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MULTIPLE-CRITERIA ANALYSIS AND CHOICE OF TRANSPORTATION ALTERNATIVES IN MULTIMODAL FREIGHT TRANSPORT SYSTEM

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In the paper the multimodal freight transportation system with a finite number of known alternatives, defined by the routes and modes, is considered. The objective of research is to suggest the approach for evaluation and choice the alternatives of cargo transportation. The following main tasks are considered: choice of indices characterizing efficiency of multimodal transportations, formation of optimization criteria of the multimodal freight transportation, construction of the model of the multimodal transportation system, calculation the performance criteria of cargo transportation. The study presents the Analytic Hierarchy Process (AHP) as the most suitable approach for comparative evaluation of different routes and modes of cargo transportation.

Keywords: multimodal freight transportation, logistic system, business-process, criteria of optimization, route, Analytic Hierarchy Process

1. Introduction

The demand for cargo transportation in Latvia has experienced high growth rates. From 1998 to 2010 the main indices of freight transport in Latvia increased significantly (see Fig. 1): cargo volume by 34.9 % and cargo turnover by 62,4 % [1]. Current trends of development of the Latvian system of freight transportation are characterized by essential increase of multimodal transportation in total amount of cargo transportation. Usage of several types of transport in multimodal transportation makes the management, loading and warehousing processes, in which various executors and various facilities are involved, significantly more complicated. Thus, considering great transportation volumes, miscalculations in the organization and management of these processes lead to considerable material and financial losses. The growth of cargo transportation claims for higher optimization of the transportation process. In practice we have to answer on two basic questions: what route to choice and what transport mode to use, and there are different methods which provide the decision-maker (DM) with a satisfactory solution.

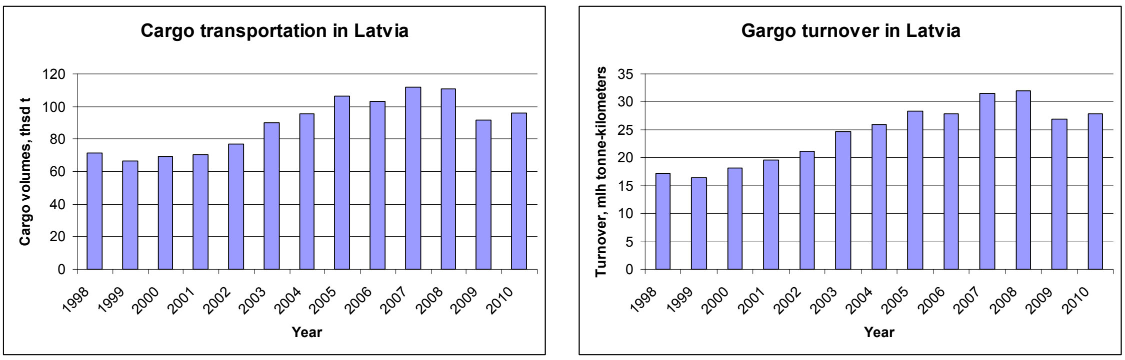

Figure 1. Main indicators of cargo transportation in Latvia in 1998–2010

As a rule, for the each multimodal freight transportation the decision-maker can offer several alternatives for cargo delivery determined by different routes or/and modes. Search for the best solution or finding a set of good alternatives in realization of multimodal freight transportation should be based on a set of the initial data, considering logistic principles, and be done using modern mathematical methods and computer engineering [2, 3]. Solving this problem we have to take in account such important factors as: a complicated structure of multimodal transportation, high dynamics and rapidity of transport processes, the random factors influencing these processes and geographical dispersion of participants of the transportation. There are a number of researches for evaluation and choice the alternatives of cargo transportation (for example, see analysis in [4]), and a lot of them are based on the cost criterion. In some papers the authors propose the multiple-criteria approach for transportation system evaluation, but for the alternative choice they include these criteria into generalized cost criteria (for example, see [5]). Multiple-criteria method is realized in the work [4], where three criteria for route choice (shipping time, shipping price, shipping safety) are applied, but in practice there exist more different indices which determine the efficiency of cargo transportation.

The objective of our paper is to suggest the multiple-criteria approach for evaluation and choice the alternatives of cargo transportation. We consider the multimodal transportation system with finite number of known alternatives defined by the routes and modes of transportation. Each alternative is represented by its performance in multiple criteria. In the presented research, the following main tasks, which require solutions in multimodal freight transportation system, are highlighted:

- construction of a mathematical model of the multimodal transportation system;
- choice of a set of indices, characterizing efficiency of multimodal transportation, and formation of an optimization criteria of the multimodal transportation system on their basis;
- development of a method for evaluation and selection of cargo transportation routes and modes.

2. Model of Multimodal Transportation System

Multimodal freight transportation system is a classic logistic system (LS) [3]. For the description of multimodal transportation system it is possible to use two approaches: functional and process.

