LOGISTICS SYSTEMS: TECHNOLOGICAL AND ECONOMIC ASPECTS OF EFFICIENCY

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Collective monograph contains the results of scientific research devoted to the search for effective scientific and applied solutions for the operation of logistics systems. The given transport and logistics solutions and proposals for information support are promising from the point of view of the integrative capabilities of national economies in terms of international connections and transportation. The criteria for the efficiency of the operation of logistics systems are proposed, as well as complex solutions that allow making a reasonable choice of the composition of consumers and partners for each enterprise, taking into account their characteristics and strategies of information interaction. The monograph is intended for practitioners in the field of logistics and scientists investigating applied problems of the operation of logistics systems, and it can also be useful for graduate students and masters of universities with the appropriate educational and scientific profile.
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ABSTRACT

Collective monograph contains the results of scientific research devoted to the search for effective scientific and applied solutions for the operation of logistics systems. The problems posed are considered through the prism of technological and economic views, which contributes to the formation of the practical significance of the results of systematic research, which are highlighted in the monograph.

Section 1 examines which multimodal logistics solutions in emergency situations and transport security threats have proven effective during the war in Ukraine. The given transport and logistics solutions can be considered promising from the point of view of integrative capabilities at a new level of transport competitiveness and defense capability.

In Section 2, practical measures are proposed to improve logistics solutions in transport and customs services in international traffic to ensure the efficiency and reliability of the national economy.

In Section 3, the impact of information provision of truck crews performing transport tasks on road traffic is investigated, and an effective scheme for information support of cargo delivery conditions is developed.

In Section 4, solutions are proposed for evaluating the effectiveness of the ecological system project using the "discounted payback period" criterion, which takes into account transformational changes in its life cycle model.

In Section 5, solutions are proposed that allow for a reasonable selection of the composition of consumers and partners for each enterprise, taking into account their characteristics and strategies of information interaction, ensuring an increase in the efficiency of the "consumer – enterprise – partner" system based on the criterion of profit maximization.

KEYWORDS

Transportation events, humanitarian supply chains, intermodal transportation, traffic safety management information systems, customs service, logistics risks, containerized transportation, cargo delivery, logistics chain of flow delays, ecological system, information interaction.

CIRCLE OF READERS AND SCOPE OF APPLICATION

The monograph is intended for practitioners who are engaged in the search and implementation of effective technological solutions in the field of logistics, in particular according to economic criteria, and scientists who investigate applied problems of the functioning of logistics systems.

The monograph can also be useful to postgraduate and master's students of universities in the relevant educational and scientific profile.

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INTRODUCTION

Logistics systems are an integral part of the sustainable development of national economies, because the timely performance of all processes occurring in society depends on the reliability of their functioning. Any violations or abnormal situations in such systems lead to a halt in other systems of the economy and may even cause a collapse. The tasks of finding and forming the most favorable conditions for the operation of logistics systems are too complex and require multifaceted research that examines such systems from different points of view, but united by a single ultimate goal – the search for the most effective technological and economic solutions according to the selected criteria. Systematic studies devoted to the following issues can be justified from this point of view:

– determination of multimodal logistics solutions in the conditions of emergency situations and threats to the safety of transportation;

– search for solutions for freight transportation logistics, taking into account customs service in international connections;

– coordination of material and information flows in intercity logistics systems;

– consideration of transformational changes in the model of the life cycle of ecological systems and evaluation of the effectiveness of relevant development projects of such systems;

– managing the company's interaction with partners and consumers.

Multimodal logistics solutions become especially relevant in emergency situations and threats to the safety of transport, which was especially pronounced during the war in Ukraine. They should also be considered in the context of the development of the state's integrative capabilities. Effective logistical solutions proposed in the monograph are considered from the local level, for logistical and logistical support during the evacuation of internally displaced persons, to the transcontinental level. The digital informational organizational and educational system of railway traffic safety management at the proposed enterprise can be scaled to the size of larger transport systems, which will ensure the highest level of traffic safety.

The logistics of cargo transportation and customs service in international communication acquires special importance in the modern conditions of martial law in Ukraine. Therefore, it is extremely important to determine the aspects of international transportation logistics related to: the development of international transport logistics, the identification of logistical risks in international transport service projects, the logistics of the use of information technologies to increase the efficiency of the organization of international cargo transportation, the specifics of the development of customs logistics, the specifics of the logistics of cross-rail transportation in international communication. The measures proposed in the monograph to improve logistics solutions in transport and customs services in international traffic have the potential to ensure the efficiency and reliability of the national economy in a practical sense.

The coordination of material and information flows in long-distance logistics systems, which is studied in the monograph, allows the implementation of such a scheme of information support of cargo delivery conditions, which ensures the timely execution of logistics chain operations.

Under modern conditions, it is important to take into account various components of the process of functioning of logistics systems, choosing the efficiency criteria accordingly. Thus, it is useful to determine the assessment of the effectiveness of the ecological system project using the "discounted payback period" criterion, the calculation of which takes into account transformational changes in the model of its life cycle. It is important to reflect the relevant decisions in the monograph, because the identification of functional dependencies between the discounted life of the totality and the cash flows during the life cycle phases of ecological projects allows to study the dynamics of the relevant changes and to apply the obtained results in forecasting the effectiveness of the ecological system project.

No less important is the view on the operation of logistics systems from the point of view of purely economic efficiency, as it depends on the perfection of the management system of the enterprise's interaction with partners and consumers. Such systems can be presented in the form of "enterprise – consumer – partner" and take into account the ratio of economic parameters of the processes of production, supply and distribution of products, including the assessment of the competitiveness of the enterprise, the attractiveness of the partner, and the readiness of the consumer. The developed complex of economic-mathematical models of the formation of the composition of the "consumer – enterprise – partner" system, the determination of the effect of the functioning of such systems and the budget of information interaction, given in the monograph, make it possible to make a reasonable choice of the composition of consumers and partners for each enterprise, taking into account their characteristics and strategies of information interaction This, in turn, allows enterprises to model connections in the "consumer – enterprise – partner" system according to the criterion of profit maximization and use the results of modeling to implement information interaction.

All these areas of research are highlighted in the monograph, which makes it relevant both for researchers of logistics systems and for their developers.

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CHAPTER 1

MULTIMODAL LOGISTICS SOLUTIONS IN THE CONDITIONS OF INCIDENTAL SITUATIONS AND THREATS TO TRANSPORT SAFETY

ABSTRACT

It is considered which multimodal logistics solutions in emergency situations and threats to transport safety have shown their effectiveness during the war in Ukraine, as well as promising transport and logistics solutions that allow integrating Ukraine into the European transport space at a new level of transport competitiveness and defense capability. Logistic solutions are proposed from the local level for logistical and logistical support during the evacuation of internally displaced persons to the transcontinental level, namely a multimodal logistics system for the transportation of passengers and goods with the participation of new high-speed railways of European track width. At the same time, both complex mathematical models of humanitarian logistics tasks used in emergency situations and simple calculation methods for use in extreme conditions are considered.

The priority of transportation safety is taken into account, therefore, a digital information organizational and educational system for managing the safety of railway traffic at an enterprise is proposed, which can be scaled up to the size of large transport systems, which will provide the highest level of traffic safety due to high-quality training of enterprise personnel, and highlights the practical experience of implementing such an information organizational-training system.

KEYWORDS

Transport events, humanitarian logistics, mathematical models of transport processes, logistics operations, humanitarian supply chains, population evacuation, intermodal transportation, traffic safety management information system.

The consequences of the war imposed by russia are horrendous, including for the transport infrastructure and transportation of passengers and goods. In addition, it showed that logistics in a war is no less important than weapons.

Unlike previous wars that our people experienced, this one, from the very beginning on February 24, 2022, finds maximum documentation and reflection in the information field. And even what has not yet been announced will eventually become available information.

Here is a piece of military news on one of the many Ukrainian websites [1], which keeps a tragic "chronicle" of the war from its very beginning to the present: ... 19:36. As a result of the shelling of the city of Liubotin, Kharkiv region, seven houses in the private sector immediately caught fire. A man died..., two more people were hospitalized ... 19:15. **russian troops are intensively shelling the Severodonetsk agglomeration: more than 20 buildings are damaged**, there is a dead several floors collapsed in one of the high-rise buildings, and a dozen of them were damaged in a day [2]. It is known about one dead in Severodonetsk and one in Rubizhne. Also in these cities, another 10 people were injured from shelling... a total of 26 people were rescued and evacuated… 18:25. **During the siege of Mariupol, about 5 thousand people died in the city – the mayor …** 90 % (2340 units) of all residential multi-storey buildings were destroyed in the city in 27 days [3].

Another website [4] reports that in Mykolaiv, as a result of enemy rocket fire, two people were killed, seven were injured, housing infrastructure was damaged, fires broke out in residential buildings, and hits on the territory of the hospital were recorded.

It hurts to read such news. But, we must do this in order to learn from them lessons for the future, until our northeastern crazy killer neighbor is finally calmed down.

The above news and information is summarized in the form of a table below in **Table 1.1** as an example.

Table 1.1 An example of the interpretation of wartime news

How many destroyed/damaged houses			**How many people**		
apartment buildings	**private**	**other**	**died**	**injured/hurt**	**rescued/evacuated/needed to be evacuated**
0	7	0	1	2	?
14	8	5	2	10	26
2340	?	?	5000	?	?
2	2	1	0	7	?
…	…	…	…	…	…
80	4	2	Probable were in the house*		

*Note: * Assumption, for information analysis purposes*

The information in **Table 1.1** is far from complete, as evidenced by the question marks "?" in cages (this is news for only one hour of the day, taken at random from the initial stage of the war). In the above example, the last row of the table, in the absence of information, contains assumptions about how many people could probably be in the house at the time of its destruction/damage by an enemy attack (average 80 people in an apartment building, 4 in a private house, 2 in other houses).

From this example, in the results of our analysis, it follows that the consequences for people who have become victims of an enemy strike on residential areas can be as follows, with the probabilities indicated in **Table 1.2** and **Fig. 1.1** below.

Table 1.2 Probabilistic estimates of the consequences of hostilities

Death	Injury	Rescue	Uncertainty	Sum of probabilities
0.0160	0.0404	0.2085	0.7351	1.0000

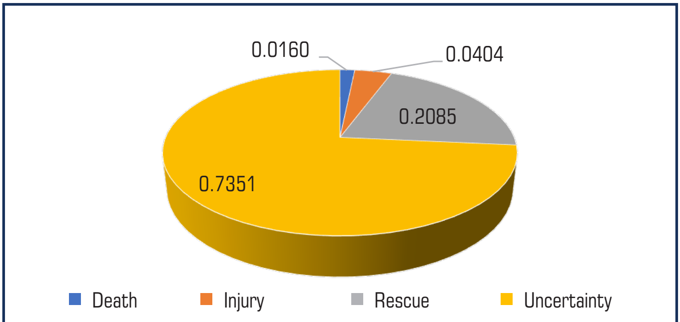

Fig. 1.1 An example of a probabilistic evaluation of the consequences of an impact on residential areas

Obviously, with more information, the results of the analysis will be more accurate, but this should be the task of individual studies. Such studies will provide a basis for building mathematical models for predicting transport and material flows, depending on the factors and scale of emergencies and the threats that caused them. Such mathematical models will make it possible to better adapt transport and logistics systems to them in order to reduce the negative consequences of such situations, damage, casualties and suffering of people.

In particular, the processing by methods of mathematical statistics of even open news information about the consequences of hostilities, including the flows of refugees and evacuees, will make it possible to create basic mathematical models for forecasting flows. Subsequent ad hoc studies of more information will help refine these traffic forecast models and use them for practical purposes, namely as inputs to humanitarian logistics transport systems in order to optimize these systems. Some optimization models of this kind are considered below.

1.1 MATHEMATICAL MODELS OF OPTIMIZATION OF TRANSPORT SYSTEMS AND TECHNOLOGIES OF HUMANITARIAN LOGISTICS

There cannot be at least two emergency situations (ES) with the same consequences. Each time, new emergencies pose new challenges in the field of humanitarian logistics, which can be defined as the "*process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as relevant information from point of origin to point* *of consumption, in order to alleviate the suffering of affected people*" [5]. However, common features can also be found in the practical experience of responding to various emergencies in order to generalize this experience and translate it into mathematical models that will help make the right management decisions. Let's try to illustrate this approach on the example of several publications on mathematical modeling of the processes of humanitarian logistics and transport services in emergency situations.

The publication [5] by a group of authors from India is devoted to the analysis of criteria for making managerial decisions in humanitarian logistics based on optimization mathematical models.

Humanitarian logistics differs from logistics operations in commercial supply chains due to a large number of features: uncertainty in the choice of route; change in the capacity of infrastructure facilities; change in demand; safety concerns; previously unused routes; other issues such as broken communications systems, limited availability of resources, and the need for efficient and timely delivery.

Fig. 1.2 shows a diagram showing two types of traffic flows:

– upper arrow, from left to right, from relief distribution centers, shelters, etc. to the disasters sites – relief distribution;

– bottom arrow, from right to left, from the disasters sites to relief distribution centers, shelters, etc. – casualty transportation/evacuation.

Fig. 1.2 Priority humanitarian logistics operations in an emergency and related traffic flows

Classifying the parameters of mathematical modeling, the authors of [5] initially consider the traffic flow "casuality transportation/evacuation" and note that most often the following are considered as objective functions of optimization problems:

– transport costs as maintenance costs, the cost of vehicle (or other vehicle) downtime and costs depending on the distance of the trip;

– loading and unloading time as the time of loading and unloading resources into the vehicle;

– distance – selection of the shortest path;

– travel time – minimum travel time;

– evacuation time – minimum evacuation time;

– quantity – unsatisfied demand and level of demand satisfaction, total number of lives saved, number of emergency units needed.

Considering the "relief distribution" transport flow, the authors of [5] define it as the flow of resources from warehouses or medical centers to affected areas. This distribution provides assistance in the form of food, medicine, shelter and other related resources to help the wounded.

Because of the uncertainty in the post-disaster environment, the maximum distribution of aid can be achieved through effective planning. Some of the uncertainties in post-disaster conditions are changes in demand, damage to transport links, damage to facilities, and scarcity of resources.

Better distribution of aid is essential to achieving demand satisfaction, reducing unmet demand, minimizing fatalities and maximizing life savings.

Most distribution models are single-purpose and deterministic (that is, they do not take into account the factors of stochasticity, randomness of processes).

The objective functions used to optimize distribution operations can be as follows: the cost of relief distribution; timing of relief distribution; speed of reaction; allocation of resources; cases with the dead; satisfaction of demand; unsatisfied demand; the total number of lives saved; the number of victims waiting for help.

The work [6] considers mathematical models of intermodal/multimodal technologies for the delivery of humanitarian aid with the participation of maritime transport (**Table 1.3**).

Table 1.3 Analysis of mathematical models of intermodal/multimodal technologies for the delivery of humanitarian aid with the participation of maritime transport

Methodology	Performance indicators	Multi-modal	Shipping	Based on maritime transport	Is a real case used?
Linear programming	Cost/Unmet demand				
Linear programming	Price	X			
Stochastic programming	Price	X			X
Linear/Integer programming	Unsatisfied demand	X			X
Mixed integer numerical programming	Cost/Unmet demand				
Integer programming	Cost/Response time				
Conceptual comparison	Price	X	X	X	X
Stochastic programming	Unsatisfied demand		X		X
Simulation	Cost/Response time	X	X	X	X
Integer programming	Response time	X	X	X	X

It is noted (mark X) that most of the models consider multimodal technologies for the delivery of humanitarian aid.

The review of humanitarian logistics studies [7] considers mathematical models of humanitarian supply chains.

The social structure of humanitarian supply chains (HSC), shown in the diagram below (**Fig. 1.3**), is considered.

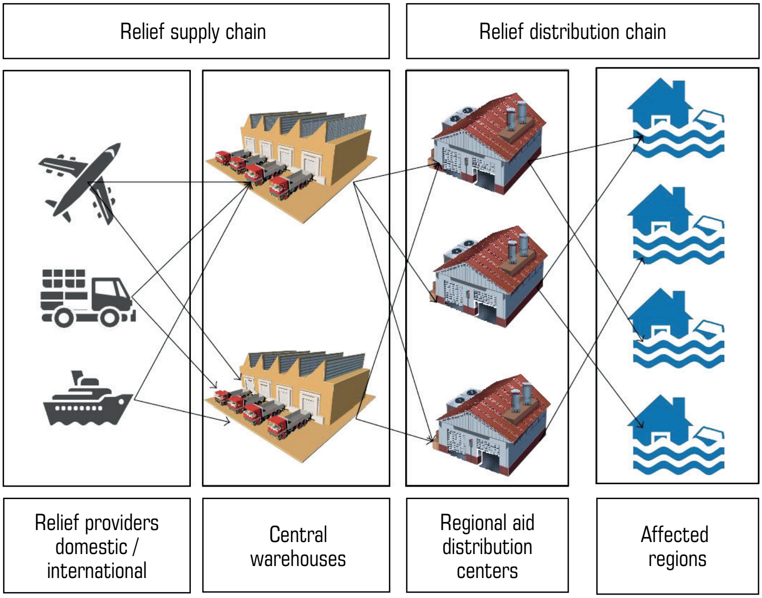

Fig. 1.3 Conceptual framework and components of the humanitarian supply chain (HSC)

A detailed analysis of the mathematical models of different authors used to optimize the transport processes of humanitarian logistics is given. In particular, below in **Table 1.4** presents descriptions of mathematical models of various problems. The content of these tables (in the columns Objective function, Constraint/solution and Problem type) deserves careful study. It shows how diverse the tasks of humanitarian logistics are and, accordingly, how differently the target optimization functions are formulated, under what restrictions decisions have to be made.

As can be seen from **Table 1.4**, in the considered models of the location of an object in the humanitarian supply chain, the only thing that is common to all HSC tasks is that the objective functions of optimization tasks are always the maximum or minimum of something. Something else follows each time from the goal that needs to be achieved in this particular emergency (cover the maximum territory, help the maximum number of people, use the least amount of transport, reduce logistics costs, etc.).

Moreover, something always interferes with the achievement of this goal (or goals) in real life – either an insufficient number of warehouses, too much demand for goods, humanitarian aid items, or an insufficient number of them, or a limited working time of drivers. What interferes in real life, in a mathematical model should be described by mathematical formulas, equations, inequalities – limitations of models that reflect reality.

Table 1.4 Site location models in the humanitarian supply chain (HSC)

Authors	Objective function	Constraint/solution	Task type
Balcik and Beamon	Maximize (demand coverage by distribution centers)	Budget constraints, inventory levels in distribution centers	Maximum coverage model
Bozorgi-Amiri et al.	Minimize (costs of pre-disaster preparation, procurement, transportation, maintenance, shortages)	Distribution center capacity, commodity flow, supply and demand	Seat partition model
Horner and Downs	Minimize (the cost of distributing relief goods)	Demand limitation, number of distribution centers	Intermediate distribution object model
Dekle et al.	Minimize (means for each area with given distance)	Determine object location for each area	Cover layout model
Hong et al.	Minimize (total logistics cost)	Distance between train and object, number of objects, demand	Object location model
Chang et al.	Minimize (transport cost, facility installation cost, life-saving equipment distance cost)	The number of objects and their capacity, the priority of allocation, storage, shortage, penalties for surplus	Seat partition model
McCall	Minimize (nautical miles of casualty, disadvantage)	Facility capacity, number of disaster preparation kits, unsatisfied demand	Object location model
Rawls and Turnquist	Minimize (costs of opening a facility, unsatisfied demand, transportation)	Location and decision on the level of stocks at each site	Seat partition model
Zhang et al.	Minimize (cost of total time to dispatch emergency resources)	Equilibrium of supply and demand for a primary catastrophe, equilibrium of supply and demand of a potential secondary catastrophe, available resources for a secondary catastrophe	Seat partition model
Akgün et al.	Minimize (risk of unsatisfied demand)	Response time, distance between object and disaster site	Object location model
Barzinpour and Esmaeili	Maximize (cumulative population coverage); Minimize (total spending)	Supply and demand, transport capacity, warehouse capacity	Seat partition model
Abounacer et al.	Minimize (distance from distribution center to demand point, number of facilities, dissatisfied demand)	Daily working hours, supply and demand, vehicle capacity	Location-transport model
Rawls and Turnquist	Minimize (costs of acquiring a product, deciding on stocks, transportation, shortages, maintenance)	Demand, number of objects, inventory level	Dynamic allocation model
Murali et al	Maximize (number of people on medication)	Supply and demand, distance, facility capacity	Maximum coverage model
Lin et al.	Minimize (shortage penalty, delivery delay, shipping cost, unfair service cost)	Number of warehouses, vehicles, travel time, number of delivery items	Object location model

In conclusion, let's note that we consider the materials presented here to be useful in solving the problems of humanitarian logistics associated with the deployment of certain objects in a certain territory affected by an emergency, such as central warehouses, regional centers for the distribution of humanitarian aid, storage facilities, warehouses, points of medical assistance, taking into account the available opportunities for transport services. Also, pay attention to the fact that in humanitarian logistics today multimodal/intermodal transport technologies have already found their rightful place, which is reflected in the corresponding mathematical models (**Table 1.3**).

Conclusions. The general analysis carried out allows to conclude that a sufficient mathematical apparatus has been developed for optimizing processes and making managerial decisions in the field of humanitarian logistics. However, the experience of the war showed that events can develop instantly, leaving no room for complex mathematical models. Both during evacuation and during the provision of assistance and material support to the victims, the time for making a decision can take not even hours, but minutes.

Therefore, along with the corresponding mathematical models and software products, simpler methods for justifying decisions, both technological and managerial, should be developed, and people who could apply these techniques even under extreme conditions should be trained.

1.1.1 EVACUATION – UKRAINIAN REALITIES AND WAR EXPERIENCE

From the above example (**Fig. 1.1**, **Tables 1.1, 1.2**) and the experience of the war, it is known that attacks on cities, as well as their threat, create huge waves of migration of people seeking salvation, which can be in the nature of a stampede, or can be more planned, organized evacuation. In our example, it can be seen that the potential evacuation flow is many times greater than the number of dead and wounded, and the same is known from the experience of other armed conflicts, wars and other emergencies.

The current legislation of Ukraine, which guides the work of the State Emergency Service (SES), provides for a certain procedure for organizing evacuation. In particular, that "... the population is subject to mandatory evacuation in the event of a threat of an accident with the release of radioactive and hazardous chemicals, catastrophic flooding of the area and earthquakes, massive forest and peat fires, landslides, other geological and hydrogeological phenomena and processes, emergency situations. at arsenals, bases (warehouses) of weapons, missiles, ammunition and rocket fuel components, other explosive and fire hazardous objects of the Armed Forces, armed conflicts (from areas of possible hostilities to safe areas)" [8].

Partial evacuation of the population is carried out on the basis of a decision of the local state administration or an official with the authority to make such a decision. To conduct a general evacuation of the population, the available vehicles of the corresponding administrative territory are involved, and in the event of an immediate threat to the life or health of the population, additional vehicles of business entities and citizens [8].

The first days of the war, a massive attack on Kyiv and other cities, shelling and battles that were already taking place in their suburbs, led to a mass escape from the war zones and the evacuation of the population. The evacuation took place in the following main ways:

– private vehicles (those who had such an opportunity), mainly in a western direction;

– evacuation bus flights (they were organized by both authorities and volunteers, private carriers, tour operators);

– by rail from Kyiv and other cities, by evacuation trains of local, distant and international traffic (since roads, bridges were overloaded, destroyed or blocked, and air traffic was stopped).

For an organized evacuation in Kyiv and other cities, prefabricated evacuation points were announced in advance, from which traffic should be carried out.

During this critical period, when everything was hanging by a thread, the situation in the transport and logistics sector, including the forced flight and evacuation of the population, managed to be maintained only thanks to self-organization, already traditional for modern Ukrainian society, mutual assistance of people, mass volunteer movement and heroic efforts of Ukrainian transportation companies.

It is impossible not to mention the huge contribution of Ukrainian railways to the salvation of thousands of people. For 8 days since the beginning of the aggression, Ukrzaliznytsia has taken more than 1 million citizens out of hot spots. Further, during the most acute period of the first months of the war, the volume of evacuation traffic only increased. So, on March 12, Ukrzaliznytsia sent at least 43 trains from Kyiv to western Ukraine. Also 8 trains from Odesa, 12 from Poltava, 18 from Vinnytsia, 5 from Zaporizhzhia. It will be possible to leave Kramatorsk, Kharkiv, Kryvyi Rih, Odesa, Zhytomyr.

Additional evacuation flights were scheduled during the day, taking into account the actual passenger traffic. All evacuation flights from east to west were free. From Lviv and other cities in the west of the country, many went further, abroad.

Helped organize international humanitarian logistics and other countries. Free rail travel for Ukrainians was introduced in 11 European countries. To take advantage of the offer, it was enough to show your passport.

In Belgium, Ukrainians were transported without paying a fare to any point on SNCB, high-speed TGV and Thalys, Eurostar trains. For Ukrainians, there was an offer of free travel throughout Hungary on MAV-START trains, on all routes in Georgia, on Deutche Bahn flights from Poland to Germany. The Netherlands provided Ukrainians with a daily ticket valid for 24 hours to board any train. Ukrainians were transported to Poland in the 2nd class across the country in TLK and IC PKP Intercity trains. In Finland, for Ukrainians, the offer is valid from the railway carrier VR, in France – on SNFC trains.

In Slovakia, citizens of Ukraine could use the services of the ZSSK railway company and the bus carrier Slovak Lines. In the Czech Republic, Ukrainians were provided with free travel on Leo Express transport (trains and buses) and CD. The latter also carries out humanitarian flights from the borders of Ukraine with Poland and Slovakia to the territory of the Czech Republic. Free travel in the municipal transport of Vienna was introduced by Austria [10].

Conclusions. Let's note that the last of the quoted paragraphs refers to the provision of intermodal (that is, mixed, bus and rail) transportation services, and in the case of Slovak carriers and the Czech operator Leo Express, multimodal transportation, the most convenient for passengers, although more complex for the operator of such transportation, which provides them.

In addition, here and above, the experience of evacuating the population outside Ukraine was considered, where governments, non-governmental organizations and citizens of other countries were involved. But a significant part of the evacuees moved to safer places within the country, they became internally displaced persons (IDPs). This ("internal") evacuation has its own characteristics.

1.2 LOGISTICS OF EVACUATION AND PROVISION OF INTERNALLY DISPLACED PERSONS

The evacuation of internally displaced persons (IDPs) in a belligerent country occurs simultaneously with hostilities and is no less important than the latter. People who are forced to evacuate under such circumstances are the most vulnerable because they were most often in or in close proximity to a war zone or other emergency.

These people are critically short of time to get to a safer place; it happens that they do not know where to find such a place or they are mistaken in their decision. There are frequent cases when people from the center of Kyiv on the first day of the war fled to Bucha or Irpin, because they believed that it was safer there, but ended up in the hell of war, and were forced to flee further.

Due to the lack or lack of time to make decisions and meetings, such people are often the least materially and financially secure, many of them escaped only in the clothes that they had, having managed to take only documents, or even without them, because everything was left in ruins or house occupied by the enemy. Therefore, the evacuation of potential IDPs should take place as quickly as possible and to the nearest safe place of temporary residence (for example, an IDP camp), which, in turn, should be located as **close as possible to trains or other sources from which logistical, medical and other provision of IDPs in safe places of temporary residence** (**Fig. 1.3** – central warehouses, regional centers for the distribution of humanitarian aid, storage facilities, warehouses, medical aid points), taking into account the available transport services. This approach fully coincides with the requirements of the current legislation of Ukraine [8], which establishes that: "The evacuation is ensured by:

– creation of evacuation authorities at the regional and local levels, as well as evacuation authorities at economic facilities;

– development of an evacuation plan for the population;

– determination of safe areas suitable for accommodating the evacuated population and material and cultural values;

– organization of notification of heads of economic entities and the population about the beginning of the evacuation;

– organization of evacuation management;

– life support of the evacuated population in places of its safe accommodation;

– participation in command and staff exercises and on-site training;

– training the population in actions during the evacuation" [8].

In addition, the legislation [8] defines the evacuation authorities: "The evacuation authorities include evacuation commissions, evacuation collection points, intermediate evacuation points, evacuation reception points… Prefabricated evacuation points are designed to collect and register the evacuated population and organize their removal (exit) to safe areas and are located near railway stations, sea and river ports, marinas, evacuation routes, as well as on existing city squares, in open safe places or safe premises".

However, in this way, the legislation creates only the preconditions for the evacuation, but its organization requires the solution of a number of practical, including calculated, problems of transport and logistics support. The current regulatory documents on the organization of evacuation do not contain guidelines or recommendations for such calculations.

Therefore, below let's propose a methodology and give examples of calculations that will help fill this gap. These calculations can be done quickly, even with a calculator, if it is not possible to apply the mathematical models discussed above.

1.2.1 CALCULATION OF EVACUATION TRANSPORT NEEDS (EXAMPLE)

Let's take a look at a specific example.

An example of calculations. Initial data and calculation formulas:

Population subject to evacuation – A_E, persons.

Evacuation is carried out by groups of 20 people in one vehicle (minibus, number of passengers seats n_A=20). Currently for evacuation from the emergency zone – T_E, hour.

Vehicle turnaround time (bus round trip) – $R_V = 2(L_E/V_E + n_A/60)$, hour (where L_E is the evacuation distance, km; V_E is the average vehicle speed during evacuation, km/h), rounded to the nearest whole number. The number of complete turnaround (turnaround trips) of the vehicle during – $n_R = T_E/R_V$ the need for vehicles units. The need for drivers $N_V = (A_E/n_A T_E)\cdot R_V$, persons (where t_D is the duration of the driver's working day, hours). Fuel requirement $2L_E\cdot(A_E/n_A)\cdot(24/T_E)\cdot(H_S/100)$, l (where H_S is the basic linear norm for the vehicle mileage, l/100 km).

Calculation results. (Calculations are made for the number of people evacuated A_E=1000 people. The time for embarkation and disembarkation of one passenger with luggage is assumed to be 1 minute).

The results of calculations for different durations of evacuation are shown in **Fig. 1.4**.

As can be seen from **Fig. 1.4**, the duration and distance of the evacuation is a determining factor for the size of the required fleet of vehicles. The shorter this duration (more urgent evacuation) and the greater the distance (to the final point of evacuation), the more vehicles are required (if the number of people and evacuated material and cultural values is unchanged). The number of seats in the vehicle affects the number of seats needed in reverse – the more seats for passengers, the less vehicles are required (ceteris paribus).

In the case when it is difficult to use the formula by which **Table 1.5** offers a simple mnemonic technique using four digits and two arithmetic operations (**Fig. 1.5**).

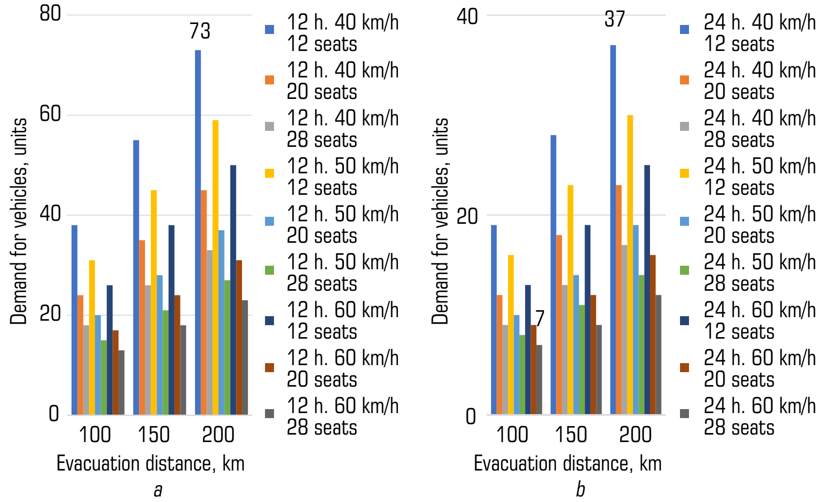

Fig. 1.4 The need for vehicles for evacuation depending on the duration, speed and passenger capacity of vehicles: *a* – duration of evacuation is 12 hours; *b* – duration of the evacuation is 24 hours (twice the time to evacuate, the number of evacuees is the same)

Table 1.5 Demand for vehicles $N_V = 2\left(L_E/V_E + n_A/60\right)\cdot\left(A_E/n_A T_E\right)$, units

T_E, h	V_E, km/h	n_A, seats	L_E, km		
			100	**150**	**200**
12	40	12	38	55	73
12	40	20	24	35	45
12	40	28	18	26	33
12	50	12	31	45	59
12	50	20	20	28	37
12	50	28	15	21	27
12	60	12	26	38	50
12	60	20	17	24	31
12	60	28	13	18	23
24	40	12	19	28	37
24	40	20	12	18	23
24	40	28	9	13	17
24	50	12	16	23	30
24	50	20	10	14	19
24	50	28	8	11	14
24	60	12	13	19	25
24	60	20	9	12	16
24	60	28	7	9	12

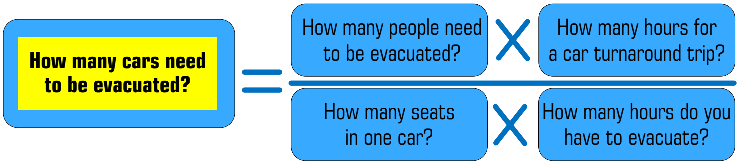

Fig. 1.5 Calculation of the required number of vehicles for evacuation

The results of calculations according to **Table 1.6** are shown in **Fig. 1.6**.

Table 1.6 Need for drivers* $a_D = T_E N_V / t_D$, persons

T_E, h	t_D, h	N_V, vehicles							
		5	**15**	**25**	**35**	**45**	**55**	**65**	**75**
12	6	10	30	50	70	90	110	130	150
12	8	8	23	38	53	68	83	98	113
12	12	5	15	25	35	45	55	65	75
24	6	20	60	100	140	180	220	260	300
24	8	15	45	75	105	135	165	195	225
24	12	10	30	50	70	90	110	130	150

*Note: * where t_D – the duration of the driver's working day, hour*

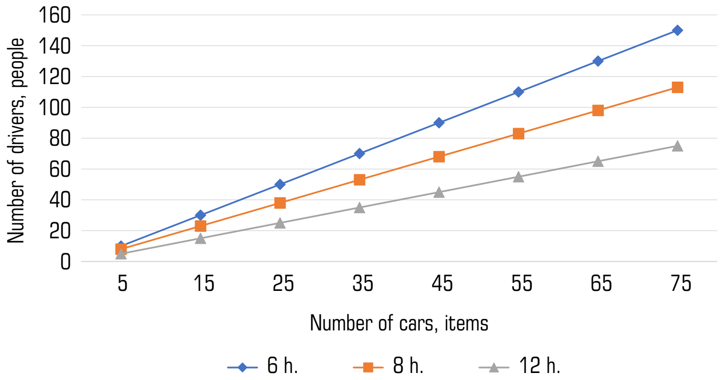

Fig. 1.6 The need for drivers of vehicles with different working hours of drivers

As can be seen from the results of the calculation, the greater the need for drivers, the longer the duration of the evacuation and the greater the required fleet of vehicles. The need for drivers decreases with the increase in the duration of their working hours and vice versa. This need can be determined without the formula, according to which the **Table 1.6** is calculated (**Fig. 1.7**).

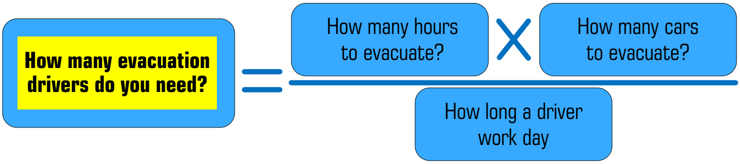

Fig. 1.7 Calculation of the need for the required number of drivers for a vehicle

Once there are answers to the most pressing questions: how many vehicles and drivers are needed to evacuate, it is possible to determine the need for fuel (**Table 1.7**).

The basic linear norm for the mileage of a vehicle is set in accordance with the Norm of fuel and lubricants consumption in road transport [11]. It is possible to calculate this need without the formula (**Fig. 1.8**), according to which **Table 1.7** (the result will be 4.2 % more than the formula).

Table 1.7 Fuel requirement $2L_E \cdot (A_E/n_A) \cdot (24/T_E) \cdot (H_S/100)$, l (where H_S is the basic linear norm for vehicle mileage, l/100 km; A_E=1000 people)

T_E, h	n_A, seats	L_E, km		
		100	**150**	**200**
12	12	5433.3	8150.0	10866.7
12	20	3260.0	4890.0	6520.0
12	28	2328.6	3492.9	4657.1
24	12	2716.7	4075.0	5433.3
24	20	1630.0	2445.0	3260.0
24	28	1164.3	1746.4	2328.6

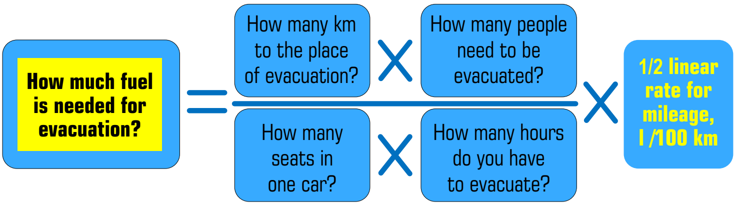

Fig. 1.8 Calculation of the need for the required amount of fuel for a vehicle for evacuation

The results of calculations according to **Table 1.7** are shown in **Fig. 1.9**.

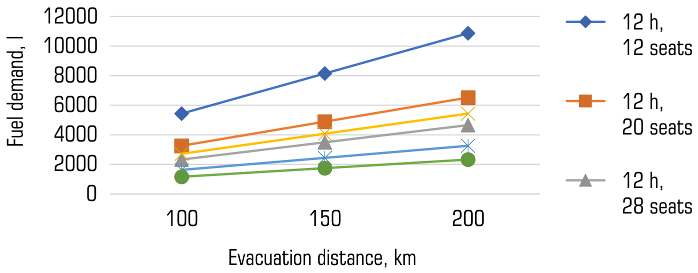

Fig. 1.9 Fuel requirement depending on the distance, duration of the evacuation and the number of seats in the vehicle

As calculations show, when using vehicles of smaller passenger capacity and reducing the duration of evacuation (ceteris paribus), the need for fuel increases significantly. That is, urgent evacuation is always more expensive. But if it is not carried out, the consequences can be even more severe.

1.2.2 LOGISTIC AND MATERIAL PROVISION OF LIVING CONDITIONS FOR EVACUATED INTERNALLY DISPLACED PERSONS

From the experience of this war, there are cases when people fled from the front-line Kharkiv, around which fighting was already going on, to supposedly safe Lviv, and there they found death during rocket fire. There are no safe places in this war. And at the same time, it is clear and verified that at least relative safety can give the maximum dispersal of people from places that can be hit by the enemy (and these are practically all settlements). Such relatively safe places (outside populated areas) may be intermediate evacuations and evacuation reception points, the organization of which is provided for by the current legislation.

Such temporary housing for refugees, internally displaced persons in places where they are evacuated can be tent (**Fig. 1.10**) or modular (**Fig. 1.11**) camps, but the requirements for any such temporary housing are the same: they must be able to quickly deploy, populate if necessary, move to another place, and they must be provided from the very beginning with everything necessary for the safe stay of people in them. That is, the issues of their food, household, medical and other types of provision should be comprehensively resolved, and this is impossible without effective logistics solutions. One possible solution is suggested below.

Fig. 1.10 Tent camp for refugees from Ukraine near Prague [12]

Fig. 1.11 Modular camp for refugees near Lviv [13]

Let's start with a regulatory document that defines that "Logistics support for evacuation consists in organizing the maintenance and repair of vehicles in the process of evacuation, supplying fuel and lubricants, spare parts, water, food and essentials, providing evacuation agencies with the necessary property" [14]. This document contains standards for food supply, water consumption for drinking, cooking, providing sanitary and living conditions, as well as for calculating the needs for various types of fuel for heating during the cold season (**Tables 1.1–1.3** of Appendix 2 of the regulatory document [14]).

The mentioned standards became the basis for calculating the minimum necessary "set" of food, water, property, equipment and other things that is necessary for the rapid deployment of a tent camp for the evacuees and their living there in acceptable conditions with supplies of water, food, etc.

The calculation was made for 100 evacuees and its results showed that all items of the specified set (set) can easily be placed in a standard 20-foot container, while there is still a reserve of its carrying capacity and volume of approximately 20 % (**Table 1.8**).

As needed, in the same containers, it is later possible to deliver the resources necessary for its inhabitants to the tent city and pick up containers, the contents of which have been used. With proper organization of such logistics, it is necessary (the so-called exchange fleet of containers will not be so large, it will depend on the frequency and distance of deliveries).

Table 1.8 Contents of a 20-foot container (for 100 people for the 1st week)

Name	**Items**	**Mass 1 item, t**	**Volume, 1 item, m^3**	**Bulk mass, t/m^3**	**Mass, t**	**volume, m^3**
Army tent (UST-56, for 20 people)	5	0.26	0.6	0.433	1.30	3.00
Diesel generator 8.5 kW	1	0.17	0.46	0.370	0.17	0.46
Solid fuel stove	5	0.04	0.07	0.571	0.20	0.35
Blanket, mat, accessories – set	100	0.003	0.006	0.500	0.30	0.60
Folding furniture – set	5	0.2	0.5	0.400	1.00	2.50
Food, dishes, cutlery – set	1	1	0.9	1.111	1.00	0.90
Water, tank	1	8.9	9	0.989	8.90	9.00
Medicines, first aid kits, equipment – set	1	1	1	1.000	1.00	1.00
Tools, materials, spare parts	1	1	1	1.000	1.00	1.00
Fuel for the stove (6.4 kg/person-day), pallets	1	4.5	6	0.750	4.50	6.00
Other (if necessary)						
TOTAL					19.37	24.81
Maximum carrying capacity and capacity of a TEU Standard container					24.00	32.10
RESERVE, %					19.3	22.7

Such a container can be transported by any means of transport, delivered to the deployment site of the tent camp by road. To remove it from the vehicle, crane equipment is not even required, there are other solutions for this – manual (**Fig. 1.12**) or electric jacks (**Fig. 1.13**) for removing containers from the vehicle and loading onto the vehicle.

Such jacks for removing or loading a container on a vehicle require 4 pieces, and their overall dimensions and weight (one jack weighs up to 200 kg) allow them to be placed in addition to that indicated in **Table 1.8** sets in the same container.

A stock of such containers (possibly in several configurations) should be stored in warehouses, it is advisable to create in the system of the State Emergency Service of Ukraine or other specific departments, organizations. Determining the rational value of such a reserve is a theoretical task that must be formulated and solved taking into account the restrictions and conditions of martial law or other emergency situations that require separate studies.

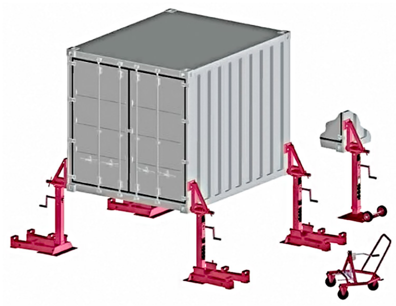

Fig. 1.12 Manual jacks for containers [15]

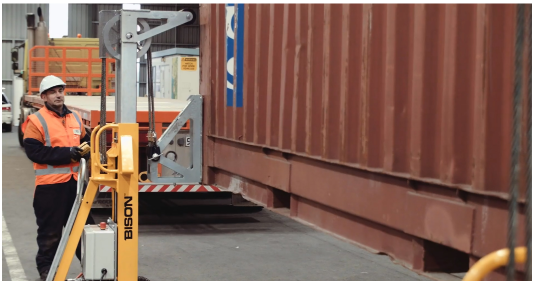

Fig. 1.13 Electric jacks for containers [18]

The problem of rational dislocation of such compositions according to different optimality criteria can theoretically be solved by different mathematical methods and tools. But here it should be noted, taking into account the experience of the war and the constant enemy strikes on various kinds of warehouses, logistics bases, that this deployment should not be permanent, it should change taking into account military risks. These risks should be taken into account in the relevant mathematical models and calculation methods.

As an **intermediate conclusion**, it should be noted that the application of the ISO container described here for the logistics and logistics of internally displaced persons and other victims of war and emergencies allows to "connect" to any multimodal transport and logistics systems, not only regional, national, but and international, global scale, as discussed below.

1.2.3 RADICAL LOGISTICAL MULTIMODAL SOLUTIONS – FOR WAR AND PEACE

In previous years, the authors emphasized the need and the great role of the new Ukrainian railway on the European track 1435 mm to ensure the defense capability of the state [17].

At the time, this argument had no economic support. Unfortunately, they appeared only as a result of the war launched by russia against Ukraine on February 24, 2022. The World Bank estimates that a russian invasion will reduce Ukraine's economy by 45 percent this year [18]! These losses could be less and how many lives could be saved if:

– the logistics of the aggressor troops, focusing mainly on rail transportation, would be significantly complicated by a different track width;

– Ukrainian troops could destroy large concentrations of troops and weapons of the aggressor on our northeastern border, in places of reloading on another route;

– NATO countries could quickly and massively provide with any assistance without delay on our western borders.

Now these "ifs" do not raise any objections, because there is a bitter experience of the war, which changed priorities. Therefore, when making government decisions to restore the country's infrastructure after the war, a program for the transition of Ukrainian railways to the 1435 mm gauge standard must be provided.

Moreover, this fully coincides with the course towards accelerated European integration of Ukraine and the tasks it faces in the transport industry in accordance with the Association Agreement with the EU, in particular, "improving the movement of passengers and goods, increasing the turnover of transport flows between Ukraine, the EU and third countries in the region by removing administrative, technical, border and other obstacles, improving the transport network and modernizing the infrastructure, in particular, on the main transport axes connecting the Parties" [19].

Now it is obvious that the transition of Ukrainian railways to the 1435 mm standard has no alternative, but it should be justified and phased. To begin with, it is necessary to revive the infrastructure of the "normal" European route, which already exists, but is hardly used. It is very important to develop projects for laying a combined track 1520/1435 mm. Where appropriate, it is possible to install gauge changers (available at Mostyska-II station of the Lviv railway, possibly at other stations) – to use the technology of transportation in wagons on bogies with variable gauge. These and other technologies and the organizational measures necessary for their implementation are the subject of separate studies.

