Ministry of Education and Science of Ukraine
Black Sea Universities Network

ODESA NATIONAL UNIVERSITY OF TECHNOLOGY

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2022

PROCEEDINGS

Black Sea Science International Competition of Student Scientific Works by Odesa National University of Technology

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ODESA, ONUT 2022

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Proceedings of International Competition of Student Scientific Works «Black Sea Science 2022» contain the works of winners of the competition.

The author of the work is responsible for the accuracy of the information.

Odesa National University of Technology, 2022.

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INTRODUCTION

International Competition of Student Scientific Works "Black Sea Science" has been held annually since 2018 at the initiative of Odesa National University of Technology (formerly Odesa National Academy of Food Technologies) with the support of the Ministry of Education and Science of Ukraine. It has been supported by Black Sea Universities Network (the Association of 110 higher education institutions from 12 countries of the Black Sea Region) since 2019, and by Iseki-FOOD Association (European Integrating Food Science and Engineering Knowledge into the Food Chain Association) since 2020.

The goal of the competition is to expand international relations and attract students to research activities. It is held in the following fields:

- Food science and technologies
- Economics and administration
- Information technologies, automation and robotics
- Power engineering and energy efficiency
- Ecology and environmental protection

The jury includes both Ukrainian and foreign scientists. In the 4 years that the competition has been held, the jury included scientists from universities of 24 countries: Angola, Azerbaijan, Benin, Bulgaria, China, Czech Republic, France, Georgia, Germany, Greece, Israel, Italy, Kazakhstan, Latvia, Lithuania, Moldova, Pakistan, Poland, Romania, Serbia, Slovakia, Switzerland, Turkey, USA.

At the same time, every year the geography has expanded and the number of foreign jury members has increased: from 46 jury members representing 25 universities from 12 countries in 2018, to 73 jury members of the 46 universities from 19 countries in 2022.

More than a thousand student research papers have been submitted to the competition from both Ukrainian and foreign institutions from 25 countries: China, Poland, Mexico, USA, France, Greece, Germany, Canada, Costa Rica, Brazil, India, Pakistan, Israel, Macedonia, Lithuania, Latvia, Slovakia, Romania, Kyrgyzstan, Kazakhstan, Bulgaria, Moldova, Georgia, Turkey, Serbia.

The interest of foreign students in the competition grew every year. In 2018, the students representing 15 institutions from 7 countries have submitted 33 works. In 2021 the number of submitted works increased to 73, authored by the students of 40 institutions from 18 countries.

The competition is held in two stages. In the first stage, student research papers are reviewed by members of the jury who are experts in the relevant fields. In the second stage of the competition, the winners of the first stage have the opportunity to present their work to a wide audience in person or online.

All participants of the competition and their scientific supervisors are awarded appropriate certificates, and the scientific works of the winners are included in the electronic proceedings of the competition. Every year the competition receives a large number of positive responses from Ukrainian and foreign colleagues with the desire to participate in the coming years.

3. INFORMATION TECHNOLOGIES, AUTOMATION AND ROBOTICS

A REAL-WORLD CASE STUDY OF A VEHICLE ROUTING PROBLEM

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Abstract. *The goal of this study is to create a route planning methodology. The created methodology assisgns cargo to a given set of vehicles in such a way that the profits would be maximized. When planning a route, the work hours of pick-up locations, are considered as well as when each cargo is ready to be picked up. Furthermore, cargo that is worth less than what it would cost to transport it, is removed from planning. Also, a unique feature to the original Pickup-and-Delivery problem with time windows is introduced. Namely, cargo can be redirected to depots for a fee, which lets drivers spend less time on the road and collect the redirected cargo in one place. The genetic algorithm method, proves to be a viable approach as it produces failry good results in relatively short time.*

Keywords: *Vehicle Routing, Optimization, Genetic Algorithm, Nearest Neighbour, Pickup-and-Delivery.*

I. INTRODUCTION

Road freight transportation is rapidly expanding in a competitive environment, hence logistics companies with limited transportation capacities are forced to look for more efficient solutions that concern the transportation of freight. One of the key indicators used to determine a company's efficiency is the profit generated by the transportation services provided, which directly depends on the route taken. Usually, a logistics manager ensures high-quality, fast transportation of a customer's cargo by striving to plan the best routes for truck drivers to take. In addition, the logistics manager has to take into account the available human resources, capacities of the vehicles, the order in which cargo is taken and the expenses that will accumulate during each planned route. All of this is considered to ensure efficient management of transportation services while minimizing the company's expenses.