Functional approach was the first for describing business-systems. It considers usage decomposition of the system, which includes three basic steps. On the first step logistic system is divided into a set of subsystems. On the next step subsystems are presented as a set of logistic functions (LF). On the final step, each logistic function is presented as a set of logistic operations (LO), which are characterized by their own set of indices.

The main disadvantage of the functional approach is dissociation of separate logistic functions and insufficient interaction among them. However, an ultimate goal of formalization of the transportation process description is not only calculation of efficiency indices, but also development of the approach to efficient control system of multimodal transportation. The last is difficult for implementing using the functional approach.

The process *approach* has found wide application recently only [6]. Thus the model of logistic system, realised at the functional approach, joins additional processes level. This level in hierarchy of the system precedes functions level. Logistic process is considered as a set of logistic functions, however in certain cases logistic process (LP) can consist of one LF. The main task of this approach is elimination of lack of the functional approach, which is noted above, and consists in absence of interaction between various LF within the limits of one system.

In the present paper the process approach is used for the description of multimodal freight transportation system. For presentation of the multimodal freight transportation system the decomposition of logistic systems $\mathbf{LS}$ are executed (see Fig. 2). The process of decomposition includes the following four steps:

1) the logistic system LS_j is divided into a set of *subsystems* $\mathbf{LT} = \{LT_1, LT_2, ..., LT_g\}$;

2) each subsystem LT_k is presented as a set of *logistic processes* $\mathbf{LP} = \{LP_1, LP_2, ..., LP_z\}$;

3) each logistic process LP_m is presented a set of *logistic functions* $\mathbf{LF} = \{LF_1, LF_2, ..., LF_r\}$;

4) each function LF_q is presented as a set of *logistic operations* $\mathbf{LO} = \{LO_1, LO_2, ..., LO_h\}$, which are characterized by own sets of indices.

The constructed system of sets allows making calculations of LS efficiency, taking in account different indices, first of all cost indices and time indices [3]. Besides, these calculations are made “bottom-up” starting from the bottom level (level of LO) and finishing by the top level (level of LS). So, the calculation process can be presented by the chain $\mathbf{LO} \rightarrow \mathbf{LF} \rightarrow \mathbf{LP} \rightarrow \mathbf{LT} \rightarrow \mathbf{LS}$.

It is necessary to underline that cost indices at the next level of hierarchical bottom-up system are calculated by simple summation of corresponding indices of the previous level. Then cost index $E(LS_j)$ for logistic system LS_j is calculated by the formula:

$$E(LS_j) = \sum_{LT_i \in LS_j} E(LT_i) = \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} E(LP_m) = \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} \sum_{LF_h \in LP_m} E(LF_h) =$$
$$= \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} \sum_{LF_h \in LP_m} \sum_{LO_p \in LF_h} E(LO_p), \quad (1)$$

where $E(S)$ is cost index for the item S.

However, calculation of time indices in the transportation system involves severe difficulties. It is necessary to take into account factors like shifts of separate operations, functions and processes for fixed moments of time, parallel and consecutive performance of separate elements of logistic system and so forth. With this aim, methods of network planning are used [7]. In considered task LO, LF, LP and LT are presented by the weighed graphs (see Section 5) in which edges are corresponding elements of appropriate hierarchy level (i.e. LO, LF, LP and LT accordingly), when time indices of functions, processes and subsystems are been calculated.

