HAL open science

Sustainable Facility Location-Routing Problem for Blood Package Delivery by Drones with a Charging Station

Shirin Ghasemi, Reza Tavakkoli-Moghaddam, Mahdi Hamid, Meysam Hosseinzadeh

▶ **To cite this version:**

Shirin Ghasemi, Reza Tavakkoli-Moghaddam, Mahdi Hamid, Meysam Hosseinzadeh. Sustainable Facility Location-Routing Problem for Blood Package Delivery by Drones with a Charging Station. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2021, Nantes, France. pp.3-14, 10.1007/978-3-030-85906-0_1 . hal-04022139

HAL Id: hal-04022139

https://inria.hal.science/hal-04022139

Submitted on 9 Mar 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution 4.0 International License

This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Sustainable Facility Location-Routing Problem for Blood Package Delivery by Drones with a Charging Station

Shirin Ghasemi [0000-0002-6515-230X], Reza Tavakkoli-Moghaddam [0000-0002-6757-926X] (✉), Mehdi Hamid [0000-0003-1498-7507] and Meysam Hosseinzadeh [0000-0001-6598-9671]

School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
tavakoli@ut.ac.ir

Abstract. This paper proposes a multi-objective integrated facility location and drone routing problem in blood package delivery by considering sustainability factors. We seek to locate the predetermined number of capacitated launching facilities and charging stations for the drones' battery. Candidate construction points are ranked by the TOPSIS method in terms of sustainability indicators. The objectives are to maximize the weight of selected points and the amount of demand coverage while minimizing the transferring and constructing facilities cost. Then, we assign drones to open launch facility and demand points to drones and launch facility. It should be noted that we consider the drone's battery consumption, and if the drone battery is not enough to continue its mission, we assign them to an opened charging station. GAMS software is employed to solve small-sized problems. The solution result indicates the performance of our model.

Keywords: Sustainable location-routing, Drone delivery system, TOPSIS method, Blood delivery

1 Introduction and Literature Review

Unmanned aerial vehicles (UAVs) or drones have attracted significant attention in differential application areas like rescue operations [1], relief distribution [2], healthcare [3], emergency applications like search and rescue [4], civilian sector [5], agriculture [6] and military [7]. However, their role in packages delivery is more common nowadays due to high traffic jams and increased competitiveness for faster service [8, 9]. Several prominent companies (e.g., Google, UPS, Flytrex, and Amazon) have resorted to using drones for package deliveries or commercial service [10]. Drone's rapid deployment ability and mobility have led to their use for transporting perishable materials or hospital packages and drugs too. Most of these materials, particularly blood products, have a short lifespan, so their delivery should be managed accurately. One of the emerging fields of using drones is their utilization as a means of delivering blood packages.

Drones, as aerial vehicles, have a much lower payload carrying capacities and range for carrying cargo than trucks; besides, as the payload increases, their maximum range of coverage decreases. That is why a drone-based delivery system needs more depots or launch sites across the distribution area. Also, unpredictable weather conditions can

dramatically affect energy consumption or the drone range, so it is necessary to construct some charging stations throughout the region. It should be noted that drones are beneficial to environmental sustainability due to less carbon dioxide (CO2) emissions in comparison with trucks [11]. Nevertheless, the charging stations release some carbon dioxide and cause air pollution. Therefore, it is necessary to consider environmental sustainability indicators for locating and constructing these facilities.

Most of the previous studies on drone delivery applications are conducted on drone scheduling and routing problems [12, 13]. Recently, researchers have much concentrated on facility location problems (FLPs) in drone delivery problems. FLPs play a crucial role in designing an efficient delivery system to increase accessibility and maximize demand coverage. Several articles focused on determining the optimal location for a relief distribution center in a post-disaster supply chain network by using drones. They aim to minimize the total cost or travel times [14, 15]. Nevertheless, the crucial aim in the relief distribution or drug and blood packages delivery is the maximum coverage of demand points, which has been rarely studied. Pulver and Wei [16] attempted to maximize primary and secondary demand point coverage in medical delivery by using drones. However, they did not take into account the capacity of each drone launching site. They also did not consider the drone's battery consumption as its payload function. Kim et al. [17] proposed a two-stage pickup and delivery model for medical delivery by using drones. First, they solved a facility location problem to construct depot facilities, second, the drone's routing problem has been addressed.