Optimization of routes in regards to various constraints is known in scientific literature as the Vehicle Routing Problem (VRP). To create a methodology for road freight transport, optimization methods applied to the Pickup-and-Delivery (PDP) are analyzed. In this case, it is assumed that each load has a predefined delivery point (one-to-one) and that the goods can only be picked up and delivered at certain hours (time windows). Also, a feature is added to redirect cargo to depots that collect it for a fee. This allows a truck to spend less time deviating from its route. Such problems are often unsuitable to linear programming methods due to extremely long computation times, therefore a metaheuristic approach is used.

II. LITERATURE ANALYSIS

Vehicle routing problems originated from the generalization of the Traveling Salesman Problem (TSP). To solve it, the simulated annealing [1] and Tabu search [2-

3] algorithms were tested. However, experiments showed that these methods require large computational time resources. Also, a genetic algorithm method has been proposed to solve this type of problem. For example, a genetic algorithm has been used to create school bus routes [4]. This study revealed that fairly good results were obtained in a relatively short time.

The creation of transport routes with time windows (VRPTW) where customers can be served only for a specified time interval is analyzed in [5]. In this article, a genetic algorithm is used to determine how many cars are needed and a Tabu search algorithm – to reduce the total distance travelled by cars. The author notes that using both algorithms is more suitable for this (VRPTW) problem, rather than using a single of the aforementioned algorithms.

A study that is closer to ours, by having separate unique pickup and delivery points for each of the goods, is analyzed in [6]. In it, a Pickup-and-Delivery with time windows (PDPTW) problem is analyzed. The study has shown that dynamic programming is not suitable for solving this problem due to the long computation time, whereas the results obtained by a genetic algorithm were able to provide (sub)optimal solutions for problems bigger by up to 25% of the original problem.

In [7] study a PDPTW problem where not all goods are required to be transported is analyzed using a hybrid genetic algorithm. The genetic algorithm would take a few minutes to produce a good and stable result, whereas linear programming methods took more than two hours to reach these results. Also, the same problem was studied in [8]. Here, three metaheuristic methods were suggested, namely the Tabu search, the genetic algorithm, and the scatter search. Although all methods provided good results, the quality of the Tabu search results as well as the speed of convergence was notably better.

Taking everything into consideration, we can state that the problem solved in this case study belongs to the group of complex combinatorial problems. Linear programming methods take too long to solve such problems, so although they are suitable in theory, they are not implemented for solving real-world problems. Various scientists solve this problem using metaheuristic methods, of which the most popular were found to be the Tabu search and the genetic algorithm approaches.

III. OBJECT, SUBJECT, AND METHODS OF RESEARCH

3.1. Object

In this study, we aim to create a route planning algorithm. The goal is to assign available cargo to a given set of vehicles in such a way that the profits would be maximized. When planning a route, the work hours of pick-up locations need to be considered as well as when each cargo is ready to be picked up. Furthermore, cargo that is worth less than what it would cost to transport it, should be removed from planning. Also, any cargo can be redirected to a depot which will collect the assigned cargo for a fee. In this study, we assume that the cargo would reach a depot at 7 p.m. the next day of when it would be ready (f.e., if a cargo is ready at 5 p.m. Monday, then it would reach the depot at 7 p.m. Tuesday). Redirecting cargo to a depot is usually done either to minimize the distance driven by a driver or to minimize the collection time of the cargo, as each cargo has a delivery deadline that when exceeded causes additional expenses. Furthermore, the mandatory breaks from driving must be considered when assessing the time it takes to get from one location to another. The Hours of Service (HoS) used in this research state that: a 45 minute break must be done after 4.5 hours of consecutive driving, an 11 hour break after driving 9 hours per day and a 45 hour break after driving 56 hours per week.

To summarize, the object of this research is to create a route planning algorithm that would have these features:

- able to process large ammounts of data;
- ensure that the capacity of a truck will not be exceeded;
- assess which goods are not profitable and remove them from planning;
- able to redirect cargo to terminals when it is more convenient;
- take into account the work hours of each location;
- estimate the cost of delays and downtime (caused by reaching a pick-up location too early, as the goods are considered to be not ready for transport or a delivery location outside of its work hours);
- able to use different time zone data;
- ensure the drivers' hours of service are not exceeded.