Due to the almost complete blocking of the transit of goods between China and the EU by the so-called Trans-Siberian route, russian and belarusian railways, Ukraine is simply obliged to offer its own Caspian-Black Sea route, no longer than the specified one, but not through seven transit countries, but through five, which will reduce the number of delays at the borders (**Fig. 1.14**). The authors have repeatedly spoken about this (for example, [17]). Within Ukraine, this should be a new high-speed railway (HSR), designed for maximum speeds of more than 250 km per hour, which will be operated on the principle of sharing [20] by both passenger and freight, intended for urgent delivery of goods.

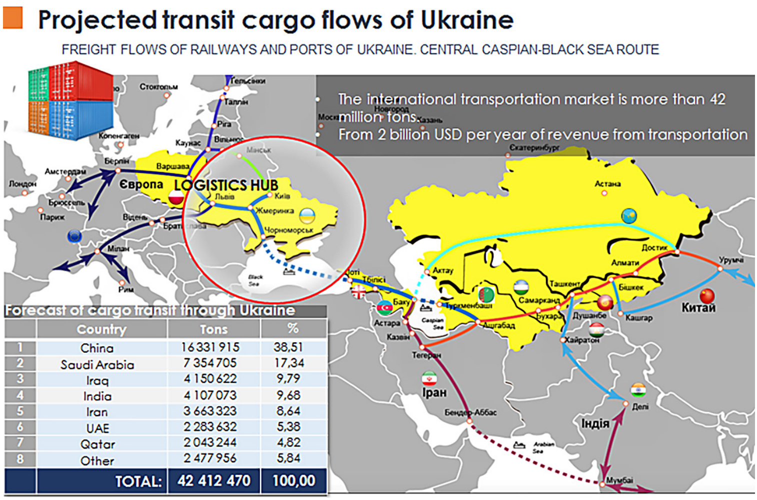

Fig. 1.14 New Ukrainian high-speed railway of 1435 mm gauge in the system of global transport links

Returning again to the experience of the war, it should be noted that the railway must also be designed taking into account the rapid evacuation of the population, the delivery of personnel and military goods, including dangerous goods. The international Caspian-Black Sea multimodal route shown in **Fig. 1.11**, has the advantage not only in a smaller number of transit countries, but also allows to connect through Poland with the future 1435 mm rail Baltica [20].

When considering alternatives for the transition strategy to the 1435 mm track standard, it should be taken into account that in Ukraine industrial access roads, also of the 1520 mm standard, have a large length. It is necessary to organize their technological interaction with the 1435 mm gauge, gradually developing the system of multimodal terminals.

Therefore, the technology of using wagons on bogies, which can change the width of the track, is also being considered. The width of the track is changed by passing the train through the overpass device. We will not delve into the technical details of this technology, which are quite fully covered in the literature, for example [21].

Approach to the economic evaluation of alternatives.

How can these alternatives be evaluated economically in order to make an informed decision about the use of variable gauge trains for freight traffic and the terminal system for servicing railway users at the junctions of different gauges?

To do this, it is necessary to compare two options for organizing the transportation of a variant by railways of different ways:

I – delivery of cargo to/from the terminal closest to the Ukrainian importer/exporter, where railway systems of different track widths interact, with rolling stock of 1435 mm track and its reloading onto rolling stock of 1520 mm (or other track width);

II – delivery from a foreign sender to a recipient by rolling stock on wheelchairs with a variable gauge.

These options serve as the basis for building an economic-mathematical model.

After determining the value of θ_i – the turnaround time of the *i*-th type of rolling stock (1435 mm wagons, 1520 mm wagons or carriages on wheelchairs with a variable track width), it is necessary to calculate the required amount (in wagons) to organize the transportation of cargo volumes Q_D (tons per day):

$$n_i^w = \frac{Q_D \theta_i}{4p_i^{AL} - W_i^T},$$

where *i* is the designation corresponding to the subscripts 1435, 1520 and GC for the respective types of wagons; p_i^{AL} is the axle loading of a 4-axle wagon of the corresponding type, tons per axle; W_i^T is the tare weight of a 4-axle wagon of the corresponding type, tons.

Some results of the calculation of wagon fleets for various volumes and options of transportation technologies are shown in **Fig. 1.15**.

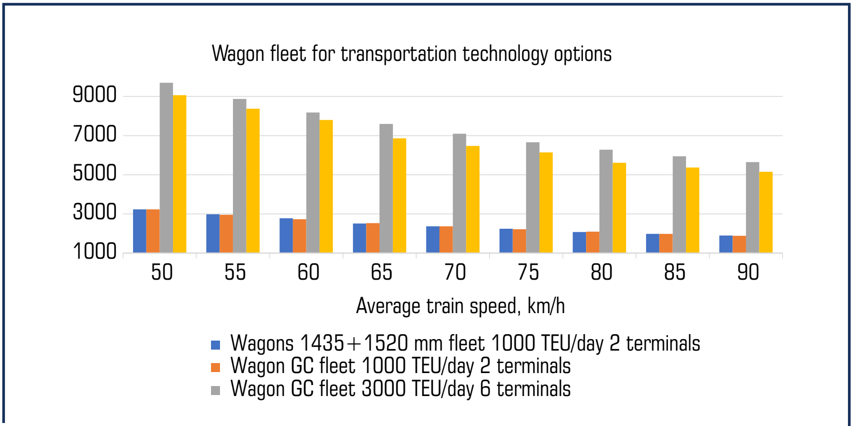

Fig. 1.15 Wagon fleet required for different volumes and technologies of transportation

As can be seen from **Fig. 1.15**, the use of wagons on bogies with varying track widths requires the largest fleet of wagons. This is explained by the longest time of circulation of such wagons noted above. Compared with the use of the fleet of 1435 mm and 1520 mm gauge vehicles and the organization of interaction at the terminals, in total this fleet is 5–11 % less (curve second from the top) than the required fleet of wheelchair vehicles with variable gauge, with the same traffic volume. The top two curves correspond to a high volume of traffic, 3000 containers per day, which are handled at the network's six terminals. With relatively small volumes of transportation (1000 containers per day, 2 terminals), there is practically no difference in the number of required wagons depending on the transportation technology (within ±1 %).

These conclusions refer to the cases of a travel distance along the route of 1435 mm, which is equal to 2000 km. With an increase in this distance to 3000 km, calculations show that up to 4 % less wagons on bogies with varying track widths are required than the total number of wagons of 1435 mm and 1520 mm tracks when organizing interaction at the terminals. However, this advantage is leveled by the fact that wagons on bogies with variable gauge are much more expensive than conventional ones and have a large tare weight. And an increase in the distance of transportation across Ukraine along the 1435 mm track is achieved by deeper introduction of it deep into the country, that is, it requires the creation of new terminals for interaction with railways of the 1520 mm track and other modes of transport.

Conclusions. The performed calculations show that the technology of transportation in wagons on bogies with a variable track width can be used with relatively small volumes of traffic, and with their growth (and in order to increase them), one should focus on the development in Ukraine of a network of railway lines of 1435 mm and systems of multimodal logistics terminals for interaction with 1520 mm railways, access roads of enterprises and other modes of transport.

Developing the proposed mathematical model, supplementing and refining the set of controlled variables – model parameters, as well as having reliable economic data, we can proceed to the construction of a more comprehensive economic and mathematical model, on the basis of which the optimal stages and geography of the gradual transition of Ukrainian railways to the 1435 mm track will be substantiated up to our eastern border.

At the same time, provision should be made for the use, where appropriate, of wagons on bogies with variable gauge. Due to the large dimension and complexity of this problem, it is obvious that its solution to the level of obtaining practical conclusions and recommendations requires a separate study.

1.3 DIGITAL INFORMATION ORGANIZATIONAL AND EDUCATIONAL SYSTEM FOR MANAGING THE SAFETY OF RAILWAY TRAFFIC AT THE ENTERPRISE

The war in Ukraine with russia, which began on February 24, 2022, has brought to life many new digital systems for rapid learning, testing and knowledge control. These developments were used as military aid and concerned mainly the training of military operators to control various types of weapons. Considering that the new weapons that the partners were transferring to Ukraine are highly intelligent, integrating the initial information of several digital communication devices and systems, it was impossible to train operators using traditional "classroom" methods and static simulators. That is why various online training complexes have been widely used, operating in a digital network 24/7. Such simulators can be used both in stationary mode and in the "field".

These systems showed high efficiency, significantly reduced the training time, the military personnel of the Armed Forces of Ukraine demonstrated a high ability to use and operate such systems and devices.

Therefore, it was concluded that it is necessary to use them to train specialists not only for military purposes, but also for civilian life, for example, in transport systems and at enterprises using technological transport. And this is the majority of enterprises in Ukraine and Western Europe.

1.3.1 PROBLEM STATEMENT

At the end of 2021, the "Regulations on the traffic safety management system in railway transport" were put into effect in Ukraine [22]. This Regulation has been developed in accordance with European concepts and regulations (for example [23]), corresponds to the Association Agreement between Ukraine and the EU. The new traffic safety management system (TSMS) has significant differences from the TSMS that existed in Ukrainian Railways JSC. Its action extends to the sphere of railway transport and, except for railways, these are all Ukrainian enterprises that have or use infrastructure and railway rolling stock (before the war it was almost 3,000 enterprises). In addition, the new Regulations on the TSMS have an option for the development of the TSMS at each enterprise, the study and certification of personnel for the TSMS.

The purpose of this section is to substantiate the structure and functionality of the enterprise traffic safety management information system (ETSMIS) for the implementation of the Regulation [22], which would solve the following tasks:

– creation and updating of the TSMS at the enterprise;

– automatic creation of certain documents;

– training, testing and preparation for certification of the enterprise personnel;

– management of risks associated with the operation of railway rolling stock and infrastructure at the enterprise;

– communication with central executive authorities;

– work on the Internet;

– implementation of the principles of aggregation and functional expansion.

In the course of the study, it was found that Ukrainian railway transport enterprises do not have a unified information system for the safety of railway traffic, which significantly affects the transmission, processing, and analysis of information in this area.

1.3.2 PRESENTATION OF THE MAIN RESEARCH MATERIALS

It was proposed to develop a model of a unified information system for traffic safety management at the enterprise, which consists of two systems: the information system for traffic safety management (ISTSM) "RAILWAY PORTAL" and the information system (IS) "TECHNICAL EDUCATION". The structure of a single system is shown in **Fig. 1.16**.

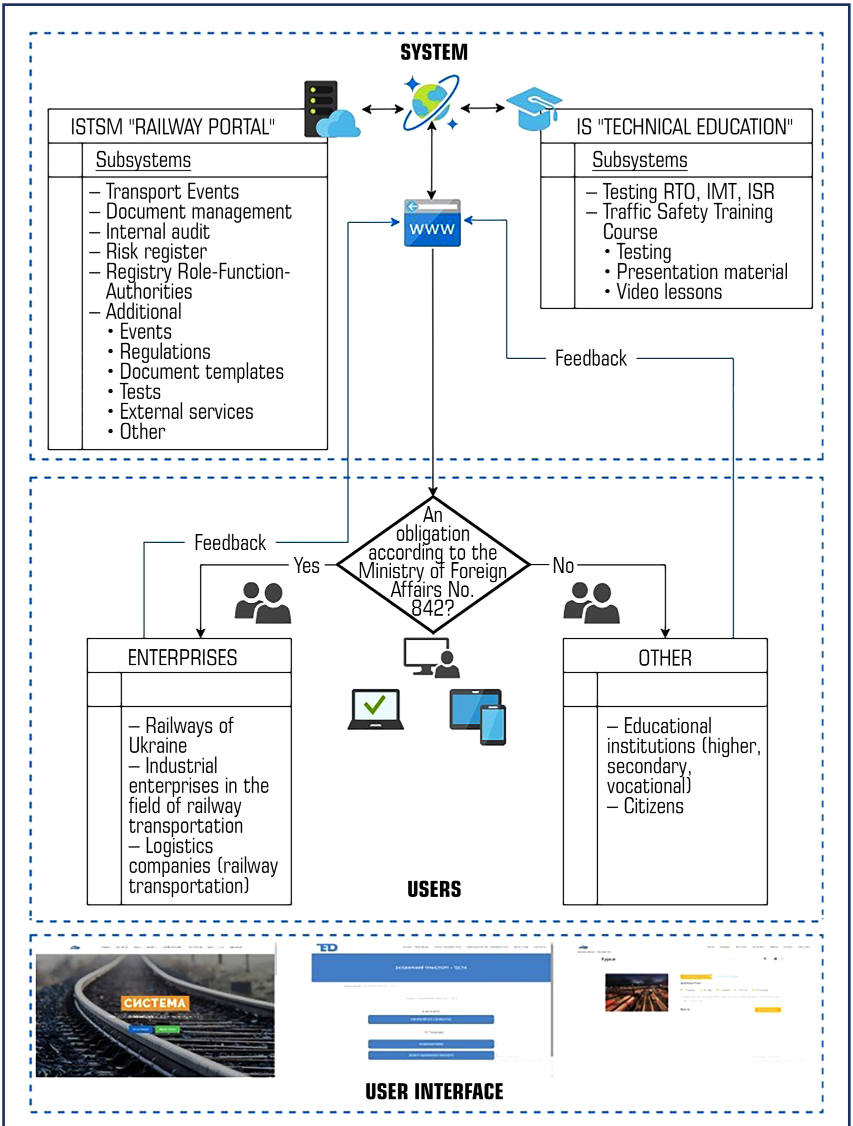

Fig. 1.16 Model of a unified information system for traffic safety management at the enterprise

After analyzing the state of affairs with the existing information systems in the field of railway transport, it was found that all of them are narrowly specialized, heterogeneous and do not perform the necessary operations for collecting and processing data in the field of traffic safety.

When designing and developing the terms of reference for the future ISTSM "RAILWAY PORTAL", its functional subsystems, according to **Fig. 1.1**, were the following subsystems: transport events; document flow; internal audit; risk register; registry role-functions-permissions; additionally (events; regulations; document templates; tests; external services), others.

Considerable attention in the design and development of ISTSM "RAILWAY PORTAL" was riveted to the compliance and functionality of subsystems with the Regulations [22] and other legal acts regulating the activities of railway transport enterprises (for example [24]).

It was also proposed to develop the functionality of information exchange with other information exchange systems (IES), which will positively affect the speed of rapid response to transport events by all participants in the process.

In addition to the ISTSM "RAILWAY PORTAL", the site RAILWAY PORTAL was created and is available on the Internet at the link http://subr.in.ua/ [25], the site of the IS "TECHNICAL EDUCATION" – http://ted.in.ua/trains/ [26], and the sub-site of the subsystem "TRAFFIC SAFETY TRAINING COURSE" of the IS "TECHNICAL EDUCATION" is available on the Internet at the link http://br.ted.in.ua/ [27]. The task of the "RAILWAY PORTAL" website is to inform the railway transport enterprises about changes in the current legislation, to popularize preventive measures for traffic safety among them, to receive official interpretations from the central executive authorities of Ukraine and other government agencies, about the current legislation and to acquaint users of the site with them in their sections (**Fig. 1.17**).

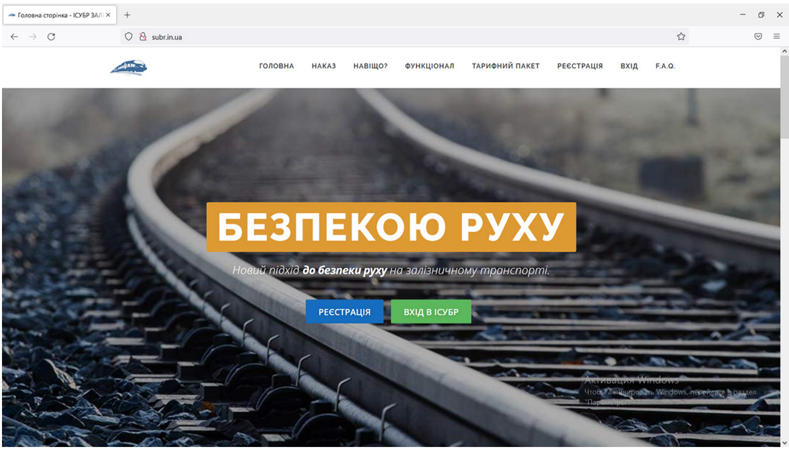

Fig. 1.17 General view of the site http://subr.in.ua/ [25]

1.3.2.1 ISTSM "RAILWAY PORTAL" SUBSYSTEMS

"Transport Events" subsystems. When creating this subsystem, an analysis of the existing bases of transport events, current legislation and the relevance of centralized accounting of transport events was used. It was found that there is only one system for recording traffic accidents in railway transport "ARM Sirena", which is used by JSC "Ukrzaliznytsia" to record its own traffic accidents. However, this automated workplace does not take into account the events that occurred due to the fault of enterprises that are not part of JSC "Ukrzaliznytsia". Accordingly, more than 90 % of the percentage of traffic events that occurred on sidings due to the fault of railway transport enterprises that own such tracks (own or leased) or through the fault of rolling stock owners are not taken into account systematically.

Thus, the proposed and implemented subsystem aims to create a unified national electronic information system for recording traffic accidents that occurred at railway transport enterprises.

In addition, in the course of the research, it was found that part of the transport events that occurred at the railway transport enterprises were hidden by the railway workers and, accordingly, the national statistics of transport events has significant accounting shortcomings. In addition, analyzing the accounting of transport events in railway transport, carried out in accordance with the legislation of the State Service of Ukraine for Transport Safety (Ukrtransbezpeka), it becomes obvious that it is impossible to establish the causal chains of these events.

These shortcomings and challenges were taken into account when developing the "Transport Events" system. The data set, which will be taken into account in the subsystem as a national one, will make it possible to systematize and automatically classify all events that will be entered by railway transport enterprises, forming interactive information sledges and tables. For example, the "Location coordinates" field will allow to display all declared events on an interactive map, which will allow to quickly identify dangerous places and take appropriate management measures to prevent traffic events in such places (such as identifying places of mass unauthorized passage of citizens across railway tracks).

Separately, it should be noted the accounting of locomotives, wagons, trains, which is proposed to be personalized, which in the future will allow creating predictive models for accidents with one or another type of rolling stock.

In the "Transport events" subsystem, drop-down lists/directories are used to the maximum (for example, "Description according to the classifier", where the Classifier of transport events [24] was used), which will allow analyzing information about traffic incidents in a multi-vector plane.

The subsystem takes into account that, according to paragraph 10 of section XII [22], the accounting of transport events is kept in the book of accounting of transport events on the territory of railway transport enterprises in paper or electronic form. The regulation also establishes the form of the book for accounting for transport events, and the subsystem (**Fig. 1.18**) takes into account and implements the mandatory fields of this book, namely:

– date, time of commission;

– type of transport event;

– the scene of the incident (station, stage, kilometer, picket);
– train number, series of locomotive or other traction rolling stock;
– the circumstances of the incident;
– identification of the structural unit and enterprise in the field of railway transport;
– the persons who conducted the internal investigation;
– the date of drawing up the act of the official investigation of the transport accident;
– the requirements of regulatory documents (name, paragraph, subparagraph) are violated;
– other.

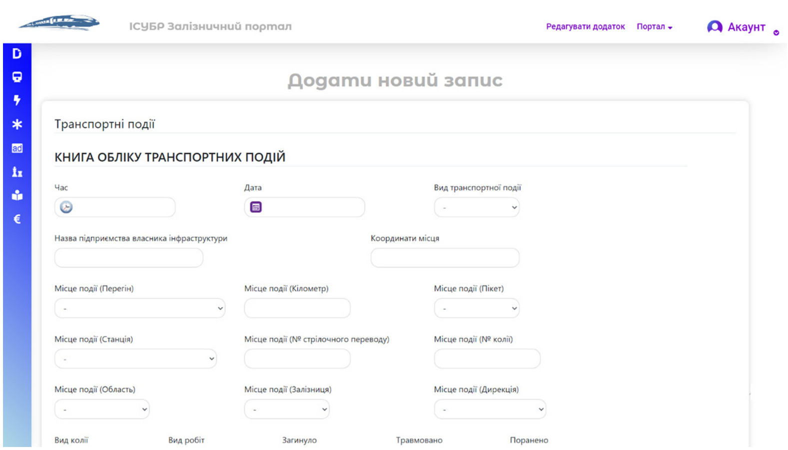

Fig. 1.18 General view of the "Transport events" subsystem

"Document management" subsystem. According to paragraphs 1–4 of section XI [22], the information of the TSMS is subject to documentation. For this purpose, the Document Management subsystem was developed, whose tasks include registration, accounting, classification and storage of documents related to traffic safety at enterprises.

During the development of this subsystem, it was found that a significant part of railway transport enterprises do not have a system for documenting information (paper or electronic) related to traffic safety. Thus, a subsystem was proposed and developed as the basis of a nationwide one.

"Internal audit" subsystem. According to clause 5 of section XIII [22], the process of carrying out an internal traffic safety audit is subject to documentation. For this purpose, the "Internal Audit" subsystem was developed, whose tasks include registration, accounting, storage of documents (acts, instructions, entries in the books of identified violations, etc.) that relate to internal audit measures, as well as classification of violations in the context of the provisions, norms and requirements of the relevant regulatory legal acts.

In addition, this subsystem establishes a clear mechanism for tracking the implementation of mandatory instructions and comments through the Events subsystem, which allows managers to quickly analyze and influence the current state of affairs in the field of traffic safety.

"Risk register" subsystem. According to paragraph 1 of Section VI. The procedures for identification of hazardous factors or threats, risk assessment, risk management [22], identification of hazardous factors or threats and risk management are the basic processes of traffic safety management at the enterprise. In order to implement this requirement, the "Risk Register" subsystem was developed, which allows using unified lists: sources of hazardous factors or threats containing the risk of negative consequences, probable causes of hazardous factors and risk assessment in terms of their frequency and severity of consequences.

The creation of unified risk registers makes it possible to analyze them at the national level and develop comprehensive measures for their management. In order to manage and prevent risks, railway transport enterprises form, approve and distribute among the personnel of the enterprise involved in traffic safety a risk register. This allows timely identification and assessment of risks that have not yet been in the field of view of the personnel of the enterprise, as well as effective management of already assessed risks. The risk register contains the following fields: source of the hazard or hazard; a dangerous factor (event) containing the risk of negative consequences; the likely cause of the hazard; negative consequence; estimated probability of occurrence of an event or conditions for its occurrence; estimated risk severity or likely consequences; risk index; management activities; the residual probability of the occurrence of the event or the conditions for its occurrence; residual risk severity or likely consequences; residual risk index.

"Registry Role-Function-Authorities" subsystem. In accordance with paragraph 3, clause 1 of Section X. Information exchange measures [22], the exchange of information on traffic safety is carried out in order to bring to the attention of the personnel of the enterprise information regarding their role, functions and powers to comply with traffic safety. ISTSM "RAILWAY PORTAL" solved this problem by creating the "Role-Functions-Authorities" subsystem, which gives railway transport enterprises the opportunity to create a unified register for a systematic presentation of information about a structural unit. This Register contains the following fields: card number; structural subdivision of the railway transport enterprise; position according to the staff list; full name; mobile phone; email address; the role of the structural unit; zone of distribution of powers; unit functions; division capabilities.

The input map in the "Role-Functions-Authorities" subsystem has several directories (Role, Distribution Zone, Functions, Authorities). The Function Directory, for example, contains the following options:

– conducting internal traffic safety audits;

– monitoring the state of traffic safety at the enterprise;

– control of the state of traffic safety in the structural subdivision;

– coordination of actions during the liquidation of the consequences of transport accidents and other emergencies;

– review and approval of internal documentation on traffic safety;

– participation in the investigation of transport events;

– organization of briefing of employees on traffic safety;
– control over the organization of technical training of employees;
– checking the knowledge of employees on traffic safety;
– coordination of activities at the enterprise in monitoring the state of traffic safety;
– coordination of work plans and preventive work plans;
– identification of hazardous factors (risks);
– notification of managers about possible transport events;
– implementation of normative acts and technical regulations on traffic safety;
– development of measures to improve the level of traffic safety;
– making proposals to improve the level of traffic safety;
– consideration of the circumstances of transport events;
– notification of subjects of information exchange about transport events;
– reporting of traffic accidents;
– accounting of transport events;
– implementation of traffic safety measures;
– personnel management of the enterprise;
– publication of mandatory instructions on traffic safety;
– development of a draft traffic safety budget;
– organization of compliance with licensing requirements in the field of transportation;
– control over the development of the TSMS at the enterprise;
– informing about the state of traffic safety;
– introduction of the TSMS at the enterprise.

The Authorities directory contains information about the activities of the traffic safety service and contains the following options:

– to demand the provision of information about traffic accidents;
– give instructions on the elimination of violations of traffic safety;
– freely visit the structural divisions of the enterprise at any time;
– prohibit the operation of rolling stock, infrastructure facilities and the performance of work that poses a threat to people and the environment until the violations of traffic safety are eliminated;
– make proposals for the removal of employees from work;
– submit proposals on the inconsistency of the position of officials who violate traffic safety requirements;
– organize and conduct conferences, seminars, meetings on traffic safety;
– check compliance with the requirements of the law and internal regulations regarding the timing, execution procedure, truthfulness and completeness, as well as the efficiency of business processes and operations;
– make decisions on the financing of traffic safety.

This approach allows to create and disseminate information about the persons responsible for traffic safety at the railway transport enterprise in the context of the functions and powers of each official. Usually, railway transport enterprises, on the basis of the data generated in the subsystem, create, approve and distribute at the enterprise the Register "The role, functions and powers of each employee of the railway transport involved in traffic safety". This allows to establish a clear, well-coordinated mechanism for the interaction of the personnel of the enterprise in matters of traffic safety.

"Additional" subsystem. Regulation [22] contains many different requirements regarding the format of data in case of their request, maintaining a list of relevant legal acts, checking knowledge before and after basic training, availability of up-to-date reporting forms and internal regulatory documents (procedures, policies, regulations, procedures, the like).

The "Additional" subsystem was created for the convenience of railway transport enterprises. It combined external services for imposing a qualified electronic signature, a list of regulations in force in the field of railway transport, templates (drafts) of documents, etc.

1.3.2.2 "TECHNICAL EDUCATION" INFORMATION SYSTEM

This system includes several subsystems implemented on different sites:

– "Testing" subsystem (http://ted.in.ua/trains/, **Fig. 1.19**) includes a set of automated tests, which in turn are divided into general ones (Rules for the technical operation of railways (RTO), Instructions for the movement trains (IMT), Instructions for signaling on the railway (ISR)) and by profession (The next station (for administrative use), Compiler of trains, Duty switch post, Head of a passenger train);

– "Traffic Safety Training Course" subsystem (http://br.ted.in.ua/) is an online learning platform that combines presentation material, video lessons and test questions.

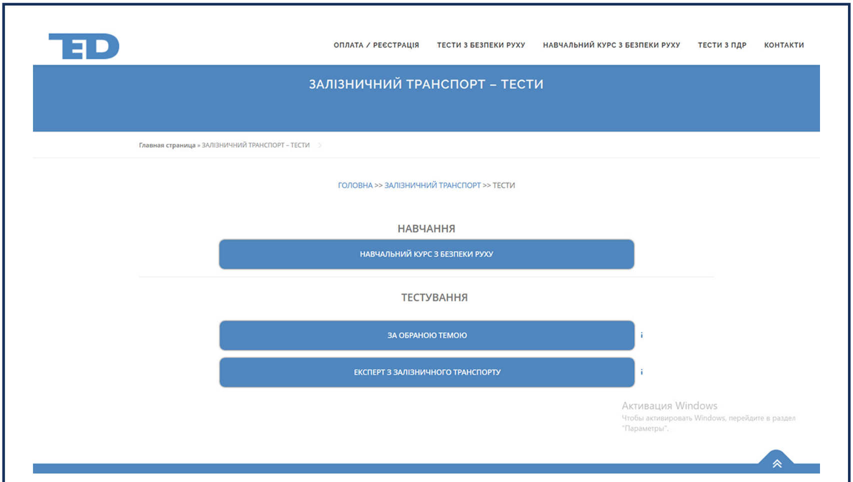

Fig. 1.19 General view of the "Testing" subsystem

The "Traffic Safety Training Course" subsystem is an introductory course and basic training, includes basic information about traffic safety, including the influence of human and organizational factors. Training guarantees the training and qualification level of the company's personnel to perform their duties in the field of traffic safety.

This course is held for managers of enterprises, traffic safety services and all personnel of the enterprise, and is carried out on the job.

The prerequisite for the creation of the subsystem "Training course on traffic safety" of the IS "TECHNICAL EDUCATION" was Section IX. Programs and procedures for training the personnel of the enterprise on traffic safety to ensure the maintenance of personnel competence [22]. The training course includes 12 thematic presentations and video lessons presented in **Table 1.9**.

Before the start of training and after its completion, the following tests are taken:

– primary check of the level of knowledge;

– checking the level of knowledge after completing the training course;

– each of which consists of 64 questions and thus achieves the goal of obtaining a slice of knowledge at the beginning of training and after its completion. As a result of passing the course, the system generates a certificate, the form of which is shown in **Fig. 1.20**.

Table 1.9 List of topics and questions of training in the "Traffic Safety Training Course" subsystem

No. of topic	Topic	Issues under consideration
1	**2**	**3**
1	Safety analysis	– fundamentals of the analysis of the state of traffic safety. Essence of analysis; – statistics of violations as the basis for determining the state of traffic safety; – causal relationships: events, causes, prerequisites; – recommendations for conducting an analysis of the safety posture in an organization
2	Railway traffic safety policy	– traffic safety policy at the enterprise; – purpose and tasks of the TSMS; – classification of traffic accidents on the main railway transport; – accounting for the type, nature and activities of the enterprise
3	Requirements of national and European legislation on traffic safety	– international organizations of transport activity on railways; – EU rail safety policy; – state of Ukrainian legislation on train traffic safety
4	Familiarity with national and European traffic safety legislation	– documents aimed at harmonizing existing EU standards and policies; – general principles of traffic safety management, as defined by the Regulation on TSMS; – regulatory framework for the safety of rail transport in the EU
5	Process of ensuring traffic safety at the enterprise. Organization of work, functions and duties of personnel	– structure and functioning of the traffic safety management system (TSMS); – the process of ensuring traffic safety at the enterprise; – the concept and policy of traffic safety at the enterprise; – work organization; – functions and responsibilities of the personnel of the enterprise to ensure traffic safety

Continuation of Table 1.9

1	2	3
6	Report on transport incidents and possible threats	– exchange of information on traffic safety at the enterprise; – mandatory reporting procedures
7	Hazard identification and risk management	– general concepts of hazards and risks; – identification of hazards and risks; – management of risks; – an example of risk identification
8	Basic principles of traffic safety management	– What is safety management and why is it important? – general principles of traffic safety management, as defined by the Regulation on TSMS; – development and control of management decisions in the field of traffic safety
9	Powers of the Ministry of Infrastructure and Ukrtranssafety	– powers of the Ministry of Infrastructure of Ukraine in terms of traffic safety; – powers of Ukrtranssafety in matters of traffic safety in the field of railway transport
10	Investigation of transport events and audit of TS state of BR at the enterprise	– procedure for investigating transport events; – traffic safety audit: what is it; – internal audit; – state traffic safety supervision
11	Distribution of functions and duties of the personnel of the enterprise in the field of traffic safety	– What personnel of the enterprise belong to the field of traffic safety (TS)? – What is the difference between functions and responsibilities? – functions, powers and duties of the personnel of the enterprise in the field of traffic safety
12	The constituent elements of the enterprise TSMS	– What is TSMS? – S TSMS components

Fig. 1.20 Certificate generated by the "Traffic Safety Training Course" subsystem of the IS "TECHNICAL EDUCATION"

Conclusions. The developed information organizational and educational system for managing railway traffic safety provides a ready-made prototype of an information management system for any enterprise in the field of railway transport, for which the creation and operation of a traffic safety management system is regulated. The system is implemented in accordance with the Regulations on the traffic safety management system in railway transport, approved by the order of the Ministry of Foreign Affairs dated December 24, 2020 No. 842 and operates on the Internet.

The developed system is the basis for the formation of a nationwide information database of traffic safety in the railway sector both for peacetime and during crisis situations [28].

CONCLUSIONS

Russia's war against Ukraine:

– led to the destruction of more than 1/3 of the railway infrastructure and led to a drop in the country's GDP by 45 %;

– showed the great importance of logistics for the defense of the state and alleviate the victims and suffering of its population from military operations;

– proved that there is no alternative to the course towards real integration of Ukraine with the Trans-European transport network TEN-T, including the transition to the 1435 mm track standard.

The provision of emergency humanitarian and military assistance requires the development of multimodal logistics technologies (primarily container transportation), as well as the introduction of interoperable (operationally compatible) rail transportation, the only high-speed and high-speed railway network with the neighboring EU countries of the track width standard 1435.

The networks of 1435 mm gauge lines should provide for the deepest possible introduction of them into the territory of the country and the creation of multimodal logistics terminals on them. The network of new Ukrainian high-speed and high-speed railways 1435 mm should be operated on the principle of shared use (shared use) both for the transportation of passengers and certain categories of goods with high added value, and be part of international transit routes, such as the Silk Road, Three Seas Initiative, continuation Rail Baltica to the Black Sea, etc.

For the interaction of new and modernized 1435 mm railways with the 1520 mm railway network, it is necessary to build a system of logistics hubs – multimodal terminals; it is possible to simultaneously use other technologies, in particular, carriages of the fleet on wheelchairs with a variable gauge, which together will allow faster full integration with the railway networks of the EU and NATO countries.

The developed information organizational and educational system for managing railway traffic safety is a prototype of an information management system at an enterprise in the field of railway transport, as well as the basis of a nationwide information database for traffic safety in the railway sector both for peacetime and during crisis situations.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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CHAPTER 1

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CHAPTER 2

LOGISTICS OF FREIGHT TRANSPORTATION AND CUSTOMS SERVICE IN INTERNATIONAL TRANSPORTATION

ABSTRACT

The logistics of cargo transportation and customs service in international communication acquires special importance in the modern conditions of martial law in Ukraine. International cargo transportation is important for supporting the economy of Ukraine. Important aspects of international transport logistics are studied: the development of international transport logistics in Ukraine in modern conditions, logistical risks in international transport service projects, the logistics of using information technologies to increase the efficiency of the organization of international freight transport, the peculiarities of the development of customs logistics of Ukraine in comparison with other countries, peculiarities of the logistics of piggyback transportation in international traffic. Practical measures are proposed to improve logistics solutions in transport and customs services in international traffic to ensure the efficiency and reliability of the national economy of Ukraine.

KEYWORDS

International transportation, customs service, logistics risks, information technologies, piggyback transportation.

The rapid development of the modern economy of Ukraine and its focus on European standards require the optimization of cargo delivery in international traffic. The state of the world market of transport services is characterized by growing competition, which is becoming more and more intense. At the same time, participants in foreign economic activity (customs carriers, buyers, dealers and manufacturers) are directly interested in prompt customs clearance of international cargo with confirmation of the customs value. One of the means of improving international transportation is customs logistics and its principles, which helps to solve complex tasks, helps to optimize the processes of export and import of goods, making them less expensive and faster.

Optimization of international transportation is not possible without the use of information technologies when designing international routes. The organization of cargo delivery in international communication requires coordination of the actions of all participants in the transport and technological process of transportation, which are regulated and determined by international and national legal bodies, environmental, political and social factors. In the conditions of a high level of competition in the market of transport services, consideration of the issues of implementing the principles of customs logistics in road transport, the search for rational ways of transport service in accordance with the best European practices, the substantiation of transport and technological schemes for the delivery of goods, the implementation of progressive forms and methods of organizing the transportation process deserve special attention, improvement of existing and development of promising transport technologies.

Customs logistics of a subject of foreign economic activity (FEA) should be understood as the theory and practice of managing material, as well as accompanying information, financial, service and other flows, which are related to the need to comply with the requirements of the state customs when conducting foreign economic operations by enterprises. The main principle of logistics, like logistics in general, is cost optimization. In transport, it is achieved by observing savings due to the scale of freight transportation and the distance of routes. Economy due to the scale of freight transportation is due to the fact that the larger the load, the lower the transport costs per unit of weight. Savings due to the distance of the route is due to the fact that the longer the route, the lower the transport costs per unit of distance. These principles must be taken into account when evaluating alternative transport service strategies.

The essence of customs logistics is a combination of logistics processes of the participants of the Customs Union (customs carriers) with the processes of customs control and clearance of goods by the customs authorities of export, import and transit countries.

The main logistics function of customs activity is the logistics organization of the process of customs control of goods, which combines the processes of applying customs regimes related to the physical movement of foreign trade goods across the customs border and delivery conditions. Logistics, in order to accelerate this process of moving goods across the customs border, improves the standard logistics requirements for both customs regimes (i.e. customs) and customs carriers.

Let's note that high-quality customs logistics is closely related to the simplification of conditions and organization of foreign trade, especially with regard to customs operations and procedures and border administration. Improving customs control is becoming increasingly important to avoid unwanted delays and reduce customs risks, because the significant number and complexity of documents during customs control create additional costs of both time and money for businesses. The more complicated, longer and more expensive the procedures, the less competitive a country is on the international market.

2.1 DEVELOPMENT OF INTERNATIONAL TRANSPORT LOGISTICS IN UKRAINE IN MODERN CONDITIONS

In recent years, logistics has become an integral part of business strategy all over the world. Logistics is used differently at different enterprises, and it depends on innovation opportunities and priorities. Along with the processes of transportation, cargo handling and warehousing, the value chain includes other types of activities that cannot be underestimated, especially if the enterprise is oriented towards the international market. Let's consider the main trends in the development of international transport logistics.

The globalization of the economy has created fierce competition among businesses for locations and accommodation, and the framework conditions of trade continue to undergo new and rapid changes. Mergers of enterprises and intensive development of information and communication systems only intensify these processes. The ability to calculate development trends is decreasing. All of this together leads to shorter planning times and requires faster decision-making and response. The division of labor of the economy, taking into account various distribution systems, is again based on communication (for example, regional networks, cooperative relations, etc.) and logistics. Therefore, it is very important to understand where logistics leads.

It's no secret that globalization of the economy is impossible without well-functioning logistics. The client does not have the goal of working with several transport and logistics companies, and therefore seeks competence in various activities on a one-stop-shop basis. In the automotive industry, this is implemented as follows: the manufacturer concentrates on design, assembly and sales. The share of participation in the production of the final product in this industry fell to 20 % [1]. Parts and components are purchased all over the world, the logistics company supplies them to various factories and distributes the goods in the trade network (supply chain management) supplies due to lack of relevant know-how. The main logistics trends can be characterized as follows:

– change of the production system. From production for the warehouse (Make-to-Stock) to production to order (Make-to-Order) [2]. For managers of manufacturing enterprises operating all over the world, the main task is to master the production of a product according to the individual requirements of customers;

– change in the distribution of goods. At this level, the traditional structure of sellers is reconciled with direct sales through a logistics company. The presence of logistics management at the manufacturer is required. At the same time, compliance with delivery terms is valued more than shortening these terms;

– merger and consolidation of trade and suppliers. Logistics plays an important role in realizing potential synergies in procurement, supply, goods receipt, distribution or e-logistics. Quantitative trends, namely: a decrease in the number of suppliers in the supply. Three quarters of international enterprises intend to reduce the number of their suppliers in the next five years. In the case of sales, as before, the reduction of delivery times remains relevant. Impact of e-business on logistics. Business processes within the framework of the B2C concept provide for the automation of more intensive deliveries, as customer expectations for shorter delivery times are higher than for conventional methods of order fulfillment. The appearance of more expensive delivery logistics and the implementation of after-sales services. Modification of processes within the enterprise with the help of expansion of electronic trading platforms. The integration of new participants into the supply chain will lead to the creation of the so-called "transparent pipeline" [3];

– changing the role of logistics in the international market. European third-level providers (3PL) are market leaders in terms of presence and process implementation capabilities. Ukrainian logisticians, as a rule, work in their country, American ones concentrate their efforts on the North American continent. In past years, the growth rate of European logistics providers on the American and European markets was 10 % per year. In the future, taking into account the development of B2C, this indicator will be exceeded;

– conquest of the logistics market by the fourth level providers (4PL).

Thus, the fourth level logistics provider as a network integrator manages all organizational and informational processes in the supply chain or enables the use of outsourcing based on the application of the Best Practice method for individual processes in order to improve the productivity of the entire network. The fourth level providers, during the creation of their own value, take some links of the supply chain and manage the entire business with the involvement of other logistics enterprises.

COVID-19 continues to have a devastating impact on the commercial trucking industry. The military conflict had a great influence on the logistics of international transport. In all countries of the world, there is an extremely high level of risk of default and insolvency in the field of road transport.

The level of risk in all regions of the world has reached the highest indicators and is nine to ten points on a scale from one to ten. This indicates an impending wave of bankruptcies in the road transport industry, which will affect the global economy and the possibility of its recovery after the pandemic.

The vast majority of motor vehicle enterprises whose interests are represented by the IRU, which is more than 3.5 million companies in the sector, belong to small and medium-sized enterprises [3]. It is the connecting link of all global supply chains and communication networks. Most of them struggle to cover their expenses. This is a huge threat to the world economy.

Tariffs for import freight transportation by road increased by 40–50 % on average. This is due to the shortage of transport in Europe, as well as increased excitement – recipients are trying to replenish stocks of goods. The lack of transport also provokes long queues at checkpoints, on average, it takes 4–5 days to drive a car one way. For example, on November 23, 2021, there was a queue of 800 trucks to leave Ukraine at the Yahodyn checkpoint [4].

The study also showed that the losses of the trucking industry at the global level reached 679 billion USD, and the passenger transport industry – at least 500 billion USD. The new data point to a particularly depressing situation in Europe, where the projected losses of freight transport operators have increased by two-thirds since the summer and reached 125 billion USD, and passenger transport operators – 94 billion USD [4].

If measures are not taken immediately, during the second wave of the pandemic, losses will increase many times over:

– road transport industry does not receive state financial assistance: without targeted measures, the sector is waiting for collapse;

– road transport losses in 2021 – both freight and passenger transport – are currently estimated at more than 1 trillion USD;

– sector is exposed to an extremely high risk of default and insolvency, which leads to mass bankruptcies of motor vehicle enterprises.

If governments do not take urgent action, a catastrophic number of transport operators will go bankrupt in the coming months, causing irreversible damage to supply chains and communication networks, and thus affecting the economy of Ukraine.

Sustainable Development Goals (SDGs) for the period until 2030, taking into account the general principles of the Muscat Treaty, approved at the IRU World Congress in Oman on November 6–8, 2018, as well as the provisions of the Ministerial Resolution "Strengthening cooperation, coordination and integration in the era of digitalization and automation on transport", adopted during the 81st session of the Committee on Internal Transport of the UNECE (February 19, 2019) [5].

The following norms must be included in the legal norms of national legislation:

– to harmonize provisions and norms of regulatory documents and standards in accordance with international agreements and UN conventions that ensure seamless international transportation and transit;

– with the joint efforts of representatives of all types of transport, take operational measures to digitize the industry and form effective interaction in intermodal transportation, striving for maximum complementarity of different types of transport;

– to ensure a smooth transition to paperless document circulation in road transport, including through the implementation of the digital TIR procedure and the electronic waybill e-CMR, which will meet the needs of all key participants in the logistics chain;

– to increase the guarantee limit for the TIR carnet to 100,000 EUR, implement new ones and promote the further promotion of existing TIR tools – iCarnet (guarantee for customs transit between the customs authorities of the same country), TIR+ (additional guarantee to the TIR carnet), eTIR, TIR-EPD (the IRU program on advance electronic information during transportation under the TIR system), participate in the implementation of intermodal projects using the TIR procedure, expand the use of subcontractors during transportation under the TIR system;

– take measures to conclude with China, as well as other countries of Asia and the Middle East, new bilateral and multilateral agreements on international road traffic, which would allow national road transport companies to gain access to the cargo base of China and Asian countries and expand the geography of transportation in new directions;

– to join the participation in the new eTIR pilot projects implemented by the IRU together with the UNECE, as well as to expand the use of the TIR digital procedure in transportation between Turkey and Iran, Georgia and Turkey, Turkey and Ukraine, along the so-called "Batumi Corridor", which covers Ukraine, Georgia, Azerbaijan and the Republic of Kazakhstan;

– to join the Additional Protocol to the Convention on the Contract for the International Carriage of Goods by Road (CMR) concerning the electronic waybill (e-CMR), and to introduce the specified electronic waybill into the practice of international road transport;

– to include in the national legislation norms that provide for mandatory initial and periodic training of drivers, minimum requirements for safety and quality standards of transport services;

– to contribute to the improvement of the working conditions of drivers, the involvement of new workers in the profession, including young people and women, and the solution of the problem of the lack of professional drivers;

– strive to simplify visa formalities, issue multiple annual visas to professional drivers, implement electronic visas as soon as possible;

– to speed up the work on agreeing changes to the European Agreement on the work of crews of vehicles producing international road transport (AETR), on the use of so-called smart tachographs, in order to support trade and tourism, prevent disruptions in the functioning of international supply chains;

– to improve the system of bilateral intergovernmental agreements on international road transport by canceling transit and bilateral permits for cargo transportation;

– to contribute to the creation of conditions for the realization of the potential of the transport market and foreign trade of their countries by raising the awareness of the ministries of transport and departments responsible for the regulation of motor transport activities, about examples of best practice with the simplification of international road transport and the transition to a permit-free principle of their execution;

– to contribute to the further development of high-quality and safe infrastructure and the creation of minimum social and living conditions for drivers while waiting for the crossing of borders or on the way through international transport and transit corridors, including TRACECA, GUAM, SCO, MTK "North-South", the Lazurite Corridor and the ring road motorways around the Black Sea, providing connections of the Trans-European Transport Network (TEN-T) with the Asian Motorway Network (AN);

– to conduct regular monitoring of the situation at border crossing points and, on the basis of best international experience, promote legal trade and cross-border transportation for the purpose of economic development, strengthening of regional stability and cooperation.

The level of risk in all regions of the world has reached the highest indicators and is nine to ten points on a scale from one to ten. This indicates an impending wave of bankruptcies in the field of road transport, which will affect the world economy and the possibility of its recovery after the pandemic and the war with russia.

