \sqrt{2\pi k}} \left(1 - \frac{3\pi(s-1)}{2 \cdot \sqrt{2\pi k}}\right) \quad [s] \quad (6)$$

$$t_{mid}(z, k) = TD(z, k) \cdot \frac{2}{3 \cdot \sqrt{2\pi k}} \left(1 - \frac{3\pi \cdot z}{2 \cdot \sqrt{2\pi k}}\right) \quad [s] \quad (7)$$

where $D(s, k)$, $D(z, k)$ - known functions.

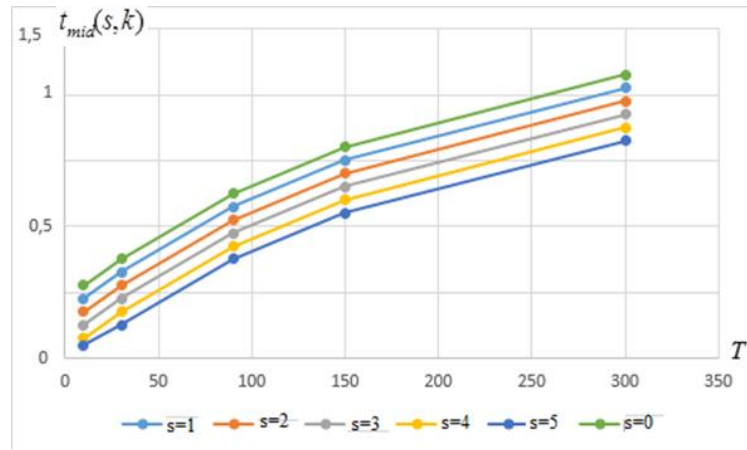


Fig. 3. Dependence on and with full operational regulation. Source: authors

Comparison of the curves shown in Figure 1 and Figure 2 and curves in Figure 3 and Figure 4 shows that the qualitative nature of the curves is the same, and the quantitative differences are significant. Unproductive downtime of cars and vessels with full operational regulation is reduced by almost 35%.

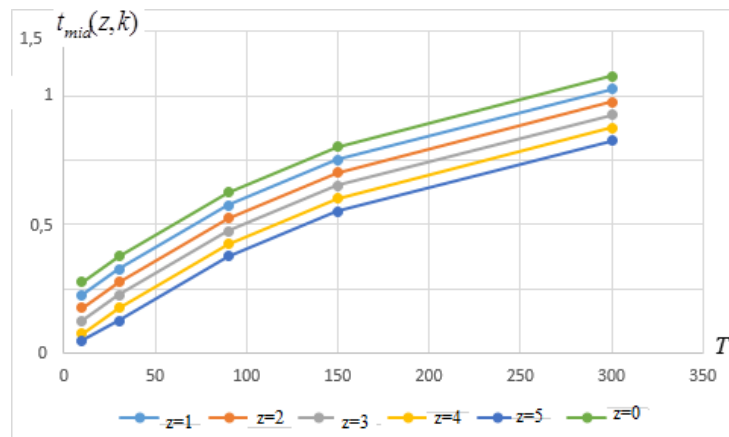


Fig. 4. Dependence on and with full operational regulation. Source: authors

Furthermore, the reduction of the initial free capacity of warehouses in the port and the initial stock of cargo leads to an increase in vehicle downtime. Accordingly, full operational regulation is especially relevant at a low capacity of the port's warehouses. The practical correspondence of the

volume of incoming and outgoing cargo usually occurs at the end of the calendar year. It is during this period of time that full operational regulation is relevant. In other periods of the year the regulation coefficient often deviates from 1, and then the downtime of vehicles in the port increases. Here, repeated regulation at certain time intervals is recommended [25]. To do this, the specified time interval is divided into equal periods, each of which is equal to $\frac{T}{n}$. Then, if in a given time interval the cargo turnover is equal k in units of loading of vessels, then in each partial interval at full operational regulation the cargo turnover will be equal $\frac{k}{n}$.

The above graphs make it possible to evaluate the effectiveness of managing multimodal traffic flows during certain periods of port operation, to obtain numerical values of time losses due to unproductive downtime of vehicles, to determine the available free storage capacity and the size of the initial technological stock of cargo in the port. The second model, which provides full multiple operational regulation of multimodal transportation, can be considered the most effective.

5. Conclusions

The study conducted by the authors of this article confirms that delivery in multimodal connection makes it possible to increase the competitiveness of the entire logistics scheme for organizing the process of cargo transportation. Thus, the urgent task of transport is to maximize the investment potential of the market. Therefore, when forming the cost of transportation, it should be taken into account that the transportation of products by rail in the direction of ports where there is a significant accumulation of cargo flows is a qualitatively different task for the organization of the transport system than the delivery of the same goods to points where there is no such concentration of cargo flows. It is the best option for the development of multimodal transport systems.

To increase the competitiveness of a multimodal transport system, modern transport operations should be based on the quality of transport services while responding flexibly to changes in demand for transported products. Activities for the implementation of multimodal transportation of goods allow the transport complex to qualitatively increase the level of organization of domestic and international transportation.

Improving the competitiveness of transport operations using marketing methods is a comprehensive system for organizing multimodal transportation and providing services aimed at better satisfying the ever-changing demand for organizing transport activities and obtaining competitive advantages on this basis. Thus, the classic tasks that form the basis of marketing theory (marketing research, target market selection, development of new technologies of transport production, development of pricing policy, timely delivery of products, and development of

marketing strategy), fully meet the objectives of the development of a transport company operating in the multimodal transport market.

For the construction of engineering models of multimodal transport systems, cases are important where the distribution of random variables obeys Poisson's law. Through this distribution important technical and economic-mathematical models of the activities of separate modes of transport have been developed.

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