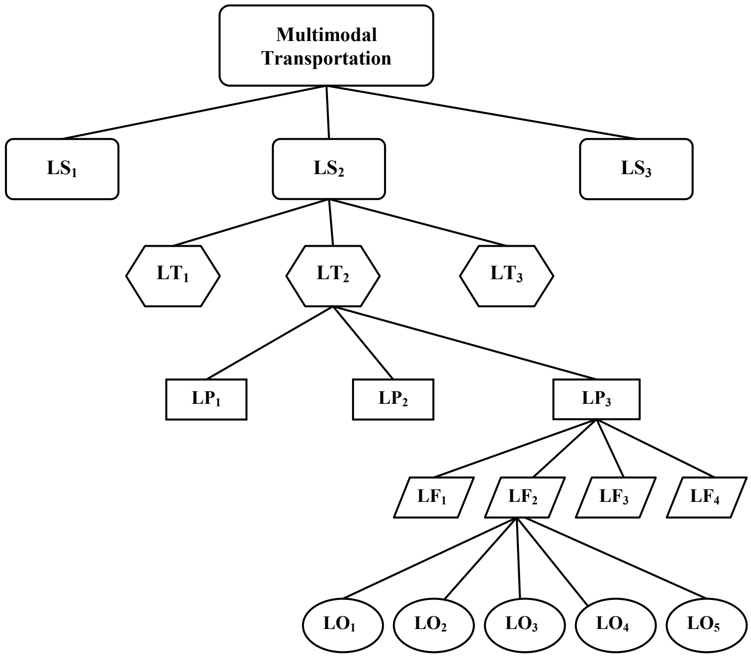

Figure 2. Decomposition of logistic system

3. Performance Criteria of the Transportation System

As it was mentioned above, we can find several alternatives for cargo delivery determined by different routes and modes, which are characterized by a set of indices for each multimodal freight transportation. To estimate the efficiency of possible transportation alternatives the system of indices, including cost, time, reliability of transportation of cargo and its safety, was offered and considered by authors in [8]. In the present research an ecological index "environmental impact from transportation" has been added to the system of criteria. It is easy to notice that the suggested indices have the various physical natures and are measured by different physical magnitudes. The part of indices is deterministic, the part is stochastic. Additional difficulties for estimating the system's indices are related to the fact that a part of indices has quantitative nature and a part has qualitative nature. For example, cost and durations of transportation are quantities, but reliability, safety and environmental impact, estimated by experts, are qualitative parameters. For conversion of qualitative indices into quantitative several approaches are offered to use, including comparative scales (for example, "Pairwise comparison scale 1–9" [9, 10]), non-comparative scales (for example, Continuous rating scale, when experts rate items by placing a mark from zero to 100), Harrington's desirability function [3], etc.

In general case a set of chosen indices is used for evaluating alternatives and searching the optimal decision in the freight transportation task, and two approaches of efficiency criteria formation can be used: mono-criterion and multiple-criteria approaches.

The *mono-criterion approach* assumes usage of one generalized optimization criterion and recognizes that various indices (delivery time, reliability of delivery, safety of cargo, etc.) can be estimated in one expression in terms of value. It allows constructing a generalized criterion of total costs E_{Σ} for realization of multimodal transportation, which unites a set of local criteria, among them:

- direct cost for freight transportation, i.e. expenses for cargo transportation, reloading and warehousing, customs operations, documentation, etc.;
- losses appearing as a result of delay in delivery schedule (including penalties for non-fulfilment of the delivery terms and the lost and-or half-received profit);
- losses from cargo loss, and deterioration of its consumer properties (partial or full damage of cargo which reduces its cost);
- expenses for capital freezing (they are defined taking into account cost of transported cargoes and time of delivery);
- losses related to currencies' exchange rates fluctuations;
- expenses for additional insurance of cargo;
- expenses for stock holding in case of irregular deliveries;
- losses related to environmental impact from freight transport.

At the same time, the given criterion can be supplemented with new components, considering concrete transportation system.

In general case total cost $E_{\Sigma}(LS_j)$ for realization of multimodal transportation of logistic system LS_j will be calculated by the following formula

$$E_{\Sigma}(LS_j) = \sum_{i=1}^{n} E_i , \tag{2}$$

where n is quantity of components (items), which form total cost for realization of multimodal transportation; E_i is a value of i-th component of expenses for realization of multimodal transportation (for example, direct cost for freight transportation; losses appearing as a result of delay in delivery schedule etc).

In this case the problem of search of optimal multimodal freight transportation system LS_{opt} on the basis of finite set of possible logistic systems $\mathbf{LS}$ has the following view:

$$E_{\Sigma}(LS_{opt}) = \min_{LS_j \in \mathbf{LS}} [E_{\Sigma}(LS_j)] . \tag{3}$$

In number of cases the constraints on used resources (time, technique, means etc.) are additionally introduced:

$$p_k(LS_j) \le p_k^{\max}, \quad k = 1,2,...,m; \ \forall LS_j \in \mathbf{LS}, \tag{4}$$

where $p_k(LS_j)$ is the value of k-th index of the logistic system LS_j; $p_k^{\max}$ is the maximum possible value for k-th index for the given multimodal transportation; m is a quantity of indices on whose constrains are imposed.

For the fixed number of variants of the systems, determined by a set $\mathbf{LS}$, the choice of an optimum variant LS_{opt} by criterion (3) consists of checking conditions (4) and calculations of total cost for realization of multimodal transportation for $\forall LS_j \in \mathbf{LS}$.

The *second approach* considers a *multiple-criteria* problem of multimodal transportation, when the system of q various criteria $C_1(LS_j), C_2(LS_j),..., C_q(LS_j)$ is used. These criteria have the various physical natures and are measured by different physical magnitudes.

A part of criteria is minimised (for example, cost and time), and a part is maximised (for example, safety of transportation, safety of cargo). In this case we have a *vector optimisation* problem of a kind:

$$C_l(LS_{opt}) \to \underset{LS_j \in \mathbf{LS}}{extremum}, l = 1,2,...,q; LS_{opt} \in \mathbf{LS}, \qquad (5)$$

where *extremum* for separate criteria corresponds to a minimum, for others – to a maximum.