3.2. Methods of research

3.2.1. Haversine distance

Haversine distance calculates the distance between two points on the earth's surface using longitude and latitude coordinates. This distance is also called the bird's flight distance as it does not take the terrain or road infrastructure into consideration.

Let earth be a perfect sphere with a radius of $r = 6367.45$ km, and points with coordinates (p_1, i_1) and (p_2, i_2) are at a distance of r kilometers from the center.

$$a = \sin^2\left(\frac{\Delta p}{2}\right) + \cos(p_1) \times \cos(p_2) \times \sin^2\left(\frac{\Delta p}{2}\right),$$

where $\Delta p = p_2 - p_1$ is the change in latitude, $\Delta i = i_2 - i_1$ is the change in longitude. Then the distance between two points d is calculated as follows:

$$d = r \times (2 \times a\tan^2(\sqrt{a}, \sqrt{1-a})).$$

3.2.2. Nearest neighbour algorithm

3.2.3. Genetic algorithm

IV. RESULTS

4.1. Problem formulation

A total of n transportation requests are represented as a directed graph $G = (V, A)$; where V is divided into nodes $P = \{1, \dots, n\}$ for pickup, $D = \{n+1, \dots, 2n\}$ nodes for delivery and $Term = \{Term^1 \cup \dots \cup Term^T\}$ for depot nodes, where T is the number of depots. Each cargo i needs to be transported from node $i \in P$ to a delivery node $n + i \in D$. The cargo three different dimensional characteristics, namely weight (w), volume (v) and loading meters (l) which we will denote as q_i^w, q_i^v, q_i^l accordingly. Let $q_{n+1}^w = -q_i^w, q_{n+1}^v = -q_i^v, q_{n+1}^l = -q_i^l$. Also, each cargo brings revenue e_i that are known beforehand. The terminals charge differently according to the weight and distance that needs to be driven, hence each terminal has different transportation prices for the cargo $Term^j = \{c_1^j, \dots, c_n^j\}$, where c_i^j is the price of i-th cargo in the j-th depot. We then introduce a binary decision variable x_{ij}^k that equals 1 if cargo i of the vehicle k is redirected to a depot j. After redirecting the cargo into a terminal, the pickup location of the cargo i will change into the location of the depot j and the transportation price of the terminal $c_i = \min\{c_i^1, \dots, c_i^T\}$ is added to the total expenses. Furthermore, each node $i \in V$ must be visited within a time window $[a_i, b_i]$. A visit requires a certain time s_i to process. The time a truck k starts servicing node i will be denoted by T_{ik} and $Q_{ik}^w, Q_{ik}^v, Q_{ik}^l$ will denote the dimensions of the truck after servicing the i-th node. Another binary decision variable x_{ijk} will be equal to 1 if the truck k will drive from node i to node j. Each arc $(i, j) \in A$ has its price c_{ij} and travel duration t_{ij}.

The mathematical model can be formulated as follows:

$$\max \sum_{k\in K}\sum_{i\in V}\sum_{j\in V}\left(e_j x_{ijk}\mathbb{I}_P(j) - c_{ij}x_{ijk} + x_{ijk}\mathbb{I}_{Term}(j)\sum_{l\in P}(e_l - c_l)\, x_l^j\right)$$

$$\sum_{k\in K}\sum_{j\in V} x_{ijk} = 1 \qquad \forall i \in P \cup Term,$$

$$\sum_{j\in V} x_{ijk} - \sum_{j\in V} x_{n+1,jk} = 0 \qquad \forall i \in P, k \in K,$$

$$c_i = \min\{c_i^1, \dots, c_i^T\}, \qquad \forall i \in V,$$

$$T_{jk} \ge \left(T_{ik} + s_i + t_{ij}\right)x_{ijk} \qquad \forall i \in V, j \in V, k \in K,$$

$$Q_{jk}^w \ge \left(Q_{ik}^w + q_j^w\right)x_{ijk} \qquad \forall i \in V, j \in V, k \in K,$$

