Multimodal transport network freight routing algorithms in optimization models

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Abstract. The development of international trade is associated with global growth in trade. For the implementation of trade between different regions, multimodal transportation is used. The cost of international logistics reaches approximately 30-50% of the total cost of production, therefore, reducing transportation costs is one of the options to increase profits and maintain competitiveness in the world market. Thus, the optimization of freight routes for moving goods through a multimodal transport network is relevant. This study discusses the problems of planning multimodal transport routes from the point of view of developing models and algorithms: characteristics of optimization models; selection of optimization models; solving optimization models with heuristic algorithms.

1. Introduction
Routing planning is a combinatorial optimization problem associated with the efficient use of resources in the system by selecting the optimal routes for distributing the flow of goods. System performance can be optimized for cost, stability, regularity, and other important factors. Routing planning of freight traffic is aimed at optimizing routes in order to move goods from the shipper to the consignee, through transport networks. The design process can be divided into levels: strategic, tactical and operational planning. Freight planning is in considered to be the third level. A short-term decision-making process in the design of the transport network takes place, but the planning of freight routes is focused directly on meeting customer needs, and its effectiveness determines the competitiveness of the carrier or a third-party logistics company in the freight market. In multimodal transportation, combinations of various modes of transport (rail, road, water and air) are used to create routes from the point of departure to the destination [1-4]. The predominant combinations in practice are road and rail, or rail and sea. The use of integrated methods of transportation of goods is more efficient from the point of view of costs and ecology, but planning of multimodal transportation routes is more complicated.

Transportation in a multimodal network means: regular maintenance and a flexible schedule. Regular maintenance means that the transportation schedule is compiled manually: the sequence of detour points along the route, the time of arrival and departure, the start time of the end of cargo handling, the terminal's throughput and the operating time. All time-related parameters: time of arrival and departure, inventory, transportation - depend on the method of transfer of cargo between the two modes of transport. Planning multimodal transportation of goods is a complex optimization task that takes into account the needs of customers, service schemes for various modes of transport, as well as cargo characteristics.
2. Theoretical basis
Multimodal transportation planning optimization models are tested by entering transportation data and then solving them using various methods: column generation; branches and borders; suboptimal solution. The last group includes genetic algorithms, a search algorithm. In recent decades, many studies have been devoted to optimizing the planning of multimodal transportation, which led to the emergence of a new direction. Almost all optimization models for the planning task of multimodal transportation of goods are based on mixed integer linear / non-linear programming. Models can be conditionally divided depending on their characteristics [5-14]:
1. The object of optimization - a single or heterogeneous product is transported.
2. The integrity of the transportation process - the compatibility of goods with other groups of goods.
3. Network objects - accounting for bandwidth, network capacity and other important factors related to transport infrastructure.
4. Transport service scheme - a single scheme or several transportation options.
5. Optimization criterion - one or several indicators will be optimized.
6. Application of the model - stochastic or deterministic.

Consider an application model of an object-based optimization model. In a multimodal transport network, a homogeneous product corresponds to an OD pair. Models whose optimization object is the same product focus on multimodal freight planning for a particular customer. The aim of the study is to obtain the optimal route for moving goods from a shipper to their destination through a multimodal transport network. For the multimodal transport network to work effectively within the geographical space, more than one product must be moved. Each type of cargo has its own class, transportation volumes, release dates, transportation periods and correspond to different OD pairs. In order to optimize network performance, many models offer the extension of a transportation facility to several goods in a multimodal transport network.

Regarding the models of transportation integrity, it is assumed that each product cannot be divided into several sub-products, and its transportation must go along the same route through a multimodal transport network. In the corresponding models, the variable $X_{ijm}^k = 1$ is defined as a directional arc (i, j) and is used to move goods k during transportation m, $X_{ijm}^k = 1$ otherwise $X_{ijm}^k = 0$. And $X_{ijm}^k$ must satisfy restriction (1) in order to guarantee the separability of the goods.

\[
\sum_m x_{ijm}^k \leq 1 \forall k \forall
\]

Without considering the restriction on the variable, the planning of multimodal routes of non-shared goods can be converted into shared.

The multimodal transport network includes objects that can be divided into two categories: stationary objects (terminals, warehouses and transport routes) and mobile objects (railway cars, locomotives, ships, planes and trucks). These objects form the material basis for route planning, and their use is aimed at organizing the transportation of goods in accordance with the requirements of customers. In most cases, the resources available for planning cargo routing in a particular multimodal transport network are limited by the number of objects and their labor productivity. There are other factors that make route planning difficult. In the formulation of the model, such a limitation is often bandwidth, the network capacity is not taken into account. For efficient freight route planning, terminal capacity and vehicle carrying capacity are usually included in model restrictions.

The transport service scheme, in a simplified form, is described as “arrival → transshipment → departure”. In fact, in addition to a flexible service scheme, there is also a scheme of planned services in a multimodal transport network. Cargo routing planning solves the problems of combining several services.

Assume the start time and the end time of the scheduled services loading in terminal i are $t_i^s = c_i^s$, accordingly time of arrival of goods k to this terminal this $t_i^{ks}$, and the time taken to load the goods k for services s this time $t_i^{ks}$. 

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If the product can use this service, we get $a_i^k + t_{ks}^i \leq s_{ss}^i$. Когда $a_i^k < s_{ss}^i$ goods k are waiting in terminal i until before $s_{ss}^i$, then it starts loading on the service s.