Chauhan et al. [18] developed a single-stage model for capacitated launch facilities and allocating demand points to drones. They proposed a function of drone energy consumption by considering drones' payload and demand point distance. They did not include charging stations in their model and assumed that the drones would be charged the night before the flight and they are fully charged in the planning periods. Hong et al. [19] developed a coverage model for a drone's delivery system that optimizes the location of recharging stations of drones. The study conducted by Shavarani et al. [20] addressed the refuel and launching stations for the drone delivery problem and try to minimize the total cost of the system. However, they assumed that in each mission just one demand point is covered. Several authors have mentioned the collaboration of trucks and drones for package delivery, which, despite the increased service speed, causes problems for the environment due to truck's CO2 emissions [21, 22]. Kitjacharoenchai et al. [23] developed a synchronized truck-drone routing model. In their proposed model, the drone mission started from the truck and after serving multiple demand points, they returned to the truck. Besides, UAV charging stations emit some CO2 gas that has not been addressed in previous research, which should be considered in locating charging stations. There are also many sustainable factors influencing the construction of launching and charging stations (e.g., availability of resources, climatic conditions of the region, and access to rescue equipment) that should be considered in the model.

In response to the urgent requirement of medical centers for blood products, we provide a sustainable integrated multi-objective facility location-routing model for blood packages delivery by drones. First, we determine several sustainable indicators to rank the potential candidate point of facility location by the TOPSIS method (as one of the

well-known multi-criteria decision-making methods). Then, our FLP model attempt to find the best point for drones' launching and charging station simultaneously, by maximizing the weight of each potential candidate point. Our model also aims to minimize the total delivery and construction cost of facilities while maximizing demand coverage. Then, we assign drones to open launch facilities according to their limited capacity, afterward we assign demand points to open launch facilities and drones. It should be noted that if a drones' battery is not enough to complete its mission, drones should be assigned to an open charging station.

To the best of our knowledge, no study considers sustainability in the combination of drones' launching and charging station location and drones' routing problem together by considering drones' battery consumption in its mission together, so our contribution is novel.

The remainder of this paper is organized as follows. The problem statement and the proposed mathematical formulation are illustrated in Section 2. The numerical results are investigated in Section 3. Finally, the conclusion and the relevant future studies are provided in Section 4.

2 Problem Definition

In this section, we present sustainable multi-objective mixed-integer linear programming (MILP) formulations for location and routing problems in blood delivery systems by drones. At the beginning of the planning period, there is a set of potential points to construct drone charging and launching facilities, which must be decided whether to open them according to sustainable indicators, which is shown in Table 1. The weight of these indicators' importance is determined according to related papers and experts' opinions. Then, each of these candidate points is ranked and weighted based on these indicators by employing the TOPSIS method that is generally proposed by Tzeng and Huang [24], which is a multi-criteria decision analysis method. This method attempts to select an alternative that has the least geometric distance from the positive ideal solution (PIS) [25] and the greatest geometric distance from the negative ideal solution (NIS) [25]. The output of the TOPSIS method is an input parameter for the mathematical model, besides our proposed model aims to maximize the total weight of the selected points.

In our model, there is a set of demand locations k with the demand of v_{kp} from blood product p; which their demand is met by the Central Blood Bank, and a set of available fully-charged drones d. It should be noted that there are two kinds of demand points, critical and non-critical points, in which all demand of critical point should be satisfied. However, for the other points, at least 70 percent of its demands should be met. Launch stations are introduced as temporary warehouses for blood packages, which are delivered to customers by drones, too. The planning period is short-term due to the nature of blood delivery and the different blood product's shelf life is about a few days to several weeks, so, they are not exposed to corruption. We aim to locate P_s launch facilities for maximizing the service rate and demand rate coverage by minimizing the total cost, including the construction cost of facilities, delivery, and drone battery consumption

cost. Then, we allocate drones to opened launch facilities by considering the facility's capacity. Then, each drone makes a one-to-many routing mission to cover the demand point, by considering the drone carrying capacity and battery consumption in its mission. In our model, if the remain drone's battery capacity is not enough for traveling between nodes *i* to *j* (it is less than the consumption battery rate between nodes *i* to *j*), it should go to an open charging station; then, it can continue its mission and visit the next demand point according to its routing. It should be noted that the amount of battery consumption rate is calculated according to the weight of the drone and its battery, the weight of the blood packets carried, and the traveled distance. Fig. 1 indicates the schematic representation of our proposed drone delivery system.

