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Route Optimization for Medication Delivery of Covid-19 Patients with Drones

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Abstract

With the developments in information technologies and the intense use of online commerce, the use of drones in distribution process has gained importance. In order to transport products to more than one location, drones can perform the distribution by following a specific route, as in the traveling salesman problem. Drones provide advantages over land transportation since they are not affected by the traffic congestion and can be used autonomously. However, the limited battery durations increase the importance of using the optimum route in distribution processes. In this study, it is aimed to use drones in drug distribution. Nowadays, due to the Covid-19 pandemic, it is aimed to distribute the drugs for the patients in an optimum way with drones. In this study, it is aimed to find the optimized routes for drones in drug distribution since Covid-19 medicine distribution is a time-critic mission. Since the number of patients in a certain area may increase very quickly, it is ensured that the patients are divided into clusters and the optimum route is determined for each cluster. We propose a hybrid model consisting of a combination of K-means clustering and Ant Colony algorithms. In particular, Covid-19 patients use the mobile part of the developed application on their smartphones and transmit their medication requests to our central server. We have compared the performance of Ant Colony, Artificial Bee and Genetic algorithm metaheuristics at the stage of determining the most suitable route according to the demands collected dynamically on the central server. In the process of determining the most suitable route, Ant Colony algorithm yields the closest to optimum results for different location groups. We have developed the mobile and web site of the application to validate the proposed drug delivery model.

1. INTRODUCTION

An optimum route determination for the product distribution is gaining importance in air transport with drones today as well as in land transport [1]. With the drone, certain parcels of products can be transported to the routes at certain points, and the drone can also be used to control or surveillance along a certain route [2]. In this study, a solution has been presented to the problem of determining the most appropriate route for the distribution of drugs with drones, especially for the distribution of covid-19 drugs to patients in different locations. Due to the Covid-19 pandemic, many patients create requests with their smart phones to gather their medicines through a drone. These collected requests are distributed according to the most appropriate route determined by the application we have developed.

Product distribution is increasingly gaining importance with industrial development and online commerce. Firms have started to look for solutions to carry out their distribution operations, usually using land vehicles and unmanned aerial vehicle (UAV) together. Drones are not affected by the traffic congestion in big cities and their costs are lower because they are autonomous; however, the battery and product carrying capacity of drones is limited [3]. For this reason, distribution with drone turns into an optimization problem. Optimization is the process of obtaining the most appropriate solution by providing certain restrictions for the given purpose or objectives [4]. In other words, it is the process of finding the best solution from the solution space of a problem.

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Even though classical mathematical methods are widely used in the solution of optimization problems, they have been insufficient in solving problems with a high problem size and difficult to express mathematically. However, acceptable successful results by heuristic/metaheuristic approaches have been obtained in solving many complex optimization problems with artificial intelligence optimization techniques. Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Genetic Algorithm (GA), Simulated Annealing (SA), Differential Evolution (DE), Particle Swarm Optimization (PSO) are among the most well-known methods used in solving optimization problems.

Optimization algorithms can generally be categorized based on solving continuous or discrete problems. The most known discrete optimization problem is the traveling salesman problem (TSP), which was mathematically defined in the 1930s. TSP aims to find the shortest possible tour back to the starting point by visiting all of the specified number of locations. Candidate solutions are permutations of the location array, which holds the order in which the locations are visited, that is, including each location exactly once. The sequence with the lowest cost among these permutations is considered to be the most optimal solution. Vehicle routing, circuit board design, data routing on the internet can be given as examples of real-life applications of the traveling salesman problem. Drone delivery problem turns into a TSP. Although the definition of TSP is simple, it is difficult to solve, and as the size of the problem increases, the solution becomes more difficult. TSP is in the NP-Hard problem class. The use of classical techniques, which require scanning the entire solution space, becomes almost impossible when the problem size increases too much. Artificial intelligence optimization techniques are widely used in the TSP solution by providing an acceptable solution even if it does not provide the optimum solution with an intuitive approach.

In this study, ACO, ABC and GA metaheuristic methods are used in different number of location groups and compared to calculate the optimum route. Based on the optimum route found, it is aimed to distribute the drugs requested to patients with drones. In the case of rapidly increased number of patients, clustering approach has been applied. A hybrid approach has been proposed using K-means and Ant Colony algorithm together. In particular, the drug demands of covid-19 patients have been collected on our server via a mobile application part of the framework software we have developed, along with location information. The mobile application, developed as a cross-platform using the Flutter framework, works on both Android and iOS smartphones. Drug requests and location information collected at the distribution center have been also grouped according to regions. Address information of the locations has been also collected with the mobile application. This information has been encrypted end-to-end and sent to the servers. The proposed web application collects requests and creates the optimum distribution routes. In the study, optimum route calculation has been performed by adapting ACO, ABC and GA algorithms to the TSP. Each algorithm has been run 20 times for location groups of different sizes, and average, min and max route lengths were calculated for comparison. As a result, ACO algorithm yields the most suitable solution in terms of route length. The mobile and web applications we have developed are available at “http://ceng.gop.edu.tr/drone-router”.

2. LITERATURE REVIEW

Drone distribution is a system that gains importance over time despite the limitations of battery and carrying capacity and it is planned to be used intensively in the future. DHL company presented the first commercial unmanned aerial vehicle “Parcelcopter” to be used in transportation works in 2014 [5]. Since the distribution centers of the companies are far from the city centers, they are generally used for distribution with land vehicles. Kim and Moon [3] proposed a distribution system in the form of drone stations in city centers for the problem of remote distribution centers. They assumed that the drone station could provide enough drones and that the station's location was not dependent on the distribution center. After the packages to be delivered by a land vehicle are left at the station, the delivery process is carried out by the drones.

