# PARALLEL DELIVERY OPERATIONS MODELLING

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Some delivery organization scheme is considered. The key point is the principle of routes parallelization using several carriers at the same time and these auxiliary carriers can be based on the main carrier. An example of such a delivery system is a van carrying several autonomous carriers, which in turn can carry out simultaneous so–called parallel deliveries. Delivery routes are determined based on the coordinates of customers, the determination of acceptable starting points for auxiliary carriers, the technical and energy limitations of the main and auxiliary carriers, and the minimization of the amount of time spent on delivery operations. The developed algorithm for solving the problem on routing of delivery using primary and secondary carriers allows to reduce delivery time and resources. The algorithm is implemented in Python using the libraries for processing and visualization of trajectories and other space–time data, packages for extracting, modelling, analyzing and visualizing street networks on the example of the Yekaterinburg city.

*Keywords: operations research; routing problem; traveling salesman problem; nearest neighbors algorithm; delivery service.*

## Introduction

The development of e-commerce leads to growth demand for delivery services. Recently, this was due to the pandemic as well. The traditional delivery service can be advanced by new modes of transportation and the use of route optimization algorithms. In addition, we must not forget about the environment protection, especially in the urban environment. And here the challenge for operations research specialists and software developers is to design new delivery methods and use alternative modes of transportation.

Many scientists and specialists deal with the problems of designing algorithms for cargo transportation, routing, and transportation management. A huge number of articles on these topics were published. Specifically in the field of e-commerce delivery, the following works can be noted. For example, the paper [1] presents an approach related to the auction distribution of orders for delivery in real time based on a special web platform. The performance of this new approach is tested and compared with current methods using multi–agent simulation. The new method significantly improves the efficiency and flexibility of delivery operations.

With regard to the use of alternative modes of transport for deliveries, such as drones, there are questions of energy consumption limitations and technical capabilities. The article [2] provides an overview of drone models and their power consumption. The relationship between the performance of various drones, their technical characteristics, design features, and the possibilities of application for delivery operations are considered. The results show that care must be taken when modelling. The selected model should be consistent with the design and purpose of using drones for delivery.

Due to the relevance of the problem of finding optimal delivery routes, many methods and applications were developed to solve optimal routing problems. Combined classical optimization methods together with heuristic algorithms lead to good results. For example, the use of traveling salesman problem methods together with the concept of parallel

delivery [3] reduces the delivery mileage and of course carbon monoxide emissions are reduced.

For more than half a century, authors were interested in routing problems [4] by exploring variants of the route selection problem starting with the mixed integer linear programming method for solving the traveling salesman problem. The article [5] describes the problem of routing vehicles and drones. As criteria, such objective functions as minimizing the maximum time for performing operations and minimizing the total time for performing operations are considered. Lower resource time estimates are introduced and mathematical rigorous proofs are given. With regard to many published reviews, the following should be noted. The paper [6] discusses approaches to optimizing the use of drones in civilians and their interaction with trucks. It describes current research on various optimization methods, including mathematical models, synchronization between drone and truck. The current so–called "last mile" delivery concept is often described as promising. In [8] this concept is explored using drones.

In this paper, the approach described in [3] is considered and developed in terms of specification of valid options and a set of admissible controls for parallel delivery using a van and two drones.

## 1. Problem Statement and Initial Data

For a delivery system consisting of a van and two drones, it is necessary to lay a route around all customers. The warehouse and delivery points are set by coordinates in relation to the road network. Delivery can be carried out both by a van and two drones launched from it. Parcels can have different weights and dimensions, and the possibility of their transportation by drones depends on these parameters. The number of parcels is also set and it corresponds to the number of customers. Figs. 1 – 3 show



**Fig. 1**. Drones take off and land on a waiting van

the allowable combinations of van and drone interactions. The movement of the van and the flight of drones are shown by arrows.



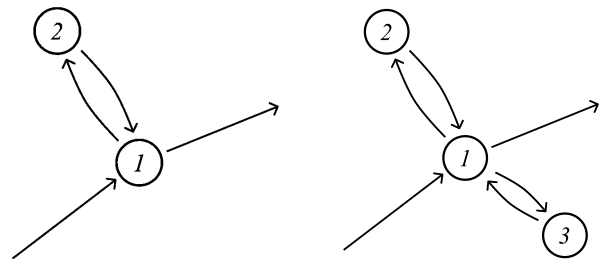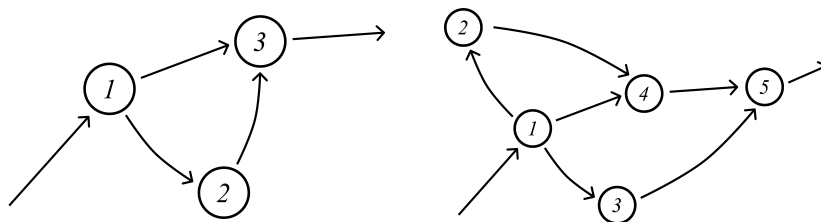**Fig. 2**. Launch and return of one or two drones to a moving van