Table 1. Evaluation criteria for location selection of launch site and charging station

sustainability	Indicators	No.	Criterion type	Launch site's location	Charging station's location
Economy	Tax policy	A1	maximize	✓	✓
	Being in line with the economic planning of the region	A2	maximize	✓	✓
	Possibility of development	A3	maximize	✓	
	Availability of resource	A4	maximize	✓	
	Policies and rules of government	A5	maximize	✓	✓
	Annual cost (operation and maintenance)	A6	minimize	✓	✓
Environment	Effect on the ecological perspective	B1	minimize	✓	✓
	Level of environmental protection	B2	maximize	✓	✓
	Climatic conditions of the region	B4	maximize	✓	
	Amount and speed of the wind	B5	minimize	✓	
	CO2 emissions	B6	minimize		✓
	destruction level of vegetation and water	B8	minimize	✓	✓
Social	Effect on traffic agglomeration	C1	minimize		✓
	Effect on nearby inhabitant	C2	minimize	✓	✓
	Proximity to a skilled workforce	C3	maximize	✓	
	Infrastructure status of operators' workplaces	C5	maximize	✓	✓
	Operator security	C6	maximize	✓	✓

The notation and the proposed multi-objective mathematical model are given below, by considering the following assumption:

1. The amount of demand in each planning horizon is proportional to the drone's payload capacity.
2. We did not consider the effect of weather conditions on the drone's battery capacity.
3. The weight and volume of different blood packages are the same.

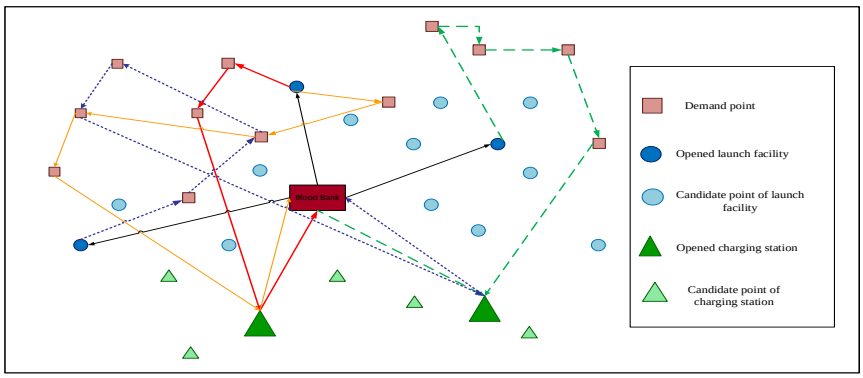

Fig. 1. Overview of the drone air delivery system

Sets:		**Parameters:**	
V	Set of all node	w_i	Weight of each candidate points ($i \in M$)
F	Set of all Charging stations	f_i	Construction cost of node $i \in M$
S	Set of all potential launch facility	c_{ijd}	Cost per mile of sending packages from node i to node j by drones d
I	Set of all candidate nodes	r_d	Battery consumption rate by the drones d per weight and unit of transported
K	Set of all demand points	v_{ip}	Amount of each demand point i of blood product p ($i \in k$)
k_1	Critical demand points that all demands must be met	CV_d	Capacity of drone d
k_2	Other demand points	m_d	Weight of the drone and its battery
P	Set of all blood product $p \epsilon P$		
Parameters:		**Variables:**	
BC_d	Drone's d battery capacity	L_i	1 if the launch facility is located at i; 0, otherwise
Ps	Maximum number of launch facility	R_i	1 if the charging station is located at i; 0, otherwise
pf	Maximum number of charging stations	Q_{id}	1 if the d-th drone d is assigned to location i; 0, otherwise
U_i	Capacity of each candidate launch facility	μ_{ijd}	1 if the arc (i, j) is traversed by drone d; 0 otherwise
d_{ij}	Travel distance between nodes i and j	Z_{ij}	1 if demand point i is assigned to launch facility j; 0, otherwise
CD_{ip}	Capacity of each launch facility i for blood product $p \epsilon P$	ρ_{ijdp}	remaining delivery demands after leaving node i if drones d travels from node i to node j (for every $i, j \in N$)
λ_d	Drone d battery consumption cost	BL_{jd}	Battery level of each drone d when arriving in vertex j
		α_k	Service rate to each demand point