In the process of the criteria system formation the authors have been focused on four groups of criteria: cost of cargo delivery, time of delivery, reliability of cargo transportation and ecological impact (or environmental impact from transportation). As a result of investigation 22 criteria were selected. The list of criteria using in the given research is presented in Table 1.

Table 1. Criteria for cargo transportation evaluation

Name of group	Criteria
Cost of cargo delivery	Costs for transportation; costs for handling; seasonal fluctuation of tariffs, costs for documentation processing; penalties (missing delivery terms); possible additional costs during transportation; additional insurance (insufficient safety)
Time of delivery	Time for transportation; time for border crossing; time for customs clearance; exchange rate fluctuation during delivery time
Reliability of cargo transportation	Exceed of delivery time; cargo safety (loss, damage of cargo); availability of transport units; safety (theft, unauthorized access to cargo); reliability of transport means
Ecological impact	Emission of CO2; emissions of harmful substances; noise and vibration; accidents and disasters from the ecological point of view; death and traumatism of people

4. Selection of the Method for a Choice of the Best Solution

There are currently various methods that have been developed and implemented to analyze and choose from a range of alternatives. These methods include multiple-criteria decision making (MCDM), multiple-criteria decision analysis (MCDA), and multiple attribute decision making (MADM) [11]. The existence of this variety of methods makes the issue of choosing the most suitable one rather difficult [12]. The authors have analysed the possibility of employing two of the most popular MCDA methods to solve the problem of choosing the best route and mode of freight transportation: the Analytic Hierarchy Process (AHP) method [9, 10] and ELECTRE method [13].

When implementing the ELECTRE method, the authors faced the problem of arranging the alternatives in the criteria table (assigning the weights). The use of a large number (22) of criteria, belonging to different professional knowledge areas resulted in an inadequate estimation of each criterion's significance. With the help of invited experts, the authors were only able to competently evaluate certain criteria which they know well. The estimations of other criteria have been arrived at by guess-work. Since the assigned weights of criteria have a great impact on the alternative choice, the authors have come to the conclusion that this method would result in largely inaccurate results.

The AHP seems to be a more attractive choice in this context since it allows structuring the choice procedure as a hierarchy of several levels. It allows the distribution of the criteria by several groups, and evaluates the significance of each group's components. Consequently, the different groups of criteria have been evaluated by different experts. For instance, the economists have assessed the cost criteria; the transport technologists have evaluated the reliability and ecological criteria, while the managers have estimated the time criteria. The opportunity of the pairwise comparison of a smaller number of criteria in every group allows the experts to determine better weighted values according to these criteria. The authors have concluded that the optimal number of criteria in each considered group should be from 3 to 7. The estimation of the significance of the criteria groups was determined by the experts with greater qualification. The AHP method also allows the possibility of controlling the consistency of the experts' judgements, making it possible to increase the reliability of estimation. In summary, the multi-criteria analysis determined the AHP as the most suitable method for comparative evaluation of different alternatives of the cargo transportation.

In the judgment of the authors, AHP method [9] is the most efficient for choice of optimal logistic system. The method allows arranging the alternatives of trasportation in the order of their efficiency and showing their difference in the given set of criteria.

5. Calculation of Delivery Cost and Delivery Time

To illustrate the offered approach, the multimodal freight transportation from Shanghai to Moscow by five alternative routes is considered. The suggested routes are the following:

- Shanghai – Hamburg – Riga – Tver – Moscow;
- Shanghai – Vladivostok – Rail Terminal in Moscow – Warehouse in Moscow;
- Shanghai – Hamburg – Kotka – Tver – Moscow;
- Shanghai – Hamburg – Klaipeda – Tver – Moscow;
- Shanghai – Alashankou – Dostyk – Rail Terminal in Moscow – Warehouse in Moscow.

Let us consider each route in details.

1. *Shanghai – Hamburg – Riga – Tver – Moscow.* This route considers transportation of cargo from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Riga. In Riga container is reloaded onto truck and delivered to the customs terminal in Tver. After customs clearance container is delivered to warehouse in Moscow for unloading.

2. *Shanghai – Vladivostok – Railway terminal in Moscow – Warehouse in Moscow.* Cargo in container is delivered from Shanghai to Vladivostok by vessel, where customs clearance is being done. Further the container is loaded onto rail platform and delivered to rail terminal in Moscow. At the terminal the container is being reloaded on truck and delivered to the warehouse of consignee.

3. *Shanghai – Hamburg – Kotka – Tver – Moscow.* This route considers transportation of cargo from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Kotka. In Kotka container is reloaded onto truck and delivered to the customs terminal in Tver. After customs clearance container is delivered to warehouse in Moscow for unloading.

4. *Shanghai – Hamburg – Klaipeda – Tver – Moscow.* This route considers transportation of cargo from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Klaipeda. In Klaipeda container is reloaded onto truck and delivered to the customs terminal in Tver. After customs clearance container is delivered to warehouse in Moscow for unloading.