2.2 LOGISTICAL APPROACH TO THE USE OF INFORMATION TECHNOLOGIES TO INCREASE THE EFFICIENCY OF THE ORGANIZATION OF INTERNATIONAL CARGO TRANSPORTATION

In the process of freight transportation, a situation often arises when the volume of goods supplied by its suppliers exceeds the capacity of the consumers' warehouses. In this case, we are faced with the need to use intermediate points for temporary storage of excess cargo and, as a result, multi-stage transport tasks (MT). Also, often the matrix of transport correspondences between suppliers, consumers and intermediate points is not specified in an explicit form, but simply a cartographic scheme of their placement is introduced, i.e. the transport task is presented using a transport network (TN). We will provide a description of the logistics approach, which with the help of information technologies (IT) solves the task of optimal organization of transportation of unbalanced TN cargo. As a result of socio-economic changes taking place in Ukraine and under the influence of globalization phenomena, the logistics supply chains of goods and raw materials at enterprises are undergoing changes. They become longer and more complex in structure. Under the influence of IT, which accompanies material and financial flows, the integration of individual links of supply chains, which are independent economic units, is strengthened. The geography of the movement of material flows is also expanding, which is manifested, in particular, in the increase of freight transportation both in intercity [6] and in the international direction by road transport.

The efficient functioning of freight complexes (FC) ensures the optimization of the rolling stock of motor transport enterprises (MTE) that carry out freight transportation. The technology of cargo delivery using VC as intermediate temporary points of its preservation during regular mass transportation of cargo will allow to increase the number of MTE road trains on the routes and increase the efficiency of their use [7].

In the case of international cargo transportation on the Ukraine-EU and EU-Ukraine route, the transshipment point can be the FC located on the Ukrainian side of the border [8, 9]. The western regions of Ukraine bordering the EU member states, under the condition of effective cross-border cooperation, make it possible to use the beneficial geopolitical potential of the state. Long-term projects regarding the use of FC along the western border are one of the options for the rationalization of freight transportation, therefore, the rational organization of work and the interaction of MTE with terminal-warehouse complexes are very important and relevant.

The aim of the work is to develop a logistic approach to increase the efficiency of the organization of mass unbalanced cargo transportation on transport networks using methods and means of information technologies.

Let's provide a description of the logistics approach that solves the task of phased transportation of goods in its network presentation. At the same time, two options are considered, when the total storage capacities of cargo consumers and intermediate points are greater or equal (the first option) or less (the second option) than the volume of cargo available at the cargo suppliers.

Let there be m points of departure (PD) of homogeneous cargo $A_1, A_2, \ldots, A_m$, which have it, respectively, in volumes $a_1, a_2, \ldots, a_m$ and n points of its receipt (PR) $B_1, B_2, \ldots, B_n$, for which there are applications in volumes, respectively, $b_1, b_2, \ldots, b_n$. At the same time, the total volume of delivery of this cargo exceeds the total volume of orders for it, i.e.:

$$\sum_{i=1}^{m} a_i > \sum_{j=1}^{n} b_j. \qquad (2.1)$$

There are also l intermediate warehouses (IW) C_1, C_2, ..., C_l for temporary storage of excess cargo, which can have it in the volumes, respectively, c_1, c_2, ..., c_l, while there can be two versions of the ratios with the mandatory fulfillment of the condition (2.1):

– 1st option:

$$\sum_{j=1}^{n} b_j + \sum_{k=1}^{l} c_k \geq \sum_{i=1}^{m} a_i; \tag{2.2}$$

– 2nd option:

$$\sum_{j=1}^{n} b_j + \sum_{k=1}^{l} c_k < \sum_{i=1}^{m} a_i. \tag{2.3}$$

Let's consider the most interesting from a practical point of view, the 2nd case of cargo delivery (2.3) on a specific example, in which the layout of the points of departure and receipt of the cargo is presented by TN.

TN has: main cargo-generating and cargo-absorbing points; the distance between them (**Fig. 2.1**), namely: the PD of the cargo is marked with black circles (Kyiv – A1, Uman – A2), the PR of the cargo – with black squares (Lutsk – B1, Lviv – B2, Ivano-Frankivsk – B3, Chernivtsi – B4) and IW – with black triangles (Rivne – C1, Ternopil – C2, Kamianets-Podilskyi – C3).

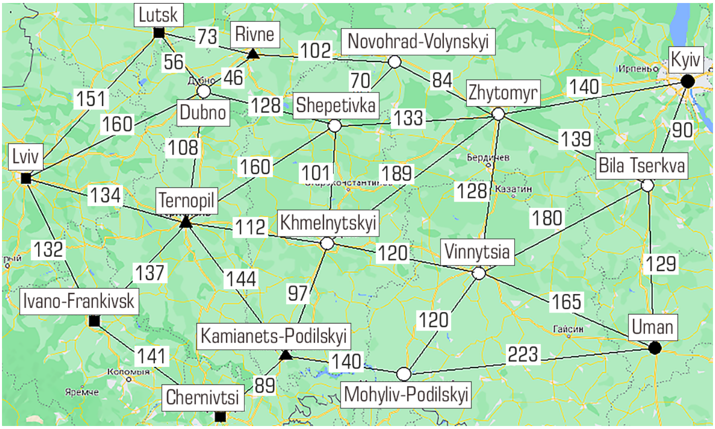

Fig. 2.1 Transport network

On the TN, the number of PD $m=2(A_1, A_2)$, which have its stocks $a_1=10$ cargo units (c.u.), $a_2=10$ c.u.; the number of PR $n=4(B_1, B_2, B_3, B_4)$, which have applications for it $b_1=2$ c.u., $b_2=2$ c.u., $b_3=2$ c.u., $b_4=2$ c.u.; the number of intermediate IW$=3(C_1, C_2, C_3)$, the capacity of which is: $c_1 = 1$ c.u., $c_2 = 1$ c.u., $c_3 = 1$ c.u. TN also has 8 intermediate transit points. **Fig. 2.2** presents TN in a simplified form.

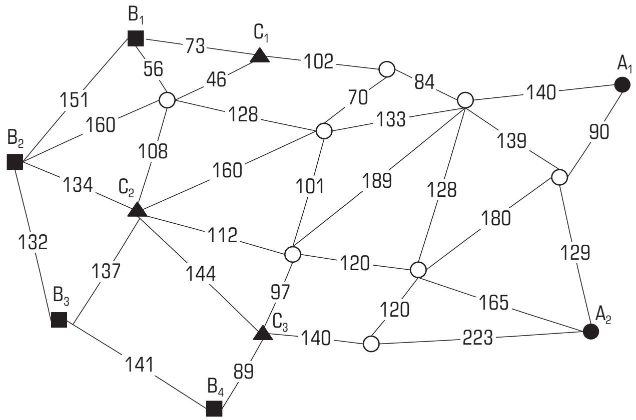

Fig. 2.2 Transport network in a simplified form

For convenience and its further processing, let's reduce the network representation of freight transportation to a matrix form. First, let's manually compile an array of distances between neighboring TN nodes. Secondly, with the help of the corresponding program, let's build an array of transport correspondences between all TN nodes of based on the obtained array [10, 11].

Applying the data of the transport correspondence matrix using the method of the shortest routes, let's find the shortest distances on the TN from each PD of the cargo to each PR and IW (**Table 2.1**), as well as from each IW to each PR of the cargo (**Table 2.2**). In parallel, routes corresponding to these distances are formed, which contain intermediate nodes. As an example, let's present the routes from the Haysyn PD to its four PRs:

Kyiv → Zhytomyr → Novohrad-Volynskyi → Rivne → Lutsk = 399;

Kyiv → Zhytomyr → Novohrad-Volynskyi → Rivne → Dubno → Lviv = 532;

Kyiv → Zhytomyr → Shepetivka → Ternopil → Ivano-Frankivsk = 570;

Kyiv → Zhytomyr → Khmelnytskyi → Kamianets-Podilskyi → Chernivtsi = 515.

A software module (SM) was built for the planning of mass freight transportation on TN based on the Delphi algorithmic programming language [12, 13].

Fig. 2.3 presents a fragment of the work of the SM, which shows the results of its operation – the volume of cargo transportation between PD A_1, A_2 and PR B_1, B_2, B_3, B_4 at the first stage of cargo delivery (its realization is 3,834 value units (v.u.)); volumes cargo transportation between PD A_1, A_2 and IW C_1, C_2, C_3 also at the first stage of cargo delivery (its realization is 1086 v.u.); volumes of cargo transportation between IW C_1, C_2, C_3 and PR B_1, B_2, B_3, B_4 at the second stage of cargo delivery (its realization is 296 t.v.u.); the volume of cargo transportation between PD A_1, A_2 and PR B_1, B_2, B_3, B_4 at the third stage of cargo delivery (its realization is 3834 t.v.u.); the total cost (current) of all three stages of cargo delivery is 9050 o.v.

Table 2.1 Distances from PD to PR and IW

PD/PR points	Lutsk	Lviv	Ivano-Frankivsk	Chernivtsi	PD/IW points	Rivne	Ternopil	Kamianets-Podilskyi
Kyiv	399	532	570	515	Kyiv	326	433	426
Uman	527	531	534	452	Uman	454	397	363

Table 2.2 Distances from IW to PR

IW/PR points	Lutsk	Lviv	Ivano-Frankivsk	Chernivtsi
Rivne	73	206	291	387
Ternopil	164	134	137	233
Kamianets-Podilskyi	308	278	230	89

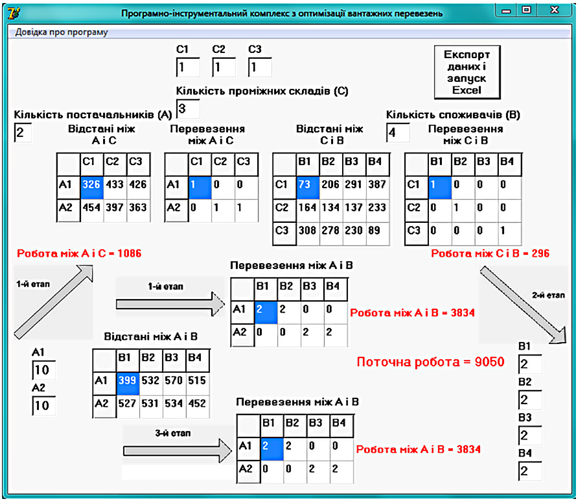

Fig. 2.3 A fragment of SM work at MT stages 1, 2, and 3

Then SM issues an informational message about the continuation of further calculations. In the case of pressing the OK key, the MT solution continues and as a final result we have (**Fig. 2.4**) a fragment of cargo delivery at the fourth stage. The results of the implementation of this stage are given here, namely: the volume of cargo delivery between PD A_1 and PR B_1 at a cost of 399 v.u. and the total cost of all four stages of cargo delivery, which is equal to 9449 v.u.

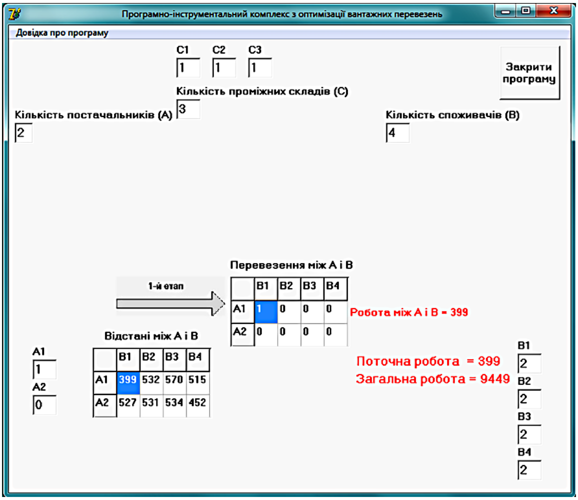

Fig. 2.4 A fragment of SM work at the 4th MT stage

The presented logistic approach to the organization of mass transportation of goods on transport networks in the event of their imbalance is implemented in the form of a software-instrumental complex that combines the stages of reducing the network representation of freight transportation to a tabular form and planning mass transportation of goods on TN. It showed its efficiency and economy in the organization of cargo transportation at the car companies of the association of international car carriers of Ukraine, both in long-distance and international connections.

This approach, which is based on the use of modern methods and means of information technology, demonstrates one of the directions of logistics for solving a multi-stage transport problem. At the same time, it has a limitation, which is contained in the fact that at the 2nd, 3rd and subsequent stages of solving the multi-stage transport problem, an assumption is made about the readiness of all its recipients to place this cargo in the volumes corresponding to their initial order, i.e. is considered in time [14, 15].

2.3 LOGISTIC RISKS IN PROJECTS OF TRANSPORT SERVICE OF INTERNATIONAL TRANSPORTATION

Development of the national network of international transport corridors (hereinafter NNITC) and bringing their condition to international norms and standards is one of the priority directions in the development of the transport industry of each country. At the same time, 2022 has become the most difficult year for the logistics infrastructure of Ukraine. Since the beginning of the russian federation's war against Ukraine, significant volumes of transport infrastructure have been damaged. In connection with the continuation of hostilities in certain territories of the country, it is currently impossible to establish the total final amount of destruction [16]. Today, transport corridors in Ukraine play an important role related to the change of transport and logistics routes, due to the reorientation of cargo flows and the increase in the load on the western border crossings for the maintenance of international cargo transportation. The challenges that are a consequence of the destruction of the transport infrastructure, and which lead to the need to increase the capacity of the western border crossings and transport infrastructure, including the development of multimodal terminals, as well as the establishment of international transport links of Ukraine, are a key and urgent issue today.

In Ukraine, there are a number of risks in the transport service of logistics flows, which is the result of a forced change in the approaches to the formation of transport logistics in connection with the closure of a number of sea ports, the destruction of transport infrastructure and, as a result, the breakdown of transport and logistics chains of transportation. Therefore, the Government of Ukraine and a large number of scientists pay considerable attention to the issue of the quality of the functioning of the international transport network in Ukraine and the improvement of the infrastructure of logistics flows for the maintenance of international cargo transportation. It is worth noting that the issue of risk management in the projects of reconstruction and development of transport networks of the highest category is currently considered particularly relevant.

Before the start of the full-scale military invasion of the russian federation on the territory of Ukraine, the regulatory and organizational aspects of the transport industry of Ukraine were harmonized with the countries of the European Union. This made it possible to meet the needs for cargo transportation and ensure the development of the country's economy by changing approaches to the formation of transport and logistics solutions and the development of modern transport infrastructure. Thus, Ukrainian legislation corresponds to European legislation regarding road traffic, basic technical requirements for roads, etc. However, despite the presence of the order of the Cabinet of Ministers of Ukraine on the approval of the transport strategy until 2030 and the developed program for the development of NNITC, there is a significant lag in ensuring the quality of transport infrastructure and risk management in road development projects of the highest category [16].

Today, scientists pay considerable attention to the issue of the development of NNITC on the territory of Ukraine for development and note the need for their development from the point of view of increasing the transit capacity of the state and the effectiveness of the interaction of various types of transport on the network of international transport corridors (hereinafter referred to as ITC). At the same time, despite the presence of a large number of developments, a number of problems require further research regarding the improvement of the level of service for carriers on the ITC road routes and the definition of a risk management strategy for the transportation of goods in international traffic.

To ensure the gradual integration of Ukraine into the European and world transport systems, it is necessary to strengthen and expand cooperation within the framework of international transport organizations, which involves the creation of a complex of services on the international road network of transport corridors that meet international standards: increasing the quality of international road transport and increasing the level of competitiveness of transport services to a level attractive to foreign carriers.

As a result of the active development of the infrastructure of transport corridors by neighboring states, competition for the provision of transport services and maintenance of the main transit cargo flows passing through the territory of our state is increasing. It is worth noting that despite the difficult situation in the logistics infrastructure of Ukraine, the European Commission made changes to the indicative maps of the Trans-European transport network, including Ukrainian logistics routes and giving them important strategic importance. At the same time, the Ministry of Infrastructure of Ukraine noted that the inclusion of logistics routes in the TEN-T network makes it possible to eliminate existing obstacles in conducting logistics operations, attract European investments for the modernization of transport infrastructure, and gain access to EU assistance tools in the development of the Ukrainian part of the TEN-T network, to develop multimodal transportation, reduce logistics costs, and improve the quality of services during the transportation of goods [17, 18].

Taking into account such a step, the transport network of Ukraine should guarantee consumers an example of a service (these are international road carriers) of a high, uniform and constant level of comfort and safety. A traffic management infrastructure with available information for users based on the interaction of traffic management projects on the international transport network at the European, national and regional levels should also be included. Therefore, taking into account the prioritization of infrastructure projects in Ukraine, the preparation of proposals for the development of the TEN-T network within the country and coordination with the TEN-T network in the neighboring countries of the European Union should take place today.

In order to evaluate the possible options for the transport service of international cargo transportation (and this includes the delivery of humanitarian aid) in risky situations (today it is a change of logistics routes in connection with military actions), it is advisable to use a mathematical apparatus of simulation modeling. It is necessary to create a risk management algorithm that will provide an opportunity to analyze external and internal factors that contribute to the quality of transport services for international transport in TEN-T transport network projects and to evaluate possible decision-making options taking into account risk.

Today, an unsatisfactory situation has developed in the market of transport services, as not all enterprises involved in the organization of international transportation services are able to provide the entire range of transport services. Some enterprises were forced to radically change the logistics routes of international transportation, some enterprises encountered technical and technological problems in the organization of transportation, which affected financial resources. To the internal factors of the unsatisfactory development of the transport market, external ones are added, which indicate the inactivity of the mechanisms of protection of Ukrainian international carriers and forwarders from foreign and domestic unscrupulous cargo owners, competitors, criminal elements on highways due to the lack of control over cargo during transportation. External factors of influence are presented in more detail in **Fig. 2.5** [18].

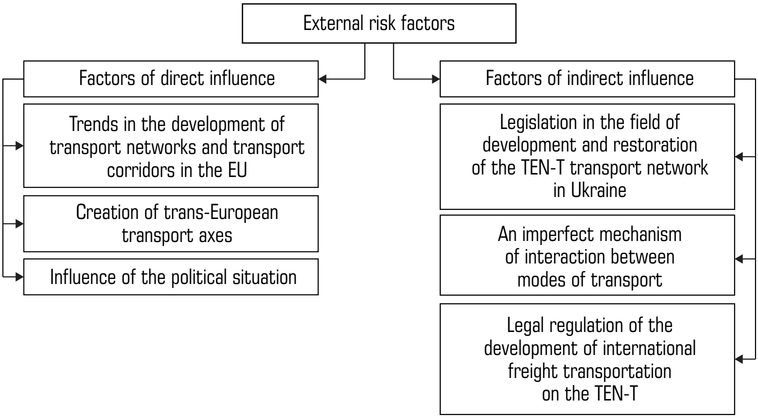

Fig. 2.5 Scheme of influence of external risk factors

As a result of the active development of the infrastructure of transport corridors by neighboring states, competition for the provision of transport services and maintenance of the main transit cargo flows is increasing.

The conducted studies show that today two main risks can be identified, which require a comprehensive solution. The main tools of the risk assessment methodology are presented in **Fig. 2.6**.

The conducted studies show that today two main risks can be identified, which require a comprehensive solution.

First of all, it is the risk of a decrease in the quality of transport services of international carriers due to non-compliance with international standards, the slow implementation of the informatization of the transport process during the delivery of goods and their lack of connection with customs technologies. Secondly, this is a significant decrease in the volume of cargo transportation due to the high level of competition between the routes of neighboring states.

The analysis of export-import and transit cargo flows confirms the loss of a significant share of freight traffic through international road transport corridors on the TEN-T network. On all ITCs passing through the territory of the country, there is a reduction in the volume of transportation and a change in their priority, which is a consequence of the military invasion of the customs territory of Ukraine. Thus, the average reduction in the volume of transportation on the national network of ITC is more than 75 %, a particularly significant reduction in the volume of transportation is observed on the ITC "Baltic-Black Sea" (93.9 %), ITC No. 9 (77.43 %), ITC No. 5 (75.44 %) [19, 20].

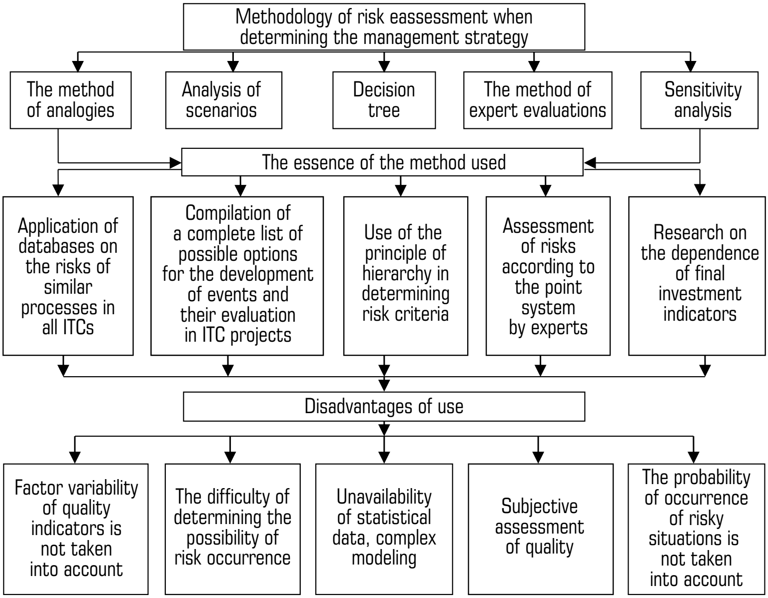

Fig. 2.6 Risk assessment methodology in transport service projects on the TEN-T transport network

Risk management on the ITC network should ensure the adoption of rational management decisions based on a reasonable choice of measures to neutralize risks and corresponding management methods.

The main strategies of risk management in projects of transport service of international transportation of international transport corridors include:

1) risk avoidance (creating a transport service quality system; bringing the level of quality to European requirements by modernizing existing and building new logistics multimodal terminals in the western regions of Ukraine with the functions of integrated transport and logistics centers, implementation of customs services and the use of modern digital solutions for managing logistics flows (TMS, YMS, WMS)). This is the most simple and radical direction in risk management projects in the organization of international cargo transportation [21, 22];

2) risk acceptance (the development of a system of restrictions that helps reduce the degree of risk in international road freight transportation) means that the participant in the transport operation (carrier) considers it appropriate to accept the risk in order to obtain higher profits or other benefits, but on the condition that this does not harm other carriers;

3) reducing the degree of risk directly by carriers involves guaranteeing the safety of cargo transportation by complying with AETR requirements, developing a contractual and legal framework

with partner countries to ensure the regulation of technological issues of international multimodal transportation.

Applying simple methods of risk analysis, it is possible to get the necessary information about the probable values of risk factors in projects and understand which factors are associated with the largest fluctuations of the output parameter (the quality of international transport service projects). At the same time, human and financial resources are saved. In particular, the application of quantitative risk analysis facilitates and makes more effective the use of the experience of experts (information from carriers), who seek to express their judgments in the form of probability distributions of different assessment values, and not in the form of reducing them to a single numerical value of the indicator.

To reduce the degree of risk, conditions should be applied that will ensure an increase in the quality of transport services, namely:

– diversification (laying of traffic routes not only on the ITC, but also on roads of international importance of class M);

– limiting (establishment of a system of restrictions, which contributes to reducing the degree of risk on the ITC);

– localization (prediction of conditions that may lead to risky situations);

– impact on the source of risk (so that the threat becomes minimal).

Thus, the improvement of the quality system in transport corridor development projects should contain components that will be used to avoid risk manifestations:

– quality assurance of transport services on road routes (quality assurance of transport services, Q_a) [23];

– quality management in ITC development projects (quality management, Q_m) [24];

– planning of the quality of transport service of motor carriers (quality planning, Q_p) [25];

– improving the quality of transport services (improving the quality, I_q) [26].

Therefore, the analysis of risks in the management of the quality of transport services of international transportation is an important component not only when attracting investment funds for the development of the TEN-T transport network within Ukraine, but also when determining the strategy for managing infrastructure objects within the limits of road routes.

The adoption of changes to legislation that simplify the procedures for attracting investments for infrastructure projects will make it possible to forecast the volumes of export-import flows, as well as to attract transit cargo flows. And the implementation of joint projects and integration with EU transport and logistics networks through the harmonization of organizational and legal aspects of activity will provide an opportunity to achieve harmonization both in terms of quantitative indicators regarding the increase in transit transportation, and in terms of a system of qualitative indicators. Such indicators include the level of ensuring the speed of transportation, the safety of transportation, compliance with weight standards, the preservation of cargo during transportation, the level of service at the state border, and others.

As a result, ensuring the quality of transport service in the continuity of cargo traffic by road transport across the state border is key to the functioning of the country's economy, ensuring the transportation of export cargo, as well as the import of humanitarian and defense cargo, which is a necessary component for the country's recovery.

2.4 PECULIARITIES OF DEVELOPMENT OF CUSTOMS LOGISTICS OF UKRAINE IN COMPARISON WITH OTHER COUNTRIES

The essence of customs logistics is a combination of logistics processes of participants in foreign economic activity with processes of customs control and clearance of goods by customs authorities of export, import and transit countries.

The main logistics function of customs activity is the logistics organization of the process of customs control of goods, which combines the processes of applying customs regimes related to the physical movement of foreign trade goods across the customs border and delivery conditions. Logistics, in order to accelerate this process of moving goods across the customs border, improves the standard logistics requirements for both customs regimes (i.e. customs) and customs carriers.

Let's note that high-quality customs logistics is closely related to the simplification of conditions and organization of foreign trade, especially with regard to customs operations and procedures and border administration. Improving customs control is becoming increasingly important to avoid unwanted delays and reduce customs risks, because the significant number and complexity of documents during customs control create additional costs of both time and money for businesses. The more complicated, longer and more expensive the procedures, the less competitive a country is on the international market [27].

In order to pass customs control, there is a need to calculate logistics processes for predicting and preventing customs risks, the need for a financial guarantee, studying customs regimes and the features of their application, choosing the most optimal of them [27].

As for the efficiency of customs logistics in international trade systems, it is evaluated using the Logistics Performance Index (hereinafter LPI), which is calculated by the World Bank for 160 countries of the world, includes various indicators that demonstrate the level of development of national sectors of logistics services and the degree of integration of countries to global value chains.

The TOP-10 countries according to the Logistics Efficiency Index are as follows: Germany, Sweden, Belgium, Austria, Japan, the Netherlands, Singapore, Denmark, Great Britain, Finland closes the top ten. The lowest position in the ranking of countries according to the Logistics Efficiency Index is occupied by Afghanistan – the sum of points is equal to 1.95, this country has the lowest score for all components of the Index [27]. In **Fig. 2.7** presents the aggregated international results of the Logistics Efficiency Index of the TOP-10 countries, Ukraine and Afghanistan (occupies the last position).

The index is based on seven main indicators of logistics efficiency: the efficiency of the customs and other border clearance process; the quality of transport and IT infrastructure in the field of logistics; ease and accessibility of organization of international transportation; competencies of the local logistics industry; the ability to track international transportation; internal logistics costs; timeliness of cargo delivery to the delivery point [27].

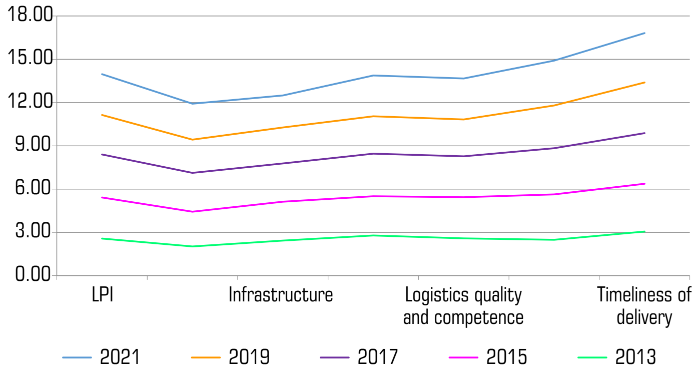

Fig. 2.7 Dynamics of Ukraine's logistics efficiency sub-indices for 2013–2021

Ukraine ranks 66th out of 160 in the ranking of the LPI based on the aggregated results of 2021. The number of points is 2.83, as a percentage of the maximum logistics efficiency index – 57.17 %. As for the LPI components, the work of the customs of Ukraine was rated at 2.49 points, which is 85th place, infrastructure – at 2.22 points (119th place), international transportation – at 2.83 points (68th place), the quality of logistics and competence – 2.84 points (61st place), cargo tracking and consumption – 3.11 points (52nd place), cargo delivery timeliness – 3.42 points (56th place). In general, the results of the efficiency of logistics processes in Ukraine **Fig. 2.7** are satisfactory [27, 28].

We are observing growth in all sub-indices and the general LPI. Undoubtedly, Ukraine has higher than average indicators in the ranking according to LPI, but there is still a need to improve the work of customs, develop infrastructure, increase the quality of logistics and reduce its cost.

In today's world, logistics has become an integral part of business strategy, especially for organizations or industries that focus on the international market. Globalization of the economy has caused fierce competition among enterprises for locations and accommodation. In addition, the conditions of trade suggest the implementation of new and rapid changes. Mergers of enterprises and intensive development of information and communication systems only strengthen these processes. In such conditions, interaction between organizations and improvement of their economic efficiency is built on logistics. This is due to the increase in the role of logistics services in the modern world market. Therefore, recently, the growth of the volume of logistics services, characteristic of developed countries, has already begun to be observed in almost all countries involved in world trade [28].

Logistics has a significant impact on the development of market relations:

– product and service competition is developing;

– costs of moving goods, i.e. procurement, warehousing, unloading and shipping of products, are reduced;

– resources are rationally used;

– branches of production infrastructure function effectively.

In general, the logistics services market in Ukraine is poorly developed, poorly structured, and there is no reliable information about its structure and revenues (**Fig. 2.8**).

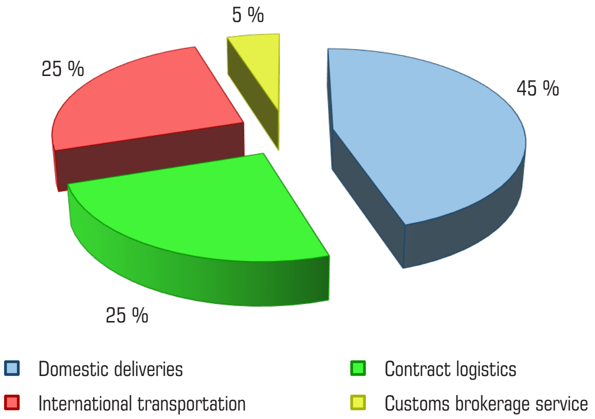

Fig. 2.8 The structure of the logistics market of Ukraine for 2021

Any cargo entering the territory of Ukraine must pass customs control – this is clearly stated in the Customs Code of Ukraine. Calculation of logistics processes from the point of view of customs operations, risk prediction and financial guarantee is the entire task of customs logistics.

Customs logistics includes a number of measures aimed at solving issues related to the organization of international delivery of products and goods. Customs logistics is designed to solve complex tasks designed to make import and export processes the most optimal and less costly [29].

Among the main tasks of customs logistics, let's highlight:

1) selection of delivery conditions;

2) choice of customs regime;

3) choosing a guarantee for the delivery of goods;

4) optimization of the customs clearance procedure;

5) improvement of the customs control procedure;

6) customs clearance;

7) placement and optimization of the functioning of cargo customs complexes;

8) outsourcing technologies in customs affairs;

9) selection of an intermediary in customs matters;

10) information provision of customs activities.

Functions of customs logistics are presented in **Fig. 2.9**.

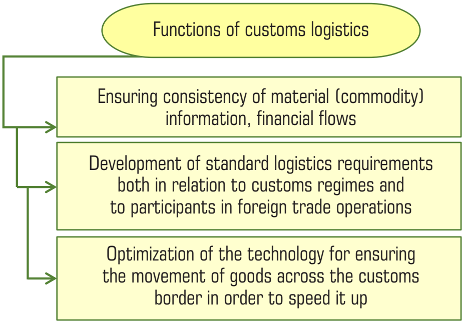

Fig. 2.9 Functions of customs logistics

The basis of customs and logistics flows are foreign trade material flows of a cross-border, transit nature. They include input (import) and output (export) types of material flows. They are accompanied by information flows: outgoing (from customs to the central authority), incoming (on the contrary), accompanying (documents for goods).

Financial flows are outgoing (transfer of duty to the state budget) and incoming (state financing of customs).

After analyzing the given data, let's conclude that the volume of implemented logistics services in the period from 2016 to 2021 is characterized by a growth trend. Comparing the total indicator for 2021 with the indicator for 2016, let's observe a two-fold increase. The index of warehouse services increased fivefold, and the value of auxiliary services in the field of transport increased by 70 % [28, 29].

This trend can be explained by the active growth of demand for logistics services, both in the world and in Ukraine. The expansion of the international network of multimodal transportation is accompanied by a change in service priorities in the direction of reducing the risk of disruptions in the continuity of transportation of goods and passengers [30].

The development of international trade, which contributed to the arrival of global manufacturers on the market together with global operators that serve them, the development of retail networks, terminal and customs clearance of goods, a large circle of participants in the supply chain, unification of rules and norms of foreign economic activity, standardization of parameters of technical means in various countries, the emergence of flexible automated production.

External economic indicators of the provision of auxiliary and additional transport services are presented in **Fig. 2.10** [31, 32].

As it is known, the main principle and method of logistics consists in finding optimal management influences on economic objects under the given conditions of their functioning. The search for optimal managerial influences includes the formalization of the goals of economic activity (construction of objective functions of optimization criteria) or the assignment of preference relations in the interval of possible results [33–35].

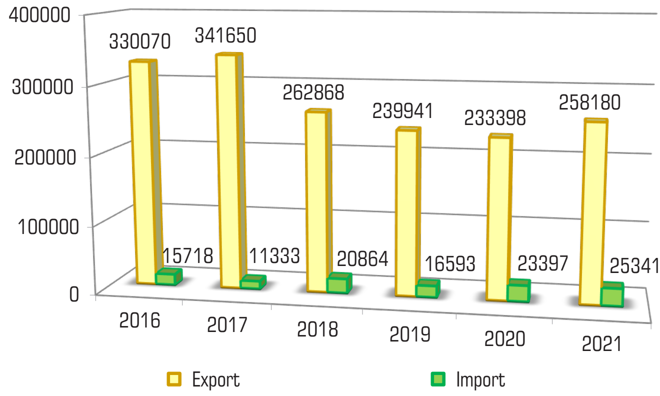

Fig. 2.10 Dynamics of foreign trade in auxiliary and additional transport services (thousands of USD)

Therefore, the customs logistics of the foreign trade entity should be understood as the theory and practice of managing material, as well as accompanying information, financial, service and other flows, which are connected with the need to comply with the requirements of the state customs affairs when conducting foreign economic operations by enterprises to ensure their competitiveness on domestic and foreign markets.

2.5 IMPROVEMENT OF THE LOGISTICS OF PIGGYBACK TRANSPORTATION IN INTERNATIONAL TRAFFIC

The current level of economic development and its globalization are making increasingly high demands on the transport sector. In the first place is the speed, economy of delivery, as well as the preservation of cargo. An important factor is the environmental friendliness of freight transportation. All of these requests are completely met by a new method of cargo delivery for our country – contra-railway transportation. piggyback transportation is a combined road and rail transportation for the delivery of goods. For such transportation, special railway platforms are needed, on which car trailers, semi-trailers, removable bodies or the entire road train together with cargo are installed and secured. It is not easy to develop piggyback transportation. One of the reasons is that they are not provided for in our customs legislation. What is a piggyback? This is a certain vehicle, a symbiosis of a car and a railway carriage, which in principle is a separate type of transport. Piggyback transportation is quite complicated, and practically no one can handle it on our transport market. This business is not developed and cannot develop if there is no economic efficiency and demand for this transportation.

The technology of piggyback transportation originated in the USA and Canada, and when it was transferred to Western Europe, it encountered significant difficulties: many artificial structures, such as bridges, tunnels, and the height of the power supply suspension, did not allow the successful application of this technology. To solve this problem, part of the artificial structures were reconstructed, pockets were deepened in the area of the bottom of the platforms, where the wheels of road trains and truck trailers descend. This technology is called a "running" highway. This is the transportation of a car with a trailer or semi-trailer on a railway platform with a lowered floor. At the same time, if the driver follows along with the cargo in a special passenger car, then it will be accompanied intermodal/combined transport. If the cargo is transported without a driver, it is unaccompanied intermodal/combined transport. Auto plants have established the production of highway tractors equipped with a sleeping place for one of the drivers, with a large fuel reserve, with speeds of 100 km/hour and above. The coupling of such a tractor with a van or with a container chassis was called a road train. The "running" highway technology has a number of significant disadvantages: the transportation of excess weight, i.e. the tractor, semi-trailer and accompanying driver; the need to create comfortable conditions for the accompanying driver during the journey. However, such technology finds its application in a number of countries with highly developed road transport [36, 37], since the increase in the volume of rail-road road transports, their routing led to the conclusion of the possibility of reducing the number of special transshipment cargo ramps at railway terminals, as well as the terminals themselves on the roads. Railway routes with trailers are formed at a limited number of nodal railway stations. Cargo from numerous customers is delivered to these hub terminals by road transport. Here they are combined into a railway route destined for another hub terminal, from which they are also delivered to the recipient by road transport to the destination.

Piggyback transportation is one of the promising areas of interaction between modes of transport, because it uses two types of transport: road and rail, and their further growth is expected. Important factors in favor of piggyback transportation are:

– a significant reduction in the time of customs and border control;
– passing customs control at the border without the direct participation of the driver;
– significant savings in costs for issuing shipping documents;
– high speed and guarantee of cargo delivery in accordance with the train schedule (justin time);
– safety of transportation in any weather conditions;
– preservation of the vehicle and its motor resources;
– maintenance of highways;
– preservation of the environment.

At the moment, the functioning of this type of combined transportation has been suspended in Ukraine. The reason for this is the imperfect legal framework, as well as the low level of education of carriers on this issue, which is quite low. Piggyback transportation for Ukraine could solve a number of problems:

– the problem of a limited number of transportation permits, including transit permits;
– the problem of wear and tear of highways;
– facilitating the work of drivers and reducing the number of accidents;
– more efficient use of fuel;
– reducing the level of environmentally harmful emissions, exhaust gases and noise;
– increasing the transit potential of the country with the lowest costs.

The potential of Ukraine in the field of piggyback transportation is quite large. Two powerful international routes pass through the territory of Ukraine: Kyiv (Ukraine) – Klaipėda (Lithuania) – Kyiv (Ukraine) – piggyback train "Viking" and Kyiv (Ukraine) – Slavkuw (Poland) – Kyiv (Ukraine) – combined transport train "Yaroslav". The question of choosing the type of connection in modern realities is becoming more and more relevant [37].

To date, many systems of cargo delivery by combined modes of transport have been developed. Wide distribution of piggyback transportation in Austria and Switzerland.

The main advantage of systems for the organization of piggyback transportation is the improvement of the efficiency and productivity of logistics processes. The system makes it possible to increase the competitiveness and quality of services during cargo transportation.

The first is the well-known RoLa (Rollende Lanrstrasse – rolling road) system of transit rail transportation through the Alps. This is the transportation of motor vehicles on railway platforms with a lowered floor using the Ro-Ro (roll-on-roll-off) horizontal method of loading and unloading, when the vehicles themselves enter or leave the railway platform. The advantages of such loading are the possibility of parallel loading and unloading of each individual platform in the train and the possibility of opening and closing on both sides of the terminal.

Let's consider the technological aspect of this system. The design involves a standard carriage consisting of two supporting ramps and three standard trolleys. Support ramps are connected in the middle compartment. Each ramp has a rotating platform and a mounting device. The platform is articulated and symmetrical with two loading platforms.

Characteristics of rolling stock: speed of movement – up to 120 km/h; wheels with a diameter of 957 mm; length – 32 m, weight – 42 tons; standard coupling devices; loading rotary platforms [38].

There is also the RoLo technique (lift-on-lift-off) – a lifting technique of loading with the help of cranes. This technique is widely used in Europe for unaccompanied trailers, has a universal platform and a saddle-shaped floor profile with pockets for trailer wheels. It is used for removable bodies and containers. The system is intended for transporting trailers on a railway platform with a lowered floor. The loading and unloading of the trailer is carried out on its own from the end of the vehicle, and the trailer is attached to the platform by the drivers themselves by installing a rolling device under the wheels.

However, such a system significantly reduces the operational characteristics of rolling stock, which must be taken into account when choosing a transportation system.

The use of these systems allowed European carriers to reduce the time required to form a piggyback train to 40 minutes. According to the latest technical standards, the requirements for piggyback transportation are as follows: vehicle waiting time – no more than 20 minutes; time to form a train – no more than 1 hour; track change time is minimal; easy access to the terminals by road and rail; the maximum border crossing time is 20 minutes for a train.

In Europe, the following cargo delivery systems are also widely used, such as Flexiwaggon, which is adapted to the specific needs of Swedish transport. The platform rotates hydraulically. The process of its management is fully automated. The truck driver has only to press a button. No equipment or special terminal is required. Flexiwaggon can move at a speed of up to 160 km/h. It takes 7 minutes to load or unload the entire batch onto the train. Loading and unloading operations can be carried out anywhere. The only requirement is the strength of the foundations, they must withstand the weight of the car. The Flexiwaggon can load 50 tonnes compared to the 42 tonnes offered by similar systems. The volume load is also higher because the Flexiwaggon platform is lower and has improved passability along the rail [39, 40].

CargoBeamer (German – freight train) combines automated, parallel, fast and inexpensive cargo transshipment between road transport and railways. A saddle platform with a floor height of 200 mm and a wheel diameter of 920 or 950 mm is used.

The vehicle is installed on a pallet, which is pulled onto the platform by electric traction. At the same time, the pallet with the trailer is loaded in the opposite direction. A strict condition for this system is the need for accurate positioning of trains at the terminal. Parallel, automated horizontal overloading of fifth-wheel coupling devices is carried out in the following sequence: the vehicle approaches the loading gate; the vehicle enters the platform attachment; removal of the semi-trailer on the platform attachment; receiving a semi-trailer; the tractor leaves the cargo gate; cargo in standby mode for an electronic loader; the electric forklift arrives at the cargo gate; start of horizontal movement; parallel horizontal loading of a semi-trailer; end of horizontal movement; the electric forklift leaves the loading gate.

The main advantages of the system are high productivity and the ability to quickly load the entire train. The difficulty in operating this system is the need for traction mechanisms for the platform and appropriate hydraulic equipment. The system is characterized by a high cost of transportation.

Modalohr is currently used in the mode of unaccompanied transportation. The Modalohr system has an extensive network on the territory of the European Union.

A feature of the system is the need for an appropriately equipped terminal. This technology is a development of the French company Lohr. It offers the possibility of sequential loading. The loading platform rotates around the middle of the train. The possibility of transporting both individual semi-trailers and road trains gives this system a great advantage in comparison with the above-mentioned systems.

The MegaSwing technology is designed for various unaccompanied transports and is currently being tested under various temperature conditions. As indicated in specialized platform used is divided into two parts with the help of hydraulic systems. The system is adapted for the transportation of any semi-trailers and containers. MegaSwing requires less investment, as it does not require the use of additional intermodal terminals and specialized equipment. Transshipment occurs horizontally (Ro/Ro). For the loading and unloading process, it is necessary for one of the employees to monitor the transshipment process and the operation of the hydraulics. There are two types of platform Single (weight – 24 t, length – 19.5 m) and DUO (6 axle) station wagon. Features of the system are ease of operation, lack of necessary precise positioning of the platform along the loading/unloading front of the vehicle, and high productivity [41].

Next, let's present the comparative characteristics of the above systems (**Table 2.3**).

Table 2.3 Comparative characteristics of the main piggyback systems of cargo transportation in Europe [38]

Features	System				
	Cargo Speed	**Flexi waggon**	**Mega swing**	**Cargo Beamer**	**Modalohr**
Maximum speed	120 km/h				
Overload time	5 min	10 min	5 min	5 min	5 min
Type of load	Horizontal				
Parallel loading/unloading	Available				
Congestion at the terminal	yes	no	no	yes	yes
The need for qualified personnel	yes	yes	yes	no	no
Maximum permissible weight	38.5 t	44 t	38.5 t	44 t	38 t
Maximum number of semi-trailers	33	27	33	31	36
Cost of platforms (EUR)	120 000	175 000	–	105 000	355 000
Terminal cost (million EUR)	2.3	–	–	1.2	3

The use of one of the above systems when carrying out cross-rail transportation significantly reduces the time spent on forming a cross-rail train, which significantly affects the time of delivery of the cargo to the recipient. Undoubtedly, the implementation of one of the above systems requires large capital investments, but the benefits that the transport industry of Ukraine can receive from this are undoubtedly greater.

According to the cost criterion, the CargoBeamer and Flexiwaggon systems are the most profitable, but they are poorly developed and technologically designed for the transportation of either individual road trains or individual semi-trailers.

In Ukraine, it is more expedient to consider the issue of implementing the Modalohr system, which is adapted for the transportation of both individual semi-trailers and road trains, and also has an extensive network of active routes across Europe.

Now let's consider the cost indicators of one or another type of transportation.

Value indicators, or more precisely, the cost of transportation is one of the factors that allows to determine the advantages of one or another type of connection. Let's create a graphic model of transportation. This will allow not only to correctly present the initial data, but also to determine the equivalent distance for direct car and piggyback connections, that is, the distance at which the transportation costs for both types of connections are equal.

Cost indicators, or more precisely, transportation costs, are one of the factors that make it possible to determine the advantages of one or another type of connection. The principle of cost minimization is at the basis of determining the efficiency of transportation, when choosing between direct road and piggyback connections [39]:

$$F = \begin{cases} C_a \\ C_k \end{cases} \rightarrow \min, \qquad (2.4)$$

where C_a – the cost of direct road transportation; C_k – costs for piggyback transportation to the same point (taking into account the costs of railway and automobile components).

The basis of the developed models is the equivalent transportation distance according to the cost criterion L_{eq} – this is the distance of direct automobile transportation, when the equality $C_a=C_k$ is fulfilled. Since the basis of the model for determining the area of effective use of backhaul coupling is the principle of cost minimization, that is, backhaul coupling will be effective if:

$$C_k<C_a. \qquad (2.5)$$

This is possible provided that:

$$L_a>L_{eq}, \qquad (2.6)$$

where L_a – the distance of a direct road connection from the consignor to the consignee.