$$Max \sum_{i\epsilon s}\sum_{j\epsilon k}\sum_{d\epsilon D}\sum_{p\in P} \alpha_j \mathrm{v_{jp}} \mu_{\mathrm{ijd}} + \sum_{i\epsilon f}\sum_{j\epsilon k}\sum_{d\epsilon D}\sum_{p\in P} \alpha_j \mathrm{v_{jp}} \mu_{\mathrm{ijd}} \tag{1}$$

$$Max \sum_{i\epsilon f} \mathrm{w_i} \times \mathrm{R_i} + \sum_{i\epsilon s} \mathrm{w_i} \times \mathrm{L_i} \tag{2}$$

$$Min\left(\sum_{i\epsilon s}\sum_{j\epsilon k}\sum_{d\epsilon D}\mathrm{d_{ij}c_{ijd}\mu_{ijd}}\right)+\left[\left(\sum_{i\epsilon s}\sum_{j\epsilon f}\sum_{d\epsilon D}\mathrm{d_{ij}c_{ijd}\mu_{ijd}}\right)+\left(\sum_{i\epsilon f}\sum_{j\epsilon k}\sum_{d\epsilon D}d_{ij}c_{ijd}\mu_{ijd}\right)\right]$$
$$+\sum_{i\epsilon v}\sum_{j\epsilon i\cup k}\sum_{d\epsilon D}\sum_{p\epsilon P}(p_{ijdp+m_d})r_d d_{ij}\mu_{ijd}\lambda_d+(\sum_{i\epsilon s}\mathrm{f_i L_i})+(\sum_{i\epsilon f}f_i R_i) \quad (3)$$

s.t.

$$\sum_i L_i \le Ps \qquad \forall i\in S \quad (4)$$

$$\sum_i R_i \le Pf \qquad \forall i\in F \quad (5)$$

$$U_i.L_i \le \sum_d Q_{i,d} \qquad \forall i\in S \quad (6)$$

$$\sum_{i\in S} Q_{i,d} \le 1 \qquad \forall d \quad (7)$$

$$\sum_{i\in S} Z_{ji} = 1 \qquad \forall j\in K \quad (8)$$

$$\sum_{j\in K}\alpha_j v_{jp} Z_{ji} \le CD_{ip}L_i \qquad \forall i\in S,p \quad (9)$$

$$\mu_{kjd}+Z_{ki}+\sum_{o\in S,o\neq s} Z_{jo} \le 2 \qquad \forall j,k\in K, i\in S, d, k\neq j \quad (10)$$

$$\sum_{j\in I}\mu_{ijd} = 1 \qquad \forall i\in K,d \quad (11)$$

$$\sum_{j\in I}\mu_{jid} = \sum_{j\in I}\mu_{ijd} \qquad \forall i\in I,d \quad (12)$$

$$\sum_{j\in I}\rho_{jidp}-\sum_{j\in I}\rho_{jidp} \ge \alpha_i v_{ip} \qquad \forall i\in K,d,p \quad (13)$$

$$\sum_{j\in I}\rho_{jidp} \le CV_d\mu_{ijd} \qquad \forall i\in I,d,i\neq j \quad (14)$$

$$\sum_{j\in K}\rho_{ijdp} \ge \sum_{j\in K} Z_{ji}\,\alpha_j v_{jp} \qquad \forall i\in S,d,p \quad (15)$$

$$\rho_{ijdp} \le (CV_d-\alpha_i v_{ip})\mu_{ijd} \qquad \forall j\in I, i\in K,p,d \quad (16)$$

$$\rho_{jidp} \ge \alpha_i v_{ip}\mu_{jid} \qquad \forall j\in I, i\in K,p,d \quad (17)$$