Yürek and Özmutlu [6] have developed a 2-stage iterative method to create the optimum route in distribution with drone. In the proposed method, the drones are intended to serve as many customers as possible in order to achieve a significant reduction in the truck's course. In the first stage, the truck route is determined, then the optimum drone route is created to minimize the truck wait. Ercan and Gencer [7] have investigated the problem of dynamically adding new targets that emerged during the process of observing the pre-determined targets of unmanned aerial vehicles to the previously created routes. Adding the new emerged target to any route is done with the help of the fuzzy logic based algorithm. In fuzzy clustering, the target is placed in front of or after the closest point on a route, considering the degree of membership within the constraints. Thus, the first round is updated without being changed completely. This study eliminates the limitations of the existing methods that are using the near neighborhood approach.

Karaboğa and Görkemli [8] have suggested a new Artificial Bee Colony algorithm named "Combinatorial ABC" for the traveling salesman problem and showed that the Artificial Bee Colony algorithm can be used for TSP. Adewole et al. [9] have solved the traveling salesman problem by using simulated annealing and genetic algorithm. It has been observed that the simulated annealing works faster than the genetic algorithm and the working time of the genetic algorithm increases exponentially with the number of cities. However, they have shown that the genetic algorithm is better than the simulated annealing in terms of solution quality.

Kuzu et al. [10] have solved and compared 18 traveling salesman problems using several metaheuristic methods. As a result of the comparison, they have shown that the genetic and the ant colony algorithm obtained more optimum results than other algorithms. Haroun et al. [11] have compared the ant colony algorithm with the genetic algorithm for TSP and have concluded that the genetic algorithm is faster in terms of computational resources, easier to apply and cost-effective while the ant colony algorithm provides better results, especially in large problems.

Makuchowski [12] has proposed an effective method to solve the symmetrical traveling salesman problem using the simulated annealing approach. Chaudhari and Thakkar [13] have performed an experimental comparison using ACO, PSO, ABC, FA and GA in solving the TSP, and have shown that ACO and GA for TSP performed better than ABC, PSO and FA. Bhagade and Puranik [14] have concluded that the artificial bee colony algorithm can be used effectively in solving the traveling salesman problem, since few control parameters are taken into account when compared to other heuristic algorithms.

Valdez et al. [15] have shown that the ant colony algorithm finds better solutions in a shorter time than the genetic algorithm that solves the TSP and the simulated annealing algorithms. Yalçıner [16] has found the optimum route for distribution from an Istanbul-based warehouse to the cities of the Black Sea Region with a simulated annealing based approach.

Torun et al. [17] have developed a hybrid path planning algorithm for autonomous robots using the random tree algorithm and artificial bee colony methods in their study. Öztürk et al. [18] have adapted the ABC algorithm to the automatic clustering problem by adding vectorial solution generation and global best region solution search mechanisms. In the proposed method, well-known image sets and data sets are tested. Xu et al. [19] have proposed a modified optimization algorithm to automatically train the parameters of a typical neural network, Feed Forward Artificial Neural Network. In the proposed algorithm, the information of neighbors with better performance is used to accelerate the convergence of working and tracking bees, respectively. Cao et al. [20] have proposed an improved Support Vector Machine (SVM) classification model based on the artificial bee colony algorithm, as the selection of SVM parameters is often based on experience. In this model, first, the traditional artificial bee colony algorithm has been optimized using global optimal solution guidance and contrasting learning ideas.

İlkuçlar and Güngör [21] have solved the physician assignment problem with a genetic algorithm. In the study, the rotation process of physicians to institutions was optimized. Aktürk [22] has shown that the difficulty level of the minefield game can be increased and decreased at the desired level by using the genetic algorithm and pixelization method together. Guo et al. [23] have proposed an intelligent diagnostic method for rolling bearings based on depth. The training speed has been improved by adapting the parallel computing to the DBN training process in order to achieve global optimization with the genetic algorithm and to achieve more successful results in diagnosis accuracy. Özgür and Erdem [24] have used genetic algorithm in intrusion detection systems. In this study, it is suggested that feature selection and classifier fusion weight determination in intrusion detection classification applications need to be performed by using genetic algorithm (GA). In the study conducted by Tarigian et al. [25], the efficiency of the genetic algorithm in optimizing the learning speed, momentum ratio and number of hidden neurons in Back Propagation Neural networks applied to the automatic plate scanner was examined.

Kılıç and Karahan [26] have proposed a robust fuzzy programming model that can be used in the fuzzy decision environment for the time-spaced vehicle routing problem using fuzzy sets and likelihood theories. An algorithm based on ant colony optimization has been developed in order to create a solution for the proposed models. Dikmen et al. [27] have optimized the Traveling Salesman Problem, one of the important problems of computer science, by using Ant Colony and Genetic Algorithms. The performance of these optimization algorithms in terms of route distance and the time to calculate this route were compared. It was found that the ant colony algorithm shows more successful performance.

3. PROBLEM DESCRIPTION AND METHODOLOGY

An empirical study has been conducted to solve the route optimization problem in order to make drug delivery in the most effective way under pandemic conditions and time-critical situations. As the number of distribution locations increases, it becomes more difficult to find the most suitable route so metaheuristic methods have been used to solve such problems. Population-based metaheuristic methods ACO, ABC and GA have been adapted to the routing problem. In order to determine which of these three methods gives better results, we have calculated the best route by increasing the number of locations from 10 to 60 by 10. Since these methods contain random coefficients, they can produce different results in each run. By running the algorithms once for the specified iteration, the shortest route change has been observed throughout the iteration. Thus, it has shown which algorithm converged faster. In order to determine the best method correctly, all three algorithms have been run 20 times under the same conditions and their average values have been checked. Moreover, in case of an increase in the number of locations in a certain region, it is divided into small regions with the clustering algorithm. In the empirical study, it is proposed to determine the most suitable route by using the clustering algorithm and the ACO algorithm together.

Mobile users create drug orders with their smartphones. The location information of the users is also collected on the web server by the developed mobile application. As seen in Figure 1, the web server collects the location information and prepares the optimum route for drug delivery.