5. *Shanghai – Alashankou – Dosty – Almaty.* Cargo in container is delivered from Shanghai to Alashankou by short see vessel. In Alashankou container is reloaded onto railway platform and further delivered to Dostyk, Chinese/Kazakhstan border point. In Dostyk the container is reloaded onto railway platform of Kazakhstan railways (changing the gauge). Further the container is being delivered to rail terminal in Moscow, where customs clearance is done. After customs clearance the container is reloaded on truck and delivered to the warehouse of consignee.

Actually we are considering five logistic systems presented by the graph on Figure 3. The edge of the graph corresponds to a logistic subsystem (or to a route stage).

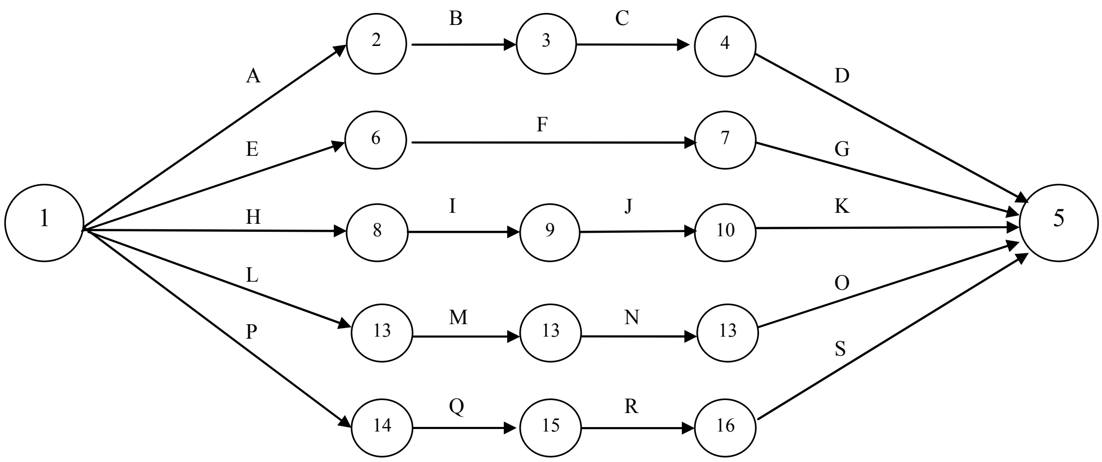

Figure 3. Logistic Systems

Description of routes LS_j, $j = 1,2,..,5$ is presented in Table 2.

Further the first route LS_1 (Shanghai – Hamburg – Riga – Almaty) will be considered in more detail. It is presented by vertexes 1-2-3-4-5 (or by edges A-B-C-D) on the graph on Figure 3. As it can be seen, logistic system LS_1 includes four subsystems (stages of routes):

stage A – cargo transportation in container from Shanghai to Hamburg, unloading of container at port of Hamburg;

stage B – loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga;

stage C – loading of container on truck at port of Riga, delivery from Riga to Almaty terminal;

stage D – delivery from customs terminal to warehouse in Moscow.

Table 2. Subsystems (stages) of routes

LS_j	Stage LT_k	Description of stage
LS_1	A	Cargo transportation in container from Shanghai to Hamburg. Unloading of container at port of Hamburg
	B	Loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga
	C	Loading of container on truck at port of Riga, delivery from Riga to customs terminal in Tver. Customs clearance
	D	Delivery from customs terminal to warehouse in Moscow
LS_2	E	Cargo transportation in container from Shanghai to Vladivostok. Unloading of container at port of Vladivostok. Customs clearance
	F	Loading of container onto rail platform, delivery from Vladivostok to rail terminal in Moscow, unloading of container at the terminal
	G	Loading of container onto truck, delivery from rail terminal to warehouse of consignee.
LS_3	H	Cargo transportation in container from Shanghai to Hamburg. Unloading of container at port of Hamburg
	I	Loading of container onto feeder vessel, delivery from Hamburg to Kotka, unloading of container at port of Kotka
	J	Loading of container on truck at port of Kotka, delivery from Kotka to customs terminal in Tver. Customs clearance
	K	Delivery from customs terminal to warehouse in Moscow
LS_4	L	Cargo transportation in container from Shanghai to Hamburg. Unloading of container at port of Hamburg
	M	Loading of container onto feeder vessel, delivery from Hamburg to Klaipeda, unloading of container at port of Klaipeda
	N	Loading of container on truck at port of Klaipeda, delivery from Klaipeda to customs terminal in Tver. Customs clearance
	O	Delivery from customs terminal to warehouse in Moscow
LS_5	P	Cargo transportation in container from Shanghai to Alashankou. Unloading of container at port of Alashankou
	Q	Loading of container onto rail platform in Alashankou. Rail transportation Alashankou – Dostyk, unloading of container at Dostyk border terminal
	R	Loading of container onto Kazakhstan rail platform at Dostyk terminal, delivery to rail terminal in Moscow. Customs clearance
	S	Loading of container onto truck, delivery from rail terminal to warehouse of consignee

Each subsystem (stage) consists of one or several logistic processes. Let us in detail consider stage C which consists of three logistic processes, shown on Figure 4: transhipment of container, customs clearance and transportation.