$$BL_{jd} \le BC_d \qquad \forall j\in I,d \quad (18)$$

$$BL_{jd} \le BL_{id}-(p_{ijdp+m_d})\,r_d d_{ij}\mu_{ijd}+BC_d(1-\mu_{ijd}) \qquad \forall i,j\in I,d,i\neq j \quad (19)$$

$$BL_{jd} \le BC_d-(p_{ijdp+m_d})r_d d_{ij}\mu_{ijd} \qquad \forall j\in F, i\in I,d \quad (20)$$

$$\alpha_j = 1 \qquad \forall j\in k_1 \quad (21)$$

$$0.7 \le \alpha_j \le 1 \qquad \forall j\in k_2 \quad (22)$$

$$L_i, R_i, Q_{id}, \mu_{ijd}, Z_{ij}\in\{0,1\},\ \rho_{ijdp}, BL_{jd}\ge 0 \quad (23)$$

The objective (1) attempt to maximize the demand coverage according to service rate of each demand point. Objective (2) maximizes the weight of the selected points for the construction of the facility. Objective (3) tries to minimize the total cost, including the construction cost of facilities, delivery, and drone battery consumption cost. Constraints (4) and (5) ensure that the number of construction facilities (launch facility and charging station) should be less than the allowed number. Constraint (6) states drones should be assigned to launch facilities according to their limited capacity. Constraint (7) ensures each drone should be allocated to at most one open facility. Constraints (8) ensure each demand point is assigned to a launch facility exactly once. Constraint (9) is about the limited launch facility's capacity for delivering packages by considering the service rate of each demand point. Constraint (10) makes sure that two consecutive demand points on a route are assigned to the same launch facility.

Constraint (11) illustrates that each demand location should be placed on exactly one drone route. Constraint (12) is the flow constraint. Constraint (13) ensures that each customer's requirements must be met according to its service rate. Constraint (14) restricts the total package load of any arc not to exceed the drone's capacity. Constraint (15) ensures that the total demands of all customers assigned to the corresponding launch facility are more than the same facility's total load by considering the service rate of each point. Constraints (16) and (17) are bounding constraints for additional variables acourding to its service rate. Constraint (18) ensures that the battery consumption between each node is less than the drones' battery capacity. Constraints (19) and (20) guarantee that reduces battery level on entry at node j based on the distance route from node i ,drone and its package weight and the drones' battery consumption rate. Constraints (21) and (22) refer to the service rate of demand points; All demand of a critical point must be met, so α_k takes the value 1 (21); for the other point, α_k will be between 0.7 and 1 (22). Constraint (23) is domain constraint.

3 Numerical Results

In this part, a simple numerical example with 20 candidate point for construction facilities, 8 kinds of drones, 15 demand point (in 3 groups; hospitals, clinics, and medical institutes), and 4 types of blood package include in O, A, B, and AB is presented. We aim to construct launch facilities and charging stations from the candidate point according to the weight of each location and demand point. Table 2 displays the weighted candidate point which gathers from the TOPSIS method. Some critical parameters of the problem are identified in the following tables. For instance, the total capacity of a launch facility from blood packages is in Table 3; the demand for different points from various blood packages is given in Table 4. Also, some physical characteristics of the drone (e.g., battery capacity, consumption rate, and drone capacity to carry blood packages) are prepared in Table 5. These parameters are gathered from the related articles and experts' opinions. It should be noted that the average weight of blood packages is 0.55 kg.

Table 2. Weighted of each candidate point that gathers from the TOPSIS method.

Candidate point for the launch site	w_s	Candidate point for the charging station	w_f
1	0.12	11	0.08
2	0.13	12	0.1
3	0.14	13	0.11
4	0.11	14	0.13
5	0.15	15	0.16
6	0.04	16	0.11
7	0.05	17	0.07
8	0.1	18	0.08
9	0.11	19	0.09
10	0.05	20	0.07

Table 3. Total capacity of a launch facility from blood packages.