$$Q_{jk}^v \ge \left(Q_{ik}^v + q_j^v\right)x_{ijk} \qquad \forall i \in V, j \in V, k \in K,$$

$$Q_{jk}^l \ge \left(Q_{ik}^l + q_j^l\right)x_{ijk} \qquad \forall i \in V, j \in V, k \in K,$$

$$T_{n+1,k} - T_{ik} - s_i - t_{i,n+1} \ge 0 \qquad \forall i \in P,$$

$$a_i \le T_{ik} \le b_i \qquad \forall i \in V, k \in K,$$

$$\max\{0, q_i^w\} \le Q_{ik}^w \le \min\{Q_k^w, Q_k^w + q_i^w\} \qquad \forall i \in V, k \in K,$$

$$\max\{0, q_i^v\} \le Q_{ik}^v \le \min\{Q_k^v, Q_k^v + q_i^v\} \qquad \forall i \in V, k \in K,$$

$$\max\{0, q_i^l\} \le Q_{ik}^l \le \min\{Q_k^l, Q_k^l + q_i^l\} \qquad \forall i \in V, k \in K,$$

$$x_{ijk}, x_i^t \in \{0,1\} \qquad \forall i \in V, j \in V, k \in K,$$

Constraints (2.2) and (2.3) ensure that each node is visited at most once. The smallest depot price is ensured in (2.4) constraint. (2.5) equation states that the departure time at node j must be later than the departure time at node i plus travel and processing time if route (i, j) is traversed. The consistency of load variables is ensured (2.6)-(2.8) constraints. Equation (2.9) introduces precedence constraints. Furthermore, (2.10) constraint impose time-window and (2.11)-(2.13) capacity constraints, respectively.

4.2. Experimental study of the method

In order to solve the problem formulated in the 4.1 subsection, a detailed route planning algorithm was made (Fig. 1). The realization of the algorithm was executed stepwise. A genetic algorithm approach was selected for further experimentation. At first, a simple shortest route-finding algorithm was developed. Then, the dimensions of vehicles and cargo were added. Next, depot locations as well as the possibility to redirect cargo to them were included. It was noticed that sometimes the route would go straight through water or the borders of neighbouring countries, hence the addition of a special zone was developed. To reach the starting country's border point, a vehicle in the special zone would have to first visit the special location from which the route to the border is undisturbed. Furthermore, the driving times and mandatory breaks of drivers were added. Finally, the work hours of each location as well as the time when each cargo is ready to be picked up were added.

To begin with, the available data set is prepared. Next, the initial population is selected. Selecting the initial population is crucial in using genetic algorithms as it directly affects the time it takes to converge. An initial population closer to the real solution leads to a faster (sub)optimal solution finding. For this study, the nearest neighbour (k-NN) algorithm is used for calculating the initial population. After finding the initial population, the genetic algorithm, depicted in Fig. 1, is initialized. The result, given by the genetic algorithm is later used to calculate the output values.