For example, Fig. 1, on the left, shows the take off, delivery to the point 2 and landing of the drone back onto a stationary van at the point 1. This procedure applies if the van in turn makes a delivery at the point 1.

On the right, a similar situation is shown only if there is an order for delivery to the point 3. Naturally, restrictions on the flight range of drones, the dimensions and weight of their parcels are satisfied.

Fig. 2, on the left, shows a situation in which a van moves from the point 1 to the point 3 while a drone delivers a package to the point 2. The points 1 and 3 may not be delivery points. On the right, we show the case when two drones simultaneously start from the van at the point 1 and return to it sequentially at different points 4 and 5 after performed deliveries to the points 2 and 3.

Here, in principle, the points 1, 4 and 5 may not be delivery points as well.

Finally, it is necessary to describe cases of successive starts and landings on a displaced van. So Fig. 3, on the left, shows the sequential delivery by two drones to different points 2 and 4.
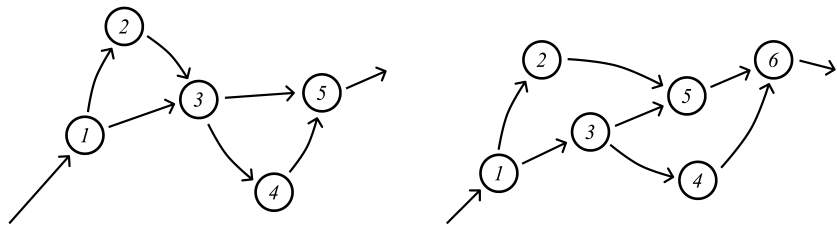


**Fig. 3**. Sequential launch and return of drones to a moving van

In this case, the van can move through the points 1, 3 and 5. And the more complex case is shown in Fig. 3 on the right. Here all the points are different.

Such a large number of combinations of interaction between delivery vehicles generates non–trivial logic in the general algorithm, the description of which can be found in the next section.

The problem is to develop an optimal route based on parallel delivery for parcels using the main carrier and the carrier, which, in turn, transports auxiliary carriers. The optimization affects drone start points to minimize the overall route duration.

## 2. Delivery Operations Simulation

According to the algorithm described in [3], the coordinates of the delivery points and the coordinates of the warehouse must first be set in relation to the road network. The weight of parcels, their quantity and dimensions are also set. The possibility of delivery using drones depends on this. Heavy and oversized cargo can only be delivered by a van. The algorithm determines the procedure for serving customers primarily by a van and the optimal launch points for drones, if it is possible to use them. The streets and intersections of the city are represented as a directed multigraph $G$ with a set of vertices $V$, edges $E_t$ and given costs of moving $C_{ij}$ along each edge for the main carrier, that is, for the van. The criterion for the cost of movements $C_{ij}$ can also be set as the value of the time spent on the given movement.

Each delivery point belongs to the vertices of the multigraph. And a route of a van starting from a warehouse or from some current point is a sequence of the vertices $\{v_1, v_2, \ldots, v_n\}$ starting from the initial point and ending with the final delivery point. The van's route is determined based on Dijkstra's nearest neighbor algorithm [7]. But the criterion for the optimality of routes is the minimum total length of the route of both the main carrier and auxiliary deliverers.

The simulated movement occurs along the edges of the graph, which corresponds to the street network of the city. Movement iterations are organized by time, during which, at an average speed of 24 km/h, the van travels a certain distance. The decision-making algorithm is the following.

1. At the next vertex of the graph, both conditions are checked for using the drone.

1.1. The range limit to the delivery point is confirmed (the distance must be less than 1 km).

1.2. The weight and size limit of the package allows the use of a drone.

Then the drone starts, and the van determines the route to the next delivery point based on the current location and starts moving. The drone, in turn, after issuing the parcel, determines the current coordinates of the van and its further route.

2. There are cases here.

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2.1. The van dispenses itself. Then either the drone has time to land on the waiting van, or the van starts moving and the drone catches up with it. It should be noted that the speed of the drone is twice the speed of the van and the time of package delivery by the drone is negligible.

