The Drone delivery problem in disaster and pandemics

Issam El Hammouti (✉ issam.elhammouti@gmail.com)

Faculty of Science, Tetuan

Azza Lajjam

Faculty of Science, Tetuan

Mohamed El Merouani

Faculty of Science, Tetuan

Research Article

Keywords: Covid-19, Simulated annealing, Meta-heuristic, Home delivery, Drone

Posted Date: October 29th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-96209/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Health Care Management Science

The Drone delivery problem in disaster and pandemics

--Manuscript Draft--

Manuscript Number:	HCMS-D-20-00502
Full Title:	The Drone delivery problem in disaster and pandemics
Article Type:	COVID-19 Issue
Keywords:	
Corresponding Author:	Issam El Hammouti Faculty of Science of Tetouan Tétouan, MOROCCO
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Faculty of Science of Tetouan
Corresponding Author's Secondary Institution:	
First Author:	Issam El Hammouti
First Author Secondary Information:	
Order of Authors:	Issam El Hammouti
	Azza Lajjam
	Mohamed El Merouani
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	Recently, the use of drone is growing in importance in several fields. Their capacity to avoid traffic jam and operate without a human pilot, make it the perfect method to home delivery in natural disasters and pandemics. This paper addresses the drone delivery problem inside Covid-19 outbreak area where quarantine status has been applied. This problem aims to minimize the time spent by a drone to complete the home delivery of pharmaceutical products and other indispensable goods to a set of residents inside the quarantine area. We propose a new mathematical formulation for the problem, and we develop a simulated annealing algorithm to solve large sized instances. To show the performance of our metaheuristic; extensive computational experience inspired by a real case of study in Morocco (Nador) are realized. Our results confirm that the proposed metaheuristic is a better alternative to solve the drone delivery problem in disaster and pandemics than the commercial solver (CPLEX 12.7)

Noname manuscript No. (will be inserted by the editor)

The Drone delivery problem in disaster and pandemics

Issam El Hammouti · Azza Lajjam · Mohamed El Merouani

Received: date / Accepted: date

Department of Mathematics, Faculty of Science of Tetouan
Mhannech Tétouan, Morocco 90000, MA
Tel.: +212-67-2382723
E-mail: issam.elhammouti@gmail.com

The National School of Applied Sciences
Mhannech Tétouan, Morocco 90000, MA

Department of Mathematics, Faculty of Science of Tetouan
Mhannech Tétouan, Morocco 90000, MA

Noname manuscript No.
(will be inserted by the editor)

The Drone delivery problem in disaster and pandemics

Received: date / Accepted: date

Abstract Recently, the use of drone is growing in importance in several fields. Their capacity to avoid traffic jam and operate without a human pilot, make it the perfect method to home delivery in natural disasters and pandemics. This paper addresses the drone delivery problem inside Covid-19 outbreak area where quarantine status has been applied. This problem aims to minimize the time spent by a drone to complete the home delivery of pharmaceutical products and other indispensable goods to a set of residents inside the quarantine area. We propose a new mathematical formulation for the problem, and we develop a simulated annealing algorithm to solve large sized instances. To show the performance of our metaheuristic; extensive computational experience inspired by a real case of study in Morocco (Nador) are realized. Our results confirm that the proposed metaheuristic is a better alternative to solve the drone delivery problem in disaster and pandemics than the commercial solver (CPLEX 12.7)

Keywords Covid-19 · Simulated annealing · Metaheuristic · Home delivery · Drones

1 Introduction

Recently, several multi-national companies was successful adopted drones as a transportation method for delivery packages of food, medicine in urban and hard to reach areas. In December 2016, the Amazon Prime service was the first completed a successful Prime Air