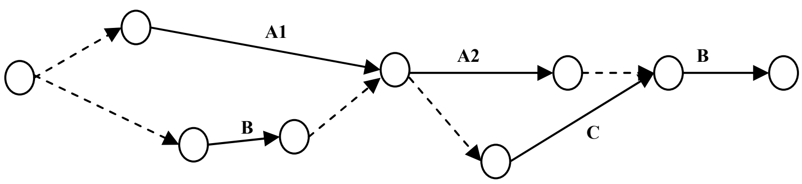

Figure 4. Logistic processes of the stage C

Each edge on Figure 4 corresponds to one process of the stage: A1 – customs clearance of incoming container; B – transhipment of container, A2 – customs clearance of outgoing container, C – cargo transportation. By dashed lines the edges used for marking "fictitious processes" (shift in time, parallel performance of processes, etc.) are shown.

Further we will make decomposition of processes into logistic functions. Let us show it on an example of process of container transhipment at port of Riga. In the offered statement of a problem, at the level of detailed elaboration accepted by us, we will allocate the following logistic functions for transhipment process:

- handling of incoming container;
- storage;
- handling outgoing container;
- processing of documents.

Schematically this process is presented on Figure 5. Each edge of the graph corresponds to a concrete function: A – handling of incoming container; B1 – processing of documents for incoming container, B2 – processing of documents for outgoing container, C – storage, D – handling of outgoing container.

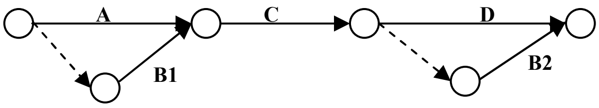

Figure 5. Process of container transhipment at port of Riga

Decomposition of the functions is shown on example of LF „Handling of outgoing container". This function consists of a set of the following logistic operations:

- receiving truck number and sending the truck for loading;
- registration of loading in IT system of terminal;
- generating PIN code for loading;
- loading of container.

Schematically function "Handling of outgoing container" is presented on Figure 6. Each edge of the graph corresponds to the concrete logistic operation: A – receiving truck number and sending the truck for loading, B – registration of loading in IT system of terminal, C – generating PIN code for loading, D – loading of container.

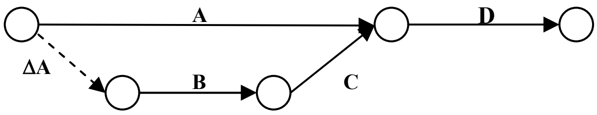

Figure 6. Logistic Function «Handling of outgoing container»

Decomposition of all elements of logistic system (route) has been similarly executed, which has allowed to define cost of transportation of cargo, using the formula (1), and to calculate time of cargo transportation from vertex 1 till vertex 5 (see Fig. 2), having defined a critical way of the obtained graph of logistic operations.

As an example, let us consider the calculation of performance duration of separate logistic function «Handling of outgoing container». The performance durations of separate operations of the function are presented in Table 3. Using the graph on Figure 6 we can find the critical way AD, it is equal 140 minutes.

Table 3. The duration of separate operations of the function "Handling of outgoing container"

Logistic Operations	Duration, minutes
A – receiving truck number and sending the truck for loading	60
ΔA – waiting time	10
B – registration of loading in IT system of terminal	15
C – generating PIN code for loading	10
D – loading of container	80

In a similar way, a critical ways for all functions, processes, subsystems and logistic system as a whole are calculated. Results of calculations of two basic indices of efficiency of the chosen routes of freight transportation (transportation cost and delivery time) are presented in Table 4. As evident from the table the decision-maker can not get a clear answer on the question what route to choice. On the one hand 1st route has the lowest cost of cargo transportation, but its delivery time is 15 days greater then smallest time. On the other hand 2nd route, which has the smallest delivery time, is more expensive (the cost is 19% greater). For the choice of route the priority between cost and delivery time should be chosen or multiple-criteria decision method should be applied (see Section 6).

Table 4. Efficiency indices of logistic systems

Route LS_j	Transportation cost, USD	Delivery time, days
1	6300	40
2	7500	25
3	6600	40
4	6800	42
5	9000	40

6. Multiple-Criteria Choice Using the AHP Method

As discussed in Section 4, the AHP method [10] has been chosen for evaluating the efficiency of the alternatives of cargo transportation from Shanghai to Moscow taking into consideration 5 possible routes suggested in Section 5. The chosen criteria for the routes and modes efficiency are described in Section 3. The created hierarchical structure of the criteria is shown on Figure 7.