Formula (2.4) can be detailed in the form:

$$\begin{cases} C_a = S_a \cdot L_a; \\ C_k = S_a \cdot L_{ad1} + T_r \cdot L_r + S_a \cdot L_{ad2} \end{cases} \rightarrow \min, \qquad (2.7)$$

where S_a and T_r are, respectively, the cost of 1 km by road transport and the tariff for transporting a car by railway, which includes all associated costs for the organization of the railway part of the rail link; L_{ad1} – the distance of the approach from the consignor to the railway station of departure; L_{ad2} – the distance of the approach from the railway station of departure to the consignee; L_{ad} – the distance between the consignor and the consignee when delivering goods by road transport [40].

To determine the equivalent distance of cargo delivery, the hypothesis was adopted that the consideration of the displacement parameters of all participants in the transport process affects the final result:

$$L_{eq} = \left(\frac{L_r\left(k^2-1\right)}{2k\left(k\cos\alpha-1\right)} \right). \qquad (2.8)$$

CHAPTER 2

In order to establish the distance of equivalent cargo delivery, the hypothesis was adopted that taking into account the location parameters of all participants in the transport process will increase the efficiency of cargo delivery in international traffic. With the help of the developed mathematical model for determining the equivalent distance according to the cost criterion, when the consignor coincides with the railway terminal of departure and the model when the consignor is far from the terminal, the factors affecting the definition of the area of effective use of piggyback connections were established.

2.6 METHODOLOGY FOR CHOOSING THE OPTIMAL LOGISTICS CHAIN OF CARGO DELIVERY IN INTERNATIONAL TRAFFIC

The structure of the technological process of delivery of a batch of cargo is described by the structure of the logistics chain (LC), which reflects the sequence of participation in the delivery process of various subjects of the transport market. At the same time, the task of choosing the optimal structure of LC should be distinguished from the task of choosing the optimal carrier (logistics operator, contractor for the performance of certain types of work, cargo terminal, checkpoint, etc.) or the optimal delivery route. The selection of optimal options for logistics chains (LC) for cargo delivery is carried out on the basis of alternative options, which largely determines the efficiency of cargo transportation.

In the work of Shyriaeva, S. and Svirin, D. [41] studied LC of supplies during international road transportation of goods, in particular: principle diagram and general structure of LC, main types of LC, options of supply chains. Unfortunately, the content of these studies is of a generalized nature, which is not specified and does not contain the specifics of international cargo transportation.

Authors Lysa, S. and Zimina, A. [42] in their article highlight the problems and prospects for the development of the cold logistics market of Ukraine, namely, they analyze approaches to the interpretation of the concepts of cold supply chains, cold logistics, logistics of perishable goods, which can be used as synonyms. The issue of managing the cold chain of supply was also considered, key logistical solutions for effective management were determined, such as: ensuring and controlling the temperature regime during transportation, storing them in specialized warehouse complexes, assembly, receiving; informational support of cold LC. The current state of logistics service of cold supply chains in Ukraine is assessed. The article is purely descriptive and statistical in nature.

In the article by Naboka, R. and Shuklina, V. [43], which is devoted to the influence of the integration of LC of supplies on increasing the company's potential, it was established that integrated LC of supplies allow the most effective implementation of the company's goals and help the enterprise to get out of the economic crisis. It has been established that when using integrated supply logistics, all functional units of the enterprise are combined into a single process, and the purpose of such unification is to prevent irrational losses of resources and achieve the maximum economic result. The authors emphasize that the integration of LC supplies leads to an increase in the potential of the entire enterprise, and all interrelated logistics functions must be performed in a coordinated manner – in the form of a single function. It was concluded that the integration of LC supplies allows to achieve a synergistic effect of the enterprise's activities. The content of the article is declarative in nature and does not contain specific measures to implement the goal of integrated supply logistics.

Scientific and methodological work of authors of Tokmakova, I., Ovchynnikova, V., Korin, M. [44] devoted to the management of supply chain management and aimed at harmonizing the interests of the participants of the process of product movement, optimization in accordance with the requirements of society as a whole and end consumers in particular. According to the authors, the management of supply chains is aimed at achieving two main effects: increasing the amount of income from sales of products/services by increasing the level of service, accuracy of supply and reducing demand fluctuations; reduction of costs by reducing the level of inventories, invoices and transactional costs in purchases, storage and marketing, as well as improving the use of production and logistics capacity. The content of work is educational in nature, provides theoretical knowledge of the management of supply chain management, but does not give practical experience.

The authors Tiurina, N., Goy, I., Babiy, I. [45] give a generalized definition of LC as a linear-orderly set of individuals and legal entities (suppliers, intermediaries, carriers, etc.), which are directly involved in bringing a particular batch of products to the consumer. Generalized examples of LC and logistics network are also given. The content of the submitted material is generalized, does not contain applied direction.

Therefore, based on the analysis of recent studies and publications concerning the issues of logistical chains of delivery of goods, it is advisable to explore in more detail the logistics chains of international car transportation of goods and focus on determining new ways of improving the efficiency of such transportation.

Let's consider the main options of LC when delivery of goods by road. For a single option of LC delivery of cargo in the logistics system, the initial link, which generates a material flow, is a cargo owner of one of the subsystems (consignor), and the final link, absorbing, is a cargo owner of the second subsystem (cargo). Accordingly, the initial and final link of the LC is the cargo. Physical movement of the material flow is carried out by the carrier. The function of organizing the process of moving material flows is implemented by the freight forwarder (4PL provider), using the resources of freight terminals (3PL providers). As the organizer of the process of realization of the need for freight owners in the movement of cargo, the freight forwarder is a link of LC, on which information flows are closed. Since the cargo owner, in order to fulfill its need for moving the cargo, appeals to the freight forwarder, the financial flow in LC passes first and foremost from the freight owner to the freight forwarder, and then – to other participants of the chain. The simplest option of LC is presented in **Fig. 2.11**.

Formally, the simplest *LC* is a collection of elements of the following species:

$$LC^{1F} = \left\{FO;C^{A};FF^{A};CP;FC\right\}, \quad (2.9)$$

where FO – consignor; C^{A} – carrier to the consignor country; FF^{A} – freight forwarder in the consignor country; CP – checkpoint at customs; FC – consignee.

CHAPTER 2

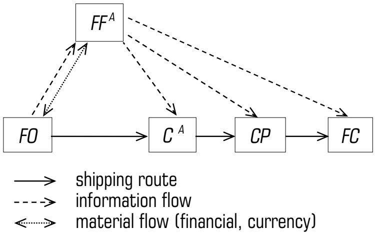

Fig. 2.11 The easiest LC option

For the presented option, the coordination of the cargo delivery process is carried out by one forwarder, one carrier is involved in the transportation, cargo terminals do not participate in the cargo delivery process. The consignor declares the need to move the delivery. The forwarder chooses a carrier that can deliver the given lot to the consignee, after contacting the consignor, bilateral agreements on the organization of delivery are concluded between the forwarder and the consignor, as well as between the forwarder and the carrier. The consignor pays for the forwarder's services, and the forwarder pays for the carrier's services from the amount received from the customer. The carrier delivers the delivery from the consignor to the consignee (if the delivery is carried out in domestic traffic) and to the border, and then from the customs checkpoint to the consignee (if the delivery is carried out in international traffic) [3]. This LC option is typical for the delivery of goods by road transport if the volume of the delivery being sent corresponds to the carrying capacity of the vehicle.

A more complex LC option with the participation of two forwarders and, accordingly, two carriers is shown in **Fig. 2.12**.

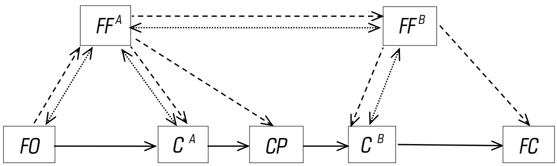

Fig. 2.12 LC option with two forwarders

This LC option (LC^{2F} type chain) is a combination of the following elements:

$$LC^{2F} = \{FO; FF^A; C^A; CP; C^B; FF^B; FC\}, \tag{2.10}$$

where C^B – carrier in the consignee's country; FF^B – freight forwarder in the country of the consignee.

The forwarder of one of the subsystems, after receiving the application from the consignor, determines the carrier for delivery of the delivery to the border, and also sends the application to the forwarder-partner. The forwarder-partner organizes the delivery of the delivery from the border to the consignee, using a carrier in the country of destination for this purpose. In this case, four bilateral agreements are signed: between the forwarder and the consignor, between the forwarder and the carrier from the shipping subsystem, between two forwarders, and between the foreign forwarder and the carrier. At the same time, the consignor pays for the services of the first forwarder, who, in turn, pays for the services of the carrier in the country of destination, as well as the services of a foreign forwarder, from the remuneration received. The forwarder-partner pays for the services of the carrier in its country from the received remuneration.

The cargo terminal takes part in the process of moving the material flow in the LC option presented in **Fig. 2.13**.

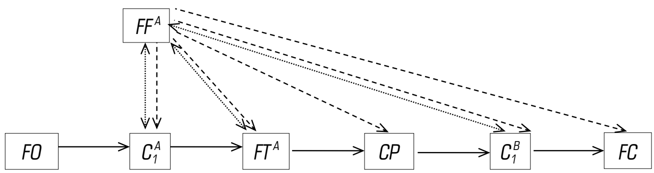

Fig. 2.13 LC option with one terminal

This LC option (LC^{1T} type chain) is a set of 7 main elements:

$$LC^{1T} = \left\{FO;FF^A;C_1^A;FT^A;CP;C_2^B;FC\right\}, \tag{2.11}$$

where C_1^A – carrier in the country of the consignor, which ensures the delivery of the cargo to the terminal; C_1^A – carrier in the country of the consignee, which ensures the delivery of cargo in international traffic; FT^A – cargo terminal in the country of the consignor.

After receiving the application from the cargo owner, the freight forwarder assesses the feasibility of delivering the cargo through the cargo terminal. If such a chain option is economically feasible, the freight forwarder searches for carriers to deliver the cargo to the cargo terminal and to take out the consolidated batch for delivery directly to the consignee. After determining the participants in the delivery process of the delivery, four bilateral agreements are signed: between the forwarder and the consignor, between the forwarder and the carrier in the country of delivery, between the forwarder and the cargo terminal, between the forwarder and the international carrier. The freight forwarder pays for the services of the carriers and the cargo terminal from the funds received in the freight forwarder's account from the cargo owner. This LC option is used when transporting a delivery of cargo to the terminal by road transport, consolidating shipments by direction and subsequent delivery by main transport (railway). A possible option is when the cargo terminal organizes the removal of a consolidated delivery, acting as a 4PL provider.

A more common option of delivery of a delivery of cargo with the participation of trunk transport is the LC option with two terminals, which is shown in **Fig. 2.14**.

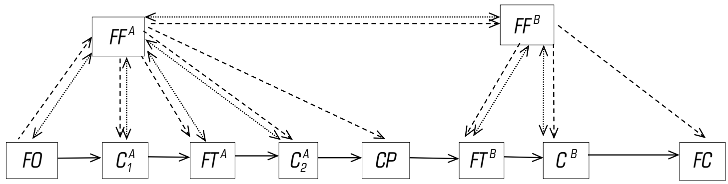

Fig. 2.14 LC option with two terminals

LC option with two LC^{2T} terminals is a set of the following elements:

$$LC^{2T} = \left\{FO; FF^A; C_1^A; FT^A; C_2^A; CP; FF^B; FT^B; C^B; FC\right\}, \quad (2.12)$$

where FT^B – cargo terminal in the country of the consignee.

In this case, the cargo owner declares the need to move the delivery. The freight forwarder, upon receiving the application, determines that the most effective option with two cargo terminals will be the most effective of the many options for LC. After that, the freight forwarder determines the carrier in the country of dispatch to deliver the delivery from the consignor to the terminal, concludes an agreement with the terminal and the trunk carrier, and also sends an application for the need to deliver the delivery with a foreign forwarding partner. The freight forwarder-partner organizes the delivery of the delivery from the terminal in its country to the consignee. For this, it chooses a carrier in the country of destination and concludes an agreement with the terminal. For this option of the chain, the following agreements are signed: in the consignor and the carrier in the country of dispatch, between the forwarder and the cargo terminal in the country of the sender, between the forwarder and the international carrier; in the country of the consignee – between the forwarder and the cargo terminal in the consignee's country, between the forwarder and the carrier in the country of destination; an agreement is also concluded between the two forwarders. The freight forwarder in the country of the consignor pays for the services of the carriers in the country of departure and destination, the terminal in the country of departure, and the services of the freight forwarder-partner from the remuneration received from the cargo owner. The freight forwarder in the country of the consignee pays the terminal and the carrier in its country from the funds received from the first freight forwarder. There is also an option where the carrier's services are paid for by the terminal in the country of the consignor, and the carrier's services for the delivery of the delivery to the consignee are paid for by the cargo terminal in the consignee's country.

Considered in **Fig. 2.12–2.15** situations can be used as the main LC options of when developing a set of alternatives. LC options are considered taking into account the availability of freight terminals and forwarder-partners in the direction of delivery.

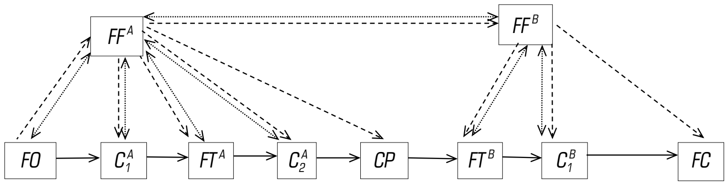

Fig. 2.15 LC option with two terminals and the *n*-th number of transit countries

The structure of any LC of cargo delivery by road transport can be attributed to one of the following options: 1FF – the simplest delivery option with one forwarder, 2FF – delivery with the participation of two forwarders without the involvement of cargo terminals, 1FT – delivery of a batch of cargo through a cargo terminal, 2FT – delivery with the participation of two cargo terminals, $N_{c.t.}$ delivery with the *n*-th number of transit countries. The set of data options of delivery of cargo delivery.

CONCLUSIONS

In recent years, logistics has become an integral part of business strategy all over the world. Logistics is used differently at different enterprises, and it depends on innovation opportunities and priorities. Along with the processes of transportation, cargo handling and warehousing, the value chain includes other types of activities that cannot be underestimated, especially if the enterprise is oriented towards the international market. Let's consider the main trends in the development of international transport logistics.

COVID-19 continues to have a devastating impact on the commercial trucking industry. The war with russia had a great impact on the logistics of international transportation. In all countries of the world, there is an extremely high level of risk of default and insolvency in the field of road transport.

The level of risk in all regions of the world has reached the highest indicators and is nine to ten points on a scale from one to ten. This indicates an impending wave of bankruptcies in the road transport industry, which will affect the global economy and the possibility of its recovery after the pandemic and martial law.

Studies have shown that the logistics of transportation and customs service in international communication acquires special importance in the modern conditions of martial law in Ukraine. International cargo transportation is important for supporting the economy of Ukraine. Important aspects of international transport logistics are studied: the development of international transport logistics in Ukraine in modern conditions, logistical risks in international transport service projects, the logistics of using information technologies to increase the efficiency of the organization of international freight transport, the peculiarities of the development of customs logistics of Ukraine in comparison with other countries, peculiarities of the logistics of cross-trailer transportation in international traffic.

The following norms must be implemented into the legal norms of national legislation:

– to harmonize provisions and norms of regulatory documents and standards in accordance with international agreements and UN conventions that ensure seamless international transportation and transit;

– with the joint efforts of representatives of all types of transport, take operational measures to digitize the industry and form effective interaction in intermodal transportation, striving for maximum complementarity of different types of transport;

– to ensure a smooth transition to paperless document circulation in road transport, including through the implementation of the digital TIR procedure and the electronic waybill e-CMR, which will meet the needs of all key participants in the logistics chain;

– to increase the guarantee limit for the TIR carnet to 100,000 EUR, introduce new ones and promote the further promotion of existing TIR tools – iCarnet (guarantee for customs transit between the customs authorities of the same country), TIR+ (additional guarantee to the TIR carnet), eTIR, TIR-EPD (the IRU program on advance electronic information during transportation under the TIR system), participate in the implementation of intermodal projects using the TIR procedure, expand the use of subcontractors during transportation under the TIR system;

– take measures to conclude with China, as well as other countries of Asia and the Middle East, new bilateral and multilateral agreements on international road traffic, which would allow national road transport companies to gain access to the cargo base of China and Asian countries and expand the geography of transportation in new directions;

– to join the participation in the new eTIR pilot projects implemented by the IRU together with the UNECE, as well as to expand the use of the TIR digital procedure in transportation between Turkey and Iran, Georgia and Turkey, Turkey and Ukraine, along the so-called "Batumi Corridor", which covers Ukraine, Georgia, Azerbaijan and the Republic of Kazakhstan;

– to join the Additional Protocol to the Convention on the Contract for the International Carriage of Goods by Road (CMR) concerning the electronic waybill (e-CMR), and to introduce the specified electronic waybill into the practice of international road transport;

– to include in the national legislation norms that provide for mandatory initial and periodic training of drivers, minimum requirements for safety and quality standards of transport services;

– to contribute to the improvement of the working conditions of drivers, the involvement of new workers in the profession, including young people and women, and the solution of the problem of the lack of professional drivers;

– strive to simplify visa formalities, issue multiple annual visas to professional drivers, implement electronic visas as soon as possible;

– to speed up the work on agreeing changes to the European Agreement on the work of crews of vehicles producing international road transport (AETR), on the use of so-called smart tachographs, in order to support trade and tourism, prevent disruptions in the functioning of international supply chains;

– to improve the system of bilateral intergovernmental agreements on international road transport by canceling transit and bilateral permits for cargo transportation;

– to contribute to the creation of conditions for the realization of the potential of the transport market and foreign trade of their countries by increasing the awareness of the ministries of transport and departments responsible for the regulation of motor transport activities, about examples of best practice in simplifying international road transport and transitioning to a permit-free principle of their execution;

– to contribute to the further development of high-quality and safe infrastructure and the creation of minimum social and living conditions for drivers while waiting for the crossing of borders or on the way through international transport and transit corridors, including TRACECA, GUAM, SCO, MTK "North-South", the Lazurite Corridor and the ring road motorways around the Black Sea, providing connections of the Trans-European Transport Network (TEN-T) with the Asian Motorway Network (AN);

– conduct regular monitoring of the situation at border crossing points and, on the basis of best international experience, promote legal trade and cross-border transportation for the purpose of economic development, strengthening of regional stability and cooperation.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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CHAPTER 3

COORDINATION OF MATERIAL AND INFORMATION FLOWS IN INTERCITY LOGISTICS SYSTEMS

ABSTRACT

The problem of the effectiveness of the use of road transport in logistics systems is considered. Carriers attract additional motor vehicles according to increasing in freight turnover, namely in long-distance routes. The trend of growth in the volume of transportation and the distance of cargo transportation has been maintained in recent years, despite the crisis periods in the economies of the European Union countries. However, the increase in the number of vehicles of fleets is accompanied by an increase in their idle time and delays in the delivery of goods. This phenomenon is explained by the lack of necessary coordination of material flows on the transport network. We considered two types of material flows, namely cargo flows and automobile flows. Both types of flows are discrete in nature. In order to represent the interaction of material flows in the logistics system, the term elementary logistics operation is used, which is the smallest constant element of the logistics chain. Despite the wide variety of processes that occur in logistics systems, the number of typical elementary logistics operations is limited and quite small. For the numerical characterization of material flows, such parameters as a tact, a front, the size of a group of material elements, and the average intensity of the flow are used. Based on the known dependencies between these parameters and taking into account the connections of elementary logistics operations, a structural model of logistics chains is built. It is taken into account that information messages in the logistics system arise when material flows change. The impact of changes in the intensity of cargo flows in logistics chains has been studied and the majority of sources of information messages in space and time have been determined. It has been proven that the use of the objectively necessary amount of information with the necessary advance time makes it possible to reduce dynamic and static delays of cargo flows to a minimum. Due to the fact that changes in the intensity of material flows occur stochastically in logistics chains, the feasibility of assessing the resistance of a given logistics system to external disturbances was developed. The influence of information provision of truck crews performing transport tasks on highway connections is studied. An information support scheme has been developed on the terms of cargo delivery with the need for the truck to arrive at the unloading point on time.

KEYWORDS

Cargo delivery, material flows, intercity transportation, continuity principle, discrete flows, sources of messages, stabilization, logistics system, flows delay logistic chain.

3.1 INTERCITY AND INTERNATIONAL TRUCK DELIVERING OF GOODS. PROBLEMS AND SOLUTIONS

The freight turnover of road transport and the delivery distance of 1 ton of cargo in the logistics systems (LS) of Europe has a steady upward trend, despite the past crisis periods of 2014 and the coronavirus pandemic of 2019–2022. This trend has been observed in recent years. Thus, the average volume of cargo transportation by road transport in the European Union in 2008–2016 was 14.86 million tons. This volume was slightly higher in 2008–2012. The volume of cargo transportation began to grow again, starting from 2014. However, this value did not reach the average level established for the European Union for the period 2008–2016 until 2016. The results of the conducted research indicate that in the period 2014–2016, the mass of goods transported by motor vehicles grew [1]. The same trends were observed in Ukraine. The cargo turnover of road transport in Ukraine amounted to 311.0 billion t-km in January-November 2020 or 102.4 % of the volume of the same period in 2018. The data on the distance of transportation of 1 ton of cargo indicate that in the structure of road trunk transportation occupies a prominent place in Europe. However, the given data do not contain a forecast of the consequences of such a trend, nor have the reasons for the corresponding growth been identified. This was all because the obvious purpose of the research was only to provide conditions for the future planning of the transport business. Therefore, one of the distinctive features of the modern economy is the growth of the share of road transport in intercity and international trade [2, 3].

It was shown in the work [4] that the satisfaction of the growing demand for long-distance freight transportation occurred due to an increase in the number of small and medium-sized transport companies. The growth is even faster due to the renewal and increase in the number of trunk road trains. However, not all researchers note that an increase in the total number of rolling stock units does not lead to a proportional increase in their carrying capacity [5]. Such a fact was not recorded by them due to outdated approaches to evaluating the performance of trucks on long-distance routes. In addition, the increase in the number of small transport companies in Ukraine is a consequence of the artificial division of enterprises in order to minimize taxes [6]. The number of new registered motor vehicle enterprises in Ukraine is decreasing [7]. Both internal and external competition in the market of transport services is growing with the indicated trends. Also, the fleet of motor vehicles, although being updated, still remains with outdated vehicles, which reduce its competitiveness and reliability of use. However, the main cause for the low productivity of trucks and road trains on intercity routes is the lack of clear communication of their crews and coordination of the information available to them. Thus, starting from 2014 to 2021, the mileage of trucks in Ukraine with cargo increased from 4042.5 to 6031.3 million km and to 6332 million km in 2020. The mileage without cargo changed, respectively grew up from 1767.8 to 3460.3 million km by 2017 and to 3021.4 million km in 2020. That is, the mileage utilization ratio decreased from 0.56 to 0.42, and then increased to 0.67 [8].

The 2014–2017 period is characterized by the main signs of a negative management of transportation processes, such as low mileage and output ratios of trucks due to a rapid increase in the number of carriers. At the same time, connecting links, i.e., logistics companies that have the most information about freight transportation, began to develop only in 2015. Companies that provide 3PL logistics services and did not have 4PL or 5PL functions in 2019 have only established themselves in Ukraine, at a time when such companies are widespread in the world.

The peculiarities of the organization of intercity road freight transportation in modern conditions are sufficiently fully researched. However, there are quite a few works that note that time has also become a very important resource in modern transport processes of intercity large-scale cargo delivery. This is due to the growth of freight traffic, significant competition of motor transport companies, restrictions on the modes of operation of road trains and the work of their crews. So far, it is used irrationally (**Fig. 3.1**). The conducted studies show that the forced downtime of motor vehicles on long-distance and international routes largely depends on the properties of the routes [4, 9, 10]. In general, these downtimes reach 75 % of the duration of the transport cycle. However, on long international routes there is an increase in the share of inter-shift rest for drivers. However, there were no actual reasons for the increase in downtime in the specified publications. The main reason for this shortcoming is the lack of understanding of the transport process as a discrete sequence of relevant operations that differ in properties, so they may be uncoordinated in the process.

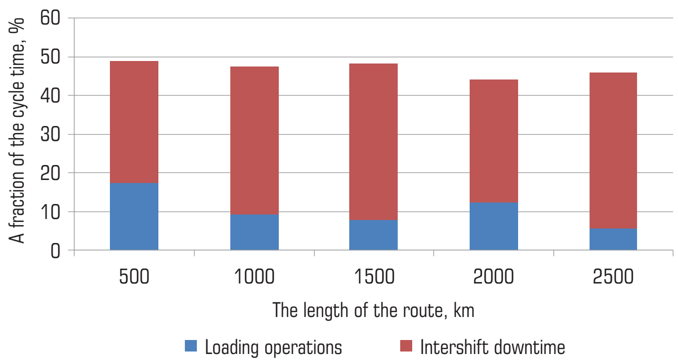

Fig. 3.1 Dependence of the structure of individual time losses for long-distance transportation of goods on the length of the route (author's research) [11]

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The approximate cycle time structure is as shown in **Fig. 3.2** on most long-distance routes (500–700 km).

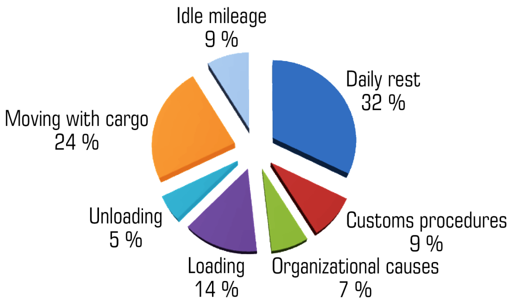

Fig. 3.2 Cycle time structure of long-distance and international freight transportation by road (author's research) [11]

The organization of intercity road transportation also has certain features that increase the problem of truck fleet productivity. Firstly, it is a considerable distance from the points of departure to the reception of goods, in which the duration of the entire process depends on the moment of departure and arrival of the road train at the place of delivery of the goods. Secondly, it is a useless mileage of motor vehicles (MV), which significantly increases the cost of transportation, so carriers cannot allow it. And thirdly, it is a wide geographical distribution of points of formation and absorption of cargo flows, due to which the development and observance of the schedule has significant limitations.

The problem of the productivity of the rolling stock has significantly worsened in connection with the significant competition of automobile carriers. Refusals occur in case of non-compliance with the terms of service provision, or non-compliance with the guaranteed parameters of the process. Across the country, they lead to inefficient use of rolling stock and delays of cargo delivery. The estimated average output ratio of the fleet of mainline MV in Ukraine is 0.45...0.66, and the average speed of cargo delivery in long-distance traffic, depending on the type of cargo, is 26...34 km/h. Therefore, on the one hand, refusals can be caused by a carrier that does not comply with delivery terms and quality of transportation. The carrier may refuse to fulfill the application due to the lack of practical benefit, on the other hand. Refusals are perceived by their customers as a reason for canceling further cooperation. In the conditions of fierce competition of carriers. As a result, the receipt of subsequent orders for transportation is reduced [11].

The work of long-distance and international carriers has recently become more difficult under the influence of a number of factors. The financial load on them has increased significantly during 2015–2021 due to a number of reasons: the prices of fuel and lubricants have risen sharply, tax rates on vehicle owners have increased, some foreign countries have introduced additional road fees and fuel import restrictions, there are additional costs and restrictions, related to the need to issue permits and other obstacles [12]. However, the statistical reports do not contain the true reasons for such financial aggravation. This leads to the need to conduct additional research to identify such causes.

Logistics and information technologies are the key to increasing competitiveness and sustainable growth of transport and industry as a whole. Today, the efforts of many enterprises are directed to the creation of their own logistics divisions or integration into regional logistics centers [13]. It starts from economic necessity. Brand logistics centers began to develop in Europe from the 1980s, which was associated with a wave of bankruptcies of wholesale trade enterprises. Mostly medium and small companies that had an outdated organizational structure and a large number of employees went bankrupt. Large firms that had sufficient financial resources to reorganize and create logistics centers, which increased the efficiency of their work, survived. Small firms that had a modern flexible production structure also survived. At the same time, new small and medium-sized companies with logistics centers and a simple and economical organizational structure were created. Ukrainian enterprises are trying to apply such positive experience, often without restrictions. As a rule, large firms that use modern management methods based on the latest information technologies (IT) achieve the greatest success. Positive results of small enterprises obviously depend on the content of integration processes. This means that there is a need to describe these processes using parametric models. However, since the approach of decomposition of a complex system is used, the essence of the effect of the centralization of transport and warehouse operations cannot yet be formalized [14].

Logistics operators of the 4^{th} generation (providing 4PL services) have successfully coped with the functions of information provision and management of transport processes until now. The best 4 of them come from the EU and outside the global environment of the Top 10. Seven of them are in the EU [15]. However, there are forecasts that in the next 10–15 years, 90 % of the growth of the world economy will take place outside the EU [12–16]. EU countries therefore have an interest in ensuring that their companies remain competitive and can access new markets and benefit from these sources of growth. This requires the use of a wide range of information technologies and a new approach to the formation of logistics systems (LS).

A characteristic feature of international road transportation of goods is the high mileage of MV on routes [17]. To increase the efficiency of this type of transportation, it is necessary to pay special attention to the process of searching for and selecting return loaded rides. The task of cargo transportation in the accompanying/return directions is partially solved, which is connected with the development of transport and information portals on the Internet. However, the problem of choosing a rational transportation option from a set of alternatives remains relevant [16]. The decision to accept this or that cargo for transportation is currently made by managers of carriers based on intuitive decisions of personal practical experience. As a rule, such strategies for making a decision about choosing a rational return trip come down to the fact that the vehicle transports the cargo whose waiting time is minimal. The work [15] proposes new decision-making strategies based on the processing of statistical information on the choice of rational return transportation.

However, the authors of the study chose statistical modeling as a methodology, which made it possible to adopt only one of the alternative strategies for building a transport cycle for the entire MV fleet in general. This is a non-detailed technique and it does not allow to develop a flexible strategy in a case where there is an opportunity to use available information. The authors consider the organization of random one-off orders. One of the reasons for the wide popularity of the use by cargo owners of such a form of concluding contracts as "one-time order" is the powerful development of information technologies, which caused the emergence and successful functioning of specialized logistics sites.

The authors of the work [15] also apply the theory of mass service systems (MSS) to plan a set of such orders, and use simulation modeling for verification. However, it was not taken into account that the freight market may have a situational advantage of supply over demand, or vice versa.

The roadmap for the development of highway road transport indicates that the use of IT can solve the current problems of highway freight transportation [17]. However, this requires a more thorough approach to the analysis of operational information, decision-making and control over their implementation. In this regard, Ukraine should focus on advanced EU countries, its producers and transport and logistics firms. Although they represent considerable competition, there are no objective obstacles for them to integrate Ukrainian carriers into the European market [16]. The benefits that Ukraine can gain from transport integration will be both direct and indirect. Direct benefits are less obvious, but available: increased access to markets, increased volume of transportation and export of transport services, inflow of capital, modernization of infrastructure, direct supply of resources from the EU, budgetary support. Intermediate benefits are more accessible: improved distribution of productive factors, redistribution of cargo flows, improvement of the efficiency of economic processes of transport and service enterprises, improvement of transport service provision standards and the level of transport safety, reduction of barriers in relations between states of EU.

Large European heavy trucks carriers face the problem of underloading their fleets due to the uneven flow of orders, low capacity of cargo terminals, and due to non-systematic planning of transport processes in most cases. A similar situation is typical for Ukraine. In addition to the indicated shortcomings, it is also possible to note the low actual level of industrialization and standardization in the segment of transportation. Product supply processes are demand-driven with very short predictable schedules. A rather low level of planning certainty is also characteristic. The lack of information about the chronological and geographical appearance of subsequent orders makes it a problem to effectively use the MV fleet, and ensure the compliance of drivers' work and rest modes. Management of transport companies operating costs increase every year since the carrying capacity of MV fleets significantly exceeds the volume of orders for intercity road freight transportation, despite their efforts [12]. Ukrainian carriers, for example, are trying to reduce the useless mileage of trucks. Carriers use various information systems for forecasting demand, planning the schedule of individual crews [18–20]. However, the information service will not work if it does not have a functional connection with cargo flows. Examples of this are software and information tools used by carriers. The most popular of them can perform many functions, including: search and selection of customers, free vehicles, drawing up routes, processing documents, calculating the cost of trips and so on. These systems make it possible to reduce downtime and wasted mileage of individual trucks. However, most of the management decisions of carriers are unsystematic. In return, transportation companies receive underutilization, downtime, and even disruptions in order fulfillment. At the same time, fines for cargo owners are inevitable. After all, companies do not take into account the basic directives of medium and large vehicles, in which vehicles can be used as efficiently as possible [20]. Therefore, the tasks of their effective operation must be solved in new conditions. First, the individual vehicles of the fleet must be coordinated. Secondly, orders for cargo transportation should be systematic, preferably periodical. Third, information about the origin and properties of orders should be used as efficiently as possible.

Carriers, which use automated information systems, are able to forecast orders in advance and allocate available MV to them. Thus, they manage to partially avoid unproductive transportation costs. However, the dynamics of order fulfillment during the planned period is significant. They are interdependent often. This imposes additional restrictions on the timetable of road trains that serve customers. The essence of the problem of organizing transportation by modern MV fleets is that two conflicting requirements are put forward to them. On the one hand, the work of the aggregate of MV should correspond to the received information about potential cargo flows and ensure the fullest possible satisfaction of the known demand. Mileage without cargo is excluded. On the other hand, the complex structure of a single transportation process for a fleet of interacting trucks has a random and cyclical character [19]. This leads to forced stoppages of road trains due to the inconsistency of their work schedule. There is obviously such a schedule that is optimal according to the specified criteria and restrictions in this regard. However, there are no prerequisites and regularities for the functioning of such schedules in the publications. The reason for this is the lack of a suitable discrete-event approach to modeling cyclic transport systems. According to scientists' conclusions, problems of this kind are solved in the context of the implementation of IT, that is, a self-organizing system and automated logistics, which is provided by intermodal transportation and efficient use of infrastructure in all modes. Road maps of the European Road Transport Research Advisory Council (ERTRAC) emphasize that long-distance and regional freight transport must become even more sustainable, while maintaining transparency and accessibility for users and system participants [21]. However, the real patterns of the development of intercity road freight transportation have not been analyzed.

As trucks carry more than 71 % of all goods transported by land, the HGV sector is the backbone of efficient freight transport in Europe. At the same time, this sector contributes to the further integration of different parts of Europe. Today, annual scientific reports of researchers note the following trends:

– approximately 29 million road trains operate on the roads of Europe and are used for long-distance transportation;

– harmful emissions from heavy vehicles are increasing and account for almost a quarter of all ground transport emissions; by 2030, CO_2 emissions are expected to increase by up to 10 %;

– due to the increase in the number of MV on highways, traffic jams and delays at transport points are increasing [22]. In addition, the known studies do not indicate that there is a growing contradiction, the meaning of which is that when the transport capacity of the carrier's fleet of vehicles increases, the duration of downtime of the rolling stock often also increases.

So far, no significant attention has been paid to the loss of time of MV while driving on intercity roads. However, traffic congestion in the EU often occurs both in and around urban areas and is worth almost €100 billion in additional costs each year, i.e. roughly 1 % of EU GDP. There are limits to how much new road infrastructure can be built because there is a strong demand for longer road life. According to the founders of the program [23] the problem of delays and traffic jams will be further aggravated by improving the use of the existing capacity of the trunk transport network. However, the authors of the program did not specify the obvious reasons for this phenomenon. New ways of organizing freight transportation and logistics in order to overcome growing electronic commerce and new technologies can also contribute to the solution of these problems. Examples can be the automation of truck traffic and processes, as well as new trends in the organization of public transportation that affect the environment. "Seamless freight transport" is important to increase the efficiency of operation and avoid overloading of trunk transport networks [24]. Freight transportation should gradually develop as integrated packages of services for the delivery of goods and raw materials, increasing the load factor, avoiding idle runs and gradually turning into a single information space. Realization of the possibilities of using digital information in road transport is a key factor in the stable delivery of goods [25]. But this should be preceded by deeper studies of information and cargo flows.

Another key point of long-distance freight transportation is the creation of multimodal solutions that contribute to the standardization and automation of loading and unloading processes to minimize the time of overloading and complexity between different modes of transport. For example, communication between "smart" vehicles and infrastructure requires harmonized infrastructure development, as well as appropriate investments by national, regional and local authorities, and the private sector. Timely prediction and early initiation of these measures is extremely important. According to the forecasts of ERTRAC SRA 2050 and ALICE Integrated Transport System, the overall goal of road freight transport is to develop affordable and efficient freight delivery solutions for European citizens. This includes intelligent logistics solutions, smart modal infrastructures and robotic cargo delivery. According to this vision, the supply chain in the future should be continuous, coordinated and environmentally safe [26]. But the theoretical basis for streamlining and optimizing supply chains from well-known sources of research is still unknown.

An important component of efficiency is the avoidance of idle runs or unclaimed vehicles. According to the AEROFLEX-27 project report, the optimization of vehicle loading refers to the reduction of empty mileage, as at EU-28 level, a quarter of all trips were made by empty vehicles (25.4 % in 2016). The share of empty runs increased to 30.3 % in domestic transport, but in international transport in 2018, it was only 14.3 % [27]. As for the priorities for the introduction of automated management of highway transport by 2030, a higher level of automation is expected in limited areas and points where the transport environment is predictable, the average speed of traffic is relatively low, and traffic can be fully controlled [23]. The complexity of IT, their application, connection and implementation of automation for the management of MV and infrastructure is constantly increasing. This is a significant obstacle to the introduction of IT. It is also important to develop decision-making strategies regarding the operational control of the MV, in particular for heavy-duty trucks. Convergence of transport and information systems is a priority task of scientific research in Europe. It is important to develop and implement reliable, complementary and highly reliable control systems and vehicle positioning technologies [27].

Labor costs make up from 35 to 45 % of operating costs for long-distance freight transportation in Europe [5]. In addition, limits on the amount of time a driver can drive in a given day or week limit the speed and availability of a long-haul truck, where individual drivers are attached to each rolling stock unit. At the same time, truckers may struggle to attract drivers for such long-distance trips. Obviously, the opportunity opened by cargo delivery automation changes the initial labor costs, and relaxes travel time restrictions, increases the productivity of MV, would be of great interest [28]. Automated vehicles provide the opportunity to revolutionize the field of highway transportation. When used correctly, automated commercial truck can increase the efficiency, flexibility and overall profitability of fleet operations. It also has great potential to effectively reduce travel costs due to congested traffic, improve driver behavior, reduce driver labor costs, and increase fleet mobility and safety. According to the International Road and Transport Union's (IRU) 2017 report, Managing the Transition to Driverless Road Freight Transport, reductions in operating costs are likely to be much greater in long-haul haulage. The labor payment accounts for a larger share of the cost base than in urban freight transportation there. In work [22] it is indicated that, in general, up to 30 % reduction of operating costs for freight transportation over long distances is possible when operating without a driver. However, this does not stipulate what achievements the carrier receives. However, there are no detailed data on the coordination of information flows with the processes that occur during cargo delivery.

The expansion of traffic flow management systems, the interaction between traffic control centers, service providers and individual vehicles, should optimally combine the information coming from the point of departure, information about road traffic and the service provider for the planning and optimization of highway freight transportation [26].

To increase the efficiency of freight transportation, more volumes of data are available, some of them are collected in "smart" infrastructure, equipped with various sensors, connected to transmission networks [29]. This data may be combined with that coming from vehicles and other sources for various purposes:

1) to assess the interaction of vehicles and infrastructure;

2) to facilitate the operation of the vehicle, provide some services or improve its safety;

3) to assess the impact of vehicles on the infrastructure, possible damage to road clothing and its service life;

4) to ensure constant monitoring of traffic and infrastructure.

Therefore, monitoring, diagnosis and maintenance of the road infrastructure are crucial to strengthen the existing restrictions. For example, data collection based on weighing in motion (Weight Into Movement (WIM)) on highways and other roadways makes it possible to carry out prevention, save money, without disrupting the operation of MTM as a whole [29].

On-board monitoring of MV (for example, weighing in motion, measurement of friction force on the road/tire, evaluation of the rolling resistance coefficient) provides a data that can be used for sustainable assessment of the infrastructure and, thus, effective diagnostics of the LS during its execution is carried out. This requires a high the level of communication between stationary and mobile logistic facilities, and communication between the vehicle and the infrastructure as a whole. Such accurate and constant monitoring is necessary to ensure higher loads or traffic intensity, a longer service life, but to maintain the accepted safety factors for greater productivity of MV in general.

3.2 DYNAMICS OF CARGO FLOWS AND INFORMATION SOURCES IN CYCLICAL LOGISTICS SYSTEMS

Goods delivery of in LS, especially those where road transport is used, is their periodic adjustment to the conditions of material production and consumption, which design discrete material flows [30]. Adaptation takes place on the basis of changes in the structure of logistic chain (LC). Therefore, the execution of logistics operations is a source of informational messages in LS. As their intensity increases, the structure of the LC becomes more complex. The structure of such operations is mostly branched. The varying duration of operations, and their structure, and random nature lead to the presence of non-productive states of delivery processes, i.e. delays in material flows. We have formulated a hypothesis that there are such sequences of logistics operations in which the total number of undesirable states will be minimal.

We will determine the adaptability of the LS of cargo delivery to changes in the parameters of incoming material flows (MF) associated with fluctuations in demand for products delivered, taking into account the known forecast. We will MF henceforth the totality of goods, including transportation means and objects, which change their spatial location relative to any two phases in a time that does not exceed the duration of their physical wear. Consumer properties of goods of any two phases do not differ significantly. MF is the spatial movement of objects and means of transportation, which are unchanged [31]. The primer physical unit of the MF is the material element (ME), which is the smallest indivisible part of the MF. Moving ME in time and space does not affect its internal structure and properties. These properties are manifested only in interaction with other elements of MF. Let's call such events *Elementary Logistics Operations* (ELO). Thus, ELO is an action aimed at changing the direction, speed, duration of spatial movement of ME. A sequence of homogeneous events that occur one after the other at random moments of time is called a flow of orders for the transportation of goods. In order to reflect the essence of material flows on trunk transport network (TTN) we will apply the following principles of their objective consideration.

The principle of elementality of material flows comes down to the fact that the smallest indivisible material element of the material flow is singled out, as well as the smallest indivisible part of delivery process is an elementary operation. ME is a part of combined groups, which can be a container, a transport package, a shipment group, a production group, etc. There are a finite number of elementary logistic operations. Elementary operations are invariant in structure and properties. However, they are characterized by such interconnections that form larger structures. Thanks to the finite number of elementary operations, it is possible to synthesize an almost infinite number of operations and processes according to established criteria.

The principle of continuity of the material flow, which also applies to discrete flows. To formulate it, we mean that a discrete MF is characterized by a sequence of moments of the beginning (completion) of elementary operations / a group of elementary operations. A changes in the direction, speed of movement or the number of material elements in a single group occur during the period when a qualitative change in the flow is present. In this case, the principle of continuity is that in any i-th continuous time interval $\Delta t = t_i + 1 - t_i$ in any completed part of the MF, the number of material elements is a constant value. This can be interpreted as the number of ME entering a given phase of the MF per unit of time is equal to the number of ME leaving this phase.

The principle of rhythmicity consists in the fact that the duration of each ELO is directly proportional to the size of the group of material elements and inversely proportional to the intensity of the MF that passes through it. That is, the dependence is valid for each i-th division of the MF:

$$\mu_i = \frac{k_i}{\tau_i}, \tag{3.1}$$

where k_i is the size of the ME group; τ_i is the *tact* of the discrete MF.

The model of typical LS of cargo delivery from the manufacturer M, by trunk transportation, to the distribution point Dp and to consumers C is shown in **Fig. 3.3**. Each ELO is evaluated by three parameters: duration t_i, tact τ_i, group size k_i, manufacturer f_i. The intensity of the MF on every i-th successive ELO is constant and is determined by expression (3.1), in connection with the principle of the indissolubility of the MF [32]. If the consumer's demand for products increases, then the intensity of material flows in LS should increase. However, this can happen successfully under two conditions. The first is: information must be provided to manufacturer M in a timely manner (in **Fig. 3.3**, the information flow is shown by a dashed line).

The advance time of information submission is comparable to the duration of the LC:

$$t_{adv} = \tau_4 \cdot f_2 + \tau_4 + \tau_3 + \tau_3 \cdot f_1 + \tau_3 + \tau_2, \tag{3.2}$$

where the tact rate of each $i+1$ ELO acceleration/deceleration is determined by the expression:

$$\tau_{i+1} = \frac{k_{i+1}}{k_i}\tau_i, \tag{3.3}$$

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and the front of trucks on the routes will be determined by the expression:

$$f_i = \left[\frac{t_{m.i}}{\tau_i} \right], \tag{3.4}$$

where $t_{m.i}$ is the mathematical expectation of the duration of movement on the i-th route; the expression enclosed in square brackets is rounded up to an integer.

Taking into account expressions (3.3) and (3.4), with constant values of the sizes of transport and consumer packages, the volume of vehicle loading, expression (3.2) will be rewritten in the form:

$$t_{adv} = \frac{1}{\mu}\left(\left(f_1+1\right)k_4+\left(f_2+1\right)k_3+k_2\right). \tag{3.5}$$

The dependence of the time required to satisfy the demand on the intensity of the material flow of the given LS is shown in **Fig. 3.4**.