xxxxxxxxxxxxxxxxxxxxxxxxxxxx

xxxxxxxxxxxxxxxxxxxxxxxxxxxx

xxxxxxxxxxxxxxxxxxxxxx

E-mail: xxxxxxxxxxxxxxxxxxxxxxxx

xxxxxxxxxxxxxxxxxxxxxxxxxxxx

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Fig. 1: a Parcelcopte

drone delivery in UK, by delivering a TV streaming stick directly to the home of a customer [6]. Later, In April 2018, Deutsche Post DHL Group, has carried out by their parcel drone called Parcelcopte (figure 1) a medical supplies delivered in Tanzania [3]. In the last Year, Alphabet Inc subsidiary company Wing, has realized over 80,000 test flights and thousands of deliveries in the US after become the first company in this countries to have a certificate to operate with drones. The delivery with Drones method is actually becomes one of the most innovative methods in delivery system. The reason for the drone delivery success is due principally to their capacity, to avoid traffic congestion, to operate faster and autonomously and to reach remote area. On the other hand, the loading capacity and flying range of the drones are limited by duration of batteries. For this reason, In a drone delivery operation, its most suitable to located the truck as close as possible of customers and save battery. Find an optimal delivery with minimization of the total path realized by a drone among the depot and the customers is the main objective of the companies to reduce service cost. All papers in the literature have addressed a simulta-

neously drones and trucks delivery system in which the drone and trucks works in collaboration to complete a home delivery operation. In this paper we approach a new variant of the delivery with drones in which the operation is realized in an quarantine area and the delivery is completed with just one drone while the truck is considered as a fixed depot with a position close to quarantine zone and form where the drone pick up packages and swapping the battery.

Drone delivery in disaster and pandemics consists of using a drone to complete the home delivery of food, goods or medicine to a set of citizens trapped in a quarantine zone whose access is forbidden for human. The most recent example of this situation is the areas affected by the outbreak coronavirus diseases [16]. In order to interrupt and curbing transmission of the virus, World Health Organization (WHO) and the majority of state governments around the world have declared a state of emergency and have put in place stricter security measures in the most affected regions. These measures include, access forbidden to the areas where the origin of the outbreak has been registered and the application of social distancing, isolation and quarantine within these areas. Therefore, thanks to the ability to transport packages and operate without a human pilot, drones have become an essential tool and an optimal and highly useful solution that is being used by many governments and private companies to complete service delivery in all security and respecting social distancing. The delivery with drones in quarantine areas consists of loading a truck with all packages to fill the orders in the affected area. Then the truck must move and choose the best position among several possible from where it can begin to perform the deliveries using a drone. In this operation, the truck is considered as a warehouse from where our drone loads the packages. Therefore, the position of the truck is one of the critical decisions for complete a successful deliveries operation. In the same context, the distance between different delivery points is an important factor to be taken into account because the order in which the drone visits each delivery points is another vital decision that can influence the cost and the deadline of this operation. In this paper, we address the drone delivery problem in a quarantine areas, which consists in find a position of the truck as well as the order that a drone must visit each delivery point in order to minimize the total path required by the drone before completed the deliveries.

There are different types of drones with different characteristics (speed, charge capacity, battery life ...). In this work we consider a mid-to-high-end drone, with the capacity to load three packets of 1 kg simultaneously.

Fig. 2: Quarantine zone affected by Covid-19 in Nador (Morocco)

Table 1: The distances in meters between different delivery points and truck position

	Truck position		Delivery Points							
	1	2	3	4	5	6	7	8	9	10
1	0	39	24	23	39	23	27	35	36	32
2	39	0	39	28	20	38	30	26	24	39
3	24	39	0	18	36	22	28	26	37	30
4	24	28	18	0	20	21	19	18	28	29
5	39	20	36	20	0	30	18	28	15	33
6	23	38	22	21	30	0	16	30	28	16
7	27	30	28	19	18	16	0	27	15	15
8	35	26	26	18	28	30	27	0	30	39
9	36	24	37	28	15	28	15	30	0	18
10	32	39	30	29	33	16	15	39	18	0

We consider also that our drone can travel a maximum distance of 10 km before its battery runs out.

The figure 2 shows an example of a quarantine zone affected by Covid-19 in Nador city (Morocco). In figure 3 we present a visual representation of three feasible solutions for a problem with 8 delivery points and 2 possible positions for the truck. The distances in meters between different delivery points are shown in table 1. As we can see in figure 3 the best solution is presented in figure 3a where the truck's position is 2.

The rest of this paper is structured as follows. Next section presents a literature review on the delivery with drones problem. Then, a new mathematical formulation for Drone delivery problem in disaster and pandemics is presented in Section 3. In Section 4, a meta-heuristic based on a simulated annealing algorithm is adapted as a method of resolution of our problem. Next, experimental results and comparisons are presented in Section 5. Finally, Section 6 concludes the paper.