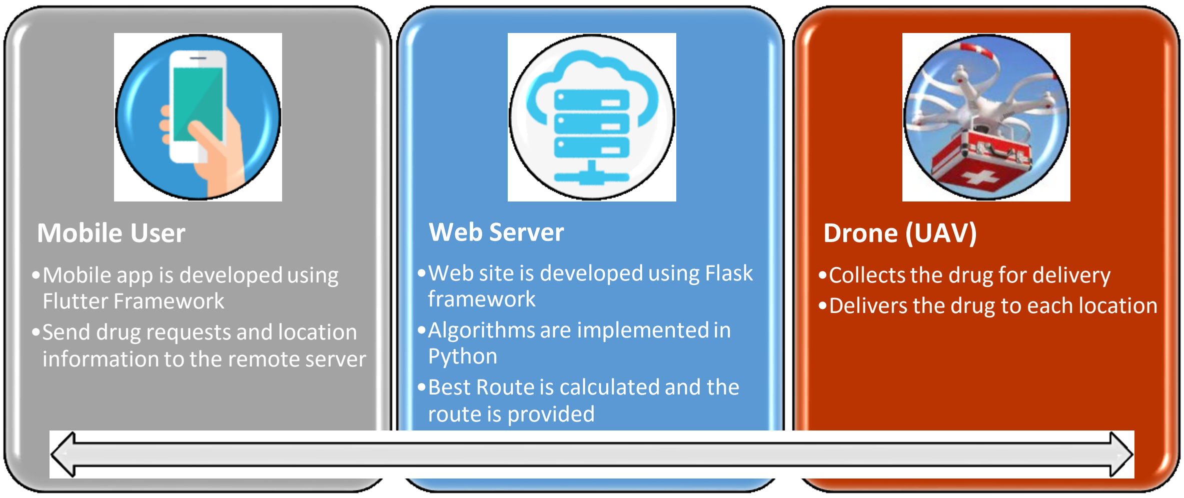


Figure 1. *The overview of the delivery with drone application*

Figure 2 shows the locations collected for drug delivery. With online commerce and recent developments in the UAV technology, the use of drones in product distribution has also gained importance. For this empirical study, we have also developed an application that will optimally distribute drugs to covid-19 patients under pandemic conditions. Adapting ACO, ABC and GA metaheuristic methods to the TSP and finding the most suitable route are performed on the server side. Thus, a sequential route is created as shown in Figure 3.

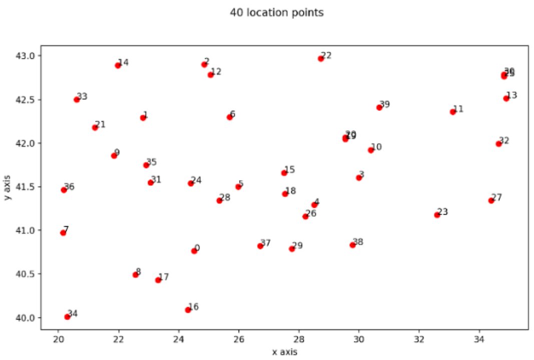


***Figure 2**. An example of the distributions of the locations*

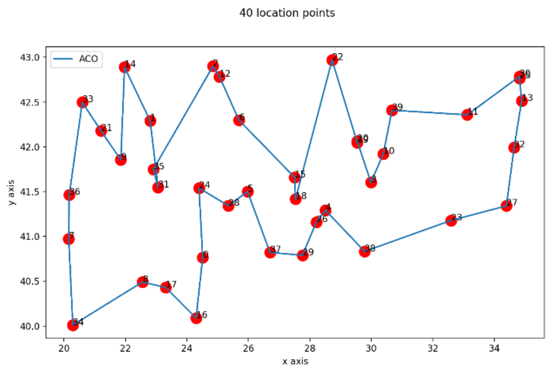


***Figure 3.** An example solution for the drug distribution*

3.1. The Artificial Bee Colony Algorithm (ABC)

The Artificial Bee Colony Algorithm is a population-based, intuitive optimization algorithm developed by Karaboğa in 2005, inspired by the foraging behaviors of honey bees to collect nectar from flowers [28]. It has been used in the solution of many optimization problems since it was developed. The ABC algorithm tries to find the maximum or minimum point of the problem among the possible solutions by finding the source with the most nectar [29]. In the ABC algorithm, the colony consists of three types of bees: employed bees, onlooker bees, and scout bees. The ABC algorithm begins by generating randomly distributed food sources, each corresponding to a solution in the solution space. These food sources are passed through the employed bees, onlooker bees and scout bees phases until the separation criterion is met, and as a result, the most appropriate value is tried to be found. As a result, this value is the optimum value that is tried to be reached.

3.2. Genetic Algorithm (GA)

GA is a population-based algorithm, whose foundation was inspired by the evolutionary structure in nature by John Holland, his colleagues and students, in the 1960s and 1970s [30]. The algorithm consists of processes that take place from the individuals (chromosomes) in the population to transfer the characteristics of the strong ones to the next generations, while the weak ones are deleted from the population over time. The genetic algorithm consists of selection, crossover and mutation operations. The genetic algorithm begins by generating random individuals (chromosome), each corresponding to a solution in the solution space. In each generation, the stronger individuals in the population are selected by different selection methods. Crossover is performed between these selected individuals to create stronger individuals. In the mutation process, the gene of an individual randomly selected from the population is changed to prevent the solution from being stuck to the local minimum. The algorithm continues the selection, crossing-over, and mutation processes until the best solution is found or the stop criterion is met. The strongest individual formed as a result of the algorithm represents the optimum solution.