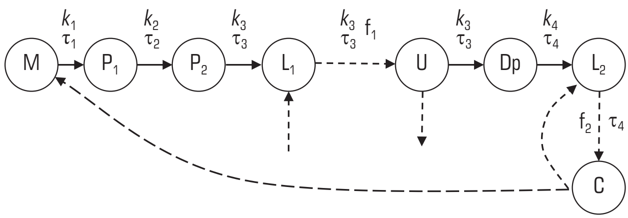

Fig. 3.3 LS of cargo delivery: M – manufactory; P_1 – packaging of goods into a consumer packages; P_2 – packaging of goods into a transport packages; L_1 – loading on a trunk road train; U – unloading; Dp – distribution of packages by consumers; L_2 – loading on a light-duty vehicle; C – consumer; $\tau_1 ... \tau_4$ – ELO tact; $k_1 ... k_4$ – size of cargo group; f_1, f_2 – fronts of motor vehicles on routes

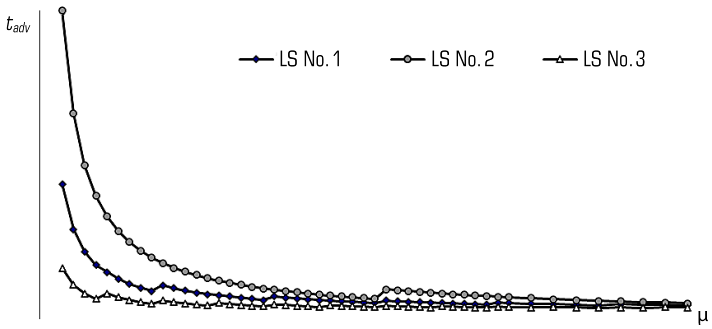

Fig. 3.4 Dependence of the necessary time advance for forecasting the demand for products on the intensity of the material flow, and the structure of the LS that provides it

Fig. 3.4 shows three dependencies for three LS models. The model of LS No. 1 is shown in **Fig. 3.3**. LS No. 2 corresponds to LS No. 1 functionally, but has a shortened structure. LS No. 2 does not have a Dn distribution center and the delivery of goods to consumers is carried out by a heavy duty trunk train. LS No. 3 is similar to LS No. 2, but transportation is carried out by a light trucks. As can be seen from the **Fig. 3.4**, the resulting dependencies are piecewise continuous. The longer the forecasting horizon (the time of the forecasted period), the more cost LS needs [33]. On the other hand, the forecasting horizon indirectly affects the amount of necessary information for managing the LS as a whole object. This time advance is too important for those LS that are characterized by high intensity of MF (small flow cycle). However, this importance is weakened if the LS becomes less dependent on product and cargo warehousing and more if its LC is shortened.

The second condition for the increase in the intensity of the MF with the growth of demand is the successful adaptation of the LS to new requirement, which is the suitability of its structure for operational restructuring. The suitability was investigated using the next example. Let's assume that at the *i*-th moment, manufacturer M (**Fig. 3.5**) received information about the demand to increase the intensity of MF μ by the amount $\Delta\mu$. Manufacturer can do it without disrupting the technology at the current production capacity by reducing the output cycle τ_1. However, the next phase of the LC is the ELO of the package P_1, which we denote by $i+1$. P_1 is not adapted to such a flow pulse like the subsequent phases of the LC. Therefore, part of the products will remain unpackaged in the manufacturer's warehouses. This is shown in **Fig. 3.5** by introducing additional ELO S_1 – first stage of storage.

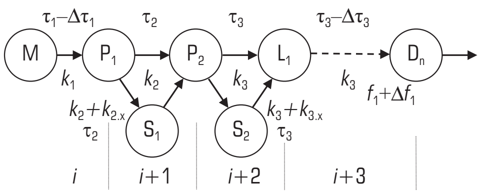

Fig. 3.5 Fragment of the LS when the material flow is increased by $\Delta\mu$

As it is possible to see, the introduction of S_1 is accompanied by additional delays of the MF part for one cycle τ_2. The next $i+2$ phase is characterized by the same impulse and, accordingly, the needs for a new stocking and a new delay τ_3. It is impossible to reserve cargo during the transportation operation, so the flow must be accelerated by the amount of $\tau_3-\Delta\tau_3$ using additionally involved MF. The front of MV will increase by Δf_1. Therefore, in such a LS, the pulsation of the MF is maintained by:

a) storage of products/cargo;

b) involvement of additional transport and technological means.

Case (a) is characterized by flow delays, (b) – by accelerations. The total delays at positive $\Delta\mu$ account for only part of the MF. Therefore, to assess the degree of adaptation of LS to new conditions, it is advisable to use specific delays in the products transportation per physical unit:

$$\Delta_k = \frac{\tau_2}{k_{2x}} + \frac{\tau_3}{k_{3x}} - \frac{\Delta\tau_3}{k_3} + \frac{\tau_3}{k_{3x}} + \frac{\tau_4}{k_{4x}}. \tag{3.6}$$

If $\Delta\mu$ is negative, that is, the intensity of the MF decreases. Then such a "wave" along the LC is balanced by a temporary decrease in the group of material elements: the sizes of transport and consumer packages, the degree of loading of the MV. This leads to the following consequences: on the one hand, MF is accelerated due to a decrease in the amount of stock of packages in warehouses. On the other hand, the MF slows down due to the reduction of the MV front during transportation. Reducing the size of packages also leads to a violation of the technology of transportation operations, as a result the cost of delivery increases. Using expressions (3.3)–(3.6), it can be shown that the ratio of the production cycle before and after the decrease in the intensity of MF in the LS is related to the ratio of the sizes of packages:

$$\frac{\tau_1}{\tau_{1.1}} = 1 - \frac{\Delta k}{k_2}. \tag{3.7}$$

As many times as the input tact increases, the size of the goods group in the consumer/transport package decreases by the same amount.

CHAPTER 3

3.3 ANALYSIS AND ARRANGEMENT OF INFORMATION FLOWS

Information flows play a key role in modern goods delivery processes. This is confirmed by a number of publications, for example, [34–37]. It has been proven that the synergistic effect of a large LS, which is characteristic, for example, of logistics centers, is a consequence of the centralization and concentration of operations of an informational and analytical nature [18]. However, there are very few works where such an effect was reflected in models and was reproduced under different flow conditions and external disturbances.

The entire volume of telemetric signals that is received by the driver/crew of a cargo MV performing the transport task of goods delivering to the LS can be conventionally divided into four categories, in the form of discrete messages. These are such messages. The first type I_1 is a message about own current coordinates and speed received from Automatic Vehicle Location (AVL). The second type is the I_2 message about traffic conditions (phase density of traffic flow, intensity, and others), received, for example, from Automotive Short Range Radar (SRR) or from cellular communication dispatch centers. The third type is a I_3 message about probable delays at the destination point. The fourth type is the I_4 message about road conditions (coefficient of adhesion, micro- and macro irregularities, etc.) obtained, for example, by comparing messages of the I_1 type from the

Global Positioning System (GPS) and from on-board measurement systems. Messages I_1–I_4 can be received in discrete-quantized form, in independent streams. But these massages can influence decision-making in different ways. It is logical to formulate the following tasks:

1) investigate the influence of the parameters of message flows I_1, I_2, I_3 on the probability of making optimal decisions;

2) to establish the limit moments of the receipt of messages, taking into account the probability of making optimal decisions based on them regarding the execution of route tasks.

The following assumptions were made when solving these problems. First, the amount of information contained in messages was calculated using the expression:

$$I = 0.5\log_2\left(1+\frac{\sigma_\lambda^2}{\sigma_\varepsilon^2}\right), \tag{3.8}$$

where Σ_λ is variance of telemetrically measured parameter; Σ_ε is variance of its measurement error.

The expression (3.8) applies to messages of all 4 types of massages, since they are all built on continuous signals. Formula (3.8) is applied with the hypothesis that the a priori and a posteriori distribution of the transmitted signal obeys the same law (entropy coefficient is constant). According to formula (3.8), it turns out that there cannot be a complete lack of information about any telemetric parameter, since the maximum value of Σ_ε is finite. So, then we will use the term *minimum available information*. Similarly, complete available information also does not exist because $\Sigma_\varepsilon>0$. Therefore, we will use the term maximum available information under the given conditions of its receipt.

Secondly, it was considered that I_4 messages were received in their entirety even before the start of MV traffic. Thus, the idealized LS for traffic conditions on a TTN is formed a priori.

Thirdly, it was assumed that the lack of maximum information contained in the received messages I_2, I_3 when choosing the LS parameters can be compensated by a directly proportional time reserve.

The fourth assumption was that messages I_2 and I_3 of any volume and category can be received at any time during the routing task. The interaction of information flows is shown on the example of a typical elementary transport task on a trunk network. Let the MV must be having loaded at point A at the moment t_0, deliver the cargo to point B and unload no later than the moment t_{11} (**Fig. 3.6**).

MV movement modelled in the presence of the maximum available information I_3 and various methods of obtaining information I_2: 0–4 – movement of the MV with a margin of time at the maximum speed under the condition of the minimum available information I_1, I_2, I_3. The speed V_{opt} deviation is maximum. 0–7 is MV trajectory with a time reserve for the maximum available information I_1, I_3, and minimum information of I_2. 0–3‴–7 is MV trajectory at a speed, which provided by the information I_2 arrived at the maximum permissible moment 3‴. Road conditions on the AB route are known. Knowing Road conditions, the driver/crew of the MV can perform the delivery with optimal parameters (for example, according to fuel consumption), which includes the selection of the average speed of movement V_{opt}. At the end point B, other MVs arrive for unloading. Since the moments of their arrival and the duration of service are random variables, a queue may form before unloading. It can be assumed that the unloading process at point B is a mass service system of the M/G/m type, using the results of earlier studies, without significant restrictions [15]. M is the input flow subject to the exponential law. G is the service process with a general duration distribution. A number of unloading devices is *m* (unloading front). If the intensity of the arrival of MV at point B and the intensity of their service are known, then it is possible to calculate the average expected duration of idle MV in the queue t_q. Taking this into account, the LS can be adjusted so that the moment of arrival t_{10} will take into account the average guaranteed delay time in the delivery of cargo $t_{10}-t_{11}$. The ideal image of the transportation of goods process of the LS is formulated in this way, subject to the maximum available information I_2 and I_3 (dash-dotted line).

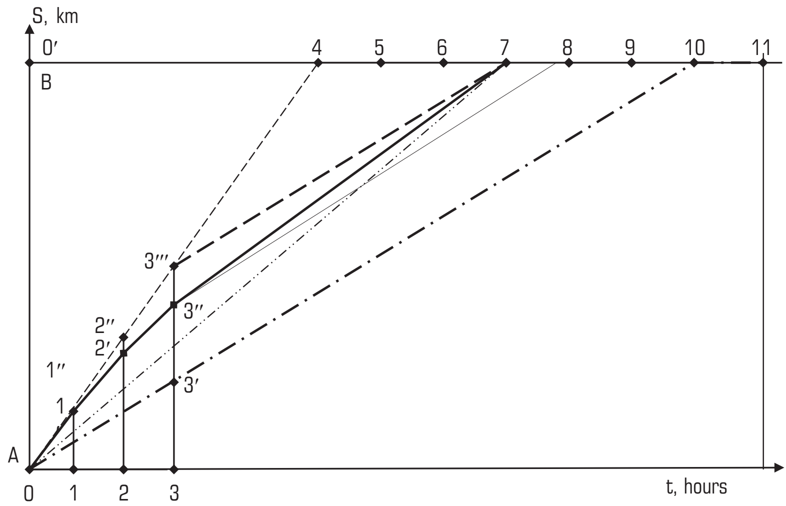

Fig. 3.6 Traffic charts of MV trajectory

It was assumed that messages I_1, I_2, I_3 periodically arrive to the MV crew. This periodicity, as well as the volume of messages, can be changed at an arbitrary, necessary interval. Accordingly, the volume of messages can be variable. If at the *i*-th moment of time, $t_0<t_i<t_{11}$, according to the next message I_1, the MV has the coordinate x_i, then, depending on the amount of information in the received messages I_1 and I_3, it should move with the time-averaged speed $V_e \geq V_{opt}$, which is determined by the formula:

$$V_e = \left(x_{11} - x_i\right) / \left(T_{opt} + \Delta t_i\right), \text{ km/hour}, \qquad (3.9)$$

where $\Delta t_i = \Delta t_{i1} + \Delta t_{i2}$, hours; T_{opt} is the optimal duration of the delivery process at the speed of V_{opt} (in the absence of obstacles from the traffic flow and queues before unloading);

Δt_{i1}, Δt_{i2} are time reserves for, respectively, delays in movement and in the queue at the end point B; it is, according to the conditions, impractical to reduce the speed below V_{opt}.

To calculate the actual average speed of MV on the TTN, a macroscopic model of the traffic flow derived from a microscopic model with consideration of Paveri-Fontan corrections was used [22]:

$$V_e = V_d - V_f = V_d - (1-p)t_r\rho\Theta, \text{ m/sec,} \tag{3.10}$$

where V_d is the average desired speed; V_f is the forced change of the desired speed under the influence of the traffic; p is the probability of overtaking; t_r is the duration of motion relaxation as a result of random disturbances; θ – speed variation.

The values of p and t_r do not depend on the individual speeds of MV in the maneuver, but on the density ρ and the average speed V at the overtaking location, i.e. $p=F_1(v,\rho)$, $p=F_2(v,\rho)$. The information is accumulated about changes in the phase density of the traffic with each message of type I_2, that is, about the range of values of the function $f(x,v,t)$. At the same time the area of definition in terms of x and t is expanded. Information on the region is available as much as possible $x \in (x_A, x_B)$, where x_A, x_B are coordinates of the starting and ending points of the route. According to the data on the posterior phase density that could be determined at the moment t_i, the value of the a priori values for the given coordinate x at the moment of time $t_j > t_i$ was calculated:

– traffic flow density:

$$\rho(x,t) = \int_0^\infty f(x,v,t)\,dv; \tag{3.11}$$

– average speed of MV in the traffic flow:

$$V(x,t) = \frac{1}{\rho(x,t)}\int_0^\infty vf(x,v,t)\,dv; \tag{3.12}$$

– variations in vehicle speeds:

$$\Theta(x,t) = \frac{1}{\rho(x,t)}\int_0^\infty (v-V)^2 f(x,v,t)\,dv. \tag{3.13}$$

One should provide research in two stages. At the first, it can be assumed that the MV crew has the minimum available amount of information based on type I_3 messages (**Fig. 3.7**).

Messages I_1 and I_2 were submitted in three different ways:

1) at the beginning of the movement, once, in the full available volume;

2) during movement, at the extreme moment in terms of the effectiveness of the decision made, in full;

3) during movement, repeatedly, in equal amounts at equal time intervals.

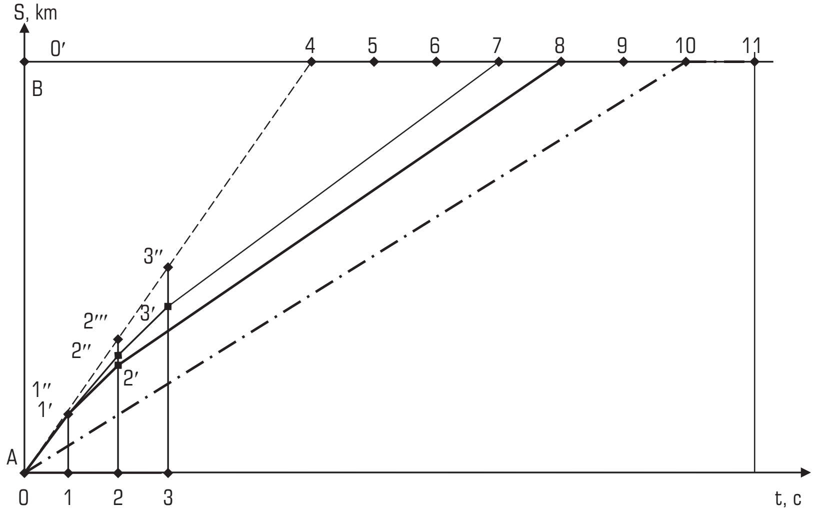

Fig. 3.7 Traffic charts of MV trajectory, if messages I_1, I_2, and I_3 are synchronous; 0-1′-2″-3′-7 – the movement of MV, provided that I_2, I_3 are received evenly, after the same intervals of time. The I_3 massage volume information is minimal. 0-1′-2′-8 – movement of the MV under the condition that I_1, I_2, and I_3 arrive uniformly, synchronously, at equal time intervals. The permissible moment of receipt of complete information is shifted to t_2

At the second stage, it was assumed that information I_1–I_3 arrives to the MV crew synchronously with the same amount at the same time intervals.

The time reserve Δt_{i2} is maximum if only one actual messages stream I_2 is available (**Fig. 3.6**) and therefore the MV crew is oriented to the moment t_7 of arrival at point B. The maximum total deviation from the optimal driving program will be achieved when the maximum available information I_2 is presented at the beginning of the movement t_0. This is due to the fact that the traffic, even in the first approximation, cannot be called stationary. Therefore, the value of the function $f(x,v,t)$ cannot be extrapolated to more than $t>t_0+\tau$, where τ is the period of discretization of I_2 messages. Therefore, decisions about the choice of V_d will not be adequate. So, there is a moment, after which the MV, moving, moreover with minimal information I_2, having received it cannot effectively use it (point 3″).This moment is called the limit for making a decision. Later, from the limiting moment, it is not advisable to also obtain information by I_2 quanta. Although this method of obtaining results has the smallest deviations from V_{opt}. If messages I_2 and I_3 are sent simultaneously, this affects not only the deviation from the optimal mode and the moment of arrival at the final destination, but also shifts the final decision-making moment to earlier times (**Fig. 3.7**).

3.4 INFORMATION SUPPORT FOR THE STABILITY OF TRANSPORT PROCESSES UNDER THE CONDITIONS OF VARIABLE MATERIAL FLOWS

The importance of the information support of LS grows especially when the LC is functioning for the supply of goods, namely as MF variable. It is then that the available messages are used to adopt LS to new conditions, that is, to stabilize business processes. In order for all intersecting LC of LS to function more efficiently, it is necessary to know the laws of their transformation in the external environment [37]. In addition, it is necessary to take into account the discrete nature of the LS, which consists of structural and parametric modules. A study of the transient processes that occur in the LS during changes in demand for goods delivered on the trunk transport network, as well as changes in supply conditions and other random external influences, was carried out. The principle of continuity of the flow was used for the maximum reduction of material flow delays in LC, which is subject to random external influences. So, if the initial ELO in the LS are characterized by the values of the input tact τ_{in}, then all subsequent ones are functionally dependent on them. The corresponding dependencies are preserved in the same way as in stationary material flows. The duration of the *j*-th ELO should be $t_j \leq \tau_i$, where *i* is the number of the previous ELO. If this ratio is not preserved, then the value of the front of the *j*-th ELO should increase according to the expression:

$$f_i = \left\lceil \frac{t_i}{\tau_i} \right\rceil, \tag{3.14}$$

where f_i is the front of technical means for performing ELO. If two adjacent ELOs have mismatched modes, then at least one of them will experience a delay. The static delay of each ELO can be calculated using the formula:

$$Z_i = \left(f_i \cdot \tau_i - t_i\right) \cdot f_i. \tag{3.15}$$

A simple linear LC, which, for example, consists of ELO: 1 – manufacturing; 2 – packaging; 3 – loading and transportation; 4 – unloading and unpacking; 5 – consumption (**Fig. 3.8**), will have static delays if the modes of its operations are inconsistent (not multiples of the clock). Each ELO of this chain is characterized by four parameters τ_j, k_i, f_i, t_i.

Since the parameters of neighboring ELOs are dependent, the following expressions are valid:

$$\tau_4 = \frac{k_4}{k_3}\tau_3,\ \tau_2 = \tau_3;\ \tau_2 = \frac{k_2}{k_1}\tau_1;\ f_3 = \left\lceil \frac{t_3}{\tau_3} \right\rceil \geq 1;\ f_1 = f_2 = f_4 = 1. \tag{3.16}$$

Thanks to them, we can get $\tau_4 = \dfrac{k_4}{k_1}\tau_1$.

Thus, the linear LC leads to a linear dependence of its parameters. The value of the criterion can be calculated using the formula:

$$Z_{\Sigma} = \sum_{i=1}^{4} \left(f_i \tau_i - t_i \right). \quad (3.17)$$

The total delays of the cargo delivery process are static, that is, they will repeat from cycle to cycle, if the intensity and modes of MF do not change. As expression (3.17) shows, these delays depend on the initial tact and on the values $k_1 ... k_4$ (**Fig. 3.9**).

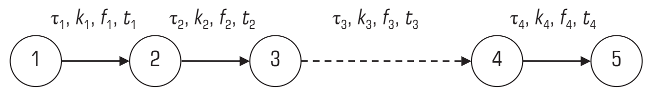

Fig. 3.8 Scheme of the model of the elementary logistics chain

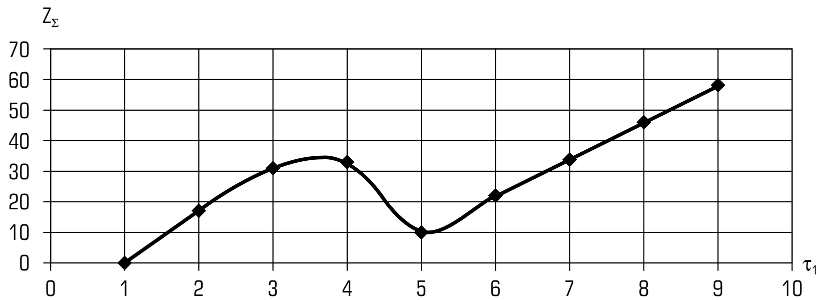

Fig. 3.9 Dependence of static delivery delays on the tact rate of the incoming MF

The quality of the built LC depends on the rational selection of parameters in expression (3.17). When the demand for the supply of goods changes, the input tact of this LC will change:

$$\tau_1^{j+1} = \tau_1^{j} \pm \Delta\tau_1, \quad (3.18)$$

where j is the index of the next phase of LC. The sign of the value $\Delta\tau_1$ depends on the type of MF change. If the volume of consumption increases, then the input tact of the LC decreases and vice versa. Depending on the value of $\Delta\tau_1$, certain changes may occur in the LC, which lead to the formation of dynamic process delays. These delays are also the reason for the mismatch of neighboring ELOs, but they have the ability to disappear if the MF in the LC stabilizes. This can be demonstrated with the help of a cyclogram of operations (**Fig. 3.10**, ***a***). Stationary flow is in two neighboring ELOs No. 1 and No. 2. Segments ABGDE are a sequence of incoming ELOs No. 1 with a constant cycle time $\tau_1=15$ hours. During ELO No. 2, the size of the group of material elements is doubled, i.e. $k_2=2k_1$. Therefore, the tact of the next ELO No. 2 also doubles and equals $\tau_2=30$ h. Such a change is shown with the help of two chains of operations: JZ and CU, according to the multiplicity of flow changes that occurred in ELO No. 2. Delays in such a LC are static. They arise due to the fact that the duration of the ELO is shorter than the duration of the tact during which it is performed. **Fig. 3.10**, ***b*** shows that the intensity of MF increases. The tact of the input operation of ELO No. 1 was initially equal to $\tau_1=15$ h. Then it decreased to $\tau_1=10$ h, which can be seen from the length of segment BG. TTS remains unchanged.

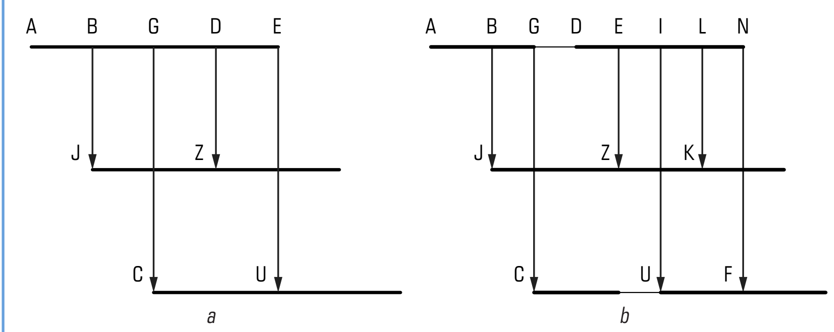

Fig. 3.10 Cyclograms of cargo delivery operations No. 1, No. 2: *a* – at stationary flow; *b* – with an increase in the intensity of MF

Therefore, the ELO No. 2 tact also doubles. It acquires the value $\tau_2=20$ h, which is visible along the length of the segment CU. However, operations that have different tacts end up in the same LC after the changes occur. This leads to forced dynamic process delays, which in **Fig. 3.10**, ***b*** is shown by dashed lines GD and UF. It is clear that the value of these delays depends on the change in the intensity of the incoming MF. The execution of ELO No. 1, for example, is delayed by the amount ΔZ, which can be determined by the expression:

$$\Delta Z_1 = Z\left(\tau_1^{j+1}\right) - Z\left(\tau_1^{j}\right). \tag{3.19}$$

The value of the difference (3.19) is affected not only by the absolute change in the tact rate $\Delta\tau_1$, but also by the number of discrete periods during which this change occurs. The task is to determine such a sequence of values for which the value of the Z_Σ criterion is minimal. The method of finite difference equations was used to solve this problem. Thus, the total delay of the process when changing the input tact $\Delta\tau_1$ in two steps can be written as a second-order differential equation:

$$\Delta^2 Z = Z\left(\tau_1^{j+2}\right) - 2Z\left(\tau_1^{j+1}\right) + Z\left(\tau_1^{j}\right), \tag{3.20}$$

which can be written as:

$$Z\left(\tau_1\right) = \tau_1 \frac{k_4}{k_2} f_1 + 2\frac{k_2}{k_1} f_2 \cdot \tau_1 + \tau_1 f_1 - T, \tag{3.21}$$

where T is the total permissible duration of operations in LC, which does not depend on their execution sequence and other organizational parameters. By introducing notations, equation (3.21) can be simplified:

$$Z\left(\tau_1\right) = A \cdot \tau_1 - T, \tag{3.22}$$

where A is a constant. Similarly, it is possible to write differential equations of higher orders. In the case when the LC is branched, that is, it has an ELO of the distribution, or a connection of the MF, it is also necessary to find the function of the output tact of the longest linear LC and write down the differential equations for this function. Let's simplify the notation, bearing in mind that the state of MF delays depends on the selected constants A and on the input flow rate τ_1. The second-order differential equation can be reduced to the form:

$$a_1 z_{j-1} + a_2 z_{j-2} + a_0\left(j\right) = z_j\,,\ j = 0,1,\ldots n. \tag{3.23}$$

It is called a linear differential inhomogeneous equation. Solution of a homogeneous equation:

$$a_1 D_{j-1} + a_2 D_{j-2} = D_j, \tag{3.24}$$

can be found in the form $z_j=\lambda_j$. Substituting z_j, $z_j-1=\lambda_j-1$, $z_j-2=\lambda_j-2$, in equation (3.23), we get the characteristic equation for determining λ:

$$P\left(\lambda\right) = \lambda^2 - a_1\lambda - a_2 = 0. \tag{3.25}$$

Its roots λ_1, λ_2 can be calculated from the formula:

$$\lambda_{1,2} = \frac{a_1 \pm \sqrt{D}}{2}, \tag{3.26}$$

where $D = a_1^2 + 4a_2$. It is proved that, depending on the sign of the discriminant D, the following three cases are possible:

1) $D>0$. Then λ_1, λ_2 are real and different, and the general solution of equation (3.24) is found by the formula $\tau_j=A_1\lambda_1^t+A_2\lambda_2^t$, where A_1, A_2 are arbitrary constants, which are determined from the initial conditions: $\tau_{j=0}=A_1+A_2$, $\tau_{j=1}=A_1\lambda_1+A_2\lambda_2$;

2) $D=0$. Then the characteristic equation has roots $\lambda_1=\lambda_2$, and the general solution (3.16) is determined by the formula: $\tau_j=(A_1+A_2 j)\cdot\lambda_1^j$, and arbitrary constants are determined from the initial conditions, that is, for $\tau_{j=0}=A_1$, $\tau_{j=1}=\lambda(A_1+A_2)$;

3) $D<0$. Then λ_1, λ_2 are complex variables $\lambda_{1,2}=\alpha\pm i\beta$, where $\alpha=a_1/2$, $\beta=\sqrt{-D}$, $i_2=-1$, which are easier to use in trigonometric form:

$$\lambda_{1,2}=\rho(\cos\omega\pm i\sin\omega),\ \rho=\sqrt{\alpha^2+\beta^2}=\sqrt{-a_2},\ \mathrm{tg}\omega=\beta/\alpha. \tag{3.27}$$

The general solution (3.27) is given:

$$\tau_j=\rho^j\left(B_1\cos\omega j+B_2\sin\omega j\right), \tag{3.28}$$

where B_1, B_2 are arbitrary constants determined from the initial conditions.

Thus, for $D<0$, the solution of the difference equation (3.23) has the character of oscillations, the amplitude of which increases if $\rho>0$ and fades if $\rho<0$. Such models of LC dynamics make it possible to find out whether an external disturbance will lead to LS in the form of a change in the input flow rate until stabilization, or dynamic delays in this connection will continue to grow from cycle to cycle.

For example, if the general solution of the difference equation has the form:

$$z_j=2^{0.5j}\left(C_1\cos\alpha j+C_1\sin\beta j\right)+1. \tag{3.29}$$

Then its partial solution depends on the initial conditions, i.e., on the time τ_{11} and on its change $\Delta\tau_1^1$. It can be seen from **Fig. 3.11** that the process of changing the value of MF by $\Delta\tau_{11}$ leads to destabilization of the LS, which manifests itself on the 3rd cycle and continues to grow.

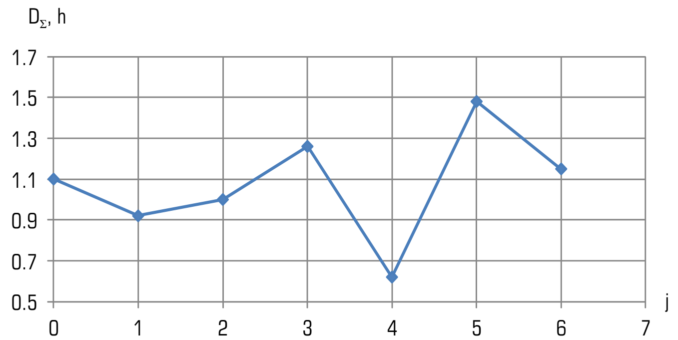

Fig. 3.11 An example of an unstable linear LC: j is the LC cycle number

CHAPTER 3

Total delays in this LC arise for two reasons. Static delays are visible at stage $j=0$, and they appear as a result of the mismatch of the tacts of neighboring ELOs. Dynamic delays in LC fluctuate in time and, in general, increase. In order to reduce fluctuations, it is necessary to change the structure of the LC, or to apply the initial redundancy of the ME to smooth out the rapid pulses of the incoming flows.

It is expedient to evaluate the level of perfection of the LC of cargo delivery on the trunk transport network by the minimum total static and dynamic delays in the LC. If the total MF on the LS is constant, then only static delays will occur. They are due to the inappropriate multiplicity of the tact and duration of ELO. The total delays cannot be reduced if only the appropriate parameters of the group k and tact τ are selected. Dynamic delays occur in LC if the tact of the initial ELO changes. Therefore, additional regulation of incoming flows is necessary, which consists in their stabilization, for example, using warehouses, or long-term forecasting.

3.5 STABILIZATION OF MATERIAL FLOWS IN LOGISTICS CHAINS

As was discussed above, the fluctuation of the MF leads to the occurrence of additional delays in the movement of the ME. MF fluctuations can be smoothed out by stream stabilization, which can be demonstrated using the following example. A typical LS was considered, consisting of LC of long-distance delivery of goods from the manufacturer to the regional network of consumers according to the flow technology studied earlier: production – packaging in consumer containers – packaging in transport packages – formation of a shipment group – loading – distribution by directions – delivery to the distribution center point – distribution by consumers – delivery on circular routes. Peculiarities of the LS model in relation to the studied trunk network are:

1) several sources of cargo flows – several manufacturers;

2) the TTN subjects is not limited in their interconnections, in particular there are no restrictions on the supply of goods from any manufacturer or from any distribution point;

3) the number of final consumers in the distribution network is finite but not fixed, that is, the volume of goods supplied is a function that depends on the intensity of consumption of goods by each consumer μ_i and the total number of consumers taken into service $i=1...n$. In the model, the principle of inseparability of the cyclic MF is preserved: with the work front $f=1$, any i-th ELO cannot start, if the previous one is not completed. The mathematical expectation of its execution duration t_i is not greater than the rhythmicity index τ. This indicator is constant if the MF is not transformed in the size of discrete groups k, or if it does not change according to the average intensity, which is determined by expression (3.1). The total intensity of MF in the network is the sum of all flows coming from sources or the sum of all flows reaching consumers (total demand). The total intensity does not depend on how branched the network is and how many end points of material flows (consumers) S_i. The delays of ME movement at a constant total flow occur as a result of the mismatch of t_i and τ_i values. It is known that with a constant total MF there is such

a LC, in which the inconsistency of the majority of the ELO of the process, therefore, the delays will be minimal [38]. Qualitative transformations of LC occur when critical values of the tact rate of the input flow are reached. If the input flow in the LC is variable, then flow delays can occur. The reason is due to the multiplicity of ELO tacts and durations, but also due to the inconsistency of neighboring operations in the LC in terms of the absolute value of the tact. We will show in more detail the formation of a flow delay when its intensity changes on the example of one ELO No. 4 (**Fig. 3.12**).

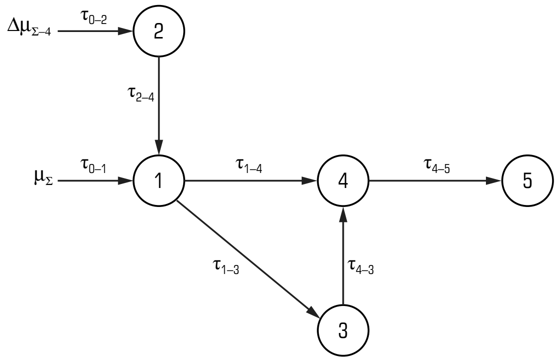

Fig. 3.12 An elementary example of changes in the structure and properties of ELO when changing the input flow: 1–5 ELO

The model shows the flows that undergo transformations in ELO No. 4, and those adjacent to ELO No. 1 and No. 5. The total flow is constant (μ_{Σ}=const). In this case, the ratio is preserved:

$$\mu_{\Sigma} = \frac{k_1}{\tau_{0-1}} = \frac{k_2}{\tau_{1-4}} = \frac{k_3}{\tau_{4-5}}, \tag{3.30}$$

where μ_{Σ} is constant average intensity of the incoming MF; k_1, k_2, k_3 are the sizes of ME groups, which, in general, can be different; τ_{0-1}, τ_{1-4}, τ_{4-5} are the tacts of the corresponding ELO. The zero operation is the arrival of the ME to the given LC.

Disturbances occur in the LC. These disturbances are transmitted in the form of an additional input flow with an intensity of $\Delta\mu_{\Sigma}$. The value $\Delta\mu_{\Sigma}$ can be positive or negative (a decrease in the total flow). It was shown in previous paragraph that additional flows necessitate the temporary reservation of part of the ME to equalize pulsations. In this case, such reservation is reflected in the form of ELO No. 2 – the reserve of the input flow, which occurs when $\Delta\mu_{\Sigma}$ has the sign "–", and ELO No. 3, which is characteristic of the case of the increase of the input flow. The stability of MF in the LC is violated at any value of $\Delta\mu_{\Sigma}$, this requires additional capacity reserves and, at the same time, leads to flow delays (**Fig. 3.13**).

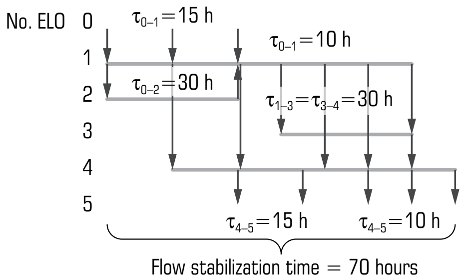

Fig. 3.13 Example of a LC cyclogram

The figure shows an example of the effect of an increase in the input MF on the stabilization of the LC. For this example, it is assumed that the sizes of groups of material elements do not change. The flow delay is a number of cycles τ_{1-3} and τ_{3-4}, which are transitions of the system from the initial (it is equal to the initial cycle τ_{4-5}) cycle $\tau_{0-1}=15$ h up to 10 h. Material flows do not carry out the necessary transformations during this delay, but accumulate in the LC. The general period of stabilization of the flow after its disturbance in this network consists of two half-periods: stabilization at the entrance and during execution, in fact, ELO No. 4. Such an example makes it possible to make an assumption that ways to stabilize flows should be sought in the structure of the LC itself.

Based on the previous considerations, let's name the possible ways of stabilization:

1) a branching of LC in directions, each of which has its own fluctuations in the intensity of flows;

2) a changing the length of the LC, using operations that are associated with the acceleration/deceleration of flows;

3) to change in the number of flow sources;

4) to change in the amount of waste.

It is also clear that the MF stabilization time will depend on the value of $\Delta\mu_\Sigma$, but in practice it cannot be controlled. The research was carried out with the isolation of each individual factor affecting MF delays. Thus, the branching of supply chains is also considered on an elementary example (**Fig. 3.14**). It specifies the point of reception and redistribution of flows ELO No. 1 and there are three finite numbers of directions in this case.

It was assumed that the sizes of ME groups did not change before and after redistribution. Prior to the change of MF was fulfilled in this LC the equality:

$$\frac{k}{\tau_{0-1}}=\frac{k}{\tau_{1-4}}+\frac{k}{\tau_{1-6}}+\frac{k}{\tau_{1-8}}=\mu_1+\mu_2+\mu_3.$$

The additional vertex 2 of the graph is formed after the increase/decrease in the intensity of MF. The vertex means a temporary delay in the flow due to the system's unwillingness to adjust to a new value of the input tact. As well as vertexes 3, 5, 7 symbolize the ELO of a temporary delay in the flow due to its inconsistency with the consumer's demand, respectively μ_1, μ_2, μ_3. A new equality is taking shape:

$$\frac{k}{\tau_{0-1} \pm \Delta\tau_{0-1}} = \frac{k}{\tau_{1-4} \pm \Delta\tau_{1-4}} + \frac{k}{\tau_{1-6} \pm \Delta\tau_{1-6}} + \frac{k}{\tau_{1-8} \pm \Delta\tau_{1-8}} =$$

$$= (\mu_1 \pm \Delta\mu_1) + (\mu_2 \pm \Delta\mu_2) + (\mu_3 \pm \Delta\mu_3), \qquad (3.31)$$

where $\Delta\tau_i$ is the change in the supply cycle of MF as a result of its new redistribution; $\Delta\mu$ is a change in the average intensity of MF due to a change in the demand for goods.

The sign $\pm$ is indicated, taking into account the increase/decrease of the total MF. The right-hand side of equality (3.31) shows that the $\pm$ signs for $\Delta\mu$ values can be different. This means that the function of ELO No. 1 is not only distributive, but also stabilizing. So, if the change in flow intensity in the direction of μ_1 is positive, and μ_2 is negative, then the total intensity of the MF will change only by $\Delta\mu_\Sigma = \Delta\mu_1 - \Delta\mu_2 + \Delta\mu_3$, The value $\Delta\mu_\Sigma$ is less than with a total increase in demand in all directions.

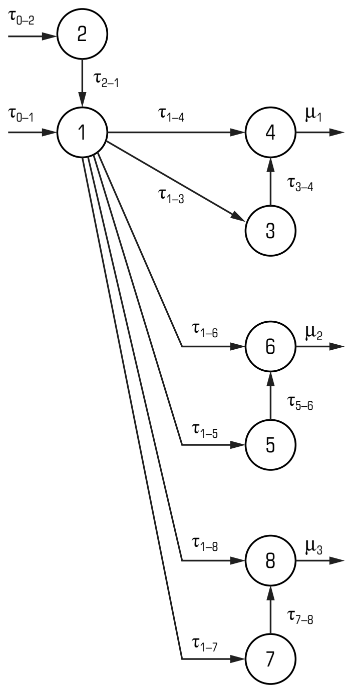

Fig. 3.14 To study the influence of branching of LC on cumulative time delays

Let's also assume that the combination of such flows, which change in intensity collectively minimizes the overall growth of μ_Σ. That can be a way to stabilize fluctuations in the LC, as this reduces the need for significant redundancy on ELO No. 2. However, even in the presence of a slight fluctuation of inputs and flows between directions, there are delays in the time of movement of products. An example of such delays is shown in the cyclogram (**Fig. 3.15**).

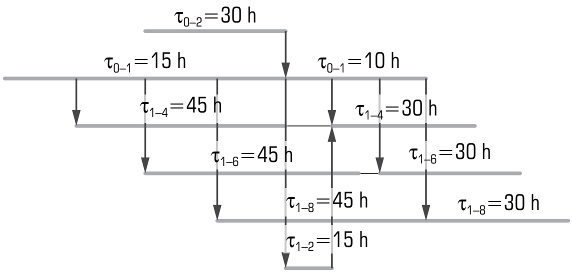

Fig. 3.15 The cyclogram of MF with their branching and change of average intensity

Flows are increasing in all three directions of intensity in this example. That means the additional flow with a cycle time of $\tau_{0-2}=30$ hours is necessary. As a result, the input tact τ_{0-2} is reduced to 10 hours and all three days off to 30 hours. Due to the fact that their previous value was 45 hours, there is a mismatch and flow breaks. There is also a need for additional stocks to stabilize the execution of cyclical LC. Modeling was carried out and the dependence of total delays on changes in flow intensity was plotted (**Fig. 3.16**). When constructing this dependence, the simplest case was considered, in which its size increases proportionally in all directions of the branched flow. Due to this, the obtained dependence is linear.

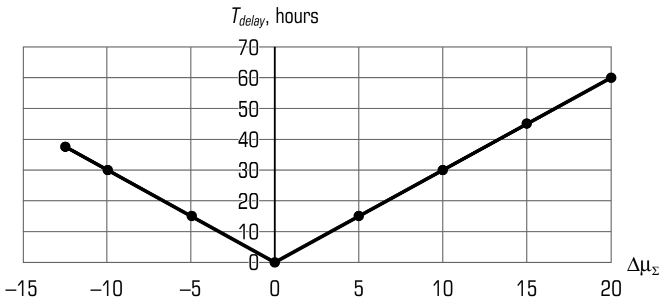

Fig. 3.16 Dependence of the total time delays of the MF on the change in its total intensity

It can be assumed that there is a suitable combination of distributed flows that leads to an optimal LC stabilization mode in which the total delays are minimal. It was also found that the increase/decrease in the branching level of the LC at a constant value of the total output flow does not affect the total duration of delays, if at the same time the different directions of the flows are not the same in response to the disturbance.

While studying the effect of the length of the LC on the stabilization period of the LC and the total delays, we took into account the known regularities of the influence of the sizes of groups of material elements on the intensity of the MF. So, if the intensity of MF in a linear LC (without branches) increases, then at each additional ELO time delays will be added to the total. However, if at the same time it is possible to increase the flow rate by reducing the size of the k_i at every i-th ELO, without disrupting the transport technology, then additional cargo storage will not be necessary. Consider the expression:

$$\mu_\Sigma + \Delta\mu = \frac{k_i}{\tau_i} + \frac{k_i}{\Delta\tau_i} = \frac{k_j}{\tau_i}, \qquad (3.32)$$

the left part of which shows an increase in the intensity of MF as a whole, the middle one shows how it is possible to stabilize the LC, using additional ELO stacking with a duty cycle $\Delta\tau_i$ when increasing the flow. The right-hand side of (3.32) shows how to avoid delays without increasing inventory. The main variable here is the size of the k_j. However, the reduction in the size of the ME group has a negative effect on the cost of resources for their movement. Therefore, the value k_j/k_i should have limited use as a stabilizing factor. It is more appropriate to perform stabilization by changing the group of material elements with a larger number of consecutive ELOs in the LC.

CONCLUSIONS

1. Adaptation of the LS to the change in the intensity of the MF leads to delays in the LC. Increasing the intensity of MF on trunk network, where transportation operations are the longest, leads to a decrease in additional time spent.

2. When organizing the delivery of goods according to the principle of "no later than the specified period" with the observance of optimal traffic modes. It is necessary to reasonably choose the method, number of sources and moments of receiving information messages about road and transport traffic conditions and conditions for the sale of the goods. The use of several independent information flows reduces deviations from the optimal program, on the other hand, it reduces the time for making effective decisions.

3. When the intensity of the input cyclic LS changes (increases or decreases), the need for redundancy functionally arises on the LC. There are also MF delays associated with a mismatch of ELO parameters.

4. To stabilize LS with minimal loss of time and money, it is advisable to apply partial and full redistribution of MF between directions and sources, as well as variable groups of material elements.

5. The model describing the dynamics of the MF in the linear LC is adequately presented in the form of a linear difference homogeneous equation of the second order. Its solution shows the way to stabilization of organizational parameters of LS.

6. It became possible to reduce the number of refusals in the execution of orders in the operating LC on the basis of the developed MF models, by an average of 30...40 % for one motor vehicle enterprise, up to 35 % of the total flow of applications. The duration of orders on long-distance routes is reduced by 12...20 %. The method of optimizing the traffic schedules of road trains based on the stabilization of freight flows and the method of optimizing the mode of work and rest of drivers have been improved. This was done taking into account the parameters of the route, improvement of the system of dispatching management of the fleet of trunk trucks with the help of a developed computer program. Unproductive time spent by road trains on intercity routes is reduced, on average, by 20...25 % of the total duration of transport cycles. The duration of cargo delivery is reduced by 15...20 %. A positive technical and economic effect from the implementation of practical methods is achieved by reducing non-productive downtime of trucks by at least 20 %, reducing fines due to violations of delivery deadlines, as well as rational use of drivers' working time.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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CHAPTER 4

ASSESSMENT OF THE EFFICIENCY OF THE ECOLOGISTIC SYSTEM PROJECT TAKING INTO ACCOUNT THE TRANSFORMATIONAL CHANGES OF ITS LIFE CYCLE MODEL

ABSTRACT

The issue of evaluating the effectiveness of the ecological system project using the "discounted payback period" criterion, which takes into account transformational changes in its life cycle model, is considered.

The specific peculiarities of the life cycle of the ecological system project were studied, in which it is proposed to include, in addition to the generally accepted pre-investment, investment and operational phases, ecologically oriented phases. Regenerative and revitalization phases are considered to be ecologically oriented, that is, during which actions aimed at reducing the eco-destructive impact of the ecological system on the environment are performed. In the regenerative phase, an ecological product is created, which includes a complex of logistics services for the promotion of reverse recycling-utilization and related flows. The revitalization phase should end with the revival of the ecosystem damaged as a result of the creation and functioning of the ecological system.