(a) The value of the total path realized by a drone is 256

(b) The value of the path realized by a drone is 277

(c) The value of the path realized by a drone is 258

Fig. 3: Three solutions possible for a problem with 8 delivery points and 2 possible positions for a truck

2 Related Work

Nowadays, the drones are increasingly operating in the civilian areas for delivery services. Generally the drones are used jointly with trucks for complete or partial delivery of foods, medicines and other indispensable goods. Many papers in the literature are addressed the drone and truck delivery problem which is classified as a variant of the vehicle routing problem or traveling salesman problem. Follow we present an ample survey on the most relevant papers in this topic.

In [11] the authors addressed the problem when a single drone works in collaboration with a single traditional delivery truck for last-mile delivery in logistics operations. The task of the drone in this operation consists in loading a package from the truck and after delivering the package to costumers, the drone returns to the truck to pick up the next package. While the drone

is flying, the truck can also deliver to other customers and rendezvous with the drone in a new location. Both a mathematical programming model and a heuristic are proposed to solve the problem and provide a solution that ensures faster delivery of customer orders at less cost to the distributor. A little later, a simulated annealing algorithm (SA) has been employed by [13] as a new alternative method to solve the mathematical programming model proposed by [11]. For its part, [4] presented both a theoretical analysis and a simulation study to show the efficiency of the drone and truck delivery system. In [2] the authors proposed an integer programming formulation for the traveling salesman problem with drone. For resolution, the authors developed several heuristics based on local search and dynamic programming. They assessed the quality of solutions found with their heuristics by making a comparison with the optimal solution for small instances. Furthermore, they presented a comparison between the drone and truck delivery system and the truck-only delivery system. To minimize the completion time of the drone and the truck in a drone and truck problem delivery, a hybrid genetic algorithm with dynamic population management, problem-tailored crossover operator and a local search technique has been implemented by [7]. The authors, has been proved in the computational results section that the results found by their proposed method improve the best known solutions presented so far in the literature. the authors in [5] extended the study on the drone and truck delivery problem by the consideration the possibility to use several drones to complete the deliveries. They proposed a nonlinear programming model to find an optimal delivery path for truck carrying drones. [10] addressed the cooperative drone and truck delivery problem. They formulated the problem as an optimal path planning problem with the objective to find the best path enabling the drones to finish all delivery in a shortest time. A new variant of the drone and truck delivery problem where the parcels delivery is performed by a fleet of trucks equipped with several drones has been presented in [17].the authors referred to this problem as the vehicle routing problem with drones. in [18] the study on the vehicle routing problem with drones has been extended considering that each drone can cooperate with different trucks contrary to [17] where the authors assumed that each drone should cooperate with exactly one truck. [15] presented a new mathematical model for the vehicle routing problem with drones which is an extension of the mathematical programming model proposed by [11]. They implemented an adaptive large neighborhood search metaheuristic to solve the problem at large instances sized. Recently, in [12] the authors addressed the drone and

truck delivery problem where a single truck cooperates with k drones to deliver a set of packages to a set of delivery points at less cost. They assumed in this paper that the truck acts as a mobile depot where each drone pick up one or more packages and recharging or swapping their battery. To solve this problem what they refer to as k -Multi-visit Drone Routing Problem, the authors proposed a heuristic called Route, Transform, Shortest Path (RTS).

In our paper we address a new variant of the drone-truck delivery problem where a drone is used to delivery packages to a set of citizens trapped in an area affected by a disaster or pandemic outbreak as Covid-19. Unlike many papers of the literature, the delivery of the packager in our problem must be carried out exclusively by the drone while the truck is used only as a depot for loading package to deliver or for changing the battery power. In the reset of this document we will refer to the problem as the drone delivery Problem in disaster and pandemics(DDPDP)

3 The drone delivery Problem in disaster and pandemics(DDPDP)

The DDPD aims to deliver packages of pharmaceutical products and other indispensable goods by a drone to a given set of residents trapped in a quarantine zone. The operation of loading package by the drone must realize from a single depot (the truck position). The depot is considering as a trucks with all package to delivers. To save cost and battery power of drone, the truck must be placed close to possible of quarantine area and delivery points. Over the course of the delivery operation, a drone can return many times to depot for loading new packages. The drone can visit a maximum of three delivery points without return to depot due to their capacity to payload of three package of 1 kg at same time. The maximum distance which can travel the drone before its battery runs out is 10 km. The objective is to minimize the path needs the drone for visit all delivery points respecting the capacity and battery power constraint.