2.2. The van is already on its way to the next target. Then the drone calculates the landing point on the van and returns.

2.3. There is situation (1) with the launch of the second drone according to the same algorithm.

Also, on the way to each target, the drone estimates the distance to the target, the battery charge and the ability to return to the van after delivery. If the restrictions are satisfied, then the drone with the parcel starts towards the target, and the van starts moving to the next delivery point. Fig. 4 presents the visualization of the described algorithm for modelling parallel delivery using the example of Yekaterinburg city.
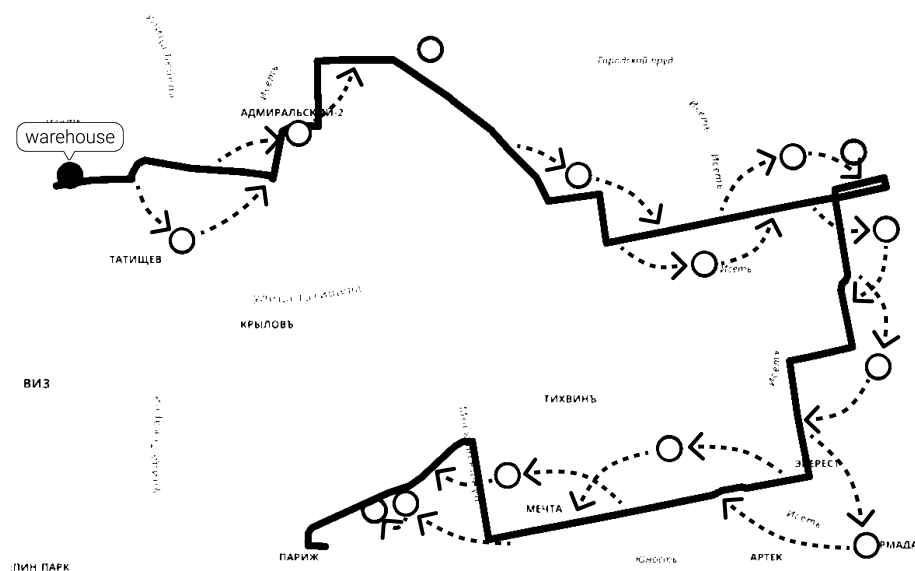


**Fig. 4.** Delivery scheme by van with drones

The developed algorithm solves the routing problem and allows obtaining data on the energy efficiency of drones under various conditions. It is possible to simulate situations depending on the number of delivery points, the number of parcels, their weight and size, and the degree of congestion of the urban transport network. The algorithm is implemented in Python 3.9 using the OSMnx libraries from the OpenStreetMap resource and NetworkX [9, 10].

The simulation results are as follows.

1. Results on distance traveled by the van are as follows.
Distance for regular delivery is 15162 m.
Distance using drones is 10170 m.

2. Results on parcels delivered are as follows.
The van delivered 4 parcels, of which 2 can be delivered by drone, but there was no available drone.
Drone No. 1 delivered 7 parcels and covered 14140,5 m.
Drone No. 2 delivered 3 parcels and covered 6495,7 m.

3. Results on time are as follows.
Time spent on parcels delivery by traditional method is 450 min.
Time spent on parcels delivery using drones is 90 min.

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# МОДЕЛИРОВАНИЕ ОПЕРАЦИЙ ПАРАЛЛЕЛЬНОЙ ДОСТАВКИ

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Рассматривается некоторая схема организации доставки. Ключевым моментом является принцип распараллеливания маршрутов с использованием нескольких перевозчиков одновременно, причем эти вспомогательные перевозчики могут базироваться

на основном перевозчике. Примером такой системы доставки может быть фургон, перевозящий несколько автономных перевозчиков, которые, в свою очередь, могут осуществлять одновременные так называемые параллельные доставки. Маршруты доставки определяются на основе координат клиентов, определения приемлемых точек старта для вспомогательных перевозчиков, технических и энергетических ограничений основных и вспомогательных перевозчиков, а также минимизации количества времени, затрачиваемого на операции доставки. Разработанный алгоритм решения задачи маршрутизации доставки с использованием первичных и вторичных перевозчиков позволяет сократить время и ресурсы доставки. Алгоритм реализован на языке Python с использованием библиотек обработки и визуализации траекторий и других пространственно-временных данных, пакетов для извлечения, моделирования, анализа и визуализации уличных сетей на примере города Екатеринбурга.

*Ключевые слова: исследование операций; задача маршрутизации; задача коммивояжера; алгоритм ближайшего соседа; служба доставки.*

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