3.3. Ant Colony Optimization (ACO)

The ant colony algorithm was proposed by Dorigo [31] for the solution of the traveling salesman problem, inspired by the behavior of the ants, and turned into a metaheuristic for combinatorial optimization problems [31, 32]. It is an algorithm that models the behaviors of ants groups such as choosing the path and path they follow in order to reach food. Despite the obstacles they encounter along their way, the ants can find the shortest path between the starting point and the food point with the help of a chemical called pheromone. The ants deposit this chemical liquid into the paths they follow and cause the amount of pheromone on the path to increase. Thus, the amount of pheromone on the shortest path, which has a higher usage rate per unit time on the route they started randomly, will be more. The subsequent ant groups also use this way to increase the amount of pheromones secreted on the path. As a result, roads with a lot of pheromones are preferred, pheromones on roads with long routes disappear due to evaporation and these roads are not preferred. The ant colony algorithm basically works in six steps. In the initial phase, the amount of pheromone is determined. Second, the ants are randomly placed at points in the problem space. Third, the ants complete their rounds by selecting nodes with the possibility of local search. Then, the length of the path the ants followed is calculated and the amount of local pheromone is updated. Fifth, Best values are calculated and taken into account in replenishing the overall pheromone amount. It is repeated after the first step until the number of cycles determined or the termination condition of the algorithm.

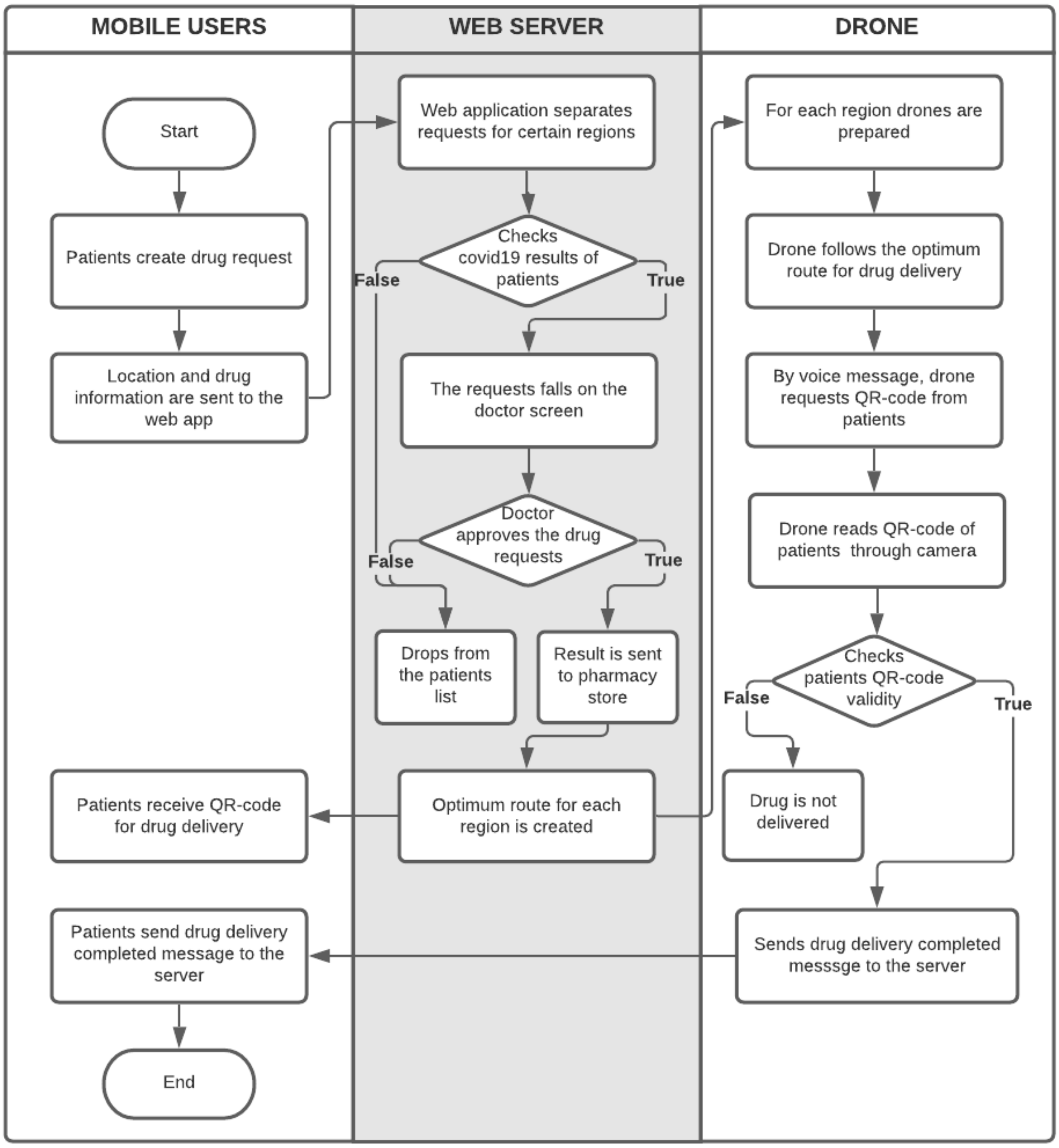


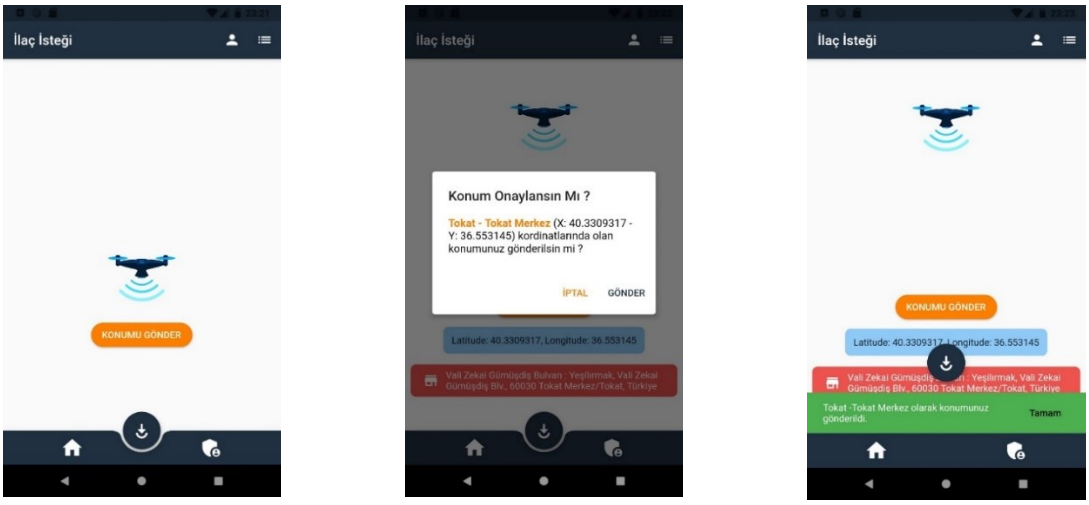
Figure 4. *The workflow diagram of the application*