Under this circumstance $t_{ks}^i$, the condition must be satisfied $t_{ks}^i \leq c_{ts}^i - s_{ss}^i$

After the implementation of services s, goods k are sent from terminal i.

Optimization criterion

Meeting the need for transportation at the lowest cost is the most important criterion for planning multimodal transportation. It comes down to choosing the most cost-effective routes for moving goods through the transport network. In addition to optimal costs, increasing the efficiency of transportation and reducing environmental pollution are of great importance. To solve these problems, reduction of transportation time and carbon emissions are also set as optimization goals in route planning. Thus, it is possible to use multi-purpose optimization models to determine rational routes that can provide a compromise between costs and transportation efficiency or between costs and carbon emissions into the environment.

The methods used to solve such problems are the weighted sum method and Pareto optimality. The first method distributes various weights relative to the target, and then combines them linearly. Multipurpose optimization turns into one objective. The second method is to obtain the Pareto boundaries of multi-purpose optimization models. A widely used approach for obtaining the Pareto boundary of multi-purpose optimizations is the method of normalized normal constraints. Sometimes, depending on the assigned practical task, a lexicographic approach to programming is chosen to solve multipurpose optimization.

Almost all studies focus on the formulation of the model. In models, parameters can be set as fixed values: need for transportation; travel time, speed; terminal transshipment time. But studies indicate that transportation needs demonstrate high uncertainty in time and space, and meeting fluctuating transportation needs is challenging due to environmental factors, congestion on the road network, traffic accidents, travel time, speed, modes of transport and working hours at the terminals. These factors increase the likelihood of transport delays at the terminals. Together with the difference in the distribution of resources across different terminals, the delivery time represents uncertainty. Thus, uncertainty is a widespread phenomenon in a multimodal transport network, and its assessment will determine the actual planning of routes for multimodal transportation of goods.

3. Decision Algorithms

The task of optimizing multimodal transportation of goods is a variety that is difficult to solve using large-scale methods, but heuristic algorithms and their variations are often used to solve problems of this kind. The general block diagram of the heuristic algorithm is shown in Figure 1.

Among heuristic methods, a genetic algorithm is distinguished, as is a classical one. In the genetic algorithm, the solution to the optimization problem is presented as a sequence of options. In the iterative process, solutions are modeled by choosing between different options and their integration. To assess the quality of solutions, suitability function is used. An option having a greater suitability and higher probability has a choice for inclusion in the next iteration.

The main stages of the genetic algorithm:

1. Finding a solution to the detour sequence.
2. Assessment of the quality of the solution using the suitability function. Given that the quality of the solution is proportional to its suitability. Therefore, for the minimization problem, the function is usually calculated as $f = 1/z$.
3. Updating the selection strategy. In the $F_i^l$ and pop denote the suitability value of the i-th sequence and the size of the set of options, respectively.

The choice of probability can be calculated by the formula:

$$p_i^l = \frac{F_i^l}{\sum_{i=1}^{pop} F_i^l} \quad \forall \ i = 1,2, \ldots, pop$$  \hspace{1cm} (2)

Then the selection operation is performed. First, the probability set of the i-th option is calculated:
Then a random number is generated \( u_i^t \in (0,1) \). If \( pp_i^t > u_i^t > pp_{i-1}^t \), \( i \)-th is involved in the next iteration.

Integration of two different options can increase the number of solutions to a problem.

4. Criterion for completion. The genetic algorithm terminates after calculating a certain number of iterations. The block diagram of the genetic algorithm is shown in Figure 1.

\[
pp_i^t = \begin{cases} 0 & i = 0 \\ \sum_{j=1}^{i} \forall i = 1,2,...,pop & \forall i = 0,1,...,pop 
\end{cases}
\]  

### Figure 1. General block diagram of heuristic algorithms [15].

The performance of heuristic algorithms is determined at the update stage. The high performance of the heuristic algorithm is the ability to conduct research at the initial iteration and the ability to obtain the optimal solution at the final stage. To improve the performance of specific heuristic algorithms, at the stage of updating it, two types of methods can be used - modification of coefficients and combinatorial optimization. The first method will work iteratively, which will avoid getting the solution variants to the optimal ones at the initial stage, and speed up the reduction to the optimal one - at the final stage. The second method is to combine various heuristic algorithms based on their advantages. In the combinatorial method, the genetic algorithm is the main one, and the search algorithm is included in the update strategy.
Figure 2. Block diagram of the genetic algorithm [16].

It should be noted that when using heuristic algorithms it is difficult to guarantee the optimality of the solution and their effectiveness. When testing heuristic algorithms, it is better to test them on small problems first, to compare the optimality of the solution with the exact solution methods. Exact solution methods can be performed by mathematical programming software. Non-linear optimization models must be linearized before using mathematical programming software. Two-stage methods can demonstrate both the optimal solution and the computational efficiency of heuristic algorithms in solving the planning problem of multimodal transportation of goods.

4. Conclusion
Currently, routing algorithms for freight transportation of a multimodal transport network in optimization models are an important stage in the effective functioning of traffic in the urban environment.

A study of the planning of a multimodal route network of freight transportation includes: a mathematical description of the transshipment process among several points; scheduling movement; stochastic analysis of statistical data; development of algorithms. To solve the combinatorial optimization problem, the linearization method, the Lagrangian relaxation method, heuristic algorithms can be used. Planning multimodal transportation of goods is a complex optimization task that takes into account the needs of customers, service schemes for various modes of transport, as well as cargo characteristics.

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