Launch facility	Total capacity of a launch facility for blood packages
l1	105
l2	80
l3	70
l4	90
l5	100

Since our developed model is multi-objective, we employ the ε-constraint method to achieve a Pareto-optimal solution. The validity of this model is evaluated by GAMS version 25.1.3 software using the CPLEX solver in a personal computer with Intel Core i5 CPU with 2.20 GHz frequency and 8.00 GB RAM. The CPU time of this model is 10.28 seconds. Fig. 2 illustrates Pareto solutions obtained by the ε-constraint method.

Table 4. Demand for different points from various blood packages.

Demand	p1	p2	p3	p4	Total
1	2	3	5	4	14
2	4	4	4	4	16
3	3	4	5	7	19
4	5	2	4	5	16
5	2	5	6	6	19
6	4	5	5	6	20
7	6	6	5	6	23
8	3	4	3	4	14
9	3	5	3	5	16
10	3	3	3	5	14
11	3	4	3	4	14
12	5	4	4	4	17
13	6	5	4	3	18
14	6	5	6	3	20
15	4	3	6	2	15

Table 5. Physical characteristics of each drone

Drones	Total blood packages	Drone's battery capacity (Ah)	Battery consumption rate ($^{Ah}/_{kg.Km}$)	Drone and battery weight (Kg)
1	35	625	3	2.8
2	55	4425	6	6
3	30	365	2.5	2.3
4	45	2900	5	5.6
5	32	530	2.8	2.5
6	38	875	3.4	3
7	36	675	3.2	2.5
8	40	1650	4.8	4.2

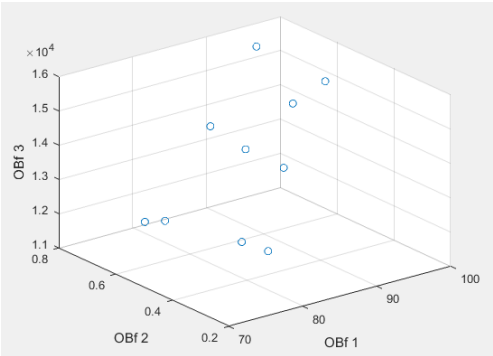

Fig. 2. Pareto solutions were obtained by the ε-constraint method

4 Conclusion

This study presented a novel location-routing problem in blood package delivery with drones by considering sustainability. The problem was supposed to locate a predetermined number of launching site and charging station of drones, considering a trade-off between three objectives, include in minimizing travel and construction cost, maximizing demand coverage, and maximizing the weight of each candidate points, which was obtained by the TOPSIS method by considering various sustainable indicators. The developed model prepares the crucial information on various aspects of the drone's location-routing problem for managers in health care seeking to construct an aerial delivery system for blood package delivery. The proposed model was solved by employing the epsilon method to validate the result. Due to the feature of the problem, developing efficient meta-heuristic or exact methods is suggested to solve large-sized problems. Moreover, the uncertainty in some parameters can be addressed in future studies.

References

1. Xiang, G., Hardy, A., Rajeh, M., Venuthurupalli, L.: Design of the life-ring drone delivery system for rip current rescue. In: Proceedings of the 2016 IEEE Systems and Information Engineering Design Symposium (SIEDS), Charlottesville, VA, USA, 26-29 April 2016, IEEE, pp. 181-186 (2016).