The phases of the life cycle are divided into stages, between which serial and parallel connections are established. The life cycle of the project is divided into time intervals during which from one to three stages of different phases of the project can proceed in parallel. A model of the life cycle of the ecological system project was developed, which shows the relationships between time intervals and cash flows corresponding to the phases of the project life cycle. A mathematical formula for calculating the discounted life of the project is proposed, which takes into account the specific features of the formation of cash flows of individual phases of the life cycle of the ecological system project. The application of the formula is possible when the assumption of constancy of cash flows of the stages of operational and regenerative phases is fulfilled, which corresponds to the impossibility of their exact forecast at the beginning of the project.

Functional dependencies between the discounted payback period and cash flows during the phases of the project's life cycle were studied. Depending on the phase of the life cycle, the dependence is expressed as a linear, polynomial or power function. The detection of functional dependencies allows to study the dynamics of changes in the discounted payback period in response to changes in the project's cash flows, which can be used to predict the effectiveness of the ecological system project.

In order to take into account the uncertainty of the conditions for the implementation of the ecological system project, an approach based on the use of the tools of fuzzy set theory is proposed.

KEYWORDS

Ecological system, project, life cycle, cash flows, discounted term of totality, uncertainty.

Preservation of the environment today is one of the most important, urgent, and comprehensive problems on which the future of mankind and life on the planet as a whole depends. The high rate of growth of material production and population, which were the determining factors of civilization development in recent years, led to a dramatic increase in anthropogenic pressure on the environment. Natural assimilation potential no longer ensures the restoration of the status quo of the natural environment – significant changes have begun in ecosystems, which are irreversible in the near future.

Recently, there has been an intensive search for a new strategy for the survival of mankind under conditions of limited natural resources and the deterioration of the natural conditions of existence of humans as biological species. The problem of the future development of civilization, in general, has come to the forefront of scientific research and public awareness in general. The way out of the current situation is the application of the concept of sustainable development, which is a natural reaction of the world community to existing threats and provides for the harmonious coexistence of nature and society. The introduction of the principles of sustainable development involves taking into consideration environmental and social factors in all spheres of human life [1].

Logistics as a field of practical activity makes its negative contribution to the state of the environment, which is explained by an increase in the share of logistic services in the formation of logistic products and the significant eco-destructive component of these services [2].

Recently, ecological logistics (ecologistics, green logistics) has been used as a modern concept of logistics. Within the concept of sustainable development, ecologistics is considered as an effective approach to the management of material and associated flows in order to reduce environmental and economic damage to the environment [3, 4].

Ecologistics contributes to the prevention and elimination of the consequences of the negative eco-destructive impact on the environment through the transformation of logistic systems, which correspond to the modern linear model of the economy, into ecologistic systems [5]. Closed ecologistic systems make it possible to introduce the principles of the circular economy into economic activity [6, 7].

The transition to a circular economy is becoming global in nature, and the benefits of implementing this concept are getting increasingly apparent. According to experts, the introduction of a closed model will create huge opportunities for the developing of a country, providing annual GDP growth of up to 7 % [8].

Environmentally-oriented logistic systems are a tool for introducing a circular model of the economy. One of the main properties of an ecologistic system is the existence of closed logistic chains, which make it possible to increase the number of products that return to the production cycle in various forms.

As a result, the eco-destructive impact on the environment is reduced by minimizing the use of natural resources and reducing environmental pollution by production and consumption wastes [9].

Improvement of the effectiveness of projects of ecologistic systems requires the use of models and methods of modern management methodologies, in particular, project management. Taking into consideration the specific features of this category of projects, due to their environmental orientation, is a relevant issue that requires additional research.

4.1 LITERATURE REVIEW AND PROBLEM STATEMENT

The issues of designing and functioning of ecologistic systems are actively studied by modern scientists. The importance of taking into account environmental requirements in the optimization of logistic structures is noted in paper [10]. The authors propose to solve the problem of optimization of return material flows from consumers to places of production or disposal within the limits of reverse logistics in combination with traditional problems of logistics.

Paper [11] emphasizes the necessity of transition to the economy of the closed cycle, explores the issues of transformation of logistic systems, and develops the structure of a closed supply chain. In article [12], the peculiarities of functioning of direct and reverse material flows are considered, the expediency of introduction of reverse logistic tools into the logistic activity of an enterprise is substantiated. The authors formed the basic models of functioning of reverse material flows under modern economic conditions, revealed the peculiarities of the motion of return and disposable and recyclable reverse material flows.

In articles [10–12], more attention is paid to taking into consideration the technical and technological aspects of the functioning of ecologistic systems during their designing, the problem of the peculiarities of projects of ecologistic systems, which are substantiated by their ecological considerations, is not tackled.

It is possible to enhance the success of the implementation of projects of ecologistic systems through the use of models and methods of project management methodology [13]. From the standpoint of the project approach, an ecologistic system is considered as a unique result obtained from purposeful temporary activity. Thus, a project of creation of an ecologistic system is given a limited period of time from its beginning to completion, which is called the project life cycle [14].

The project approach involves dividing the project life cycle into phases that are characterized by obtaining a specific product. According to the requirements of the World Bank and the United Nations Economic Development Unit (UNIDO), the project life cycle is divided into pre-investment, investment, and operational phases. Paper [15] emphasized that the project life cycle includes the initial, intermediate, and final phases, which is an enlarged version of gradual project splitting. In paper [16], it is proposed to divide a project not only into phases but also into stages, between which a fuzzy correspondence is established. But in research [15, 16], the need to devote time to neutralizing the eco-destructive impact of a project and its products on the environment is not taken into consideration.

The growing importance of the problem of environmental protection and possible impacts associated with the products that are produced and consumed requires the extension of the life cycle through the addition of eco-oriented phases [17]. The life cycle stages should include the purchase of raw materials, production, and pre-processing usage after the end of service life, re-usage and residual disposal. In article [9], the life cycle is understood as successive and interconnected stages of products (or services), from purchasing raw materials or production from natural resources to disposal. The life cycle stages include the purchase of raw materials, designing, production, transportation/supply, use, final treatment, and/or processing, and final disposal. These papers take into consideration the environmental characteristics of a product but do not address the issues of environmental aspects in the life cycles of projects.

Recently, there have been positive trends of taking into consideration the environmental component in the project activity. The P5 standard includes such areas as "Personnel, Planet, Profit, Process, Product" [18]. In paper [19], the P5 standard was developed, a cognitive model of the project life cycle in the form of communications between the states of the project system was constructed, but not enough attention was paid to the environmental component of a project.

A change in views on the duration and composition of the life cycle phases affects the process of forming project parameters – specific characteristics, on the management of which depends on the project success and effectiveness. The authors of papers [20, 21] draw attention to the need to manage the temporal characteristics of life cycle phases. However, the authors of the research do not consider the issue of the impact of the environmental characteristics of project products on the project effectiveness.

In papers [22, 23], the issues of project time management are considered at the level of studying the formation of the project work schedule. In article [24], it is proposed to use the tools of artificial intelligence to form a schedule of project works. However, environmentally-oriented works of a project do not receive due attention in the time-table and schedule of works.

The method of static and dynamic planning of the characteristics of a project with limited resources is proposed in research [25]. Researchers in papers [26, 27] focus on taking into account the limited resources when determining the project parameters. It is proposed to make compromise decisions between the time and monetary characteristics of a project in case of limited resources in article [28]. But in the above research, the authors, while studying the relationship between limited resources and project parameters very thoroughly, do not separate the environmental component and do not explore its impact on the assessment of the project's effectiveness.

The performed analysis of scientific research on the subject of the project life cycle and formation of project parameters showed that researchers do not pay enough attention to the impact of the project life cycle characteristics on its effectiveness. The life cycle of a project of an ecologistic system has its own specific features, taking which into consideration will make it possible to determine more accurately the project parameters and their impact on the effectiveness of this type of project.

4.2 DETERMINING THE SPECIFIC FEATURES OF THE LIFE CYCLE OF A PROJECT OF AN ECOLOGISTIC SYSTEM

The tool of the introduction of a new, circular model of the economy is an ecologistic system, which implies a closed logistic system as a set of elements-links, interconnected in the process of managing the motion of logistic flows, which takes into account an eco-destructive impact on the environment [5].

An ecologistic system is based on the creation of recycling and disposal flows, which close logistic chains and ensure the circularity of a system. Recycling and disposal flow return products, their parts, components, materials to the process of production and consumption as secondary material resources, components, and products, which makes it possible to reduce consumption of primary resources and extend the service life of products. Thus, a product goes through certain stages of the life cycle to its full disposal. The product life cycle changes its structure and lasts longer due to the implementation of the process's characteristic of a circular model of economy proposed by the Ellen McArthur Foundation [8].

Changes in the life cycle of a product are reflected in the composition and duration of the life cycle of a project of its creation, as the life cycle of a product is an integral part of the life cycle of a project. The project life cycle is divided into separate phases, which, in turn, are divided into stages that end with the receipt of intermediate project results [29]. Project phases can differ not only quantitatively, but also qualitatively (having the same name, phases in different application areas may have different content load). Even in one application area, projects can differ in the number and duration of life cycle phases.

The project life cycle of an ecologistic system has differences from the project life cycle of a logistic system in its classical sense, based on the specific features of this type of project. It is proposed to divide the project life cycle of an ecologistic system into traditional pre-investment, investment, and operational phases, as well as environmentally-oriented regeneration and revitalization phases, on which circular processes and works on the ecosystem renewal will be carried out [17].

At the pre-investment phase, a documented project of an ecologistic system, which must meet all the requirements of project management standards, is designed. The classical definition of a document indicates: a document (from the Latin documentum – an instructive example, sample, proof) is a material object that contains particular information, intended to transmit it in time and space. During the pre-investment phase, project documentation, which is the material carrier of information about a project, is formed from separate documents. Work on project documentation is carried out throughout the phase and includes all project management processes. Based on the information reflected in it, further development of a project until its completion is carried out.

In the investment phase, an ecologistic system in the material representation is created. It is a complex, structured, dynamic system consisting of elements (subsystems, units), interconnected in the process of environmentally-friendly management of the motion of logistic flows. An ecologistic system differs from the logistic one by the existence of the elements that promote the return of material flows.

The creation of an ecologistic system in the investment phase makes it possible during the operational and regeneration phases to provide customers with a range of logistic services that contribute to the effective organization of the motion of material flows (direct and reverse). Logistic services (warehousing, transport, sales, supply, etc.) are the parts of a logistic product and are provided during the operational phase of a project. The complex of logistic services provided in the operational phase must ensure the motion of a material flow in compliance with the rules of ecologistics [5].

In the regeneration phase, recycling logistic services related to the maintenance of return material flows are provided. The logistic operations that form the return logistic services include: collection and return of goods, transportation, warehousing of returned goods and spare parts, recyclables, disassembly of damaged goods or of those with the finished service line, disposal, etc. [9]. To provide recycling logistic services, it is necessary to create an ecologistic system, which will include the appropriate infrastructure that will be the material basis for the promotion of recycling and disposal flow.

In the case of the organization of recycling and disposal flows and the closure of logistic chains, it is about short-term regeneration, in other words, rapid recovery of products or the formation of recyclable material resources. Establishment and operation of the facilities of the transport and logistic infrastructure of an ecologistic system: cargo terminals, warehousing complexes, distributing, repair centers, and other facilities, as well as the creation of communications between these facilities, have a negative effect on the environment. Negative consequences can appear in the short-term, medium-term, and more often in a long-term prospect. To perform a set of actions to eliminate eco-destructive consequences and restore an ecosystem requires time, which is determined by the duration of the latter, revitalization phase of a project of an ecologistic system [17] (**Fig. 4.1**).

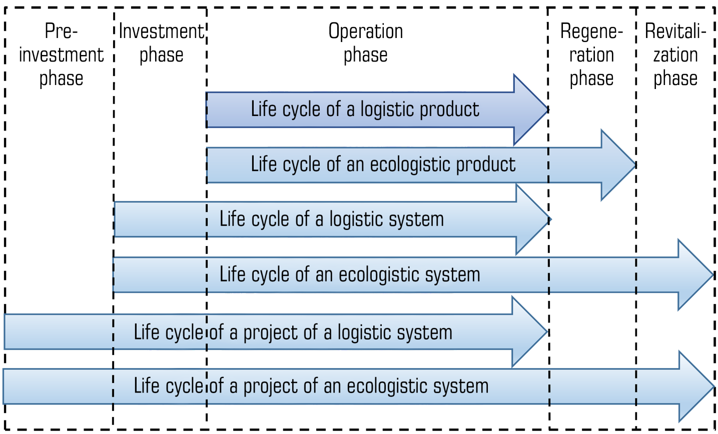

Fig. 4.1 Structure of life cycles of a project of logistic and ecologistic systems

Thus, the greening of a logistic system will result in an increase in the number of phases and the duration of the project life cycle.

4.3 MODEL OF THE LIFE CYCLE OF A PROJECT OF AN ECOLOGISTIC SYSTEM

The life cycle model is presented in the form of a sequence of stages that can overlap and (or) be repeated cyclically according to the project's field of application, size, complexity. In the projects of ecologistic systems, the phases of the life cycle can proceed both consecutively, one after another, and overlap. The investment phase occurs only after the end of the pre-investment phase. The regeneration phase begins before the end of the operational phase when a product from a final consumer enters the reverse flow of material resources. The revitalization phase begins together with the investment phase, proceeds during the operational and regeneration phases, and lasts until the project completion.

The phases of the life cycle of a project of an ecologistic system make up set C^f, $(f=\overline{1;F})$ are the project phases. Project phases are divided into stages that make up set S^{fj}, j $(j=\overline{1;J})$ are the stages of a project phase. The stages are characterized by obtaining intermediate results – intermediate project products.

Time intervals $[t_i;\ t_{i+1}]$ $(i=\overline{1;I-1})$, where t_i is the beginning, t_{i+1} is the end of a time interval of the duration of the stage of a project phase that are milestones correspond to the stages of project phases. It is proposed to separate the following significant events of a project that occur at a certain moment within the life cycle of a project of an ecologistic system:

– t_0 is the project beginning, the pre-investment phase;

– t_1 is the beginning of the investment and revitalization phases, completion of the pre-investment phase;

– t_2 is the beginning of the operational phase, completion of the investment phase;

– t_3 is the beginning of the regeneration phase;

– t_4 is the completion of the operation phase;

– t_5 is the completion of the regeneration phase;

– t_6 is the completion of a project, of a revitalization phase.

Thus, the life cycle includes set TI^i, $(i=\overline{1;I-1})$ of time intervals $[t_i;\ t_{i+1}]$ – periods of time, the beginning and the completion of which are the events that correspond to the beginning or the completion of a project phase.

The life cycle of an ecologistic system project includes the phases that differ in the number of stages in their composition:

– phase 1, pre-investment – $P^{11}_{[t_0;t_1]}$;

– phase 2, investment – $I^{21}_{[t_1;t_2]}$;

– phase 3, operation – $O^{31}_{[t_2;t_3]}$, $O^{32}_{[t_3;t_4]}$;

– phase 4, regeneration – $R^{41}_{[t_3;t_4]}$, $R^{42}_{[t_4;t_5]}$;

– phase 5, revitalization – $V^{51}_{[t_1;t_2]}$, $V^{52}_{[t_2;t_3]}$, $V^{53}_{[t_3;t_4]}$, $V^{54}_{[t_4;t_5]}$, $V^{55}_{[t_5;t_6]}$ [30] (**Fig. 4.2**).

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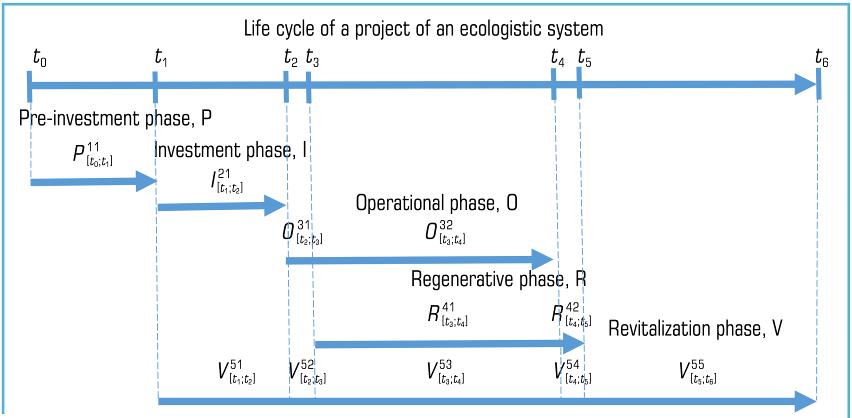


Fig. 4.2 Graphic model of the lifecycle of a project of an ecologistic system

The stages of the life cycle of a project of an ecologistic system are completed by obtaining a result – an intermediate phase product (in case of a single-stage phase) or a stage product (in case of a multi-stage phase), which belongs to a set of project products $R^{fj}_{[t_i;t_{i+1}]}$, $(f=\overline{1;F})$, $(j=\overline{1;J})$, $(i=\overline{1;I-1})$.

4.4 EVALUATION OF THE EFFECTIVENESS OF THE ECOLOGICAL SYSTEM PROJECT USING THE DISCOUNTED PAYBACK PERIOD OF THE PROJECT

Obtaining project products $R^{fj}_{[t_i;t_{i+1}]}$ is characterized by corresponding cash flows $CF^{fj}_{[t_i;t_{i+1}]}$, $(f=\overline{1;F})$, $(j=\overline{1;J})$, $(i=\overline{1;I-1})$. To characterize cash flows in the life cycle of a project of an ecologistic system, a set of cash flows generated by intermediate project products is used:

$$CF^{fj}_{[t_i;t_{i+1}]}=\begin{Bmatrix} CF^{11}_{[t_0;t_1]};\ CF^{21}_{[t_1;t_2]};\ CF^{31}_{[t_2;t_3]};\ CF^{32}_{[t_3;t_4]}; \\ CF^{41}_{[t_3;t_4]};\ CF^{42}_{[t_4;t_5]};\ CF^{51}_{[t_1;t_2]};\ CF^{52}_{[t_2;t_3]}; \\ CF^{53}_{[t_3;t_4]};\ CF^{54}_{[t_4;t_5]};\ CF^{55}_{[t_5;t_6]} \end{Bmatrix}.$$

When calculating cash flows that arrive within time interval $[t_i;\ t_{i+1}]$, $(i=\overline{0;I-1})$, it is necessary to take into account the cash flows generated during the creation of phase products or products of the project's phases or stages that flow during the given interval of time:

$$CF_{[t_i;t_{i+1}]}=\sum_{f=1}^{F}\sum_{j=1}^{J}CF^{fj}_{[t_i;t_{i+1}]}, \tag{4.1}$$

where $CF^{fj}_{[t_i;t_{i+1}]}$ is the cash flows generated during stage j in phase f of the project that is completed within time interval $[t_i; t_{i+1}]$, $(i=\overline{0;I-1})$.

It is proposed to evaluate the effectiveness of a project of an ecologistic system using the criterion of the *Discounted Payback Period (DPP)* as an integrated indicator that takes into consideration the effectiveness of project management in each time interval of the life cycle.

Since modeling of cash flows is carried out at the beginning of a project when it is difficult to accurately predict their values, let's assume that the regeneration phase begins almost simultaneously with the operational phase, in other words, $\Delta t_{23}=(t_3-t_2)\to\min$ and $\Delta t_{45}=(t_5-t_4)\to\min$. In this case, it is possible to assume that cash flows during the operational and regeneration phases take conditionally constant values:

$$CF_{[t_2;t_3]}=CF_{[t_3;t_4]}=CF_{[t_4;t_5]}=CF^{\text{const}}_{[t_i;t_{i+1}]},\ \left(i=\overline{2;5}\right). \quad (4.2)$$

The discounted payback period corresponds to the point in time when the NPV (Net Present Value) of a project is equal to zero, that is, according to formula:

$$-I_0+\sum_{i=1}^{T}CF_i\cdot q^i=0, \quad (4.3)$$

where I_0 is the initial investment in a project; $q=1/(1+r)$ is the discount factor; r is the discount rate. According to [31], to calculate the discounted payback period at constant values of cash flows, let's use:

$$DPP=\log_q\left[1-\frac{I_0(1-q)}{CF_{\text{const}}\cdot q}\right], \quad (4.4)$$

where CF_{const} is the constant cash flows in a project.

Derive the formula of the *DPP* for a project of an ecologistic system, taking into account the specific features of the composition of its life cycle.

Since cash flows during the time interval $[t_2; t_5]$ have constant values, that is $CF_{[t_i;t_{i+1}]}=\text{const}$, $(i=\overline{2;4})$, formula (4.4) will take the form:

$$CF_{[t_0;t_1]}\cdot q^{t_1}+CF_{[t_1;t_2]}\cdot q^{t_2}+\sum_{i=2}^{T}CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}+CF_{[t_5;t_6]}\cdot q^{t_6}=0. \quad (4.5)$$

Hence, it follows:

$$\sum_{i=2}^{T}CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}=-CF_{[t_0;t_1]}\cdot q^{t_1}-CF_{[t_1;t_2]}\cdot q^{t_2}-CF_{[t_5;t_6]}\cdot q^{t_6}, \quad (4.6)$$

$$\sum_{i=2}^{T}q^{t_{i+1}}=\frac{-\left(CF_{[t_0;t_1]}\cdot q^{t_1}+CF_{[t_1;t_2]}\cdot q^{t_2}+CF_{[t_5;t_6]}\cdot q^{t_6}\right)}{CF^{\text{const}}_{[t_i;t_{i+1}]}}. \quad (4.7)$$

Convert the formula of the sum of the first terms of geometric progression and write it down:

$$\sum_{i=2}^{T} q^{t_{i+1}} = \frac{q^{t_i}\left(1-q^T\right)}{1-q}. \quad (4.8)$$

Then,

$$\frac{q^{t_2}\left(1-q^T\right)}{1-q} = \frac{-\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)}{CF^{\text{const}}_{[t_i;t_{i+1}]}}, \quad (4.9)$$

$$q^T = 1 + \frac{\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)(1-q)}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}. \quad (4.10)$$

The payback period can be calculated from the following formula:

$$DPP = T = \log_q\left[1 + \frac{\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)(1-q)}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right], \quad (4.11)$$

if conditions are satisfied:

$$1 + \frac{\left(CF_{[t_0;t_1]}\cdot q^{t_1} + CF_{[t_1;t_2]}\cdot q^{t_2} + CF_{[t_5;t_6]}\cdot q^{t_6}\right)(1-q)}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}} > 0,\ q>0,\ q\neq 1. \quad (4.12)$$

The discounted payback period of a project depends on the values of cash flows in different time intervals $[t_i;\ t_{i+1}]$, $(i=\overline{0;I-1})$, the duration of these intervals, and the discount factor, the value of which depends on the discount rate.

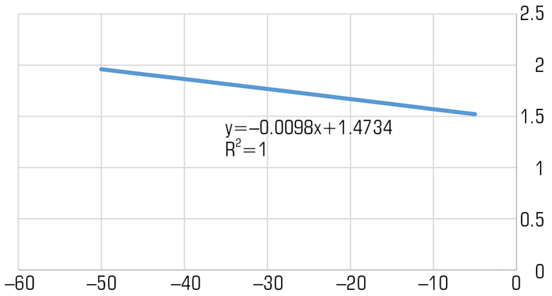
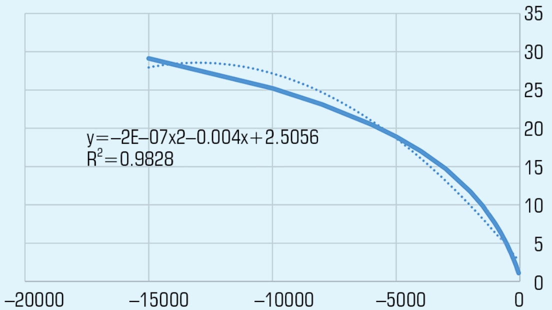
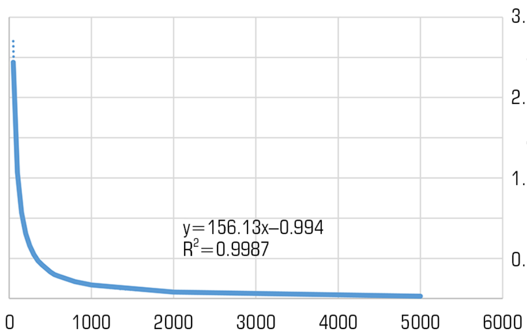
4.5 DETERMINATION OF FUNCTIONAL DEPENDENCIES BETWEEN THE DISCOUNTED LIFETIME AND CASH FLOWS DURING THE LIFE CYCLE PHASES OF THE ECOLOGICAL SYSTEM PROJECT

During the study, experimental calculations were performed, which made it possible to identify the dependences between cash flows during the project life cycle and the discounted payback period of a project on an ecologistic system. The obtained results are shown in **Table 4.1**.

The experimental data were approximated, as a result of which the mathematical equations that describe functional dependences between argument and the value of the function were obtained. The cash flow of pre-investment phase $CF_{[t_0;t_1]}$, cash flow of investment phase $CF_{[t_1;t_2]}$, cash flows of project's operational and regeneration phases $\sum_{i=2}^{5} CF^{\text{const}(O,R)}_{[t_i;t_{i+1}]}$, cash flows of revitalization phase

$\sum_{i=1}^{5} CF_{[t_i;t_{i+1}]}^{V}$ are the arguments of the function. The value of the function is discounted payback period of a project of an ecologistic system *DPP*.

Table 4.1 Functional dependences between cash flows and a payback period of a project of an ecologistic system

Indicator	**Chart of functional dependence**
1	**2**
Cash flow of pre-investment phase $CF_{[t_0;t_1]}$	
Cash flow of investment phase $CF_{[t_1;t_2]}$	
Cash flows of project's operational and regeneration phases $\sum_{i=2}^{5} CF_{[t_i;t_{i+1}]}^{const(O,R)}$	

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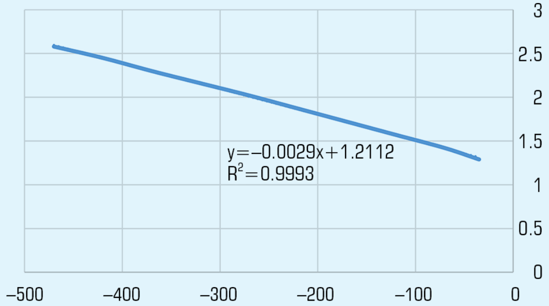
Continuation of Table 4.1

1	2
Cash flow of revitalization phase $\sum_{i=1}^{5} CF^{V}_{[t_i;t_{i+1}]}$	

For each of the analyzed parameters, the degree of approximation was determined with the help of approximation reliability R^2 and the most appropriate functional dependence was chosen.

The performed study showed that the dependence between the discounted payback period *DPP* and cash flow of the investment phase $CF_{[t_1;t_2]}$ is described by a polynomial (square trinomial) $y=-2E-07x^2-0.004x+2.5056$ at approximation reliability $R^2=0.9828$. Thus, the analytic expression to determine the dependence is the polynomial function of the form $y=ax^2+bx+c$ $(a\neq0,\ b\neq0)$ with the region of determining $(-\infty;\ 0)$. There is an inverse dependence between the payback period and the cash flows of the investment phase, an increase in the payback period gradually slows down at an increase in investment costs in the creation of an ecologistic system.

Dependence of the discounted payback period *DPP* on cash flows of the project's operational and regeneration phases $\sum_{i=2}^{5} CF^{const(O,R)}_{[t_i;t_{i+1}]}$ is expressed by function $y=156.13x^{-0.994}$ with approximation reliability $R^2=0.9987$. The analytical expression to determine the dependence is the power function of the form $y=ax^n$ $(a\neq0)$ with the region of determining $(0;\ +\infty)$. There is a direct relationship between the payback period and the cash flows of the operational and regeneration phases, the rate of an increase in the payback period slows down at an increase in cash flows.

The dependence that is observed between the discounted payback period and cash flows of the pre-investment and revitalization phases is linear and is expressed by function $y=-0.0098x+1.4734$ with approximation reliability $R^2=1$ and $y=-0.0029x+1.2112$ with approximation reliability $R^2=0.9993$, respectively. The dependence in both cases is expressed analytically by a linear function of the form of $y=kx+b$ $(k\neq0)$ with the region of determining function $(-\infty;\ 0)$. There is an inverse dependence between the payback period and the costs of the pre-investment and investment phases.

The conducted study revealed the dependences between the criterion of project effectiveness – the discounted payback period and cash flows, which received functional expression. The dynamics of changes in the payback period are represented by various mathematical functions depending on the phase, to which the cash flows belong. Detection of this phenomenon will make it possible to predict the changes in the payback period of a project depending on the changes in cash flows of each phase of the project life cycle.

4.6 ESTIMATES OF THE EFFECTIVENESS OF THE ECOLOGICAL SYSTEM PROJECT UNDER CONDITIONS OF UNCERTAINTY

In conditions of uncertainty, it is possible to evaluate the effectiveness of the project of the ecological system through a fuzzy defined DPP thanks to the application of the tools of the theory of fuzzy sets. In particular, by introducing fuzzy values of cash flows corresponding to certain time intervals of the project's life cycle. The reason for such actions is the lack of an opportunity to accurately forecast future values of cash flows in the pre-investment phase.

When calculating the DPP, it is suggested to take into account the impact of uncertainty by taking into account the fuzziness of the values of money $CF_{[t_i;t_{i+1}]}$, which are generated at time intervals $[t_i;t_{i+1}]$ and correspond to individual stages of the life cycle of the ecological system project. $CF_{[t_i;t_{i+1}]} = \left\{ \left(CF^{n[t_i;t_{i+1}]}_{[t_i;t_{i+1}]};\ \mu_{CF_{[t_i;t_{i+1}]}} \left(CF^{n[t_i;t_{i+1}]}_{[t_i;t_{i+1}]} \right) \right) \right\}, \left(n_{[t_i;t_{i+1}]} = \overline{1, N_{[t_i;t_{i+1}]}} \right)$ is a fuzzy set of cash flows of the time interval $[t_i;t_{i+1}]$, $(i = \overline{0; I-1})$, the life cycle of the ecological system project.

Cash flows $CF^{fj}_{[t_i;t_{i+1}]}$ vary throughout the life cycle and take, depending on the inflows $IF^{fj}_{[t_i;t_{i+1}]}$ and outflows $OF^{fj}_{[t_i;t_{i+1}]}$, positive or negative values depending on the stage of the project.

The set of time intervals TI^i includes two subsets:

– a subset of time intervals $TI^i(OF)$ to which cash flows $CF^{fj}_{[t_i;t_{i+1}]}$ correspond, consisting only of outgoing cash flows $IF^{fj}_{[t_i;t_{i+1}]}$, i.e.

$$TI^i(IF; OF) \in TI^i(IF = 0; OF \neq 0),$$

$$TI^i(OF) = \left\{ [t_0;t_1]; [t_1;t_2]; [t_5;t_6] \right\};$$

– a subset of time intervals $TI^i(IF, OF)$ to which cash flows $CF^{fj}_{[t_i;t_{i+1}]}$ correspond, consisting of incoming $IF^{fj}_{[t_i;t_{i+1}]}$ and outgoing $IF^{fj}_{[t_i;t_{i+1}]}$ cash flows, i.e.

$$TI^i(IF; OF) \in TI^i(IF \neq 0; OF \neq 0),$$

$$TI^i(IF;OF) = \left\{ [t_2;t_3]; [t_3;t_4]; [t_4;t_5] \right\}.$$

Cash flows are formed at time intervals that belong to set $TI^i(OF)$ outgoing cash flows for:

– pre-investment phase:

$$CF_{[t_0;t_1]} = CF^{11}_{[t_0;t_1]} = OF^{11}_{[t_0;t_1]}; \quad (4.13)$$

– investment phase:

$$CF_{[t_1;t_2]} = CF^{21}_{[t_1;t_2]} + CF^{51}_{[t_1;t_2]} = OF^{21}_{[t_1;t_2]} + OF^{51}_{[t_1;t_2]}; \quad (4.14)$$

– the last stage of the revitalization phase:

$$CF_{[t_5;t_6]} = CF^{56}_{[t_5;t_6]} = OF^{56}_{[t_5;t_6]}. \quad (4.15)$$

The time intervals $TI^i(IF;OF)$ of the life cycle, which are characterized not only by outgoing, but also by incoming cash flows, include cash flows:

– the first stage of operation and the second stage of the revitalization phase:

$$CF_{[t_2;t_3]} = CF^{31}_{[t_2;t_3]} + CF^{52}_{[t_2;t_3]} = IF^{31}_{[t_2;t_3]} + OF^{31}_{[t_2;t_3]} + IF^{52}_{[t_2;t_3]} + OF^{52}_{[t_2;t_3]}; \quad (4.16)$$

– the second stage of the operational, the first stage of the regenerative and the third stage of the revitalization phases:

$$CF_{[t_3;t_4]} = CF^{32}_{[t_3;t_4]} + CF^{41}_{[t_3;t_4]} + CF^{53}_{[t_3;t_4]} =$$

$$= IF^{32}_{[t_3;t_4]} + OF^{32}_{[t_3;t_4]} + IF^{41}_{[t_3;t_4]} + OF^{41}_{[t_3;t_4]} + IF^{53}_{[t_3;t_4]} + OF^{53}_{[t_3;t_4]}; \quad (4.17)$$

– the second stage of the regenerative and the fourth stage of the revitalization phases:

$$CF_{[t_4;t_5]} = CF^{42}_{[t_4;t_5]} + CF^{54}_{[t_4;t_5]} = IF^{42}_{[t_4;t_5]} + OF^{42}_{[t_4;t_5]} + IF^{54}_{[t_4;t_5]} + OF^{54}_{[t_4;t_5]}. \quad (4.18)$$

The cash flows of the project $CF_{[t_i;t_{i+1}]}$ are formed from the incoming $IF_{[t_i;t_{i+1}]}$ and outgoing $OF_{[t_i;t_{i+1}]}$ flows corresponding to the time interval $[t_i;t_{i+1}]$, and in fuzzy defined conditions can be represented in the form of fuzzy sets:

– $IF_{[t_i;t_{i+1}]} = \left\{ \left(IF^{k_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]}; \mu_{IF_{[t_i;t_{i+1}]}} \left(IF^{k_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]} \right) \right) \right\}$, $\left(k_{[t_i;t_{i+1}]} = \overline{1, K_{[t_i;t_{i+1}]}} \right)$ – a fuzzy set of incoming cash flows during the time interval $[t_i;t_{i+1}]$, $\left(i = \overline{0; I-1} \right)$ of the life cycle of the ecological system project (**Table 4.2**);

– $OF_{[t_i;t_{i+1}]} = \left\{ \left(OF^{l_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]}; \mu_{OF_{[t_i;t_{i+1}]}} \left(OF^{l_{[t_i;t_{i+1}]}}_{[t_i;t_{i+1}]} \right) \right) \right\}$, $\left(l_{[t_i;t_{i+1}]} = \overline{1, L_{[t_i;t_{i+1}]}} \right)$ – a fuzzy set of initial cash flows during the time interval $[t_i;t_{i+1}]$, $\left(i = \overline{0; I-1} \right)$ of the life cycle of the ecological system project (**Table 4.3**).

Table 4.2 Incoming cash flows of the ecological system project

Time interval $\left[t_i;t_{i+1}\right]$	**Fuzzy value of incoming cash flows**
$\left[t_0;t_1\right]$	–
$\left[t_1;t_2\right]$	–
$\left[t_2;t_3\right]$	$IF_{[t_2;t_3]} = \left\{\left(IF_{[t_2;t_3]}^{k_{[t_2;t_3]}};\mu_{IF_{[t_2;t_3]}}\left(IF_{[t_2;t_3]}^{k_{[t_2;t_3]}}\right)\right)\right\},\ \left(k_{[t_2;t_2]} = \overline{1,K_{[t_2;t_2]}}\right)$ $IF_{[t_2;t_3]}^{31} = \left\{\left(IF_{[t_2;t_3]}^{31h};\mu_{IF_{[t_2;t_3]}^{31}}\left(IF_{[t_2;t_3]}^{31h}\right)\right)\right\},\ \left(h = \overline{1,H^{31}}\right)$ $IF_{[t_2;t_3]}^{52} = \left\{\left(IF_{[t_2;t_3]}^{52h};\mu_{IF_{[t_2;t_3]}^{31}}\left(IF_{[t_2;t_3]}^{52h}\right)\right)\right\},\ \left(h = \overline{1,H^{52}}\right)$
$\left[t_3;t_4\right]$	$IF_{[t_3;t_4]} = \left\{\left(IF_{[t_3;t_4]}^{k_{[t_3;t_4]}};\mu_{IF_{[t_3;t_4]}}\left(IF_{[t_3;t_4]}^{k_{[t_3;t_4]}}\right)\right)\right\},\ \left(k_{[t_3;t_4]} = \overline{1,K_{[t_3;t_4]}}\right)$ $IF_{[t_3;t_4]}^{32} = \left\{\left(IF_{[t_3;t_4]}^{32h};\mu_{IF_{[t_3;t_4]}^{32}}\left(IF_{[t_3;t_4]}^{32h}\right)\right)\right\},\ \left(h = \overline{1,H^{32}}\right)$ $IF_{[t_3;t_4]}^{41} = \left\{\left(IF_{[t_3;t_4]}^{41h};\mu_{IF_{[t_3;t_4]}^{41}}\left(IF_{[t_3;t_4]}^{41h}\right)\right)\right\},\ \left(h = \overline{1,H^{41}}\right)$ $IF_{[t_3;t_4]}^{53} = \left\{\left(IF_{[t_3;t_4]}^{53h};\mu_{IF_{[t_3;t_4]}^{53}}\left(IF_{[t_3;t_4]}^{53h}\right)\right)\right\},\ \left(h = \overline{1,H^{53}}\right)$
$\left[t_4;t_5\right]$	$IF_{[t_4;t_5]} = \left\{\left(IF_{[t_4;t_5]}^{k_{[t_4;t_5]}};\mu_{IF_{[t_4;t_5]}}\left(IF_{[t_4;t_5]}^{k_{[t_4;t_5]}}\right)\right)\right\},\ \left(k_{[t_4;t_5]} = \overline{1,K_{[t_4;t_5]}}\right)$ $IF_{[t_4;t_5]}^{42} = \left\{\left(IF_{[t_4;t_5]}^{42h};\mu_{IF_{[t_4;t_5]}^{42}}\left(IF_{[t_4;t_5]}^{42h}\right)\right)\right\},\ \left(h = \overline{1,H^{42}}\right)$ $IF_{[t_4;t_5]}^{54} = \left\{\left(IF_{[t_4;t_5]}^{54h};\mu_{IF_{[t_4;t_5]}^{54}}\left(IF_{[t_4;t_5]}^{54h}\right)\right)\right\},\ \left(h = \overline{1,H^{54}}\right)$
$\left[t_5;t_6\right]$	–

Table 4.3 Outgoing cash flows of the ecological system project

Time interval $\left[t_i;t_{i+1}\right]$	**Fuzzy value of outgoing cash flows**
1	**2**
$\left[t_0;t_1\right]$	$OF_{[t_0;t_1]} = \left\{\left(OF_{[t_0;t_1]}^{l_{[t_0;t_1]}};\mu_{OF_{[t_0;t_1]}}\left(OF_{[t_0;t_1]}^{l_{[t_0;t_1]}}\right)\right)\right\},\ \left(l_{[t_0;t_1]} = \overline{1,L_{[t_0;t_1]}}\right)$ $OF_{[t_0;t_1]}^{11} = \left\{\left(OF_{[t_0;t_1]}^{11g};\mu_{OF_{[t_0;t_1]}^{11}}\left(OF_{[t_0;t_1]}^{11g}\right)\right)\right\},\ \left(g = \overline{1,G^{11}}\right)$
$\left[t_1;t_2\right]$	$OF_{[t_1;t_2]} = \left\{\left(OF_{[t_1;t_2]}^{l_{[t_1;t_2]}};\mu_{OF_{[t_1;t_2]}}\left(OF_{[t_1;t_2]}^{l_{[t_1;t_2]}}\right)\right)\right\},\ \left(l_{[t_1;t_2]} = \overline{1,L_{[t_1;t_2]}}\right)$ $OF_{[t_1;t_2]}^{21} = \left\{\left(OF_{[t_1;t_2]}^{21g};\mu_{OF_{[t_1;t_2]}^{21}}\left(OF_{[t_1;t_2]}^{21g}\right)\right)\right\},\ \left(g = \overline{1,G^{21}}\right)$

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Continuation of Table 4.3

1	2
$\left[t_2;t_3\right]$	$OF_{[t_2;t_3]}=\left\{\left(OF_{[t_2;t_3]}^{l_{[t_2;t_3]}};\mu_{OF_{[t_2;t_3]}}\left(OF_{[t_2;t_3]}^{l_{[t_2;t_3]}}\right)\right)\right\},\ \left(l_{[t_2;t_2]}=\overline{1,L_{[t_2;t_2]}}\right)$ $OF_{[t_2;t_3]}^{31}=\left\{\left(OF_{[t_2;t_3]}^{31g};\mu_{OF_{[t_2;t_3]}^{31}}\left(OF_{[t_2;t_3]}^{31g}\right)\right)\right\},\ \left(g=\overline{1,G^{31}}\right)$ $OF_{[t_2;t_3]}^{52}=\left\{\left(OF_{[t_2;t_3]}^{52g};\mu_{OF_{[t_2;t_3]}^{31}}\left(OF_{[t_2;t_3]}^{52g}\right)\right)\right\},\ \left(g=\overline{1,G^{52}}\right)$
$\left[t_3;t_4\right]$	$OF_{[t_3;t_4]}=\left\{\left(OF_{[t_3;t_4]}^{l_{[t_3;t_4]}};\mu_{OF_{[t_3;t_4]}}\left(OF_{[t_3;t_4]}^{l_{[t_3;t_4]}}\right)\right)\right\},\ \left(l_{[t_3;t_4]}=\overline{1,L_{[t_3;t_4]}}\right)$ $OF_{[t_3;t_4]}^{32}=\left\{\left(OF_{[t_3;t_4]}^{32g};\mu_{OF_{[t_3;t_4]}^{32}}\left(OF_{[t_3;t_4]}^{32g}\right)\right)\right\},\ \left(g=\overline{1,G^{32}}\right)$ $OF_{[t_3;t_4]}^{41}=\left\{\left(OF_{[t_3;t_4]}^{41g};\mu_{OF_{[t_3;t_4]}^{41}}\left(OF_{[t_3;t_4]}^{41g}\right)\right)\right\},\ \left(g=\overline{1,G^{41}}\right)$ $OF_{[t_3;t_4]}^{53}=\left\{\left(OF_{[t_3;t_4]}^{53g};\mu_{OF_{[t_3;t_4]}^{53}}\left(OF_{[t_3;t_4]}^{53g}\right)\right)\right\},\ \left(g=\overline{1,G^{53}}\right)$
$\left[t_4;t_5\right]$	$OF_{[t_4;t_5]}=\left\{\left(OF_{[t_4;t_5]}^{l_{[t_4;t_5]}};\mu_{OF_{[t_4;t_5]}}\left(OF_{[t_4;t_5]}^{l_{[t_4;t_5]}}\right)\right)\right\},\ \left(l_{[t_4;t_5]}=\overline{1,L_{[t_4;t_5]}}\right)$ $OF_{[t_4;t_5]}^{42}=\left\{\left(OF_{[t_4;t_5]}^{42g};\mu_{OF_{[t_4;t_5]}^{42}}\left(OF_{[t_4;t_5]}^{42g}\right)\right)\right\},\ \left(g=\overline{1,G^{42}}\right)$ $OF_{[t_4;t_5]}^{54}=\left\{\left(OF_{[t_4;t_5]}^{54g};\mu_{OF_{[t_4;t_5]}^{54}}\left(OF_{[t_4;t_5]}^{54g}\right)\right)\right\},\ \left(g=\overline{1,G^{54}}\right)$
$\left[t_5;t_6\right]$	$OF_{[t_5;t_6]}=\left\{\left(OF_{[t_5;t_6]}^{l_{[t_5;t_6]}};\mu_{OF_{[t_5;t_6]}}\left(OF_{[t_5;t_6]}^{l_{[t_5;t_6]}}\right)\right)\right\},\ \left(l_{[t_5;t_6]}=\overline{1,L_{[t_5;t_6]}}\right)$ $OF_{[t_5;t_6]}^{56}=\left\{\left(OF_{[t_5;t_6]}^{56g};\mu_{OF_{[t_5;t_6]}^{56}}\left(OF_{[t_5;t_6]}^{56g}\right)\right)\right\},\ \left(g=\overline{1,G^{56}}\right)$

The cash flows of the project $CF_{[t_i;t_{i+1}]}^{fj}$, which correspond to the stage j $(j=\overline{1;J})$ of the project phase f $(f=\overline{1;F})$, are formed from the input $IF_{[t_i;t_{i+1}]}^{fj}$ and outgoing $OF_{[t_i;t_{i+1}]}^{fj}$ flows and in fuzzy defined conditions can be represented in the form of fuzzy sets:

– $IF_{[t_i;t_{i+1}]}^{fjh}=\left\{\left(IF_{[t_i;t_{i+1}]}^{fjh};\mu_{IF_{[t_i;t_{i+1}]}^{fj}}\left(IF_{[t_i;t_{i+1}]}^{fjh}\right)\right)\right\},\ \left(h=\overline{1,H^{fj}}\right)$ – a fuzzy set of incoming cash flows corresponding to stage j of phase f of the project during the time interval of the life cycle of the ecological system project;

– $OF_{[t_i;t_{i+1}]}^{fjg}=\left\{\left(OF_{[t_i;t_{i+1}]}^{fjg};\mu_{OF_{[t_i;t_{i+1}]}^{fj}}\left(OF_{[t_i;t_{i+1}]}^{fjg}\right)\right)\right\},\ \left(g=\overline{1,G^{fj}}\right)$ – a fuzzy set of initial cash flows corresponding to stage j of phase f of the project during the time interval $\left[t_i;t_{i+1}\right]$ of the life cycle of the ecological system project.

