Optimizing cargo delivery employing vehicles of different carrying capacity

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Abstract. Consider the problem of mathematical modeling. Making optimal use of vehicles of different carrying capacity can help minimize delivery costs. This article presents the models for finding the optimal delivery solution for ring roads and pendulum routes. The models were created for several car parks (depot) with vehicles of various carrying capacity. We also have taken into consideration that some routes are unavailable for particular types of transport.

1. Introduction
In many situations, low-tonnage vehicles are more appropriate to deliver goods [1]. This is due to some obstacles with delivering goods within the city. These obstacles occur due to the heavy traffic in the main highways, courtyards infrastructure, the need to leave a car in a small free area near the ramp or on the “patch” near the house. The situation is the same when it comes to small consignments within agricultural areas or factory territories where the manageability of heavy vehicles or trailer-trucks is extremely limited.

This paper reviews some routing schemes in terms of optimizing cargo delivery:
– when using freight transport of various carrying capacity;
– when it is impossible to use certain types of freight transport on certain routes.

2. The issue of cargo delivery (overview)
The issue of optimizing, namely, minimizing, delivery costs is a multidimensional task. Such optimization has various goals and applications:
– from a common transportation problem in which the routes between suppliers and consumers are clearly defined; while the task is reduced to determining the amount of goods transported along these routes to optimize the total costs,
– to complex logistic tasks which take into account the capabilities of suppliers (including the production structures) and customers (which may be associated with further transportation systems, e.g., a seaport, or, for a factory, the production capacity).

Nowadays, a great number of different methods have been developed to find the optimal solution with regard to the nature and goals of cargo delivery in various conditions. An overview of various goal statements and methods to achieve them can be found in [2, 3, 4, 5].

2.1. Routing tasks
The routing is a part of these big logistical tasks. Routing is regarded as the search for an optimal route scheme that minimizes the delivery cost from suppliers (manufacturers, from warehouses, etc.) to
customers (consumers). A detailed classification of routing problems and a review of methods for solving them can be found in [6]. In routing, there are many wording options that take into account the location peculiarities of routes and possible requirements for goods delivery. There are also methods to address the aforementioned issues that are determined by:

1. Customer requirements are characterized by:
   a) the location of consumers (a graph of paths and endpoints of routes);
   b) consumer requests for the volume of goods (e.g. goods of various types, or the so-called multi-product tasks);
   c) the time periods by which the consumer should receive goods (tasks with “time windows”),
   d) time limits for handling charges.
2. The distribution network (routes) that is characterized by pendulum, cyclic, and tree-like schemes of route networks.
3. The fleet of vehicles that is characterized by:
   a) the places of departure and destination (transport companies) and the location of consignors and consignees,
   b) the carrying capacity of vehicles (expressed as the maximum volume of transported goods or the accommodation capacity (e.g. trays)),
   c) devices for handling charges,
   d) the roads trafficability for the particular vehicle,
   e) vehicle maintenance costs.

We can also distinguish a specific class of routing tasks. In this class, the delivery tasks and exporting other goods from other consumers are simultaneously solved (pickup and delivery problems).

Usually, the goal of optimization is to minimize the total cost of transportation, also by choosing the optimal route. However, sometimes there can be a multicriteria problem (with different, often conflicting, goals):
- minimization of total costs that usually depends on the total distance traveled by cars or the total travel time, and on the costs of using particular vehicles;
- reducing the number of vehicles (or drivers);
- correlation of routes lengths with travel time and vehicle loading;
- minimization of fines related to customer service quality.

Also, sometimes it is necessary to take into account that some factors are time-dependent and are possible to occur.

2.2. The mathematical formulation of routing tasks

The mathematical formulation of tasks depends on the aforementioned routing types. Therefore, we will illustrate only one of the possible tasks. It is the so-called routing problem with partial unloading of goods for each consumer and the possible loading of different product from this consumer (VRP with Pickup and Delivery – (VRPPD)).

This task can be regarded as a search for some simple ring routes that require minimal costs with the following restrictions:
- each ring route begins and ends at the starting point (“depot”);
- each consumer is attended to in only one ring route;
- the value of the cargo along each ring route should be non-negative and should not exceed the carrying capacity \( C \);
- for each consumer \( i \) (different from the “depot”), consumer \( D_i \) should be attended to on the same ring route as consumer \( i \) [5].

There are many variations of restrictions. Restrictions appear in tasks with partial handling charge at consumers’ or with the imposition of time restrictions on the delivery of goods. Options with several “depots” or several types of vehicles are possible. Also, the task can be temporary in nature.
when delivery can take several days. In addition, some task components (number and customer requests, path length, etc.) may be random.

Various approaches to modeling and mathematical formulation of these problems can be found in [5, 7, 8].

2.3. Methods for solving routing tasks

The classical transportation task belongs to the class of linear programming problems. Therefore, various modifications of the so-called simplex method are usually used to solve it [9, 10].

Methods for solving routing tasks, in contrast to the simplest transport task, as a rule, include integer constraints. Therefore, integer programming methods are the basis for their solution [11] (e.g. the "branches and bounds with clipping" method).

Methods for solving routing problems can be divided into “exact” and “heuristic”.

“Exact” methods are usually various versions of the “branches and borders with clipping” method [5, 12]. Since the computational costs for implementing such methods can increase significantly with increasing degree of the task (a large number of consumers, routes, or restrictions), various heuristic approaches are often used [13]. The use of heuristics does not allow obtaining “exact” solutions but only a so-called good solution. However, it can significantly reduce computational costs.

In more complex logistics tasks, a strict mathematical formulation can be difficult to use due to a large number of additional conditions that describe the behavior of suppliers and consumers. In such cases, simulation methods can be used [14, 15]. Sometimes, genetic optimization algorithms are used to solve transportation tasks [8].

