Methods of decision-making for the transportation of combined consignments in conditions of uncertainty

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Abstract. The shipment of combined consignments is presented in the form of a decision-making task in the context of uncertainty caused by a significant number of facilities and elements in the transport system involved in the movement of goods. All variables for calculations in a given task are evaluated and entered by the transport organizer under the same state of objective conditions (object). In organizing transport the forwarding agent follows the experience of previous shipments with some degree of accuracy and assumes the result of each of the available alternatives to solutions. In many cases, the forwarding agent is forced to use a significant information array according to the working conditions of the transport modes and can only indicate many of all those pairs of outcomes for which the first outcome in the pair is preferable to the second. Besides, there are no numerical estimates of the outcomes until the completion of the shipment itself. In case of multi-criterion outcome estimates, significantly more complex mathematical models of the choice situation arise than in the single-criterion case. However, the forwarding agent may choose an alternative based on the calculation of a generalized value satisfying the limitations of the unwinding shipment.

1. Introduction
The decision-making problem on the shipment of combined consignments within the hinterland is to choose the best of a number of acceptable delivery options [1–3].

Let us formulate the problem as follows.
Multiple $X$ variants (finite or infinite) are specified. The choice of any of the variants $x_i \in X$ leads to some outcome $y_i \in Y$, where $Y$ – a set of possible outcomes (results of a specific solution, in our case, developed routes). It is necessary to choose such an option $x_i$ in order to get the optimal (according to some criterion $F$ – delivery time or cost of transportation) from the list of alternative outcomes $y_i$.

For example, for delivery of a small consignment from point $A$ (maritime terminal) to point $B$ (consignee’s warehouse) (Fig. 1) the forwarder may use heavy containers to the nearest railway station working with such containers, new means of consolidation of combined consignments (in-container modules) to the railway station working with low-tonnage containers, railway rolling stock to the station closest to the consignee’s warehouse, and further the road transport [4–5]. Depending on the location of the consignee’s warehouse, both the method of consolidation of combined consignment and the type of means of transport involved may vary.

At the same time, the delivery of heavy containers is carried out on railway platforms by high-speed trains at a special tariff, low-tonnage containers – in low-sided cars, and packaged goods – in covered cars at loaded speed. Hence, the difference in the speed and cost of delivery to the destination.
At the same time, the use of container technologies imposes time limits on the use of containers in hinterland. For heavy containers, this is the time of its free use (as a rule, 8 days is assigned by the owner of the cargo sea line), for in-container modules this is a doubled or tripled period of sea container ships entering the sea terminal (12–24 days) [6–8].

Such restrictions form the so-called planning horizons for attracting containers for transportation by time and distance of transshipment points from the sea container terminal [9–11].

The presence of several possible transport routes implies the need to assess the various and sometimes contradictory parameters of the options under consideration, which leads to a large dimension of the problem [12–14].

How to build a route and how to consolidate a small consignment in order to reduce delivery time or transport costs?

Figure 1. Selection of the optimal cargo delivery route

2. Methods and Materials
The stated problem may be considered as a decision problem: many alternatives consist of many railway stations for transferring goods from one mode of transport to another on the horizons of transport planning, i.e. of many real numbers \( x \). Moreover, each decision corresponds to its own result (outcome) – route \( A \rightarrow B \).

Thus, we formulated the problem of deciding on transportation in conditions of uncertainty due to a significant number of facilities and elements in the transport system involved in the movement of goods.

Obviously, all variables for calculations in such a problem are evaluated and introduced by the organizer of transportation under the same state of objective conditions (object). At the same time,
based on the experience of previous shipments with a certain degree of accuracy the forwarding agent assumes the result of each of the available alternatives to solutions despite the fact that there are no numerical estimates of outcomes before the completion of the shipment itself.

In our case, the example is to choose from the following set of alternatives (Fig. 2):
1. $x_1$: organization of transportation of combined consignments in a heavy cargo container with subsequent transshipment to the railway transport;
2. $x_2$: delivery of combined consignments by rail through carload shipment;
3. $x_3$: organization of transportation of combined consignments in a low-tonnage container (internal container module) with subsequent transshipment to road transport.

![Figure 2. Problem definition in general terms](image)

Based on Figures 1 and 2, we can assume that the forwarding agent on route $A-B$ would prefer $x_1$ over $x_2$, considering that the delivery rate in this case would be significantly higher. This preference may be referred to as $(x_1, x_2)$ or $x_1 > x_2$ ($x_1$ is better than $x_2$). Similarly, it can be assumed that $x_2 > x_3$. At the same time, by comparing $x_1$ and $x_3$, we can understand the choice of $x_3$ compared to $x_1$ (advantages of container shipment remain for longer distances). Thus, the preference system is given by a set of pairs: $(x_1, x_2)$, $(x_2, x_3)$, $(x_3, x_1)$. Therefore, there is no preferred alternative. What principles should we follow in decision-making in such situations?

On route $A$–$B'$, the outcome $x_3$ will be preferable to $x_2$, for example, in terms of delivery speed. Similarly, it can be assumed that $x_2 > x_1$ (reduction in the number of transshipments of goods between modes of transport). Comparing $x_1$ and $x_3$, we can understand the choice of $x_3$ compared to $x_1$ (load
capacity and cargo capacity of the sea container are maximally used). Thus, the preference system is given by a set of the following pairs: \((x_3, x_2), (x_2, x_1), (x_1, x_3)\).