4. IMPLEMENTATION AND COMPUTATIONAL RESULTS

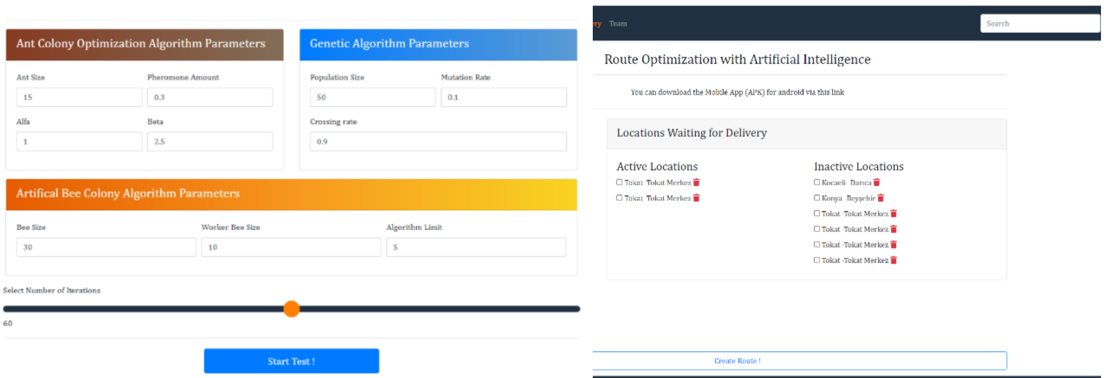
On the mobile side of this study, flutter framework software, which enables cross-platform application development, has been used. Applications can be developed for Android and iOS platforms with the flutter framework software using the Dart programming language. The server side is developed using the Flask framework software and the python programming language. The adaptation of metaheuristic methods to the TSP and the algorithms have been developed in python language.

Figure 4 shows the workflow of the application. The mobile user (Patient) has requested the medication. Patient and location information are sent to the server. The test result of the patient is checked on the server and the drug approval is displayed on the doctor's screen. A drug approvement notification is created. After the doctor's approval, the request is forwarded to the pharmacy department. In addition, optimum route is created for users in certain regions. The optimum route is sent to the drone center, at the same time the QR-Code created for each patient is sent to both the mobile users and the drone center. The drones start the distribution in the direction of the determined route and when they reached the desired coordinate, the patient is asked for the QR-Code. After this QR-Code is read with the drone's camera and approved, the drug is released to the patient.

As seen in Figure 5, a dynamic interface is presented in the TSP part of the mobile and web interface to see the effect of the change of parameters used in metaheuristic methods on the optimum route. In the distribution with drone interface, data from mobile users are collected on the server with the Restful API. It is provided dynamically to extract the optimum route for the desired number of locations from these collected data and to display their graphical results.



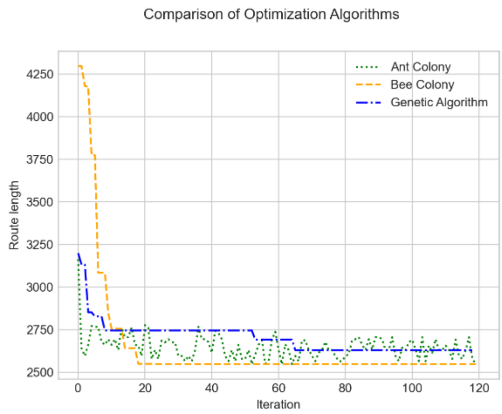
(a) The mobile interface of the application



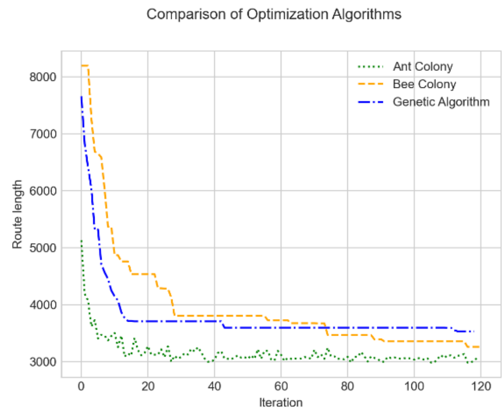
(b) The web interface of the application

Figure 5. *The mobile and web interfaces of the application*

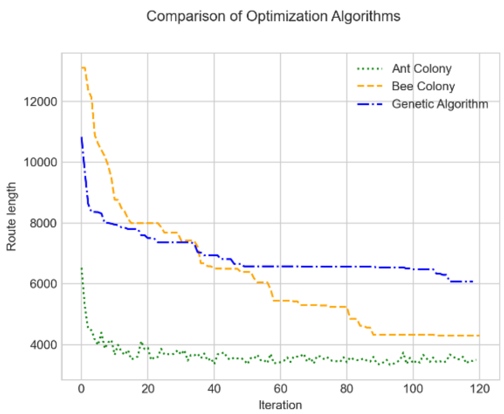
All three algorithms have been run once and the results are presented in Figure 6. In this one run, each algorithm performed 120 iterations. When looking at the comparisons of these runs, it is seen that the algorithm that converges to the optimum value in the fastest way is ACO. Hyperparameters used in algorithms are as follows: ACO: Pheromone Amount: 0.95, Alpha: 1, Beta: 2, Ant size: 2 * number of nodes or patients. ABC: Food source size: 2 * number of nodes or patients, Algorithm limit: 5. GA: Population size: 2 * number of nodes or patients, Mutation rate: 0.1, Crossing rate: 0.9. The effect of hyperparameters on solutions can be observed with the application presented on the http://ceng.gop.edu.tr/travellingsalesmanproblem web page.