To calculate fuzzy defined cash flows $CF_{[t_i;t_{i+1}]}$, incoming $IF_{[t_i;t_{i+1}]}$ and outgoing $OF_{[t_i;t_{i+1}]}$ cash flows corresponding to a time interval $\left[t_i;t_{i+1}\right]$, it is advisable to use trapezoidal fuzzy numbers. This assumption is based on the fact that the flows (input and output) are defined on the set of real numbers R. Fuzzy numbers used in the calculation of the fuzzy expressed DPP value of the ecological system project:

1. *Cash incoming flows*:

$$\left(IF_{[t_2;t_3]1},IF_{[t_2;t_3]2},IF_{[t_2;t_3]3},IF_{[t_2;t_3]4}\right)=\begin{pmatrix}IF^{31}_{[t_2;t_3]1}+IF^{52}_{[t_2;t_3]1},IF^{31}_{[t_2;t_3]2}+IF^{52}_{[t_2;t_3]2},\\IF^{31}_{[t_2;t_3]3}+IF^{52}_{[t_2;t_3]3},IF^{31}_{[t_2;t_3]4}+IF^{52}_{[t_2;t_3]4}\end{pmatrix}, \quad (4.19)$$

$$\left(IF_{[t_3;t_4]1},IF_{[t_3;t_4]2},IF_{[t_3;t_4]3},IF_{[t_3;t_4]4}\right)=\begin{pmatrix}IF^{32}_{[t_3;t_4]1}+IF^{41}_{[t_3;t_4]1}+IF^{53}_{[t_3;t_4]1},\\IF^{32}_{[t_3;t_4]2}+IF^{41}_{[t_3;t_4]2}+IF^{53}_{[t_3;t_4]2},\\IF^{32}_{[t_3;t_4]3}+IF^{41}_{[t_3;t_4]3}+IF^{53}_{[t_3;t_4]3},\\IF^{32}_{[t_3;t_4]4}+IF^{41}_{[t_3;t_4]4}+IF^{53}_{[t_3;t_4]4}\end{pmatrix}, \quad (4.20)$$

$$\left(IF_{[t_4;t_5]1},IF_{[t_4;t_5]2},IF_{[t_4;t_5]3},IF_{[t_4;t_5]4}\right)=\begin{pmatrix}IF^{42}_{[t_4;t_5]1}+IF^{54}_{[t_4;t_5]1},IF^{42}_{[t_4;t_5]2}+IF^{54}_{[t_4;t_5]2},\\IF^{42}_{[t_4;t_5]3}+IF^{54}_{[t_4;t_5]3},IF^{42}_{[t_4;t_5]3}+IF^{54}_{[t_4;t_5]4}\end{pmatrix}. \quad (4.21)$$

2. *Cash outgoing flows*:

$$\left(OF_{[t_0;t_1]1},OF_{[t_0;t_1]2},OF_{[t_0;t_1]3},OF_{[t_0;t_1]4}\right), \quad (4.22)$$

$$\left(OF_{[t_1;t_2]1},OF_{[t_1;t_2]2},OF_{[t_1;t_2]3},OF_{[t_1;t_2]4}\right), \quad (4.23)$$

$$\left(OF_{[t_2;t_3]1},OF_{[t_2;t_3]2},OF_{[t_2;t_3]3},OF_{[t_2;t_3]4}\right)=\begin{pmatrix}OF^{31}_{[t_2;t_3]1}+OF^{52}_{[t_2;t_3]1},OF^{31}_{[t_2;t_3]2}+OF^{52}_{[t_2;t_3]2},\\OF^{31}_{[t_2;t_3]3}+OF^{52}_{[t_2;t_3]3},OF^{31}_{[t_2;t_3]4}+OF^{52}_{[t_2;t_3]4}\end{pmatrix}, \quad (4.24)$$

$$\left(OF_{[t_4;t_5]1},OF_{[t_4;t_5]2},OF_{[t_4;t_5]3},OF_{[t_4;t_5]4}\right)=\begin{pmatrix}OF^{42}_{[t_4;t_5]1}+OF^{54}_{[t_4;t_5]1},OF^{42}_{[t_4;t_5]2}+OF^{54}_{[t_4;t_5]2},\\OF^{42}_{[t_4;t_5]3}+OF^{54}_{[t_4;t_5]3},OF^{42}_{[t_4;t_5]4}+OF^{54}_{[t_4;t_5]4}\end{pmatrix}, \quad (4.25)$$

$$\left(OF_{[t_3;t_4]1},OF_{[t_3;t_4]2},OF_{[t_3;t_4]3},OF_{[t_3;t_4]4}\right)=\begin{pmatrix}OF^{32}_{[t_3;t_4]1}+OF^{41}_{[t_3;t_4]1}+OF^{53}_{[t_3;t_4]1},\\OF^{32}_{[t_3;t_4]2}+OF^{41}_{[t_3;t_4]2}+OF^{53}_{[t_3;t_4]2},\\OF^{32}_{[t_3;t_4]3}+OF^{41}_{[t_3;t_4]3}+OF^{53}_{[t_3;t_4]3},\\OF^{32}_{[t_3;t_4]4}+OF^{41}_{[t_3;t_4]4}+OF^{53}_{[t_3;t_4]4}\end{pmatrix}, \quad (4.26)$$

$$\left(OF_{[t_5;t_6]1},OF_{[t_5;t_6]2},OF_{[t_5;t_6]3},OF_{[t_5;t_6]4}\right). \quad (4.27)$$

3. *Cash flows*:

$$\begin{pmatrix} CF_{[t_0;t_1]1}, CF_{[t_0;t_1]2}, \\ CF_{[t_0;t_1]3}, CF_{[t_0;t_1]4} \end{pmatrix} = \begin{pmatrix} IF_{[t_0;t_1]1} - OF_{[t_0;t_1]4}, \\ IF_{[t_0;t_1]2} - OF_{[t_0;t_1]3}, \\ IF_{[t_0;t_1]3} - OF_{[t_0;t_1]2}, \\ IF_{[t_0;t_1]4} - OF_{[t_0;t_1]1} \end{pmatrix}, \quad (4.28)$$

$$\begin{pmatrix} CF_{[t_1;t_2]1}, CF_{[t_1;t_2]2}, \\ CF_{[t_1;t_2]3}, CF_{[t_1;t_2]4} \end{pmatrix} = \begin{pmatrix} IF_{[t_1;t_2]1} - OF_{[t_1;t_2]4}, \\ IF_{[t_1;t_2]2} - OF_{[t_1;t_2]3}, \\ IF_{[t_1;t_2]3} - OF_{[t_1;t_2]2}, \\ IF_{[t_1;t_2]4} - OF_{[t_1;t_2]1} \end{pmatrix}, \quad (4.29)$$

$$\begin{pmatrix} CF_{[t_5;t_6]1}, CF_{[t_5;t_6]2}, \\ CF_{[t_5;t_6]3}, CF_{[t_5;t_6]4} \end{pmatrix} = \begin{pmatrix} IF_{[t_5;t_6]1} - OF_{[t_5;t_6]4}, \\ IF_{[t_5;t_6]2} - OF_{[t_5;t_6]3}, \\ IF_{[t_5;t_6]3} - OF_{[t_5;t_6]2}, \\ IF_{[t_5;t_6]4} - OF_{[t_5;t_6]1} \end{pmatrix}, \quad (4.30)$$

$$\begin{pmatrix} CF^{const}_{[t_i;t_{i+1}]1}, CF^{const}_{[t_i;t_{i+1}]2}, \\ CF^{const}_{[t_i;t_{i+1}]3}, CF^{const}_{[t_i;t_{i+1}]4} \end{pmatrix} = \begin{pmatrix} IF^{const}_{[t_i;t_{i+1}]1} - OF^{const}_{[t_i;t_{i+1}]4}, \\ IF^{const}_{[t_i;t_{i+1}]2} - OF^{const}_{[t_i;t_{i+1}]3}, \\ IF^{const}_{[t_i;t_{i+1}]3} - OF^{const}_{[t_i;t_{i+1}]2}, \\ IF^{const}_{[t_i;t_{i+1}]4} - OF_{[t_i;t_{i+1}]1} \end{pmatrix}. \quad (4.31)$$

4. *Discounted cash flows*:

$$\left(CF_{[t_0;t_1]1} \cdot q^{t_1}, CF_{[t_0;t_1]2} \cdot q^{t_1}, CF_{[t_0;t_1]3} \cdot q^{t_1}, CF_{[t_0;t_1]4} \cdot q^{t_1}\right), \quad (4.32)$$

$$\left(CF_{[t_1;t_2]1} \cdot q^{t_2}, CF_{[t_1;t_2]2} \cdot q^{t_2}, CF_{[t_1;t_2]3} \cdot q^{t_2}, CF_{[t_1;t_2]4} \cdot q^{t_2}\right), \quad (4.33)$$

$$\left(CF_{[t_5;t_6]1} \cdot q^{t_6}, CF_{[t_5;t_6]2} \cdot q^{t_6}, CF_{[t_5;t_6]3} \cdot q^{t_6}, CF_{[t_5;t_6]4} \cdot q^{t_6}\right), \quad (4.34)$$

$$\left(CF^{const}_{[t_i;t_{i+1}]1} \cdot q^{t_2}, CF^{const}_{[t_i;t_{i+1}]2} \cdot q^{t_2}, CF^{const}_{[t_i;t_{i+1}]3} \cdot q^{t_2}, CF^{const}_{[t_i;t_{i+1}]4} \cdot q^{t_2}\right). \quad (4.35)$$

5. *Amount of discounted cash flows*:

$$\begin{pmatrix} \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_1, \\ \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_2, \\ \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_3, \\ \left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_4 \end{pmatrix} = \begin{pmatrix} CF_{[t_0;t_1]1}\cdot q^{t_1} + CF_{[t_1;t_2]1}\cdot q^{t_2} + CF_{[t_5;t_6]1}\cdot q^{t_6}; \\ CF_{[t_0;t_1]2}\cdot q^{t_1} + CF_{[t_1;t_2]2}\cdot q^{t_2} + CF_{[t_5;t_6]2}\cdot q^{t_6}; \\ CF_{[t_0;t_1]3}\cdot q^{t_1} + CF_{[t_1;t_2]3}\cdot q^{t_2} + CF_{[t_5;t_6]3}\cdot q^{t_6}; \\ CF_{[t_0;t_1]4}\cdot q^{t_1} + CF_{[t_1;t_2]4}\cdot q^{t_2} + CF_{[t_5;t_6]4}\cdot q^{t_6}; \end{pmatrix}. \tag{4.36}$$

6. *Cash flow ratio*:

$$\begin{pmatrix} \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_1, \\ \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_2, \\ \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_3, \\ \left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_4 \end{pmatrix} = \begin{pmatrix} \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_1}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_4}; \\ \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_2}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_3}; \\ \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_3}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_2}; \\ \dfrac{\left(\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}\right)_4}{\left(CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}\right)_1} \end{pmatrix}. \tag{4.37}$$

7. *Discounted payback period*:

$$\begin{pmatrix} DPP_1; \\ DPP_2; \\ DPP_3; \\ DPP_4; \end{pmatrix} = \begin{pmatrix} \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_1 (1-q)\right)_1, \\ \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_2 (1-q)\right)_2, \\ \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_3 (1-q)\right)_3, \\ \log_q\left(1+\left(\dfrac{\sum CF_{[t_i;t_{i+1}]}\cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]}\cdot q^{t_2}}\right)_4 (1-q)\right)_4 \end{pmatrix}. \tag{4.38}$$

Therefore, if at the beginning of the ecological system project it is possible to predict the value of cash flows for various stages, phases and time intervals of the life cycle, as well as to determine the value of the discount rate of cash funds, the *DPP* of the project is calculated according to formula (4.11). In conditions of uncertainty, it is proposed to calculate the fuzzy expressed *DPP* value of the project using a sequence of mathematical expressions represented by formulas (4.19)–(4.38).

4.7 EXPERIMENTAL CALCULATIONS REGARDING THE EVALUATION OF THE EFFECTIVENESS OF THE ECOLOGICAL SYSTEM PROJECT

Input data for *DPP* calculations of the ecological system project are presented in **Table 4.4**. According to the data presented in **Table 4.4**, the value of the project equal to 1306 years was obtained.

In conditions of uncertainty, the effectiveness of the project of the ecological system is evaluated with the help of a fuzzy defined way of introducing fuzzy values of cash flows $CF_{[t_i;t+1]}$ that correspond to the time intervals $[t_i;t_{i+1}]$ of the life cycle of the project.

To calculate fuzzy defined $CF_{[t_i;t+1]}$ and *DPP* let's use trapezoidal fuzzy numbers (**Table 4.5**).

Table 4.4 Cash flows of the ecological system project

project phase	Cash flows, *CF*, c.u					
	Phase interval					
	$[t_0;t_1]$	$[t_1;t_2]$	$[t_2;t_3]$	$[t_3;t_4]$	$[t_4;t_5]$	$[t_5;t_6]$
Discounted cash flows, CF_{disc}	–3182	–438017	360631	327847	298042	–84671

Table 4.5 Fuzzy numbers for determining cash flows/discounted cash flows of an ecological system project

Cash flows			
$CF_{[t_0;t_1]}$	$CF_{[t_0;t_1]1}$	–4500	0
	$CF_{[t_0;t_1]2}$	–4100	1
	$CF_{[t_0;t_1]3}$	–3600	1
	$CF_{[t_0;t_1]4}$	–3200	0
$CF_{[t_1;t_2]}$	$CF_{[t_1;t_2]1}$	–550000	0
	$CF_{[t_1;t_2]2}$	–540000	1
	$CF_{[t_1;t_2]3}$	–520000	1
	$CF_{[t_1;t_2]4}$	–500000	0
$CF_{[t_2;t_3]}$ $CF_{[t_3;t_4]}$ $CF_{[t_5;t_6]}$	$CF^{const}_{[t_i;t_{i+1}]1}$	460000	0
	$CF^{const}_{[t_i;t_{i+1}]2}$	430000	1
	$CF^{const}_{[t_i;t_{i+1}]3}$	400000	1
	$CF^{const}_{[t_i;t_{i+1}]4}$	380000	0

Continuation of Table 4.5

$CF_{[t_5;t_6]}$	$CF_{[t_5;t_6]1}$	–180000	0
	$CF_{[t_5;t_6]2}$	–160000	1
	$CF_{[t_5;t_6]3}$	–130000	1
	$CF_{[t_5;t_6]4}$	–110000	0
Discounted cash flows			
$CF^{disc}_{[t_0;t_1]}$	$CF^{disc}_{[t_0;t_1]1}$	–4091	0
	$CF^{disc}_{[t_0;t_1]2}$	–3727	1
	$CF^{disc}_{[t_0;t_1]3}$	–3273	1
	$CF^{disc}_{[t_0;t_1]4}$	–2909	0
$CF^{disc}_{[t_1;t_2]}$	$CF^{disc}_{[t_1;t_2]1}$	–454545	0
	$CF^{disc}_{[t_1;t_2]2}$	–446281	1
	$CF^{disc}_{[t_1;t_2]3}$	–429752	1
	$CF^{disc}_{[t_1;t_2]4}$	–413223	0
$CF^{disc}_{[t_2;t_3]}$	$CF^{disc}_{[t_2;t_3]1}$	345605	0
	$CF^{disc}_{[t_2;t_3]2}$	323065	1
	$CF^{disc}_{[t_2;t_3]3}$	300526	1
	$CF^{disc}_{[t_2;t_3]4}$	285500	0
$CF^{disc}_{[t_3;t_4]}$	$CF^{disc}_{[t_3;t_4]1}$	314186	0
	$CF^{disc}_{[t_3;t_4]2}$	293696	1
	$CF^{disc}_{[t_3;t_4]3}$	273205	1
	$CF^{disc}_{[t_3;t_4]4}$	259545	0
$CF^{disc}_{[t_4;t_5]}$	$CF^{disc}_{[t_4;t_5]1}$	285624	0
	$CF^{disc}_{[t_4;t_5]2}$	266996	1
	$CF^{disc}_{[t_4;t_5]3}$	248369	1
	$CF^{disc}_{[t_4;t_5]4}$	235950	0
$CF^{disc}_{[t_5;t_6]}$	$CF^{disc}_{[t_5;t_6]1}$	–106444	0
	$CF^{disc}_{[t_5;t_6]2}$	–94617	1
	$CF^{disc}_{[t_5;t_6]3}$	–76876	1
	$CF^{disc}_{[t_5;t_6]4}$	–65049	0

Fuzzy numbers that represent operations on discounted cash flows corresponding to time intervals $\left[t_i;t_{i+1}\right]$, $(i=\overline{0;l-1})$ of the ecological system project life cycle are presented in **Table 4.6**.

Table 4.6 Fuzzy numbers for determining the amount of discounted cash flows/ratio of discounted cash flows/discounted payback period of the ecological system project

Amount of discounted cash flows		
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_1$	–565080.0	0
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_2$	–544624.8	1
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_3$	–509900.8	1
$\left(\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}\right)_4$	–481181.1	0
Ratio of discounted cash flows		
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_1$	–1.80	0
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_2$	–1.65	1
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_3$	–1.44	1
$\left(\frac{\sum CF_{[t_i;t_{i+1}]} \cdot q^{t_{i+1}}}{CF^{\text{const}}_{[t_i;t_{i+1}]} \cdot q^{t_2}}\right)_4$	–1.27	0
Discounted payback period		
DPP_1	1.87	0
DPP_2	1.70	1
DPP_3	1.47	1
DPP_4	1.28	0

As a result of calculations using fuzzy numbers, a fuzzy trapezoidal number was obtained that reflects the value of the DPP of the project under conditions of uncertainty (**Fig. 4.3**) and is determined by formula (4.39):

$$\mu_A(DPP) = \begin{cases} 0, \ x < 1.28, \ x > 1.87; \\ \dfrac{x - 1.28}{1.47 - 1.28}, \ 1.28 \le x \le 1.47; \\ 1, \ 1.47 \le x \le 1.70; \\ \dfrac{1.87 - x}{1.87 - 1.70}, \ 1.47 \le x \le 1.28. \end{cases} \quad (4.39)$$

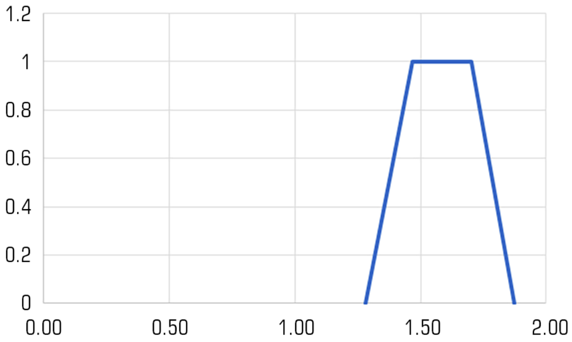

Fig. 4.3 Fuzzy meaning of the DPP of the ELS project

Thus, the evaluation of the effectiveness of the ecological system project was carried out using the proposed DPP calculation formula, which takes into account the cash flows of the project phases that occurred as a result of transformational changes in the life cycle of the ecological system project due to the greening of logistics. Experimental calculations confirmed the adequacy of the proposed DPP calculation mechanism in deterministic conditions and conditions of uncertainty.

CONCLUSIONS

1. The modern linear model of the economy is not perfect, as it constantly requires the involvement of additional primary resources, which passing through a man-made system as a result produce a large amount of waste. The tool for introducing a more humane circular model is an ecologistic system, which makes it possible to significantly reduce the eco-destructive impact on the environment through the creation of closed logistic chains. An ecologistic system has specific characteristics that distinguish it from a logistic system. In particular, the project life cycle of an ecologistic system includes ecologically-oriented phases, during which measures are taken to preserve and restore the ecosystem.

2. The model of the life cycle of a project of an ecologistic system includes five phases: pre-investment, investment, operational, regeneration, and revitalization, which take place over six time intervals. The pre-investment, investment, and operational phases are carried out sequentially, the regeneration phase begins immediately after the start of the operational phase, the revitalization phase proceeds in parallel with the investment, operational, and regeneration phases. The end of the revitalization phase means the end of a project. The model of the life cycle of an ecologistic system, in which the life cycle is divided into phases, stages, and time intervals, was presented.

3. A formula for calculating the discounted payback period of a project of an ecologistic system, which takes into consideration the specifics of cash flows of project phases, was developed. The application of the formula is possible on the condition that cash flows from the beginning of the operational phase to the end of the regeneration phase are conditionally constant. Due to the use of the proposed formula, the functional dependences between the discounted payback period and cash flows during the phases of the project life cycle were determined. It was found that the dependence of the project payback on cash flows has a different nature at different phases of the life cycle. There is a linear relationship between the discounted payback period and the cash flows of the pre-investment and revitalization phases. The dependence on the cash flows of the investment phase is expressed by the polynomial quadratic function, and the cash flows of the operational and regeneration phases are expressed by the power function. Identification of functional dependences makes it possible to explore the dynamics of changes in the discounted payback period and to predict its value in the event of changes in project cash flows.

4. Calculation formulas are proposed for determining the discounted payback period, which take into account the cash flows of ecologically oriented phases of the project under conditions of uncertainty. As a result of calculations using fuzzy numbers, a fuzzy trapezoidal number was obtained that reflects the value of the discounted term of the project under conditions of uncertainty. Experimental calculations have confirmed the adequacy of the proposed mechanism for evaluating the effectiveness of the ecological system project, which takes into account transformative ecologically oriented changes in the model of the project's life cycle, caused by the needs of modernity.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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CHAPTER 5

MANAGEMENT OF THE INTERACTION OF THE ENTERPRISE WITH PARTNERS AND CONSUMERS: MODELS, METHODS AND INFORMATION INTERACTION

ABSTRACT

The management of the interaction of an enterprise with partners and consumers is based on the system "enterprise – consumer – partner", takes into account the ratio of economic parameters of the processes of production, supply and distribution of products, including an assessment of the competitiveness of the enterprise, the attractiveness of the partner, the readiness of the consumer and the developed complex of economic and mathematical models for forming the composition of the system "consumer – enterprise – partner", determining the effect of its operation and the budget of information interaction, the features of which are the allocation of four blocks of models, which allows for a reasonable choice of the composition of consumers, partners for each enterprise, taking into account their characteristics and information interaction strategies, allowing enterprises to model communication in the system "consumer – enterprise – partner" according to the criterion of maximizing income and use the results of modeling for the implementation of information interaction.

KEYWORDS

Interaction management, enterprise, partners, consumers, economic and mathematical models, information interaction.

In the process of functioning in the market, the social component of the enterprise is revealed, which characterizes the internal relations between members of the team and external relations between the enterprise and potential or real consumers, competitors, partners, government bodies, and other contact groups. Therefore, the key factor in the strategic management of the development of the marketing activity of an enterprise is the refinement and development of the theory and practice of managing the interaction of an enterprise in the system "consumer – enterprise – partner", which together allows solving an important problem – scientifically sound generation of information interaction strategies for each enterprise [1].

Within the framework of the concept of strategic management of the marketing activity of an enterprise, it is proposed (**Fig. 5.1**): to consider a modern enterprise as an open socio-economic system, the basis for the development of which is marketing as a business philosophy; when studying an industrial enterprise, separately investigate its social and economic components; to improve the efficiency of the functioning of the enterprise and its market counterparties, to implement the association in the system "consumer – enterprise – partner"; to form marketing strategies for an industrial enterprise based on an assessment of three components – its competitiveness, the business attractiveness of partners in cooperation with them and the consumer's readiness to consume the products of this enterprise; define the concept of "information interaction" as a process of formation and implementation of long-term relations for the exchange of information between an enterprise, partners and consumers, where the enterprise plays a leading role, indirectly uniting its partners and consumers, in order to ensure an increase in the profits of all subjects of the aforementioned system based on the usefulness of the information received, contributing to the formation of the surplus value of the received resources and products. The implementation of the concept is carried out according to the proposed methodological approach to the formation of strategies for information interaction of an enterprise, which is based on three components – the competitiveness of an enterprise, the business attractiveness of its partners in cooperation with it, and the readiness of consumers to consume the products of this enterprise. Each quadrant of the developed approach corresponds to a specific position of consumer readiness, business attractiveness of a partner and competitiveness of an enterprise, which allows to reasonably choose an appropriate strategy for information interaction between an enterprise and market entities (with a definition of types, information interaction tools, types of expenses) according to an improved classification and methods for calculating the budget on marketing communications that can be used in the formation of the budget for the information interaction of this enterprise. Information interaction should take place on the basis of the formed budget, so it is necessary to improve the methodological approach to modeling the information interaction budget [1–12].

The main idea of managing the interaction of an enterprise with partners and consumers is that the object of management is the relationship (communications, information interaction) with consumers and partners implemented in the system "consumer – enterprise – partner". The presence of two-way communication in the system "enterprise – partner – consumer" is an information interaction that promotes active exchange between all types of communicators: the enterprise and its supply partner, and the enterprise and the consumer to meet the demand that arises in the process of activating the needs of consumers [2]. Within the framework of the "enterprise – partner – consumer" system, not only communication flows, but also information flows take place, which is largely due to the development in addition to traditional, virtual communications; and virtual communications. Due to the wide range of virtual communications, the concept of marketing communications is no longer enough to determine all the processes that take place between the subjects of interaction in the market. Marketing communications are a narrow understanding that constitutes information interaction. Thus, it allows to expand the boundaries of marketing communications and talk about such a concept as information interaction, which becomes much more understandable.

Theoretical provisions of strategic management of the development of marketing activities of the enterprise

Enterprise theories	Development theories	Marketing as a philosophy of enterprise development
– Enterprise theories: neoclassical, institutional, neo-institutional, evolutionary, entrepreneurial, knowledge-based integration theory. – Systems analysis theory. – Marketing theory. – Strategic management theory. – Innovation development theory. – Synergetics theory. – Interdisciplinary approach theory. – Behavioral theory. – Theory of motivation theory. – Risk theory	– The concept of development as a philosophical and economic category. – Contradictions of development. Development factors	– Marketing in the process of development of a modern company. Aspects of marketing. Relationship between strategic marketing and strategic management. The evolution of marketing strategies. – Principles of enterprise systems theory
↓	↓	↓
Consolidated theoretical provisions of strategic management of the development of marketing activities of an industrial enterprise	1. The development of an industrial enterprise is a process of changing the structure and properties of a given socio-economic system for a more complete responsibility for the conditions of the external and internal environment. 2. Classification of types of development: – in accordance with the nature of occurrence: a) development aimed at changing the internal environment; b) development aimed at changing the external environment; – depending on the nature or context of the transformations: a) development through economic transformations; b) development through social transformations; – on the basis of the clarity of the process: a) explicit; b) latent. 3. External contradictions: contradictions of the macro environment; contradictions of the immediate environment; contradictions in the microenvironment. Internal contradictions: contradictions that increase the flexibility and adaptability of the system; contradictions leading to the formation of a new dissipative structure; emerging contradictions: between the integrity of the enterprise and the need for the autonomy of its structural divisions; between the planned development and the uncertainty of its conditions; between centralization and decentralization of management; between scientific and creative approaches in decision making; between diligence and creativity of employees	1. The modern development of an enterprise is possible only on the basis of marketing activities, and marketing is the basis for the development of an enterprise. The role of marketing in strategic management is manifested at all levels of the enterprise management hierarchy in general (corporate), business, functional and operational. 2. Strategic marketing and strategic management are dual concepts, not alternatives, that is, they exist in close relationship, but marketing in this relationship is the primary element. Strategic marketing is the orientation of any activity to the consumer; in space, strategic marketing is the first stage of the life cycle of an object; in time, strategic marketing is the first general management function. 3. Today, the theory of partnership marketing is becoming increasingly important, which makes it possible to increase the efficiency of an enterprise in the market and in the macro environment, helps in the fight against intense competition for consumer loyalty and loyalty from other contact groups; contributes to building strong relationships with the consumer based on a broader perception of their needs

The concept of strategic management of marketing activities. The evolution of strategic management of the development of advertising activities. Approaches to the strategic management of marketing activities

↓

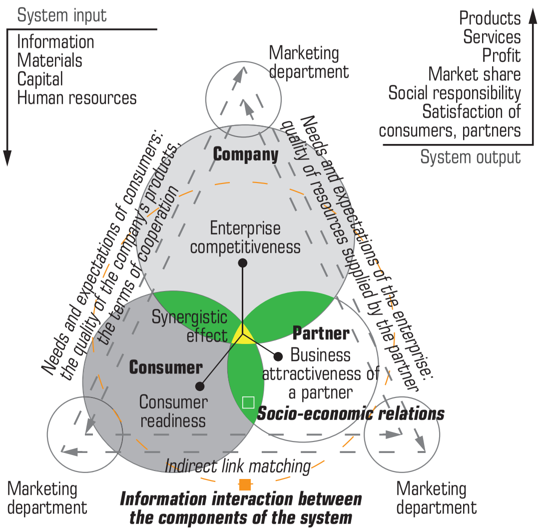
Strategic management of marketing activities can be considered as a subsystem within the strategic management system and has the right to use the principles of the systemic paradigm. The formation and observance of a proactive strategy allows the enterprise to strengthen its position in the fight against competitors and threats from other elements of the external environment

↓

Fig. 5.1 (beginning) Structural and logical scheme of work

The concept of strategic management of the development of marketing activities of an industrial enterprise

"Consumer – enterprise – partner" system



Basic provisions of the concept

1. A modern enterprise is an open socio-economic system, the development of which is based on marketing as a business philosophy.
2. In the process of functioning and development of an enterprise, consumers of its products and partners, it is advisable to consider it as a "consumer – enterprise – partner" system.
3. The main components of the formation of marketing strategies in the process of strategic management of the development of the marketing activities of an enterprise are its competitiveness, the business attractiveness of partners in cooperation with it and the readiness of consumers to consume the products of this enterprise.
4. The competitiveness of an enterprise is determined through the definition of its state, which is reflected in the ability to compete, allows to satisfy certain interests of owners, staff, consumers, partners, including the state, by more attractive means or on more attractive (effective) conditions compared to other entities market.
5. The business attractiveness of a partner should be considered as its property to satisfy the business interests of the enterprise in supplying the resources necessary for the development of the latter.
6. Readiness of the consumer to consume products (industrial and technical purposes) is his/her ability and desire to use the company's products in his/her own business process.
7. Communications become an important factor in the successful and efficient functioning of the enterprise, in the process of implementation of which the social function of the enterprise is revealed, which characterizes internal relations between team members and external relations between the enterprise and potential or real consumers, competitors, partners and other contact groups.
8. There is an active exchange of information between the enterprise, its partners and consumers – information interaction. The concept of "information interaction" should be defined as the process of formation and implementation of long-term relations for the exchange of information between the components of the "consumer – enterprise – partner" system in order to increase the profit of all subjects based on the usefulness of the information received, which will contribute to the formation of the added value of the resources and products received

The system of principles for the development and implementation of the concept of strategic management of the development of the marketing activities of an enterprise

At the stage of research of the problem of strategic management: clarity of the problem statement and limitations of the study, substantiation of the starting position and directions for the development of the study, methods of deduction and induction, interdisciplinary, systemic approaches, analysis, synthesis and generalization	At the stage of developing the concept of strategic management: socialization, communication, proactivity, reflectivity, non-linearity, limited diversity, efficiency	At the stage of practical implementation of the concept: a combination of traditional and specific components, the formation of strategies, the possibility of alternatives, universality

Fig. 5.1 (continuation) Structural and logical scheme of work

Methodological approach of strategic management of the development of marketing activities

Methodological support of competitiveness

The concept of "competition", "competitive advantage", "strategic potential", "competitive strategy" and "level of competitiveness".
Approaches to the definition of the concept of competitiveness.
Methods for determining and evaluating the competitiveness of an enterprise

Classification of competitiveness indicators by internal and external directions:
– characteristics of the internal environment: financial resources, fixed assets, development, labor resources, information and innovation resources, management activities, competitiveness of products;
– indicators of the external environment:
a) general in relation to the market: market capacity, level of market concentration, level of diversification of competitive enterprises in the target market, level of entry barrier, purchasing power of market entities;
b) indicators of macro, business interenvironment: political, institutional, socio-cultural, economic, environmental

Methodological support of business attractiveness of a partner

The concept of "partnership", "business attractiveness of a partner".
Methods for determining and evaluating the business attractiveness of a partner

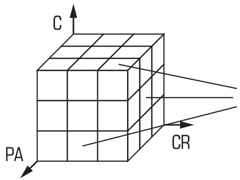
Evaluation scorecard in terms of two aspects:
a) resource aspect: indicators of the financial position; fixed assets, technical condition, intensity and efficiency of use of fixed assets; equipment usage indicators; human resources; indicators of innovation activity and efficiency of innovation processes; informational; investment in integrated marketing communications; participation in marketing activities, the degree of use of promotions, PR, the method of individual work with partners; enterprise brand value and its rating;
b) organizational and managerial aspect: characteristics of the effectiveness of the organizational structure, characteristics of the effectiveness of the company's managers

Methodological support of consumer readiness

The concept of "loyalty", "readiness of the consumer", "satisfaction".
Relationship between the concepts of "readiness" and "loyalty".
Approaches to the definition and evaluation of an industrial consumer

A two-level system of indicators for assessing consumer readiness:
– the first day includes the following indicators: an active need for consumption and the desire to purchase products, the ability to purchase products, the ability to effectively use products in their own business process and the ability to sell finished products;
– the second level includes the characteristics of the organizational structure, organization of labor and the composition of human resources; indicators of the organization of the use of innovative resources; characteristics of the organization of management activities at the enterprise

Determination of strategies for managing the development of the marketing activities of the enterprise



CR – consumer readiness
PA – business attractiveness of a partner
C – competitiveness

Enterprise marketing strategies

The position of an industrial enterprise in a three-dimensional space of states in three components: the consumer's readiness to use industrial and technical products, the business attractiveness of a partner and the competitiveness of an enterprise with the definition of a set of corporate, competitive and functional strategies and methods of information interaction

Fig. 5.1 (continuation) Structural and logical scheme of work

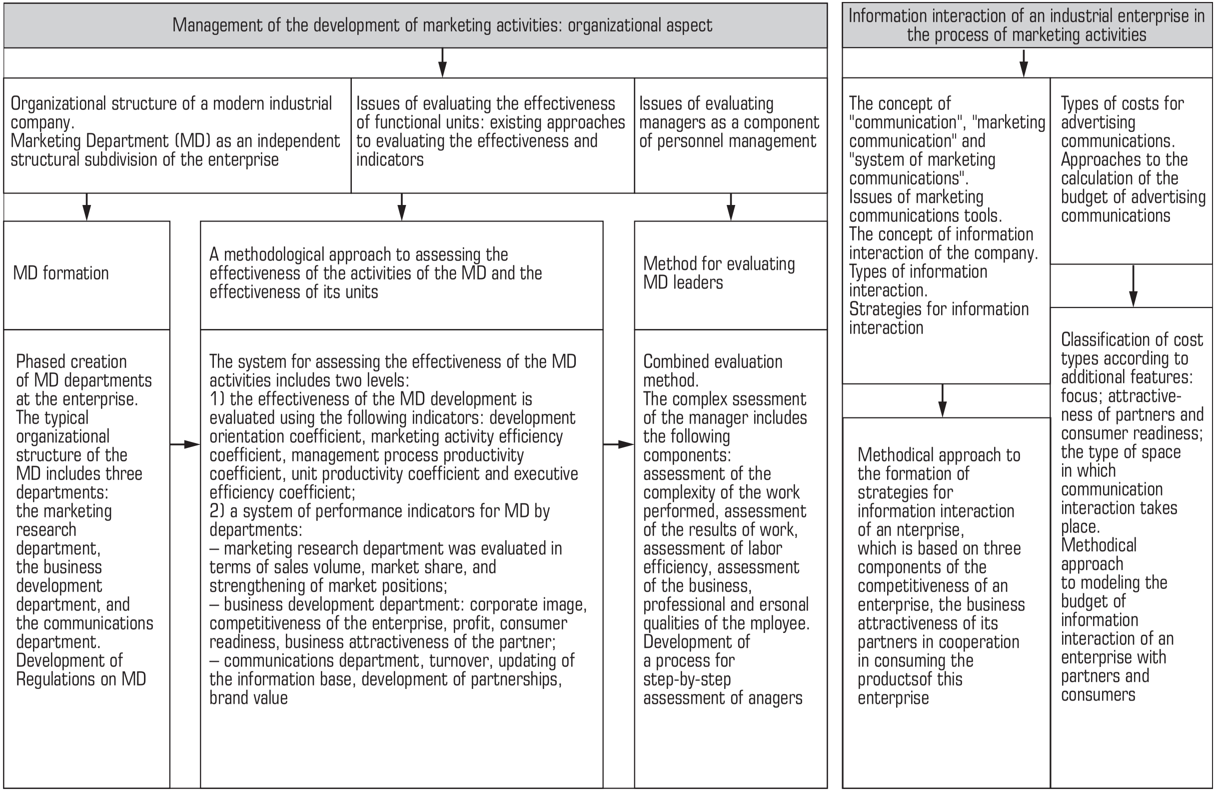


Fig. 5.1 (continuation) Structural and logical scheme of work

Marketing communications are one of the tools of information interaction, therefore, properly formed marketing communications will allow to fully approach the goal of information interaction – establishing long-term and mutually beneficial relationships with partners and consumers. Realization of this goal is one of the most important and at the same time complex tasks. This is due to the formation of an effective combination of means of advertising communications, with the correct selection of tools for information interaction. The overall size of the company's costs and their effectiveness depend on this.

Therefore, the purpose of this section is to manage the interaction of an enterprise with partners and consumers according to the proposed set of economic and mathematical models for determining the relationship of an enterprise, partners, consumers, taking into account the conditions of competition and the formation of an enterprise communications budget as part of the "consumer – enterprise – partner" system, which will allow determining the level of profit of the enterprise, depending on the competitiveness, the ratio of the attractiveness and readiness of partners and consumers of different levels with whom the enterprise works and to make a choice of an information interaction strategy. This complex allows enterprises to model communications in the "consumer – enterprise – partner" system according to the criterion of profit maximization, which is subsequently used to implement information interaction.

To achieve this goal, the following conceptual model for the formation of the composition of the "consumer – enterprise – partner" system, the definition of the effect of their functioning and information interaction, presented in **Fig. 5.2**.

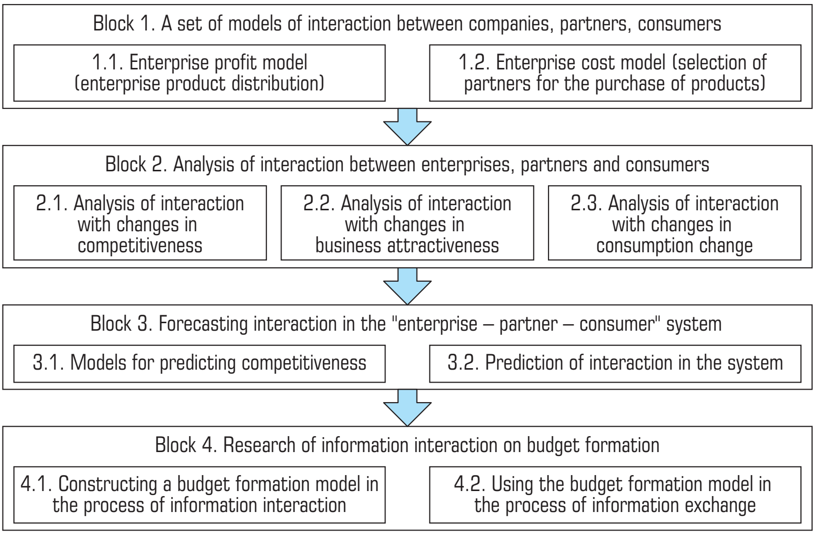


Fig. 5.2 The model for forming the composition of the "consumer – enterprise – partner" system, determining the effect of their functioning and information interaction

Block 1. A set of models of interaction between companies, partners, consumers.

Many possible buyers and partners are legal entities, for each of which a marketing strategy can be applied in accordance with the ratio of the levels of competitiveness of the enterprise, business attractiveness and readiness as a consumer.

The structure of the set of possible consumers of each company can be used to form the composition and size of information interaction, taking into account the peculiarities of using information interaction tools, restrictions on the low level of consumer readiness and allocated funds.

Let's assume that we are considering the production and consumption of certain products in the field of mechanical engineering with the corresponding provision with the necessary components produced by partners, namely components, materials, semi-finished products for this enterprise, supplied in batches or by the piece (using the example of 2019).

Details, equipment in reporting are in batches and in pieces. To ensure the production of the main competing industrial enterprises that provide the demand for the same type of products, the corresponding functionally similar products of partner enterprises, which differ in the price of supplies, can be used. In this case, the supply volumes can be measured in batches containing the assortment of products necessary for production or their parts in accordance with the production need or the creation of stocks for future production. According to the assumptions made regarding the composition of enterprises in the engineering industry, their possible partners and possible consumers, let's consider the formation of a mathematical model to determine the set of reasonable buyers and the set of reasonable partners. As an objective function, it is advisable to use the total income from attracting potential partners and consumers to the relationship.

Thus, it is advisable in this block to construct models in two directions:

1) the profit model of enterprises;

2) the enterprise cost model.

Let's consider any of the models.

1.1. Profit model of enterprises.

This model allows to determine the set of partners and consumers consuming the products of the enterprises under study.

Let's introduce the following notation:

I – a set of enterprises;

J – a set of partners;

K – a set of consumers;

x_{ij} – a variable that determines the choice for consumption of products of the i-th enterprise by the j-th partner, $i \in I$, $j \in J$;

y_{ik} – a variable that determines the choice for consumption of products of the i-th enterprise by the k-th consumer, $i \in I$, $k \in K$;

k_i – integral indicator of competitiveness of the i-th enterprise, $k_i \in [0,1]$, $i \in I$;

a_j – integral indicator of business attractiveness of the j-th partner, $a_j \in [0,1]$, $j \in J$;

b_k – integral readiness index of the k-th consumer, $b_k \in [0,1]$, $k \in K$;

v_j – annual volume of consumption products for the j-th partner, [thousand UAH], $j \in J$;

w_k – annual volume of consumption of products by the k-th consumer, [thousand UAH], $k \in K$;

p_{ij} – proceeds from the purchase of products of the i-th enterprise by the j-th partner, [thousand UAH], $i \in I$, $j \in J$;

q_{ik} – proceeds from the purchase of products of the i-th enterprise by the k-th consumer, [thousand UAH], $i \in I$, $k \in K$;

V_i – total volume of products of the i-th enterprise, produced for its partners and consumers, [thousand UAH], $i \in I$.

In these notations, variable indicators of competitiveness, business attractiveness and readiness for consumption are introduced.

The proposed definition of the content of the business attractiveness of partners and the readiness of consumers allows to interpret them as the probability of an appropriate interaction of an enterprise with a partner or consumer, and on the other hand, the competitiveness of an enterprise – as the probability of cooperation with potential partners and buyers, that is, these indicators affect the probability of making a profit enterprise. Due to the fact that the profit of enterprises needs to be adjusted for the magnitude of the probability, from the point of view of studying the economic effect, let's consider not the absolute indicator of profit, but its expected monetary value (taking into account the probability). This value can be represented by the following decision tree (**Fig. 5.3**).

Thus, the expected monetary value (EMV) of profit is defined as the sum of EMV of the profit (EP) received from sales of products to partners and EMV of the profit received from of sales of products to consumers.

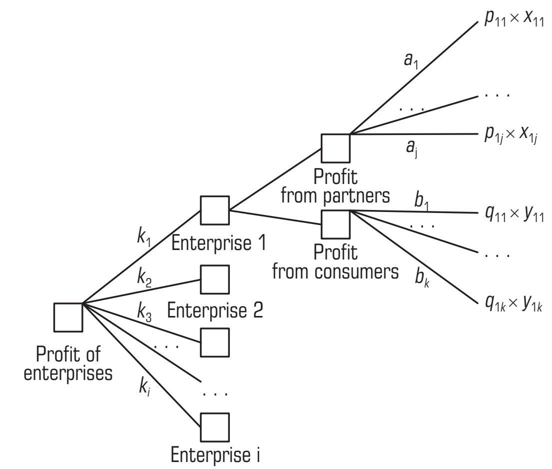


Fig. 5.3 Decision tree for model construction 1

The objective function takes the form:

$$EP = \sum_i k_i \left(\sum_j a_j \cdot p_{ij} \cdot x_{ij} + \sum_k b_k \cdot q_{ik} \cdot y_{ik} \right). \tag{5.1}$$

Each enterprise will sell its products to partners and consumers in order to maximize its profit, so the objective function must comply with the maximization criterion, i.e.

$$EP \to \max.$$

To solve this problem, let's construct a system of constraints:

1. Restriction of output by each enterprise.

The available volume of consumption of the products of each enterprise by partners and consumers is limited by the volume of production of each enterprise, that is, the share corresponding to the competitiveness of the enterprise:

$$\sum_j v_j x_{ij} + \sum_k w_k y_{ik} \le V_i. \tag{5.2}$$

2. Limiting the consumption of partners and consumers. The volume of satisfaction of consumers and partners should not exceed their needs, i.e.

$$\sum_i v_j x_{ij} \le v_j,\ \sum_{\mathrm{i}} w_k y_{ik} \le w_k.$$

3. Limitation of the number of satisfied consumers and partners by one enterprise. The maximum number of partners and consumers served by one enterprise should not exceed their maximum number, as well as the values and should not be negative:

$$\sum_j x_{ij} \le j,\ x_{ij} \ge 0;\ \sum_k y_{ik} \le k,\ y_{ik} \ge 0.$$

Thus, model 1.1 takes the form:

$$EP = \sum_i k_i \left(\sum_j a_j \cdot p_{ij} \cdot x_{ij} + \sum_k b_k \cdot q_{ik} \cdot y_{ik} \right) \to \max,$$

$$\begin{cases} \sum_j v_j x_{ij} + \sum_k w_k y_{ik} \le V_i, \\ \sum_i v_j x_{ij} \le v_j, \sum_i w_k y_{ik} \le w_k, \\ \sum_j x_{ij} \le j, x_{ij} \ge 0, \\ \sum_k y_{ik} \le k, y_{ik} \ge 0. \end{cases} \tag{5.3}$$

1.2. Enterprise cost model.

With the help of the cost model, a set of partners is formed, in which the enterprise will purchase products for itself:

z_{ij} – a variable that determines the level of supplies of products of the *j*-th partner for the *i*-th enterprise, [batches], $i \in I$, $j \in J$;

c_j – price of products of the *j*-th partner, [thousand UAH/batch], $j \in J$;

s_i – annual volume of consumption for the *i*-th enterprise of the products of partners, [thousand UAH], $i \in I$;

d_j – annual output of the *j*-th partner required for the main production of enterprises in the engineering industry, [thousand UAH], $j \in J$;

The principle of constructing this model is similar to the principle of constructing model 1.1. The target variable is the expected monetary value of the costs, which has the form:

$$EZ = \sum_i k_i \sum_j a_{ij} \cdot c_j \cdot z_{ij} \cdot d_j .$$

Since the costs at the enterprise are better the lower they are, this objective function must be minimized, i.e.

$$EZ \to \min. \quad (5.4)$$

The limitations are:

1) limitation of partners' own products.