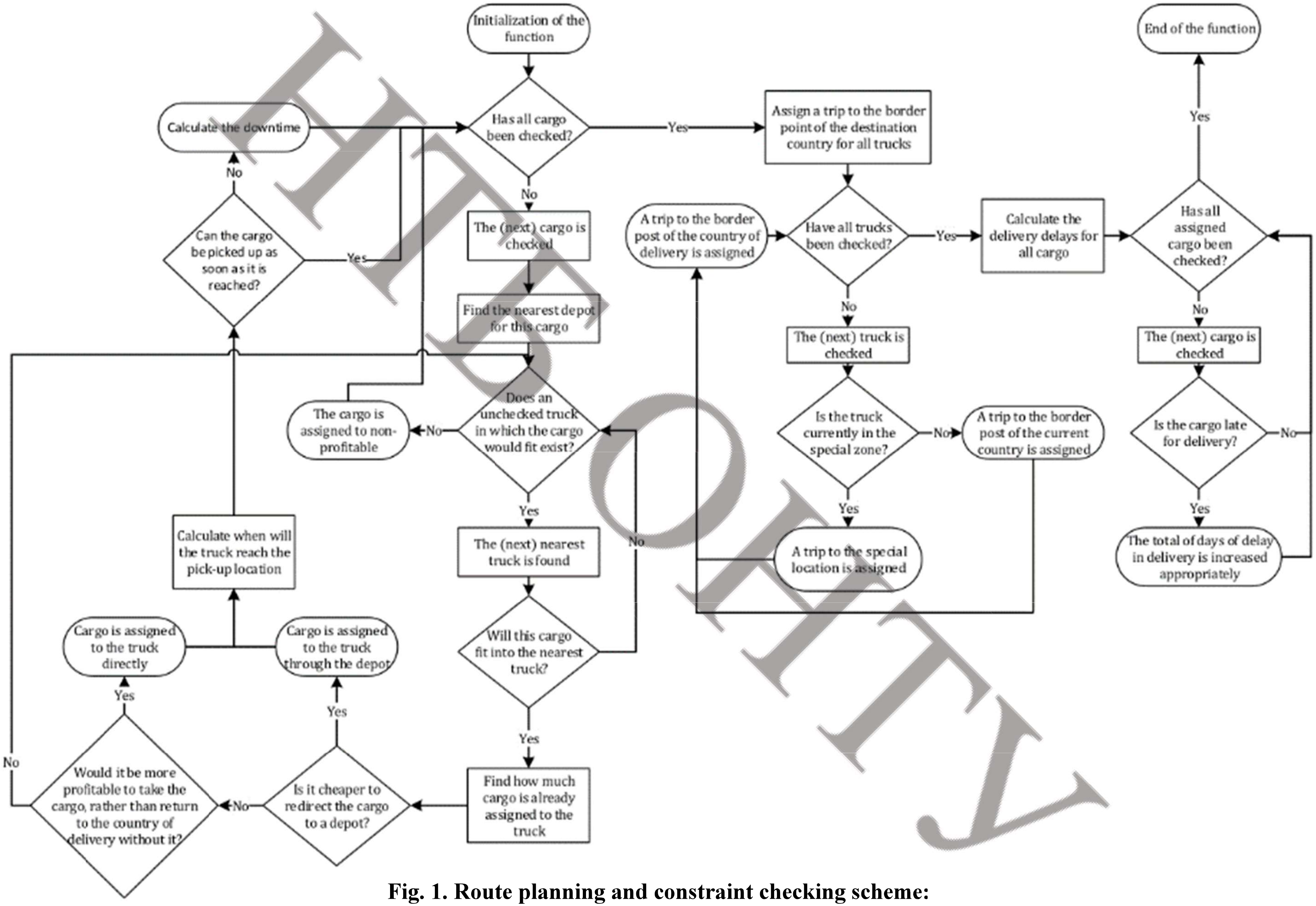


Fig. 1. Route planning and constraint checking scheme:

The effectiveness of the genetic algorithm is also affected by the selected model parameters. To increase the genetic algorithm's efficiency, the results of different operators of several components of the genetic algorithm were tested 50 times and their values were compared. For the selection component, the linear-rank (lr), the nonlinear-rank (nlr), the proportional/roulette wheel (rw) and the unbiased/tournament (tour) selection operators were compared. As for the crossover component, the cycle (cx), the partially matched (pmx), the order (ox) and the position-based (pbx) crossover operators were compared. What concerns the mutation component, the simple inversion (sim), insertion (ism), exchange/swap (sw), displacement (dm) and scramble (scr) mutation operators were compared. The comparison of these different operators (Fig. 2) revealed that the best results are achieved with the tournament selection, position-based crossover, and swap mutation operators. Also, experiments were performed to determine favourable probabilities between crossover and mutations pairs in the parental chromosome. The results presented in Figure 3 show, that using the probability of crossover p_k equal to 0.8 and the probability of mutation p_m equal to 0.5, yields the highest profits.