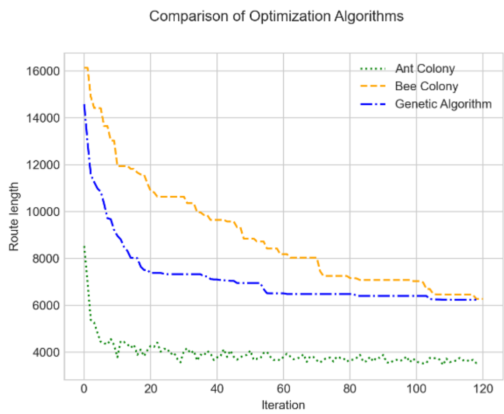
a)10 location points



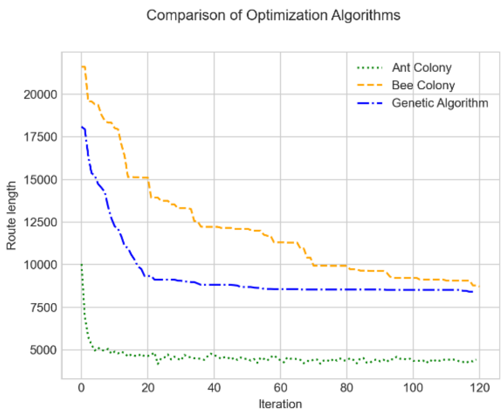
b) 20 location points



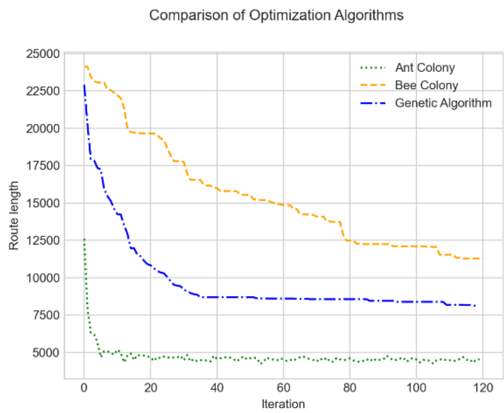
c) 30 location points



d) 40 location points



e) 50 location points



f) 60 location points

Figure 6. *Comparison of the route length in one run*

As seen in Figure 7, all three algorithms were run 20 times at the same iteration number for different location points and the results have been collected. Population-based metaheuristic methods ACO, ABC and GA are in an advantageous position as they try to find solutions at many points in the search space. The task of seeking solutions at many points in these metaheuristics is fulfilled by ants in ACO, bees in ABC and chromosomes in GA. Agents in each method aiming to reach the optimum solution also share information with each other and increase the quality of the solution. When the performances of the methods are examined at different location points in Figure 7, the best results are produced by ACO.

Generally, lowest standard deviation occurs in the ACO algorithm. In the other two methods, standard deviations change.

In the study, the closest results to the optimum have been found by the ACO algorithm. The average values, maximum and minimum limits obtained by running metaheuristic methods 20 times for each location group in different sizes are shown with box plots. One of the main purposes of this study is to compare the performances of each metaheuristic algorithm in predetermined iteration numbers.