Each partner has limited volumes of its own products:

$$\sum_i z_{ij} d_j \le d_j ; \quad (5.5)$$

2) ensuring production.

The volume of deliveries of partner products should ensure the main production of each enterprise:

$$\sum_j z_{ij} d_j \ge s_i . \quad (5.6)$$

Thus, model 1.2 has the form:

$$EZ = \sum_i k_i \sum_j a_{ij} \cdot c_j \cdot z_{ij} \cdot d_j \to \min,$$

$$\begin{cases} \sum_i z_{ij} d_j \le d_j , \\ \sum_j z_{ij} d_j \ge s_i . \end{cases}$$

The constructed models 1.1 and 1.2 will help to form the budget for information interaction in the "enterprise – partner – consumer" system.

Block 2. Analysis of interaction between enterprises, partners, consumers.

When solving models 1.1 and 1.2 with fixed values of competitiveness, business attractiveness and readiness for consumption, let's obtain a fixed maximum depreciation of profits and a minimum value of enterprises' costs. However, it should be noted that since the economic system is prone to change, the value of competitiveness, business attractiveness and readiness for consumption may change over time, in addition, there may be a purposeful change in these parameters to achieve greater profits and lower costs. Let's analyze the interaction between enterprises, partners, consumers when changing the parameters of their competitiveness and changing indicators of business attractiveness of partners and consumer readiness for consumption.

Let's conduct research for three enterprises Enterprise 1, Enterprise 2 and Enterprise 3, which have functionally similar products, nine partners and 29 consumers.

Data on enterprises are presented in **Table 5.1**. The set of possible consumers of the products of these enterprises, estimates of their consumption levels, obtained on the basis of marketing research, statistical analysis and retrospective data of enterprises on the volume of product consumption and assessment of readiness for consumption are given in **Table 5.2**. The set of possible partners of the enterprise and their selected characteristics are given in **Table 5.3**.

Table 5.1 Enterprises and assessment of their competitiveness

Name	Integral indicator of competitiveness (actual values)	Annual consumption of partners' products, batches/year	Annual output in 2018 prices, thousand UAH/year
Enterprise 1	0.389	22	280
Enterprise 2	0.471	20	370
Enterprise 3	0.358	20	250

Table 5.2 Potential consumers of products

Enterprise	Integral indicator of consumer readiness in 2019	The volume of consumption of products, thousand UAH/year	Profit from the consumption of products of enterprises, thousand UAH/year		
			Enterprise 1	Enterprise 2	Enterprise 3
1	2	3	4	5	6
Consumer 1	0.4855	48	17.48	19.81	22.14
Consumer 2	0.4131	48	14.87	16.85	18.84
Consumer 3	0.6907	32	16.58	18.79	21.00
Consumer 4	0.9983	64	47.92	54.31	60.70
Consumer 5	0.9221	64	44.26	50.16	56.06
Consumer 6	0.5565	48	20.03	22.71	25.38
Consumer 7	0.5667	48	20.40	23.12	25.84

Continuation of Table 5.2

1	2	3	4	5	6
Consumer 8	0.3564	24	6.42	7.27	8.13
Consumer 9	0.4074	58	17.72	20.08	22.45
Consumer 10	0.3197	24	5.75	6.52	7.29
Consumer 11	0.1206	64	5.79	6.56	7.33
Consumer 12	0.5878	48	21.16	23.98	26.80
Consumer 13	0.4864	48	17.51	19.85	22.18
Consumer 14	0.9932	32	23.84	27.02	30.19
Consumer 15	0.7568	32	18.16	20.58	23.01
Consumer 16	0.3946	24	7.10	8.05	9.00
Consumer 17	0.1653	24	2.98	3.37	3.77
Consumer 18	0.5183	32	12.44	14.10	15.76
Consumer 19	0.2002	32	4.80	5.45	6.09
Consumer 20	0.9418	24	16.95	19.21	21.47
Consumer 21	0.9049	24	16.29	18.46	20.63
Consumer 22	0.4328	32	10.39	11.77	13.16
Consumer 23	0.7418	32	17.80	20.18	22.55
Consumer 24	0.9547	32	22.91	25.97	29.02
Consumer 25	0.4934	24	8.88	10.07	11.25
Consumer 26	0.9701	48	34.92	39.58	44.24
Consumer 27	0.5138	24	9.25	10.48	11.71
Consumer 28	0.9258	24	16.66	18.89	21.11
Consumer 29	0.598	32	14.35	16.27	18.18

Table 5.3 Potential business partners

Enterprise	Integral indicator of business attractiveness of a partner, 2019	The volume of consumption of products, thousand UAH/year	Partner's production volume, batches/year	The price of the partner's products, thousand UAH/batch	Profit from the consumption of products of enterprises, thousand UAH/year		
					Enterprise	Enterprise	Enterprise
Partner 1	0.39	112	10.2	0.24	18.72	21.22	23.71
Partner 2	0.41	128	15	0.22	14.76	16.73	18.70
Partner 3	0.34	64	7.5	0.33	16.32	18.50	20.67
Partner 4	0.45	48	6.4	0.35	16.20	18.36	20.52
Partner 5	0.51	84	4.4	0.3	18.36	20.81	23.26
Partner 6	0.34	48	7	0.3	8.16	9.25	10.34
Partner 7	0.35	48	5.4	0.28	8.40	9.52	10.64
Partner 8	0.56	48	6.2	0.29	35.28	39.98	44.69
Partner 9	0.39	48	3.5	0.35	16.97	19.23	21.49

Block 2.1. Analysis of interaction when changing in competitiveness.

To study the interaction within the "enterprise – partner – consumer" system, let's analyze the interaction with the actual data of competitiveness and a change in competitiveness by 0.1 units (imitation of the system behavior).

Partners of the company and its consumers with the competitiveness of the company 1 – 0.389 are presented in **Table 5.4**.

Partners of the company and its consumers with the competitiveness of the company 2 – 0.471 are presented in **Table 5.5**.

Table 5.4 Interaction of company 1 with partners and consumers

No.	Scope of supply, thousand UAH	Volume of purchase, batches
1	112	5.2
2	1,892,035	4.4
3	6,107,965	7
4	48	5.4
5	48	0
6	32	0
7	32	0
Total	280	22

Table 5.5 Interaction of company 2 with partners and consumers

No.	Scope of supply, thousand UAH	Volume of purchase, batches
1	0	5
2	0	15
3	34	0
4	48	0
5	64	–
6	64	–
7	32	–
8	24	–
9	32	–
10	48	–
11	24	–
Total	370	20

Partners of enterprise 3 and its consumers with a competitiveness of 0.358 are presented in **Table 5.6**.

Table 5.6 Interaction of company 3 with partners and consumers

No.	Scope of supply, thousand UAH	Scope of purchase, thousand UAH
1	128	0
2	0	3.1
3	48	2.8
4	50	4.4
5	0	6.2
6	0	3.5
7	24	–
Total	250	20

The simulation of the system behavior is carried out on the basis of model 1.1 with a change in its competitiveness by 0.1 and under otherwise equal conditions, i.e. the competitiveness of other enterprises, the attractiveness of partners and the willingness to consume do not change.

The results of the simulation, namely the dynamics of the dependence of profits and costs of each enterprise on changes in competitiveness, are given in **Table 5.7**.

The dynamics of the dependence of profits and costs of each company on the configuration of competitiveness is given in **Table 5.7**.

Table 5.7 Dependence of profit on the configuration of competitiveness for different companies

Competitiveness	Enterprise 1 (0.389)		Enterprise 2 (0.471)		Enterprise 3 (0.358)	
	Income	Costs	Income	Costs	Income	Costs
0.1	209.1	3.8	164.6	3.7	207.5	4.1
0.2	221.7	4.4	183.8	4.2	221.6	4.6
0.3	234.2	5.0	203.1	4.8	235.7	5.2
0.4	246.7	5.6	224.9	5.3	252.5	5.7
0.5	260.4	6.0	253.7	5.6	269.6	6.2
0.6	278.4	6.4	282.5	6.0	286.7	6.6
0.7	298.1	6.8	311.2	6.3	318.9	7.0
0.8	317.8	7.2	340.0	6.7	341.4	7.4
0.9	337.5	7.6	368.7	7.1	363.9	7.8
1	357.2	8.0	397.5	7.4	386.4	8.2

Let's conduct a study of the interaction between enterprises, partners and consumers based on the analysis of income and expenses with changes in competitiveness. The dependence of EMV profits on the configuration of competitiveness and growth of EMVs in the enterprise is shown in **Fig. 5.4**, **5.5**.

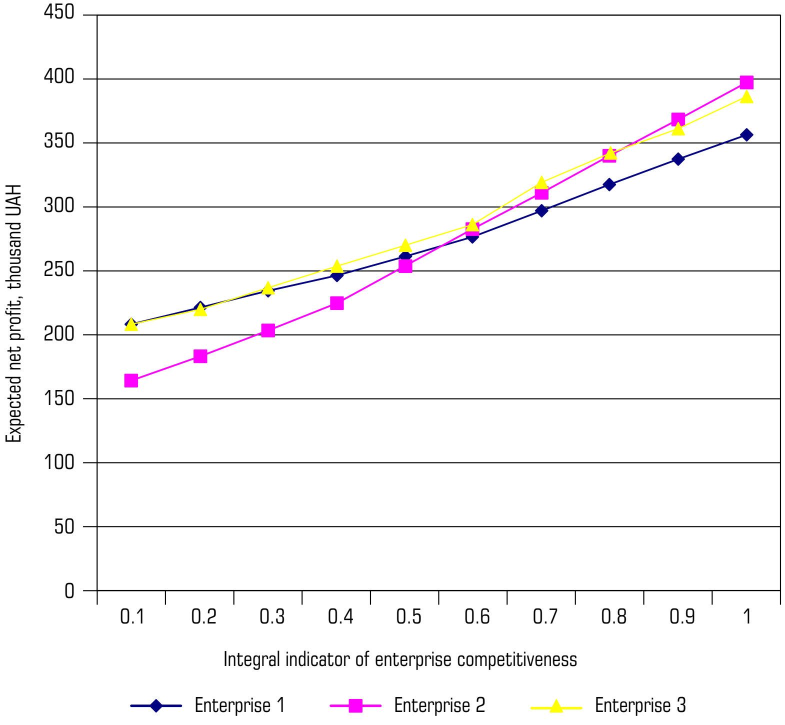


Fig. 5.4 Dependence of the expected monetary value of net profit on changes in the competitiveness of the enterprise

Analysis of **Fig. 5.4**, **5.5** allows to draw the following conclusions:

1) with a change in competitiveness by 0.1 units, the total EMV profit of enterprises constantly increases;

2) the greatest growth is observed at enterprise 2, the smallest – at enterprise 1;

3) for some values of competitiveness, there is a sharp change in the growth of EMV profits;

4) growth in enterprise 1 is, with competitiveness, from 0.1 to 0.3 – 12.5 thousand UAH per 0.1 unit of competitiveness, from 0.4 to 0.6 – the return on increasing competitiveness

increases, from 0.7 up to 1 return of the post and is at the level of 20 thousand UAH from each unit of competitiveness;

5) for the second enterprise, indirect growth is carried out with an increase in competitiveness from 0.3 to 0.5 by 30 thousand UAH;

6) the third enterprise is characterized by a significant increase with a change in competitiveness from 0.6 to 0.7 by 30 thousand UAH.

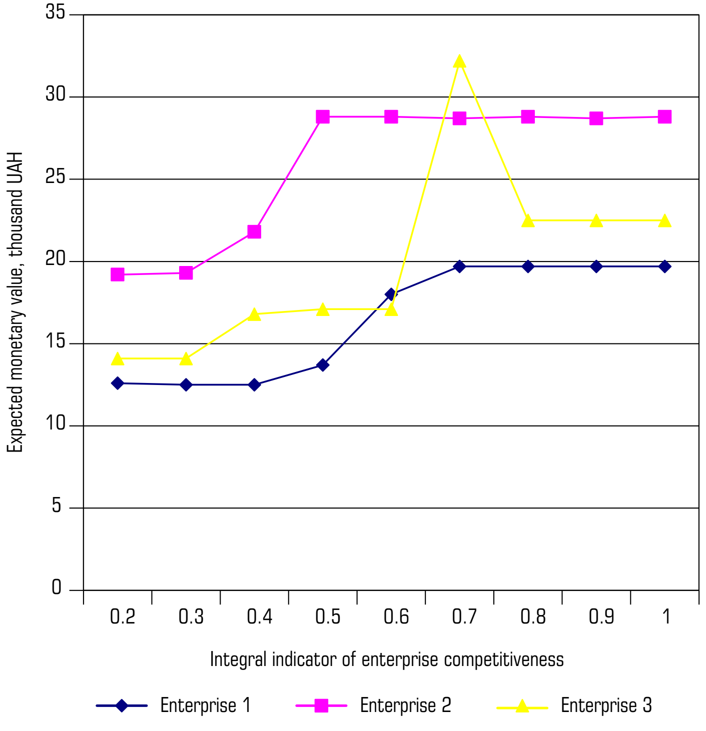


Fig. 5.5 Growth in the expected monetary value of the enterprise

Block 2.1, 2.2. Analysis of interactions when business attractiveness and readiness for consumption change.

For engineering enterprises, it is impossible to influence the change in the consumer market, therefore, to analyze the interaction, it is necessary to analyze what is best for enterprises or a change in their competitiveness or a change in business attractiveness and readiness for consumption. To do this, let's perform a series of experiments. The essence of each experiment will be to evaluate the effects of a change in competitiveness and a change in business attractiveness and willingness to consume by a certain amount. Since the purpose of the experiments is to determine the best direction of change, the experiments will be carried out until the data allow to unambiguously conclude the best effect. As a step in the experiments, let's determine 0.05, which, on the one hand, is quite small, and on the other hand, it will allow to analyze all changes quite clearly. As a result of the experiments, it was determined that three experiments are sufficient for an unambiguous conclusion, the results of which are given in **Table 5.8**.

Table 5.8 Experiments to evaluate the effect of increasing competitiveness and improving the consumer environment

No. of experiment	Increasing performance	The effect of increasing competitiveness	The effect of improving consumer conditions	Effect difference
1	0.05	274.5	258.1	16.4
2	0.1	303.7	264.8	38.9
3	0.15	332.9	270.2	62.7

Based on the data, the following conclusions can be drawn:

1) the effect of increasing the competitiveness of enterprises is greater than the effect of improving the consumer environment (business attractiveness and readiness for consumption) by almost five times. So, for competitiveness, it is 30 thousand UAH for an increase in the competitiveness of all enterprises by 0.05 units, and for the consumer market – about 6 thousand UAH for a similar increase;

2) since it is easier for enterprises to improve their competitiveness than consumer conjuncture, they need to focus on these actions (they give a greater effect).

Thus, the analysis of interaction in the system "consumer – enterprise – partner" showed that the greatest effect in this system is observed when focusing on increasing the competitiveness of enterprises, namely the second enterprise, for which this effect is greatest.

Block 3. Forecasting interaction in the "consumer – enterprise – partner" system.

The purpose of this block is to study the behavior of the system in future periods of time to develop strategies for information exchange. The results of blocks 2.2 and 2.3 showed that the greatest effect is achieved from a change in competitiveness, therefore, when developing enterprise strategies, it is necessary to focus on predicting the competitiveness indicators of each enterprise and predicting the interaction in the "consumer – enterprise – partner" system.

Block 3.1. Models for predicting competitiveness.

The initial data for predicting competitiveness is the dynamics of this indicator for three enterprises for the period 2010–2019, given in **Table 5.9**.

The following algorithm should be used to forecast competitiveness indicators (**Fig. 5.6**).

Table 5.9 Dynamics of competitiveness indicators for three enterprises

No. Enterprise	Years									
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Enterprise 1	0.21	0.256	0.245	0.276	0.289	0.31	0.309	0.358	0.346	0.389
Enterprise 2	0.259	0.289	0.315	0.345	0.352	0.376	0.382	0.405	0.43	0.471
Enterprise 3	0.178	0.215	0.201	0.235	0.224	0.274	0.282	0.305	0.315	0.358

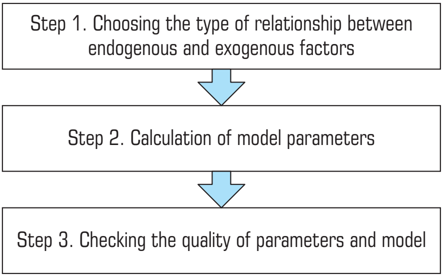


Fig. 5.6 Algorithm for making models

Step 1. Choosing the type of relationship between endogenous and exogenous factors. To implement this step, let's use graphical analysis. The dynamics of the competitiveness indicator is shown in **Fig. 5.7**.

Analysis of **Fig. 5.7** indicates the possible construction of one of two types of models: a linear model $k_i(t) = a_i + b_i \cdot t$ or a nonlinear one – exponential $k_i(t) = a_i \exp^{b_i \cdot t}$.

Step 2. Calculation of model characteristics. The least squares method is used to calculate the parameters. As a result of the calculation, the following predictive models were obtained (**Table 5.10**).

As evidenced by the parameters of the linear model, the highest growth rate of the competitiveness indicator is observed for the second enterprise (0.021), and the enterprise also has the best starting conditions (indicator a=0.246).

Step 3. Checking the properties of the parameters and the model.

To check the quality of the model parameters, the Student's criterion was calculated and compared with the table.

As a result of the test, all parameters are statistically significant. To test the adequacy of the model, the multiple correlation coefficient was used. Its value for all models is greater than 0.9, however, for linear models, the value of the coefficient is slightly higher than exponential ones, so let's use linear models for further fprediction.

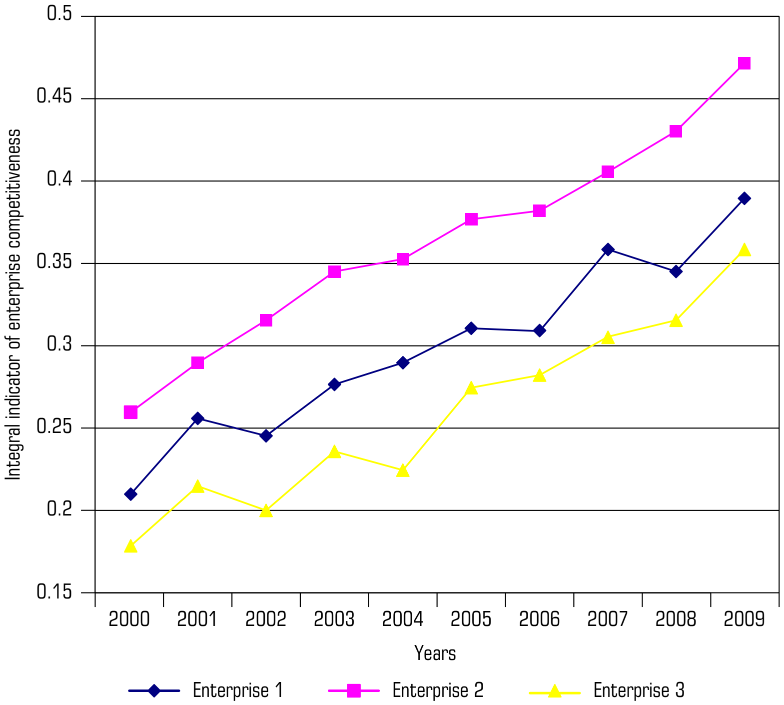


Fig. 5.7 Dynamics of competitiveness indicators

Table 5.10 Predictive models

Linear model	**Exponential model**
$k_1(t) = 0.201 + 0.017 \cdot t$	$k_i(t) = 0.21\exp^{0.059 \cdot t}$
$k_1(t) = 0.246 + 0.021 \cdot t$	$k_i(t) = 0.26\exp^{0.058 \cdot t}$
$k_1(t) = 0.157 + 0.018 \cdot t$	$k_i(t) = 0.17\exp^{0.072 \cdot t}$

Block 3.2. Prediction of interaction in the system.

To carry out prediction, let's use the models built in blocks 3.1 and blocks 1.1, 1.2.

The results of predicting competitiveness indicators according to the model from block 3.1 are given in **Table 5.11**.

Table 5.11 Competitiveness prediction results

No. Enterprise	Years		
	2020	**2021**	**2022**
Enterprise 1	0.396	0.414	0.432
Enterprise 2	0.478	0.499	0.52
Enterprise 3	0.36	0.378	0.396

Let's analyze the interaction for the period 2020–2022 based on the use of models 1.1 and 1.2. The interaction between enterprises and partners in 2020 is given in **Table 5.12**.

Table 5.12 Interaction between enterprises and partners in 2010

Partner	Enterprise		
	1	**2**	**3**
1	0	0	0
2	0	0	0
3	0	0	0
4	16.2	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	10.46936	32.98726
9	10.18634	0	0

Interaction between enterprises and consumers in 2020 is given in **Table 5.13**.

Table 5.13 Interaction between enterprises and consumers in 2020

Consumer	Enterprise		
	1	**2**	**3**
1	**2**	**3**	**4**
1	48	0	0
3	0	0	32
4	0	64	0
5	0	64	0
6	5.481171	0	42.51883
7	0	0	48

CHAPTER 5

Continuation of Table 5.13

1	2	3	4
12	0	0	48
13	48	0	0
14	0	32	0
15	0	27.28268	4.717324
18	32	0	0
20	0	24	0
21	0	24	0
22	15.18774	0	0
23	0	18.14781	13.85219
24	0	32	0
25	24	0	0
26	0	48	0
27	22.76245	0	1.237546
28	0	24	0
29	7.756374	0	24.24363

Interaction between partners and enterprises in 2020 is given in **Table 5.14**.

Table 5.14 Interaction between partners and enterprises in 2020

Partner	Enterprise		
	1	**2**	**3**
1	3.7	3.1	3.4
2	3.2	9.7	2.1
3	3.0	1.8	2.7
4	3.0	0.6	2.7
5	0.0	0.0	1.2
6	2.6	2.0	2.4
7	2.4	1.4	1.6
8	2.9	0.6	2.7
9	1.1	0.8	1.2

An analysis of the data in **Tables 5.12–5.14** shows that enterprises first try to satisfy the needs of consumers, and then the needs of partners, the needs of consumers are fully satisfied as they bring more profit than interaction with partners. The results of calculating the effects of interaction for 2020–2022 are presented in **Tables 5.15–5.17**.

Table 5.15 Calculation of the effect of interaction in 2020

	Enterprise 1	Enterprise 2	Enterprise 3	Total
Interaction "company – partner"	20.04788	5.338987	27.13893	52.5258
Interaction "enterprise – consumer"	75.77669	282.5849	123.6513	482.0129
Total	95.82457	287.9238	150.7903	534.5387

Table 5.16 Calculation of the effect of interaction in 2021

	Enterprise 1	Enterprise 2	Enterprise 3	Total
Interaction "company – partner"	16.78431	0.878463	32.22922	49.89199
Interaction "enterprise – consumer"	78.40839	286.2402	119.922	484.5705
Total	95.19269	287.1186	152.1512	534.4625

Table 5.17 Calculation of the effect of interaction in 2022

	Enterprise 1	Enterprise 2	Enterprise 3	Total
Interaction "company – partner"	–6.46778	1.26783	52.33954	47.16
Interaction "enterprise – consumer"	104.8552	287.8642	94.77537	487.49
Total	98.38738	289.13	147.1149	534.65

Analysis of the data in **Tables 5.15–5.17** allows to draw the following conclusions:

1) the predictive results of interaction do not change over time, it is stipulated that the system "consumer – enterprise – partner", in which all elements interact only with each other and the overall potential of the system does not change;

2) the second enterprise has the highest profit, which is determined by the presence of the highest level of competitiveness;

3) the second enterprise also has a constant profit, which is maximum for it, at the same time, profits are redistributed between the first and third enterprises;

4) in 2022, the first enterprise did not supply anything to its partners, which gave a negative indicator of the effect in the "enterprise – partner" system;

5) the general trend is an attracting role in the enterprise in the system of consumers. Thus, the first and second enterprises almost do not supply their products to partners.

A graphical representation of the interaction within the "consumer – enterprise – partner" system for three years (2020–2022) and the combined effect of this interaction are shown in **Fig. 5.8**.

As can be seen from **Fig. 5.8**, the balance in the system is maintained by replacing some of its elements, namely, some partners and consumers are excluded from the system. Thus, a mathematical model was proposed that describes the relationship between an enterprise, partners, consumers in a competitive environment.

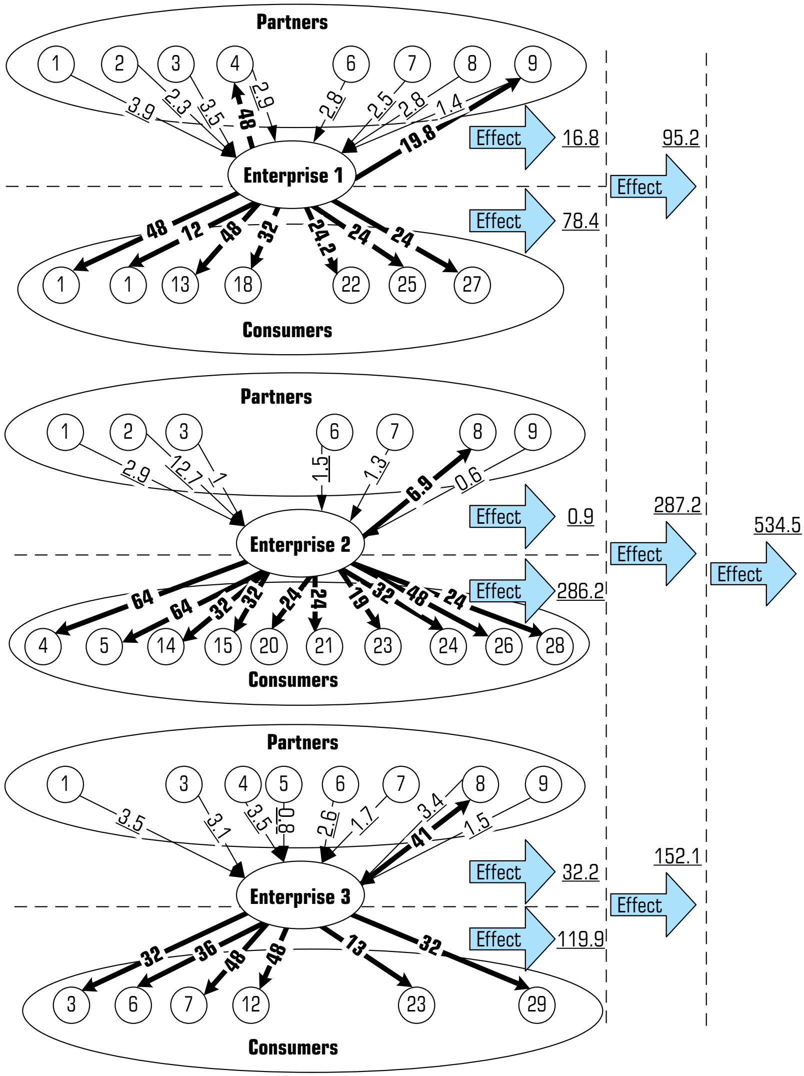


Fig. 5.8 The effect of interaction in the "consumer – enterprise – partner" system in 2021

The interaction model of the "consumer – enterprise – partner" system takes into account the ratio of the economic parameters of the enterprise: the size of the supply and distribution of products, integral indicators of the enterprise's competitiveness, business attractiveness of the partner and consumer readiness. Having these parameters, it is possible to get the value of the volumes of production, consumption, supply of partners that meet the criterion of optimality (max) profit and restrictions on the volume of production, supply, consumption and accepted concepts.

The proposed approach has shown its effectiveness, which makes it possible to model the market relations of any industrial enterprise considered in a competitive environment as part of a "consumer – enterprise – partner" complex system and operating in unstable conditions of the modern socio-economic environment.

Block 4. Research of information interaction on budget formation.

Conceptually, the information interaction of an enterprise with partners and consumers should provide them with the necessary information in a timely manner with maximum efficiency. Evaluation of the effectiveness of information interaction can be performed using expert assessments that reflect the effect or importance of the real correlation of factors influencing the feasibility of attracting certain partners to cooperation, and consumers – to purchase products manufactured by the enterprise for a period of time determined by an expert.

The level of information interaction is limited to minimum and maximum values that correspond to reasonable amounts of information for a particular time and circumstances or technological limitations. Each period of time has its own limitations, which correspond to the prevailing real circumstances. The period of time for which the task of determining information interaction should be considered can be determined by an expert. The implementation of information interaction can be performed at the expense of funds allocated by the enterprise for these purposes or provided by creditors.

This block is implemented in two stages.

Stage 1. Constructing a budget formation model in the process of information interaction.

Considering the foregoing, let's use the following notation to construct a mathematical model. Let:

L – set of types of information interaction;

J – set of existing and potential partners;

K – set of existing and potential consumers;

v_l – volume of information interaction with partners in the l-th type, $l \in L$ [packages];

w_l – volume of information interaction with consumers for the l-th type, $l \in L$, [packages];

c_l – cost of a unit of information interaction for the l-th type, $l \in L$, [thousand UAH/package];

C_0 – amount of funds allocated for information interaction for the period of time under consideration. Since the profit of the enterprise acts as a means for carrying out information interaction, then this model has $C_0 = p_0$ from the previous model;

$v_l^{\min}$, $v_l^{\max}$ – minimum and maximum volume of information interaction with partners in the l-th type $l \in L$;

$w_l^{\min}$, $w_l^{\max}$ – minimum and maximum volume of information interaction with consumers for the l-th type $l \in L$;

e_l^p – expert assessment of the expected effect of information interaction with partners in the l-th type for the considered period of time $l \in L$;

e_l^c – expert assessment of the expected effect of information interaction with consumers in the l-th type for the considered period of time $l \in L$.

Then it is possible to see the following task of determining the size of the company's information interaction with partners and consumers.

Let's find the volume of information interaction of the enterprise with partners and consumers $\{v_l\}$, $\{w_l\}$, providing a maximum estimate of the total efficiency S as an estimate of the total effect from the implementation of all types of information interaction with all possible partners and consumers:

$$S = \sum_{l \in L} \left(e_l^p v_l + e_l^c w_l \right) \rightarrow \max, \tag{5.8}$$

under restrictions:

$$\sum_{l \in L} c_l \left(v_l + w_l \right) \le C_0; \tag{5.9}$$

$$v_{l_1}^{\min} \le v_{l_1} \le v_{l_1}^{\max},$$

$$v_{l_2}^{\min} \le v_{l_2} \le v_{l_2}^{\max},$$

....

$$v_{l_j}^{\min} \le v_{l_j} \le v_{l_j}^{\max}; \tag{5.10}$$

$$w_{l_1}^{\min} \le w_{l_1} \le w_{l_1}^{\max},$$

$$w_{l_2}^{\min} \le w_{l_2} \le w_{l_2}^{\max},$$

....

$$w_{l_j}^{\min} \le w_{l_j} \le w_{l_j}^{\max}. \tag{5.11}$$

$$v_l, w_l \ge 0, \ \ l \in L. \tag{5.12}$$

Limitations (5.10) and (5.11) are due to the relevant technological and economic factors that affect either the organization of execution or the profitability of the corresponding information interaction. Therefore, problem (5.8)–(5.12) cannot be classified as a linear programming problem, taking into account constraints (5.10) and (5.11). But its solution can be performed using appropriate application packages, such as the above-mentioned WB 7.0 or the "Search for a solution" module as part of Excel, included in MS Office, solving the current sequence of linear programming problems containing part of the constraints of the type (5.10) and (5.11). Without limiting the content and showing the possibilities of the proposed approach, let's assume that the conditions of information interaction are reflected by the following data. **Table 5.18** shows expert assessments of the effects of information interaction with partners on a 7-point scale.

Table 5.18 Expert assessment of the effect of types of information interaction with partners

Name of partner company	Partners	Expert assessments of the effect of types of information interaction						
		Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing
1	Partner 1	7	4	3	3	5	6	6
2	Partner 2	6	5	4	5	4	5	7
3	Partner 3	6	6	3	4	4	5	5
4	Partner 4	3	4	4	5	4	4	5
5	Partner 5	5	5	4	5	4	3	6
6	Partner 6	4	4	4	4	3	4	6
7	Partner 7	7	7	6	6	6	6	7
8	Partner 8	5	6	7	6	5	6	6
9	Partner 9	7	7	5	7	5	6	6
	Average value	5.56	5.33	4.44	5.00	4.44	5.00	6.00

The corresponding assessments of the effects of information interaction by experts on a 7-point scale for consumers are given in **Table 5.19**.

The conditions for information exchange are presented in **Table 5.20**.

Table 5.19 Expert assessment of the effect of types of information interaction with consumers

Consumers	Name of the enterprise of the potential consumer	Expert assessments of the effect of types of information interaction						
		Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Consumer 1	1	7	4	3	3	5	6	6
Consumer 2	2	6	5	4	5	4	5	7
Consumer 3	3	6	6	3	4	4	5	5

Continuation of Table 5.19

1	2	3	4	5	6	7	8	9
Consumer 4	4	3	4	4	5	4	4	5
Consumer 5	5	5	5	4	5	4	3	6
Consumer 6	6	4	4	4	4	3	4	6
Consumer 7	7	7	7	6	6	6	6	7
Consumer 8	8	5	6	7	6	5	6	6
Consumer 9	9	7	7	5	7	5	6	6
Consumer 10	10	7	5	5	5	7	7	5
Consumer 11	11	6	5	4	5	6	4	5
Consumer 12	12	7	4	3	3	5	6	6
Consumer 13	13	6	5	4	5	4	5	7
Consumer 14	14	6	6	3	4	4	5	5
Consumer 15	15	3	4	4	5	4	4	5
Consumer 16	16	5	5	4	5	4	3	6
Consumer 17	17	4	4	4	4	3	4	6
Consumer 18	18	7	7	6	6	6	6	7
Consumer 19	19	5	6	7	6	5	6	6
Consumer 20	20	7	7	5	7	5	6	6
Consumer 21	21	7	5	5	5	7	7	5
Consumer 22	22	6	5	4	5	6	4	5
Consumer 23	23	5	6	7	6	5	6	6
Consumer 24	24	7	7	5	7	5	6	6
Consumer 25	25	7	5	5	5	7	7	5
Consumer 26	26	6	5	4	5	6	4	5
Consumer 27	27	7	4	3	3	5	6	6
Consumer 28	28	6	5	4	5	4	5	7
Consumer 29	29	6	6	3	4	4	5	5
Average value		5.86	5.31	4.45	5.00	4.90	5.21	5.79

Table 5.20 Conditions of information exchange

Indicators	Characteristics of types of information interaction						
	Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing
Unit cost, thousand UAH/package	1.2	2.4	3	0.2	0.7	0.5	2
Minimum amount of information for partners, package	100	20	20	5	20	10	20
Maximum amount of information for partners, package	150	40	30	20	30	20	30
Minimum amount of information for consumers, package	100	20	20	5	20	10	20
Maximum amount of information for consumers, package	150	40	30	20	30	20	30

Stage 2. Using the budget formation model in the process of information exchange.

Depending on the amount of funding, the distribution of information interaction, which corresponds to the maximum effect, has the following form, **Tables 5.21–5.26**.

Table 5.21 Volumes and effect of information interaction with funding in the amount of 100 thousand UAH and actual expenses of 92 thousand UAH

Interaction subjects	Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing	Effect evaluation
Volumes of interaction with partners, package	0	0	0	5	0	10	20	387.93
Volumes of interaction with consumers, package	0	0	0	5	0	10	20	

Table 5.22 Volumes and effect of information interaction with funding in the amount of 200 thousand UAH and actual expenses of 120 thousand UAH

Interaction subjects	Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing	Effect evaluation
Volumes of interaction with partners, package	0	0	0	5	20	10	20	574.75
Volumes of interaction with consumers, package	0	0	0	5	20	10	20	

Table 5.23 Volumes and effect of information interaction with funding in the amount of 300 thousand UAH and actual expenses of 120 thousand UAH

Interaction subjects	Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing	Effect evaluation
Volumes of interaction with partners, package	0	0	0	5	20	10	20	1160.96
Volumes of interaction with consumers, package	100	0	0	5	20	10	20	

Table 5.24 Volumes and effect of information interaction with funding in the amount of 400 thousand UAH and actual expenses of 360 thousand UAH

Interaction subjects	Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing	Effect evaluation
Volumes of interaction with partners, package	100	0	0	5	20	10	20	1716.51
Volumes of interaction with consumers, package	100	0	0	5	20	10	20	

Table 5.25 Volumes and effect of information interaction with funding in the amount of 500 thousand UAH and actual expenses of 456 thousand UAH

Interaction subjects	Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing	Effect evaluation
Volumes of interaction with partners, package	100	20	0	5	20	10	20	1929.39
Volumes of interaction with consumers, package	100	20	0	5	20	10	20	

Table 5.26 Volumes and effect of information interaction with funding in the amount of 600 thousand UAH and actual expenses of 592 thousand UAH

Interaction subjects	Internet technologies	Advertising brochures	PR	Personal selling	Advertising in magazines	Sales promotion	Direct marketing	Effect evaluation
Volumes of interaction with partners, package	100	20	20	5	20	10	25	2166.55
Volumes of interaction with consumers, package	105	20	20	5	20	10	20	

It should be noted that the corresponding calculations can be carried out at an enterprise that occupies a free point in the space of "enterprise competitiveness" – "partner's business attractiveness" – "consumer readiness" values. At the same time, it can be expected that with the growth of all the above indicators, expert estimates of the effect of information interaction will decrease. This situation is a consequence of the saturation of all subjects with the necessary information, which leads to the expediency of data exchange in the minimum necessary volumes, reflecting the essence of phenomena without an excess part. An increase in the need and volume of information exchange can be expected with the appearance of a significant modernization of existing or new products with the aim of a more detailed description and increase in production volumes to master new markets and expand partnerships.

For an enterprise located at a certain point in the space "enterprise competitiveness – business attractiveness of a partner consumer readiness", the above calculations can be used to select an information interaction strategy to move the enterprise to another point in the specified space with a higher level of competitiveness and maintain a higher value of partner attractiveness and readiness of consumers There is no doubt the need for cyclical repetition of these actions after the implementation of the planned measures and information interaction with the assessment of the results obtained and the determination of funds that can be directed to continue these procedures in the new conditions.

Fig. 5.9 contains a graphical representation of the modeling of the dependence of the effect of information interaction on the level of funding and the effect of the consequences of the implementation of the chosen strategy.

Fig. 5.9 shows the dependence of the amount of funding and the chosen strategy. At the same time, strategy 1 corresponds to an enterprise with low competitiveness, which has the ability to achieve a higher level of consumption of its products while meeting the requirements of consumers. To do this, depending on the financing of information exchange, more fully depicting the minor achievements of the enterprise, as far as possible, satisfies the demand of consumers as much as possible. Depending on the amount of funding for strategies 2, 3, 4, the change in the effect of information interaction for more well-known enterprises in terms of the quality and functionality of their products is reflected, while the effect is reduced for enterprises that produce products that are more well-known to consumers.

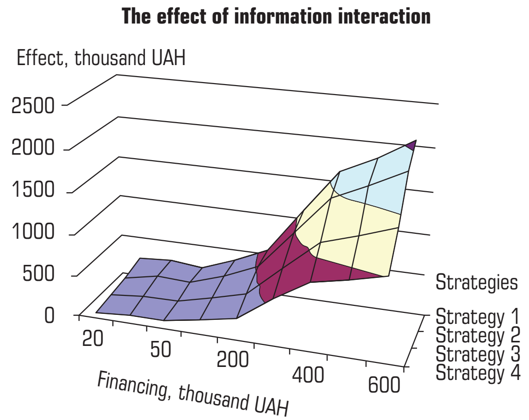


Fig. 5.9 Dependence of the effect of information interaction on the amount of funding and the chosen strategy

The calculated experimental effect for various strategies makes it possible to determine the interaction and effect for the "Enterprise-Partner-Consumer" system in the forecast period. As a result of calculations in block 3, the overall economic effect from the interaction in the system was obtained, which did not change during the study period (2020–2022) and amounted to 534 thousand UAH. Let's use this effect as a budget for information exchange.

As a result of calculations of information interaction with such financing, the following information interaction data were obtained (**Table 5.27**).

Table 5.27 Volumes and effect of information interaction with financing in the amount of 534 thousand UAH

Interaction subjects	**Internet technologies**	**Advertising brochures**	**PR**	**Personal selling**	**Advertising in magazines**	**Sales promotion**	**Direct marketing**	**Effect evaluation**
Volumes of interaction with partners, package	100	20	10	10	20	10	25	2127.7
Volumes of interaction with consumers, package	105	20	10	10	20	10	20	

Graphically, information interaction can be represented as follows (**Fig. 5.10**).

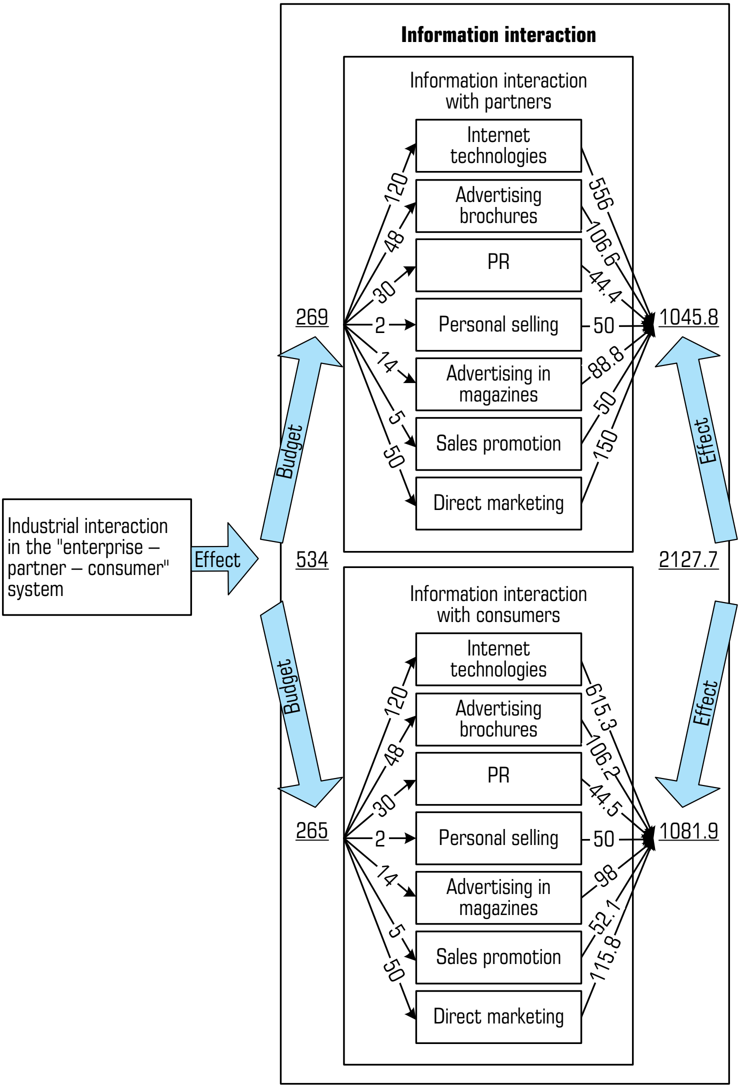


Fig. 5.10 Graphic representation of information interaction in the "consumer – enterprise – partner" system

CONCLUSIONS

Information interaction in the "enterprise – partner – consumer" system is the key to the effectiveness of its functioning. Determining the appropriate areas of interaction and its volume is conceptual in each case in time and space of relations between enterprises, their partners and consumers, especially in a competitive environment. This requires the construction of weighted estimates of the volume of information interaction, which can be carried out using the developed methodology based on mathematical modeling of the formation of a set of probable partners and consumers based on the competitiveness of enterprises, the attractiveness of partners and the readiness of consumers. Thus, the constructed model of information interaction allows, based on the effect of production interaction (forming the budget), to investigate information interaction in the "consumer – enterprise – partner" system and calculate the economic effect of this interaction for each component in the system. The effect of information interaction under given conditions can be estimated taking into account expert assessments of the effect of the relevant areas of interaction, technological limitations and funding volumes using mathematical modeling. The results of numerous studies confirm the above conclusions. The results obtained indicate the feasibility of using the proposed approach in the formation of strategies for information interaction in the "enterprise – partner – consumer" system in market conditions.

An increase in funding for information interaction leads to an increase in its effect. For enterprises that are in more favorable conditions, i.e. with higher competitiveness, a higher level of business attractiveness of the partner and consumer readiness, one can expect a decrease in the effects of information interaction, i.e. a decrease in the values of expert assessments of the usefulness of such interaction due to an increase in the level of mutual awareness of the participants in the interaction about all the necessary aspects of cooperation and consumption. This provision demonstrates a relative decrease in the effect of information interaction with a decrease in the level of effects from such interaction with the appropriate ratios of the competitiveness of the enterprise, the attractiveness of the partner's business and the readiness of the consumer.

With the help of managing the interaction of an enterprise with partners and consumers, based on the "consumer – enterprise – partner" system, and the developed complex of economic and mathematical models for the formation of the composition of this system, determining the effect of its functioning and information interaction, one can obtain estimates of the volumes of production, consumption, supplies from partners that meet the criterion of optimality (max) of profit and are limited in terms of objects of production, supply, consumption, as well as accepted concepts.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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