On route \(A-B''\), the outcome \(x_1\) will be preferable to \(x_2\), for example, in terms of delivery speed. Similarly, it can be assumed that \(x_3 > x_1\), at the cost of transportation. At the same time, comparing \(x_2\) and \(x_3\), we can understand the choice of \(x_2\) compared to \(x_3\) (reduction in the number of transshipments of goods between modes of transport). Thus, the preference system is given by a set of the following pairs: \((x_1, x_2), (x_3, x_1), (x_2, x_3)\).

### 3. Discussion

Each of the considered problems may be considered as a simple model of a group selection problem. There are many solutions \(X: X = \{x_1, x_2, ..., x_m\}\). There is a group of \(n\) forcing criteria and a final choice (solution). Each criterion of a group with the number \(i = 1, ..., n\) has its own preference system on a set \(X\) given by the binary ratio \(R_i \subset X \times X\),

\[
R_i = \{(x_j, x_k), ..., (x_p, x_m)\}.
\]

Here: \(R_i\) – set of ordered pairs of elements from \(X\), with the inclusion of some pair \((x_i, x_i)\) in the set \(R_i\) means that from the positions of the \(i\) member of the group the option \(x_i\) is preferable to the option \(x_j\): \(x_i > x_j\). It is required according to a given system \(R_1, ..., R_n\) of qualitative and time preferences to build a group preference system \(R = f (R_1, ..., R_n)\), where \(f\) – some function that implements the accepted preference matching principle.

![Figure 3. Relationship of alternatives to outcomes under different types of uncertainty](image-url)

*Figure 3. Relationship of alternatives to outcomes under different types of uncertainty*
If we consider routes $A-B$ ($A-B'$, $A-B''$) as options for delivering goods to the same destination inscribed in a transport system having an alternative location of planning horizons, then the preference system will take the following form:

1. $R_1 = \{(x_1, x_2), (x_2, x_3), (x_3, x_1)\}$.
2. $R_2 = \{(x_1, x_3), (x_2, x_1), (x_1, x_3)\}$.
3. $R_3 = \{(x_1, x_2), (x_3, x_1), (x_2, x_3)\}$.

As we have seen, uncertainty in the selection and implementation of the association of alternatives with outcomes is quite complex (Fig. 3).

When considering each problem separately, case 2 in Fig. 3 corresponds to decision-making under conditions of certainty: the points on the $y$ axis indicate the outcomes corresponding to the choice of alternatives $x_1$, $x_2$, $x_3$ (three alternatives and three defined outcomes).

Case 1 describes the problem of decision-making in conditions of uncertainty: after choosing any of the alternatives $x_1$, $x_2$ or $x_3$, only the interval of the appropriate outcome $y$ can be specified.

Case 3 reflects the decision-making under risk conditions.

Figure 3 also shows graphs of the corresponding densities of the event probability distribution $y$ depending on the choice of the alternative $x_1$, $x_2$ or $x_3$.

As already noted above, each of the cases reviewed may additionally have its own outcome quality assessment mechanism not directly related to the occurrence mechanism $y$ in the given $x$ (Fig. 4).

Figure 4. Relationship of alternatives to outcomes according to different quality assessment criteria (in particular, by cargo delivery time)

The simplest situation occurs when each outcome $y$ can be estimated by a specific real number according to some given mapping

$$f: Y \to R.$$
In this case, the comparison of the outcomes is reduced to the comparison of numbers corresponding to them, for example, the outcome $y_i$ may be considered more preferable than $y_j$ if $f(y_i) > f(y_j)$ (maximization problem). The outcomes are equivalent if $f(y_i) = f(y_j)$. To compare the outcomes themselves, the following expressions are used:

$$y_i > y_j, \quad y_i \sim y_j.$$

In other words, we have a function $f$ called the optimality criterion function.

Assuming that the relationship between multiple alternatives and multiple outcomes is deterministic:

$$y = \varphi(x),$$

then the function $f$ given on the set $Y$ is transformed into some function $J$ given on $X$ and being the superposition of $\varphi$ and $f$:

$$f: Y \rightarrow R, \quad J = f \cdot \varphi.$$

In this case, the problem of choosing the optimal outcome is reduced to the problem of choosing the optimal alternative on set $X$ and is solved directly by the methods of optimization theory.

In our case, we deal with a situation where, unlike the choice of “speed” or “cost” of the outcome, $y$ is estimated not by one number $f(y)$, but by several. In other words, there are several measures of the quality of the solution (criteria) described by the functions $f_k: Y \rightarrow R, \quad k = 1, 2, \ldots, m,$

and each of the private target function $f_i$ needs to be minimized.

4. Conclusion

In the case of multi-criterion outcome estimates, significantly more complex mathematical models of the choice situation arise than in the single-criterion case. The criteria are usually contradictory and, as a rule, reach maximums at various points $y \in Y$. Here, variants $y_i, y_j$ that are incomparable according to the vector criterion $f = (f_1, \ldots, f_m)$ already appear.

Besides, in our case, the above restrictions on the use of marine containers and in-container modules within hinterland limits allow using the restriction method as the main one in this system, allowing for the pre-selection of alternatives and the selection of the transport route (option) itself.

At the same time, the effectiveness of applying the restriction method depends on the reasonable choice of the alternative under consideration.

In the above system, the adaptive reconciliation method may also be used to select the proposed alternative. Wherein, for each alternative, a generalized value is calculated:

$$O3 = \sum_{i=1}^{n} W_i \cdot Alt_{i},$$

where $Alt_i$ – value of the $i$ criterion for this alternative.

The forwarding agent may choose an alternative with a maximum generalized value from among the alternatives satisfying the restrictions.

The weights of the criteria ($W_i$) are calculated using one of the weight assignment methods, the Monte Carlo method, or the guaranteed result principle.

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