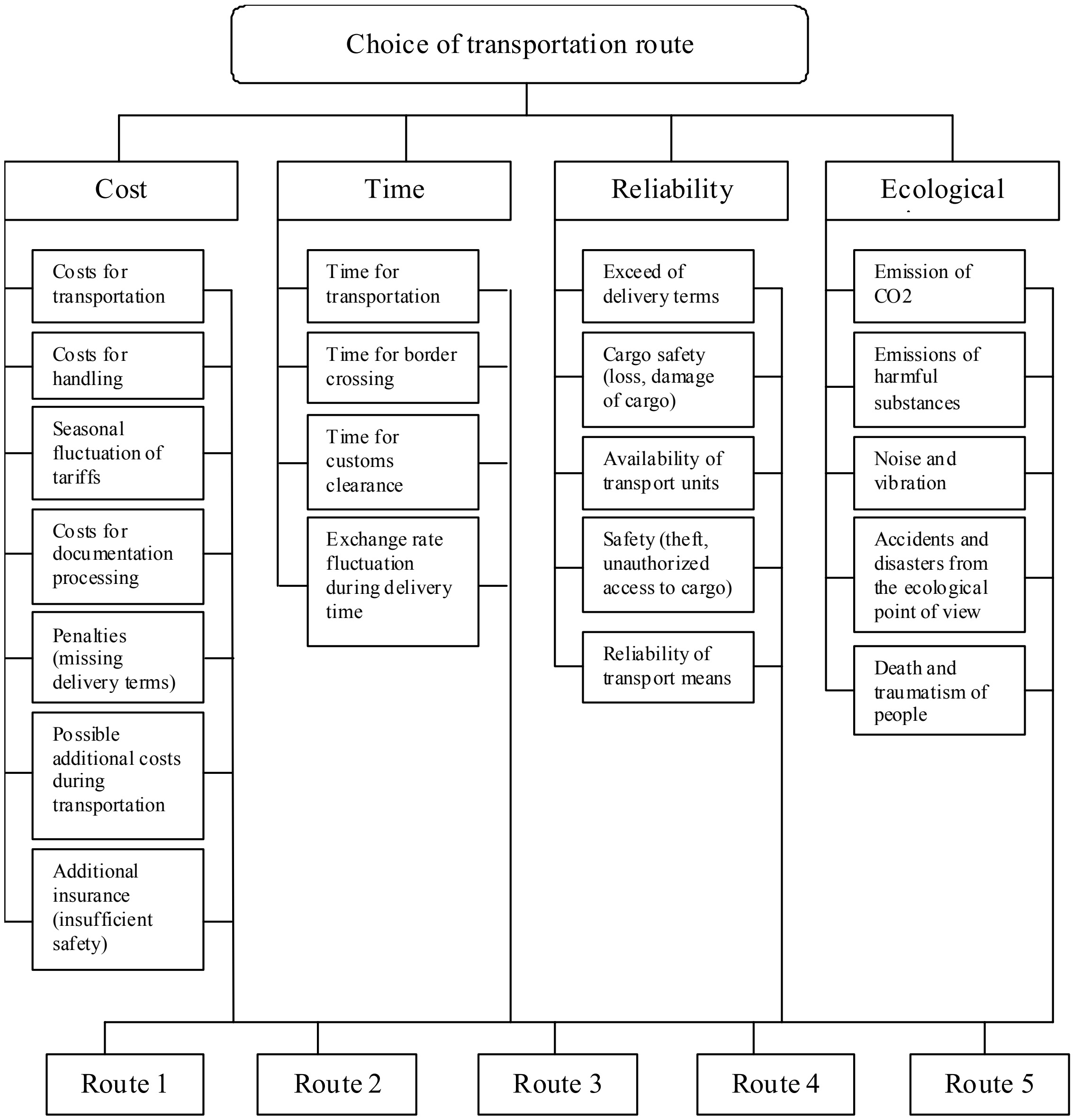

Figure 7. Hierarchy of the criteria for evaluating the routes of cargo transportation

To perform the calculations of criteria, the authors have used standard algorithms of the AHP method with the commonly used pairwise comparison scale 1–9. This scale proposed by Saaty [10] has the following values: 1 – if two alternatives **A1** and **A2** are equal in importance; 3 – if **A1** is weakly more important than **A2**; 5 – if **A1** is strongly more important than **A2**; 7 – if **A1** is very strongly more important than **A2**; 9 – if **A1** is absolutely more important than **A2**; and 2, 4, 6, and 8 are intermediate values between the two adjacent judgments. The summary data of the pairwise comparisons for the criteria of the first hierarchy level for each group are presented in Table 5. The importance of the criteria is evident from the evaluation of the criteria priority vector. It is easy to notice that "Cost" criteria with value 0,5813 of priority vector are more important for the multimodal freight transportation.