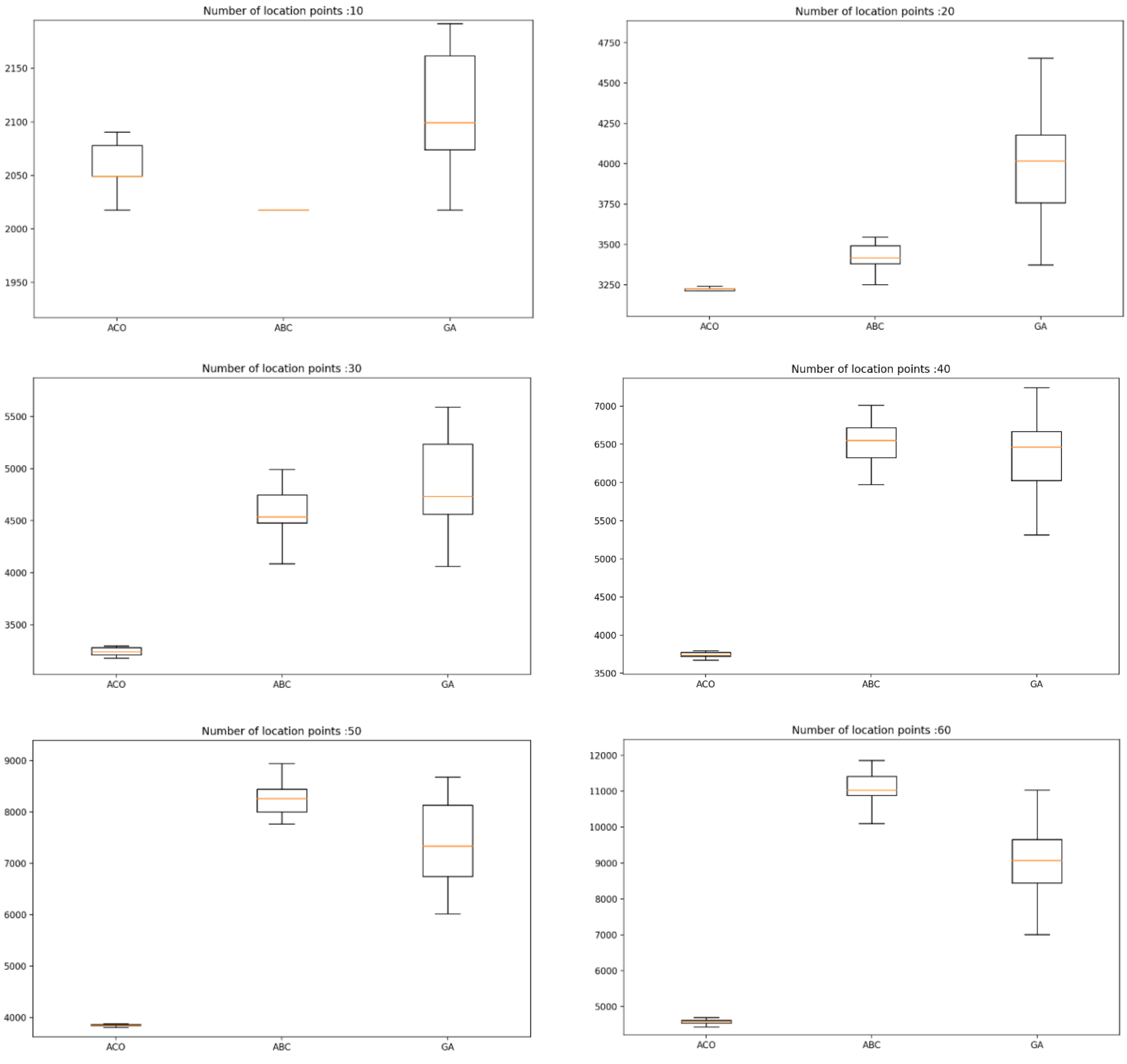
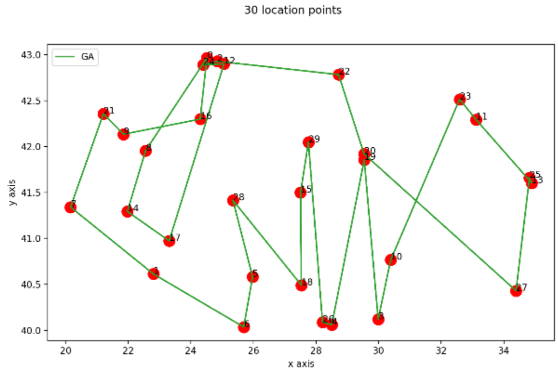
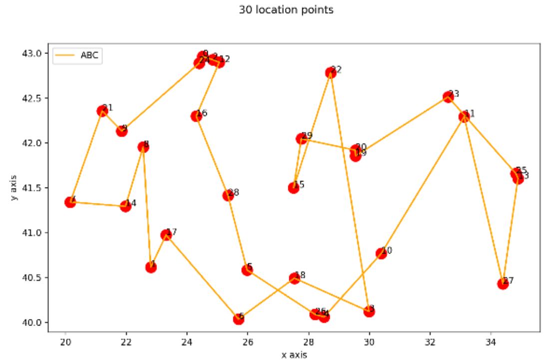


Figure 7. *Statistical properties of the different number of location points for 20 times run*

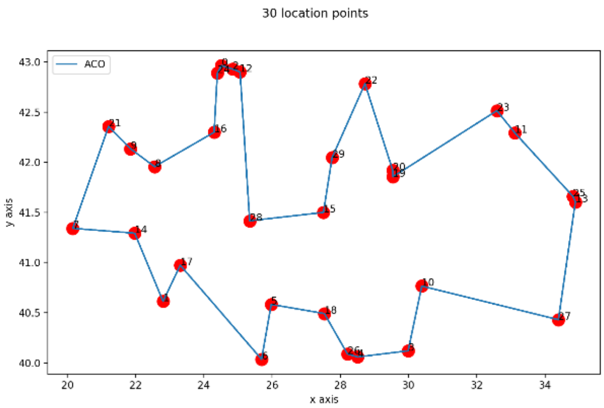
One of the optimum route examples created by these algorithms is given in Figure 8. In Figure 8, optimum routes produced by the ACO algorithm are given with the routes created by other two algorithms.



a)A GA route with 30 location points (54.11 km)



b) An ABC route with 30 location points (41.96 km)



c) An ACO route with 30 location points (33.77 km)

Figure 8. *An Optimal route in km by each algorithm for medication delivery*

5. CLUSTERING THE LOCATIONS

Since the number of patients in a certain area may increase very rapidly, clustering may be required considering both the drone capacities and the number of available drone resources. In clustering, the number of clusters can generally be determined by the elbow method, but in our practice, the number of clusters is determined by dividing the total number of patients requesting medications by the number of patients planned to be served by one drone. K-means clustering method is to partition a data set consisting of N data objects into K clusters given as input parameters. The aim is to ensure that within-cluster similarity is maximum and inter-cluster similarity is minimal. K-means is one of the most commonly used clustering algorithms. It is easy to apply. It can cluster large-scale data quickly and effectively. "K" refers to the number of fixed sets needed before starting the algorithm. With its repetitive partitioner structure, the K-means algorithm reduces the sum of the distances of each data to the set it belongs to. The K-means algorithm tries to detect K clusters that will make the square error the smallest.

Figure 9 presents the clustering process for patients' locations. If the number of patients in a certain area exceeds a threshold, clustering is performed. With the number of clusters determined according to the number of patients and drone capacity, the K-means algorithm is run and the locations are divided into specified clusters in Figure 9b. Then, as seen in Figure 9c, the optimum route is determined by running the ACO algorithm for each cluster and a drone is assigned to each cluster. Since drones distribute medications with limited resources in terms of batteries and product carrying capacity, it becomes important for them to carry out the distribution process with optimum routes. For this reason, algorithms giving the optimum route at different location numbers have been compared in Figure 10 and ACO algorithm yields the best result for each location. ABC algorithm produced the worst results. Basically, it can be said that the reason for this situation is that the ABC and GA algorithms start the solution with random points according to ACO algorithm and do not consider the distance parameter in the iteration. After approximately 30 locations, GA produced more successful results than ABC.