3.1 Mathematical formulation:

To formulate a mathematical model for the problem we assume the following assumptions and notation:

Assumptions

- The drone may visit three delivery points per sortie.
- At each delivery point, a single package is delivered.
- The weight of each package must not exceed 1kg.

- Each delivery point is visited by the drone exactly once.
- After 10 km flying, the drone must change its battery.
- The required time for launch and recovery of drone is neglected.
- The required time for change battery and loading packages is neglected.

Notation

- P set of possible truck position, $P = \{1, \dots, p\}$
- R set of residents trapped in a quarantine zone, $R = \{p + 1, \dots, r\}$
- U set of customers and possible truck position. $U = P \sqcup R$
- $d_{kk'}$: The distance required for the drone to travel from $k \in U$ to $k' \in U$
- D_{max} : The maximum distance which can travel the drone before its battery runs out (In this model we assume $D_{max} = 10$ km)

Decision variable

$x_{kk'} = 1$ if the drone travels from $k \in U$ to $k' \in U$ and $= 0$ otherwise.

With the assumptions and notation presented above, our mathematical model is formulated as follows:

Objective function:

$$\text{Min} \sum_{k \in U} \sum_{k' \in U} x_{kk'} * d_{kk'} \quad (1)$$

Subject to:

$$x_{ij} + x_{i'j'} \leq 1, \quad \forall j, j' (\neq j) \in P, i, i' \in R \quad (2)$$

$$x_{ji} + x_{j'i'} \leq 1, \quad \forall j, j' (\neq j) \in P, i, i' \in R \quad (3)$$

$$x_{ji} + x_{i'j'} \leq 1, \quad \forall j, j' (\neq j) \in P, i, i' \in R \quad (4)$$

$$x_{jj'} = 0, \quad \forall j, j' (\neq j) \in P \quad (5)$$

$$\sum_{k \in U} x_{kk'} = 0, \quad \forall k' (\neq k) \in U \quad (6)$$

$$\sum_{k \in U} x_{ik} = 1, \quad \forall i \in R \quad (7)$$

$$\sum_{k \in U} x_{ki} = 1, \quad \forall i \in R \quad (8)$$

$$x_{ii'} + x_{i'i} \leq 1, \quad \forall i, i' (\neq i) \in R \quad (9)$$

$$x_{ii'} + x_{i'h} + x_{hh'} \leq 2, \quad \forall i, i' (\neq i), h (\neq i'), h' (\neq h) \in R \quad (10)$$

$$d_{1i} * x_{1i} + d_{ii'} * x_{ii'} + d_{i'h} * x_{i'h} + d_{h1} * x_{h1} \leq D_{max}, \quad \forall i (\neq 1), i' (\neq (1, i)), h (\neq (1, i, i')) \in R \quad (11)$$

$$d_{li} * x_{li} + d_{ii'} * x_{ii'} + d_{i'l} * x_{i'l} \leq D_{max}, \quad \forall i (\neq 1), i' (\neq 1) \in R \quad (12)$$

$$d_{1i} * x_{1i} + d_{i1} * x_{i1} \leq D_{max}, \quad \forall i (\neq 1) \in R \quad (13)$$

$$x_{kk'} \in \{0, 1\}, \quad \forall k, k' \in U \quad (14)$$

The objective function(1) minimizes the path of the drone to visit all delivery points. Constraints(2), (3),(4) ensure that the loadings packages by the drone is realized from a single truck position (depot). Constraint (5) prohibits the traveling of drone between two different truck positions. Constraint (6) enforces the drone to move from a delivery point to another delivery point different or from the truck position from a delivery point. Constraints (7), (8), (9) ensure that each delivery point is visited exactly once by the drone. Constraint (10) makes sure that the drone may visit a maximum of three delivery points without return to depot. Constraint (11), (12), (13) guarantee that after $D_{max}=10$ km of flight, the drone must come back to truck position for change battery. Constraint (14) defines the type of decision variable.