Table 5. Paired comparisons matrix for criteria (first hierarchy level)

Criteria	Cost	Time	Reliability	Ecological impact	Priority vector
Cost	1	4	5	6	0,581288
Time	1/4	1	2	5	0,220842
Reliability	1/5	1/2	1	5	0,147686
Ecological impact	1/6	1/5	1/5	1	0,050185

We have calculated the matrices of the evaluations of the priority vector for the suggested routes based on the evaluation of the criteria priority vector of two levels of the hierarchy. Table 6 gives an example of the results of pairwise comparisons and a normalised evaluation of the criterion "Costs for transportation" and Table 7 presents an example of calculating the priorities of the second level criteria "Cost". Similar calculations were made for the second level criteria Time, Reliability and Ecological impact.

Table 6. Paired comparisons matrix and results of a normalised evaluation of the criterion "Costs for transportation"

	Route 1	Route 2	Route 3	Route 4	Route 5	Priority vector
Route 1	1	4	2	2	6	0,388889
Route 2	1/4	1	1/3	1/3	4	0,100583
Route 3	1/2	3	1	1	5	0,233552
Route 4	1/2	3	1	1	5	0,233552
Route 5	1/6	1/4	1/5	1/5	1	0,043424
Total	2,4167	11,2500	4,5333	4,5333	21,0000	1,000000

Table 7. Matrix of evaluations of the vector of the criteria priorities of the "Cost" group

<table>
<tr><th rowspan="4">Alternatives</th><th colspan="7">Criteria</th><th rowspan="4">Priorities in group "Cost"</th></tr>
<tr><th>Costs for transportation</th><th>Costs for handling</th><th>Costs for documentation processing</th><th>Seasonal fluctuation of tariffs</th><th>Possible additional costs during transportation</th><th>Additional insurance (insufficient safety)</th><th>Penalties (missing delivery terms)</th></tr>
<tr><th colspan="7">Numerical value of priority vector</th></tr>
<tr><td>0,435534</td><td>0,104360</td><td>0,024950</td><td>0,085610</td><td>0,077539</td><td>0,064833</td><td>0,207172</td></tr>
<tr><td>Route 1</td><td>0,388889</td><td>0,346426</td><td>0,339458</td><td>0,285322</td><td>0,219304</td><td>0,083582</td><td>0,152554</td><td>0,292452</td></tr>
<tr><td>Route 2</td><td>0,100583</td><td>0,062969</td><td>0,068448</td><td>0,081937</td><td>0,052682</td><td>0,399669</td><td>0,488307</td><td>0,190261</td></tr>
<tr><td>Route 3</td><td>0,233552</td><td>0,206030</td><td>0,206514</td><td>0,285322</td><td>0,456028</td><td>0,083582</td><td>0,161589</td><td>0,227056</td></tr>
<tr><td>Route 4</td><td>0,233552</td><td>0,346426</td><td>0,339458</td><td>0,285322</td><td>0,219304</td><td>0,083582</td><td>0,152554</td><td>0,224798</td></tr>
<tr><td>Route 5</td><td>0,043425</td><td>0,038150</td><td>0,046121</td><td>0,062097</td><td>0,052682</td><td>0,349586</td><td>0,044995</td><td>0,065433</td></tr>
</table>

The evaluations of the vector of the global alternatives priorities are shown above in Table 8. The results of the evaluations show that route 2 has the highest value of priority 0,291997 and will be selected for cargo transportation from Shanghai to Moscow.

Table 8. Evaluating result for freight transportation from Shanghai to Moscow

Alternatives	Criteria				Global priorities
	Cost	Time	Reliability	Ecological impact	
	Numerical value of priority vector				
	0,581288	0,220842	0,147686	0,050185	
Route 1	0,290658	0,079618	0,125299	0,063250	0,208218
Route 2	0,194134	0,487666	0,371898	0,329346	0,291997
Route 3	0,226390	0,121666	0,108371	0,074537	0,178212
Route 4	0,223518	0,068267	0,135682	0,067550	0,168433
Route 5	0,065299	0,242783	0,258749	0,465317	0,153140

7. Conclusions

The constructed model of multimodal transportation system allows calculating total cost for freight transportation and total delivery time over considered routs. The received results allow choosing the most favourable route for which the criterion of system's efficiency has the optimal value.

The AHP seems to be the most attractive multiple-criteria method in this context since it allows structuring the choice procedure as a hierarchy of several levels. It allows for the distribution of criteria into several groups and the evaluation of the significance of every group's component. Consequently, the different group's criteria have been evaluated by different experts with proper qualification.

Further guidelines of the current research are the following: to find an optimal solution of the transportation problem using the simulation approach; to consider the cases with different optimization criteria.

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