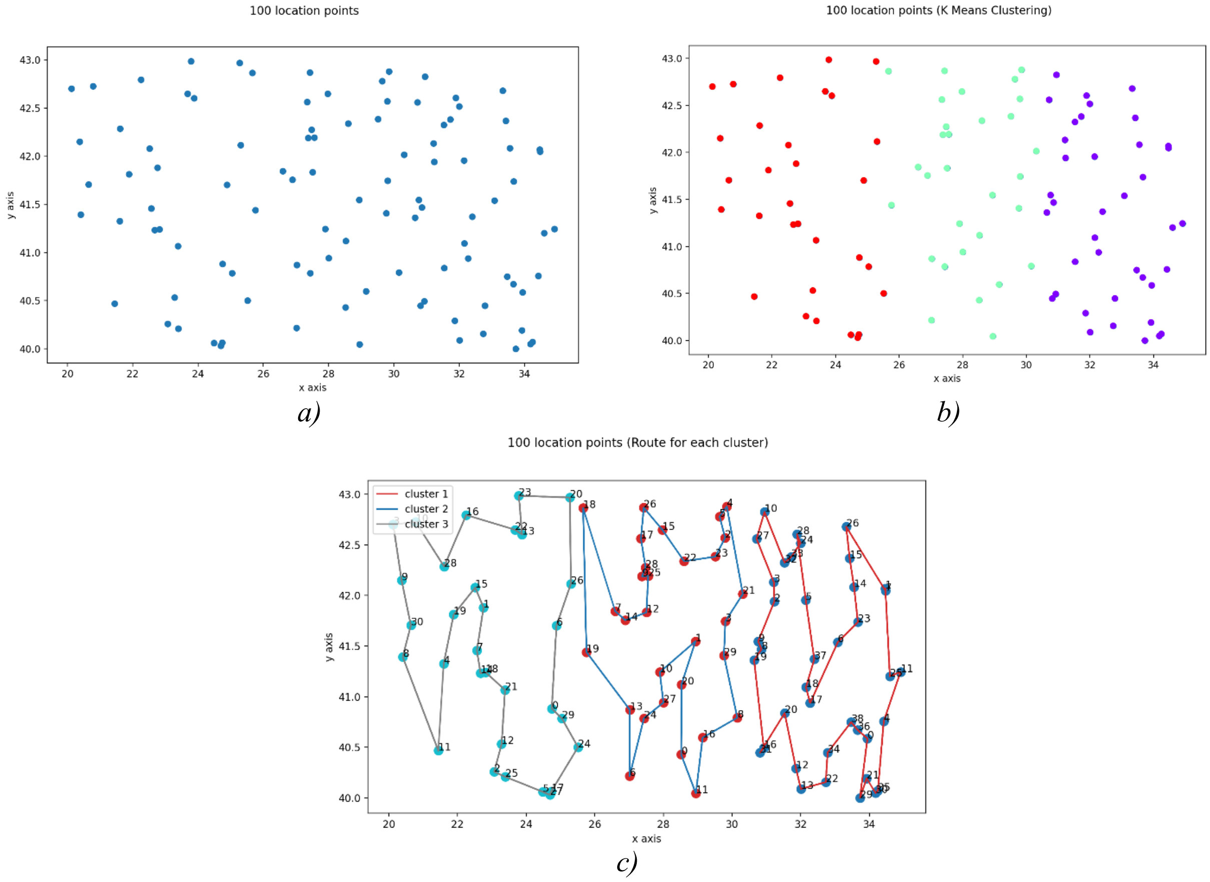


Figure 9. *a) Locations of the patients b) Three clusters for the patents' locations c) Optimal route for each cluster*

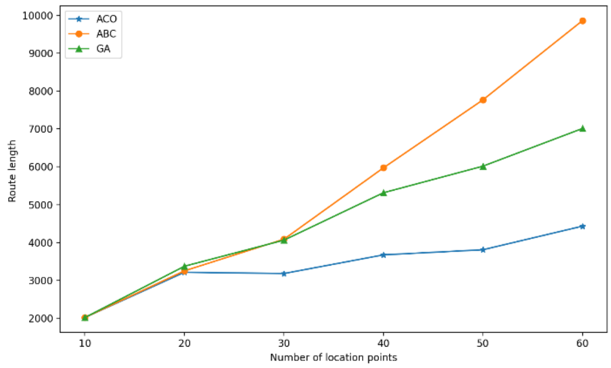


Figure 10. *Comparison of the optimal results for each algorithm*

6.CONCLUSIONS

Drone technology is also improved in parallel with the developments in informatics and mechatronics technologies. Along with online trade and industrial developments, drones (UAVs) have started to be used in the air transportation in distribution process. Companies have started to use land vehicles and drones together for transportation from distribution points located far from city centers to distribution stations in the city. Although drones provide advantages in terms of not being affected by traffic congestion and being autonomous, they also experience various capacity constraints. The most important capacity constraints of drones are battery and parcel limits. Therefore, it is very important to find the optimum route for the location points to be distributed.

In this study, it is aimed to distribute medications, especially covid-19 treatment drugs, to end users with drones due to the covid-19 pandemic. For the distribution of necessary drugs to patients with a positive Covid-19 diagnosis, patients will first make a request from the mobile application. These requests will be collected on a web server and distributed to location groups in the certain regions.

Since there are too many locations for distribution and considering the limitations of drones, the optimum route should be determined. In order to determine the optimum route, ACO, ABC and GA metaheuristic algorithms have been compared and as a result of the experimental studies, the results closest the optimum were produced by the ACO algorithm adapted to route planning. If the number of patients is too high in a specific region, it is planned to separate patients according to certain clusters with clustering based on the machine learning algorithm, to extract the optimum route for each cluster and to distribute to each cluster. We have implemented K-means algorithm to define clusters for distribution. A hybrid approach has been proposed using K-means and Ant Colony algorithm together.

In the future, considering the battery constraints of drones, those with a battery time below a certain value can be directed to charging centers at certain points in city centers. These charging stations are planned to be added to the model keeping in mind that it will change the structure of the model since the starting points will change by adding these charging stations.

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