2. Golabi, M., Shavarani, S. M., Izbirak, G.: An edge-based stochastic facility location problem in UAV-supported humanitarian relief logistics: A case study of Tehran earthquake. Natural Hazards 87(3), 1545-1565 (2017).
3. Scott, J., Scott, C.: Drone delivery models for healthcare. In: Proceedings of the 50th Hawaii International Conference on System Sciences, Hilton Waikoloa Village, Hawaii, USA, 4-7 January 2017 (2017).
4. Karaca, Y., Cicek, M., Tatli, O., Sahin, A., Pasli, S., Beser, M. F., Turedi, S.: The potential use of unmanned aircraft systems (drones) in mountain search and rescue operations. The American Journal of Emergency Medicine 36(4), 583-58 (2018).
5. Thiels, C. A., Aho, J. M., Zietlow, S. P., Jenkins, D. H.: Use of unmanned aerial vehicles for medical product transport. Air Medical Journal 34(2), 104-108 (2015).
6. Albornoz, C., Giraldo, L. F. Trajectory design for efficient crop irrigation with a UAV. In: Proceedings of the 2017 IEEE 3rd Colombian Conference on Automatic Control (CCAC), Cartagena, Colombia, 18-20 October 2017, IEEE, pp. 1-6 (2017).
7. Udeanu, G., Dobrescu, A., & Oltean, M. (2016). Unmanned aerial vehicle in military operations. Scientific research and education in the air force, 18(1), 199-206.
8. Hong, I., Kuby, M., Murray, A. T.: A range-restricted recharging station coverage model for drone delivery service planning. Transportation Research Part C: Emerging Technologies 90, 198-212 (2018).
9. Shavarani, S. M., Nejad, M. G., Rismanchian, F., Izbirak, G.: Application of hierarchical facility location problem for optimization of a drone delivery system: a case study of Amazon prime air in the city of San Francisco. The International Journal of Advanced Manufacturing Technology, 95(9), 3141-3153 (2018).
10. Mack, E.: How delivery drones can help save the world. Forbes, Forbes Magazine (2018).
11. Goodchild, A., Toy, J.: Delivery by drone: An evaluation of unmanned aerial vehicle technology in reducing CO2 emissions in the delivery service industry. Transportation Research Part D: Transport and Environment 61, 58-67 (2018).
12. Peng, K., Du, J., Lu, F., Sun, Q., Dong, Y., Zhou, P., Hu, M.: A hybrid genetic algorithm on routing and scheduling for vehicle-assisted multi-drone parcel delivery. IEEE Access 7, 49191-49200 (2019).
13. Hu, M., Liu, W., Lu, J., Fu, R., Peng, K., Ma, X., Liu, J.: On the joint design of routing and scheduling for vehicle-assisted multi-UAV inspection. Future Generation Computer Systems, 94, 214-223 (2019).
14. Chowdhury, S., Emelogu, A., Marufuzzaman, M., Nurre, S. G., Bian, L.: Drones for disaster response and relief operations: A continuous approximation model. International Journal of Production Economics 188, 167-184 (2017).
15. Golabi, M., Shavarani, S. M., Izbirak, G.: An edge-based stochastic facility location problem in UAV-supported humanitarian relief logistics: a case study of Tehran earthquake. Natural Hazards 87(3), 1545-1565 (2017).
16. Pulver, A., Wei, R.: Optimizing the spatial location of medical drones. Applied Geography 90, 9-16 (2018).
17. Kim, S. J., Lim, G. J., Cho, J., Côté, M. J.: Drone-aided healthcare services for patients with chronic diseases in rural areas. Journal of Intelligent & Robotic Systems 88(1), 163-180 (2017).
18. Chauhan, D., Unnikrishnan, A., Figliozzi, M.: Maximum coverage capacitated facility location problem with range constrained drones. Transportation Research Part C: Emerging Technologies 99, 1-18 (2019).

19. Hong, I., Kuby, M., Murray, A.: A deviation flow refueling location model for continuous space: a commercial drone delivery system for urban areas. In: Advances in Geocomputation, Springer, Cham. pp. 125-132 (2017).
20. Shavarani, S. M., Nejad, M. G., Rismanchian, F., Izbirak, G.: Application of hierarchical facility location problem for optimization of a drone delivery system: a case study of Amazon prime air in the city of San Francisco. The International Journal of Advanced Manufacturing Technology 95(9), 3141-3153 (2018).
21. Wang, D., Hu, P., Du, J., Zhou, P., Deng, T., Hu, M.: Routing and scheduling for hybrid truck-drone collaborative parcel delivery with independent and truck-carried drones. IEEE Internet of Things Journal 6(6), 10483-10495 (2019).
22. Murray, C. C., Chu, A. G.: The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery. Transportation Research Part C: Emerging Technologies 54, 86-109 (2015).
23. Kitjacharoenchai, P., Min, B. C., Lee, S.: Two echelon vehicle routing problem with drones in last mile delivery. International Journal of Production Economics 225, 107598 (2020).
24. Tzeng, G. H., Huang, J. J.: Multiple attribute decision making: methods and applications. CRC Press (2011).
25. Assari, A., Mahesh, T., Assari, E.: Role of public participation in sustainability of historical city: usage of TOPSIS method. Indian Journal of Science and Technology 5(3), 2289-2294 (2012).