3. Setting the task

According to the aim of this study, we will determine the optimal composition of the vehicle fleet for the delivery of goods to consumers.

We will consider three cases:

a) a fleet with one type of heavy goods vehicle,

b) a fleet with several types of vehicles of different carrying capacity,

c) several fleets with vehicles of various carrying capacity.

The option with a radial route diagram does not require any routing. In the radial diagram, routes are defined by the distance between the vehicle fleet (“depot”) and consumers. In addition, having one type of vehicle does not require optimization since the number of vehicles on each route is determined by the volume of goods transported by the consignor (consignee). The only parameter to be determined is the number of vehicles of a certain type. This will depend on customers’ needs, vehicle carrying capacity, route availability, and fuel consumption.

Nevertheless, this structure of the model will be preserved in more complex cases. Basically, this is a common transportation task (with one supplier) but with different types of vehicles.

The formal statement of the problem (its mathematical formulation) can be written as follows.

\[
\begin{align*}
X_{ij} & \text{ is the quantity of the product/goods, Cost}_{ij} \text{ is costs associated with delivery along route } i \text{ (to consumer } i) \text{ by vehicle } j. \\
\text{Consumer (route) } i & \text{ is characterized by distance Distance}_i \text{ and demand Demand}_i. \\
\text{Vehicle } Auto_j & \text{ is characterized by Auto_Capacity}_j \text{ and average fuel consumption per 100 km Fuel_Consumption}_j. \\
\text{Minimized:} & \\
\sum_{ij} X_{ij} \cdot Cost_{ij} & \\
\text{under restrictions:} & \\
\text{for each route (consumer), } i \text{ number of deliveries to the } i-\text{consumer by all types of } j \text{ vehicles should attend to their needs:}
\end{align*}
\]
\[ \sum_j X_{ij} \geq \text{Demand}_i \]

the amount of goods exported by all types of j transport to the i-consumer should not exceed stocks in the warehouse; for simplicity, we will take stocks equal to the sum of all consumer requests:

\[ \sum_j X_{ij} \geq \text{Depot\_capacity}_j \]

In addition to the standard restriction system of the transportation task, we will introduce \( \text{Available}_{ij} \) parameter for the availability of i-route for the j-type of vehicle.

After optimization, the number of cars for a given direction is determined by dividing the amount of cargo transported in this direction by the vehicle capacity (the total value is rounded to the nearest upper integer).

4. The case of several suppliers with vehicles of different carrying capacity and restrictions on the availability of the delivery route

This case will represent a general transport task with any number of suppliers, any number of vehicle types, and restrictions on the availability of the delivery route.

In order not to complicate the model with a large amount of source data, we will use the case of two suppliers and four types of vehicles. Generalisation for a larger number of suppliers and vehicles will only require adding the source data which will not affect the main part of the model.

Figure 1 shows the distribution network that we will use as an example.

![Figure 1. Two-supplier transportation scheme with five consumers.](image_url)

Such a scheme provides a large number of options by changing the number of stocks in the 1st and 2nd warehouses, by closing various routes for any vehicles, by changing the consumers’ needs, the distance between warehouses and consumers. Given the additional restrictions on the availability of certain routes, this scheme can be considered relevant to the goal of this study.

In this model, the objective function and constraint system are the same as in the aforementioned one. Now, it is necessary to enter another index to iterate over all the options with suppliers. In particular, the main operator with the objective function should now be written as:

\[ \text{MIN} = \text{@SUM} (\text{PATH}(I,J,K) \mid \text{Available}(I,J,K) \#NE\#0: \text{COST}(I,J,K)) \]

Similar changes to the third index should be made for other operators. Naturally, all source data should contain full source information with regard to several warehouses/suppliers.

Although all the routes are available for all types of vehicles, unlike the model with one warehouse (fleet), the optimal distribution of goods along routes is not known in advance.

The software was developed to determine the optimal use of vehicles.
With the developed model, it is possible to vary the different availability of routes for different types of vehicles:

- to close some routes for all types of vehicles (because there is no such road or it is under repair),
- to close some routes for multi-ton trucks (e.g. because there are bridges in the countryside that do not support the weight of the truck or the dimensions of the bridge do not match the track of the truck),
- to close some routes for small-capacity freight transport with a trailer due to their low manoeuvrability in certain parts of the route.

As an example, we consider the following scheme (Figure 2).

![Figure 2. Scheme of routes with two warehouses (some roads are missing, two routes are partially accessible).](image)

Compared to the previous scheme (Figure 2), in which all suppliers were available for all modes of transport from both depots, now

- there is no route from the first warehouse to the second consumer (the second row in the Available matrix below),
- there is no route from the second warehouse to the fourth consumer (the last row in the Available matrix below),
- the route from the second warehouse to the third consumer is not available for multi-ton trucks (ninth line),
- the route from the first warehouse to the fourth consumer is not available for freight transport with a trailer (fourth line).

In the model, it is reflected in the data matrix Available:

\[
\text{Available} = (1, 1, 1, 1, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0);
\]

It is easy to make other changes to the initial data of the model and promptly determine the optimal distribution of vehicles for various situations.

5. Conclusion
1. We have tried to justify the prospects of using vehicles of various carrying capacities for the carriage of goods under various conditions:
   – inside the city in terms of heavy traffic in the main highways, difficulties when driving through domestic territories, the need to maneuver in a small area;
   – in rural areas;
   – in-plant territories.
2. We have studied some variants of transportation tasks with the use of different types of vehicles of various carrying capacity.
3. The developed software helps quickly assess the fleet of transport vehicles depending on the customers’ needs and road traffic for various types of vehicles.

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