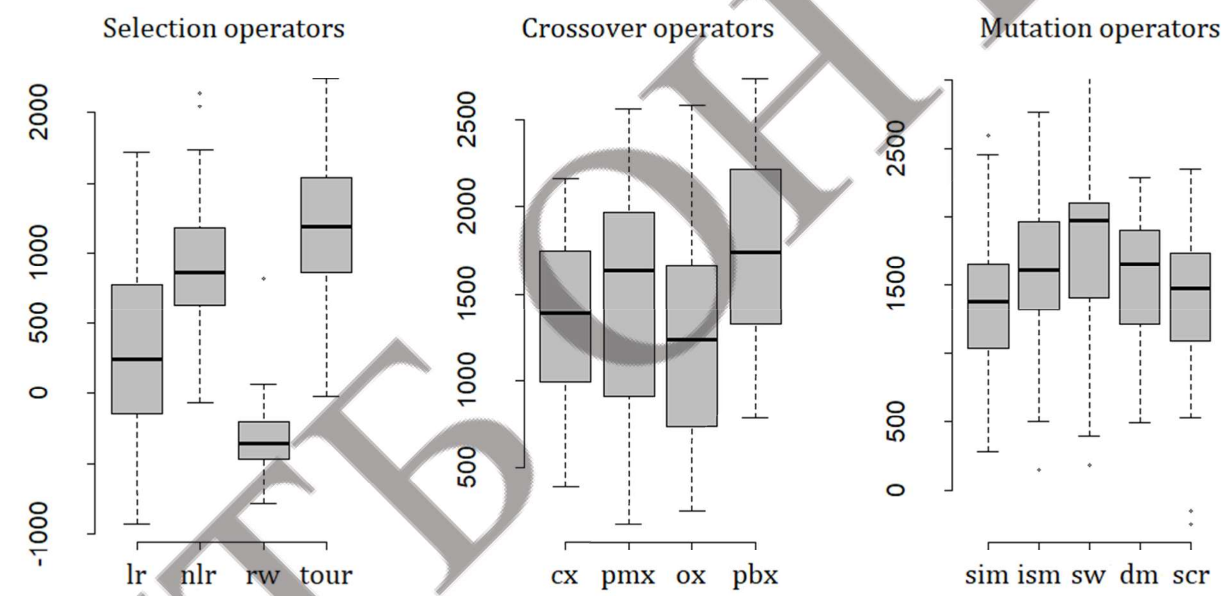


Fig. 2. Comparison of values generated with different genetic algorithm operators

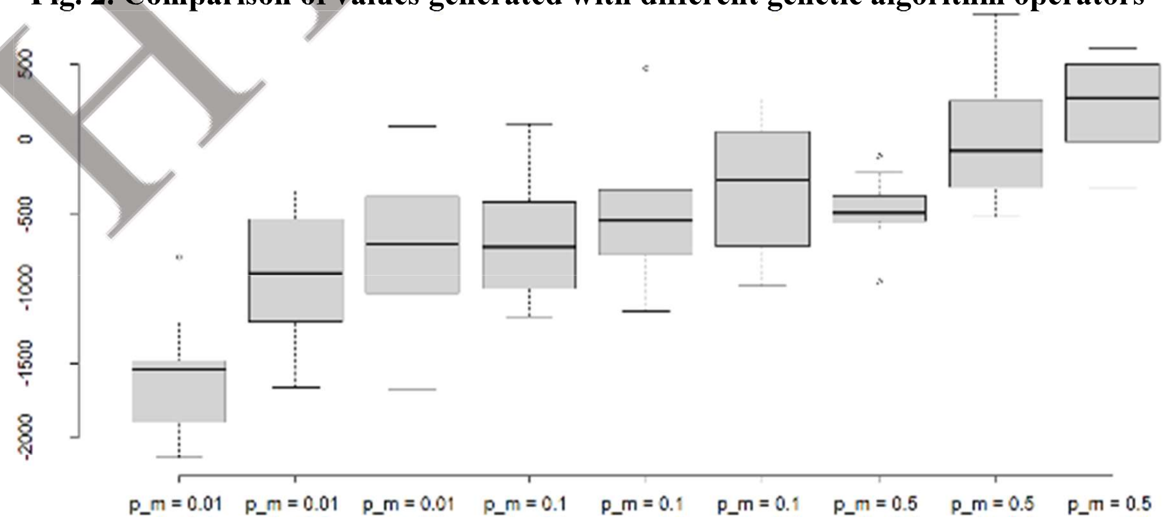
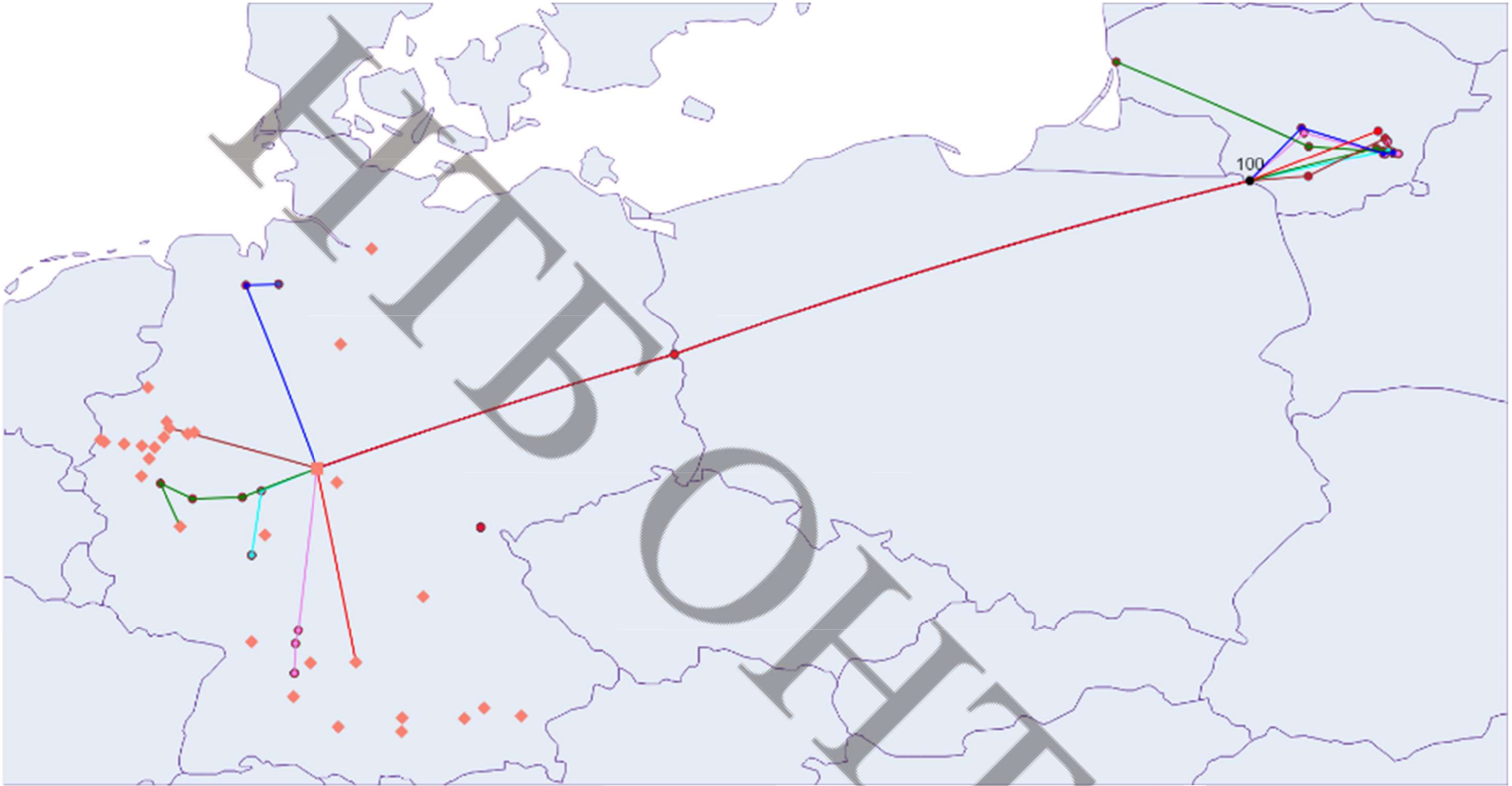


Fig. 3. Comparison of values generated with different crossover and mutation probabilities



In Figure 4, a visualization of the results after 100 iterations of the genetic algorithm are presented. It took about 10

Fig. 4. Visualization of the results

minutes of computing time to produce these results. Different colored lines represent routes of individual trucks. Diamond shaped locations are cargo redirected to the depot (a square of the same color). In this case, a special zone is constructed around the bottom of Germany as to ensure that the truck does not enter Czechia. The red dot near the west-most of Czechia is the special location that trucks would need to pass before continuing their drive to the border.

V. CONCLUSIONS

Taking everything into consideration, the literature analysis concludes that using metaheuristic methods is best for real-world applications. The most frequently used methods were the genetic algorithm and the Tabu search. In this study we confirm the viability of utilizing the genetic algorithm for route planning systems with various constraints.

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