4 Simulated annealing algorithm for DDPP

Simulated annealing algorithm (SA) inspired by the mechanism of the slow cooling of the metal by the controlled decrease of the temperature to form a crystal lattice with minimal energy, is a meta-heuristic developed by [8]. SA starts from a state with a high degree of temperature (T_i) which decreases during the execution of the algorithm by means of coefficient of cooling (c) until a final temperature (T_f). First of all, the SA procedure starts with an initial solution as the best current solution. After this, another solution is generated from the neighborhood of the best current solution. The quality of the new solution is compared to the best solution registered at this time. In a minimization problem, if the new solution is less than the best solution, the new solution becomes the best current solution, from which the search will continue. The process will continue until a number maximum of iteration (K_{max}). To avoid the local minimum, the SA uses a probability to accept a solution as the best even if it is worse than the interior. SA has been adapted to solve a wide variety of hard optimization problems, as the berth allocation problem [1], the vehicle routing problem ([9] and room scheduling problem [14]. In the following subsections we present the general procedure of the proposed SA.

4.1 Encoding solution

The encoding of solution is the primary issue when developing any meta-heuristic. In Our SA proposed, a solution is represented by an array of $2*N+1$ cells, where N is the number of delivery points. The first and the last cell contains the truck position, the cells with odd indices contains an integer number in the interval $[m+1,$

$N]$. Where m is the assumed number of possible truck position. This integer number represents the delivery points visited by the drone. The cells with even indices may contains an integer number which represent the truck position, this happen when the drone return to the truck position after visited a delivery point or may contains the same integer number of the previous cell which mean that the drone well visit another delivery point without return to the truck position. For example, the solution presented in figure 3a can be represented as in figure 4 :

2	6	6	10	10	7	2	4	4	3	3	8	2	9	9	5	2

Fig. 4: Representation of a solution for the drone delivery problem

The decoding of the solution presented in figure 4 is the following: the drone start from the truck position number 2 to visit the delivery points 6, 10 and 7 respectively without come back to the depot (the truck position), However, after visited the delivery point 7 the drone must return to truck position 2 for loading three new packages for visit the next three delivery points 4, 3 and 8. After the delivery of the package for the delivery point 8, the drone come back again to the truck position to loading the last two packages and travel from the truck position to the points 9 and 4 respectively. Finally the drone return to the depot after the operation is completed.

4.2 Initialization

The initial solution has a primordial impact one the fast convergence of the meta-heuristics. For this reason, a heuristic is applied at the beginning of our algorithm to generate an initial solution. The heuristic is based on strategy to visit the maximum delivery points as possible without return to truck position (VMP). Indeed, If we assume that a drone, have a battery power and a capacity to loading packages unlimited, Obviously the shortest path for the drone is the path where the drone does not return to the truck position (warehouse) until all packages are delivered. The VMP heuristic applied in our algorithm is described in Algorithm 1:

4.3 Calculating objective function

The value of the objective function is calculated as the total distance between each two delivery points visited

Algorithm 1 The VMP heuristic

```

1  N= set of points delivery
2  M= set of truck positions
3  D[N+M][N+M]=Matrix of distance between all points to visit by the drone
4  Dmx =The maximum distance which can travel the drone before its battery runs out
5  S[2*N+1]= { } ; ▷ Table which represent the solution
6  Visited[N] = { } ; ▷ Set of the visited delivery points by the drone
7  K=0;
8  D=0;
9  P= Random(M);
10 S [0] = {P};
11 for  $i = 1 ; i > 2 * N ; i++$  do ▷ Randomly Generate a delivery point from N
12     x=Random (N);
13     if  $x \notin \text{visited}$  then
14         Visited = {x};
15         D =D+ d[S][i-1][x] ;
16         if  $k \neq \text{maximum packages to loading} \ \& \ D \leq Dmx$  then
17             S[i] = {x};
18             S[i+1] = {x};
19             K=K+1;
20         else
21             S[i] = x;
22             S[i+1] = y;
23             K = 0;
24             D = 0;
25     else
26          $i--$ ;
27 S [2*N] = P;
28 Return S ;

```

---

successively by the drone. For example, the objective function value for the solution in figure 2.a is computed as follow:

$$\begin{aligned}
 & D[2][6] + D[6][6] + D[6][10] + D[10][10] + D[10][7] + D[7][2] + \\
 & D[2][4] + D[4][4] + D[4][3] + D[3][3] + D[3][8] + D[8][2] + \\
 & D[2][9] + D[9][9] + D[9][5] + D[5][2] = 38 + 00 + 16 + 00 + 15 \\
 & + 30 + 28 + 00 + 18 + 00 + 26 + 26 + 24 + 00 + 15 + 20 = 256
 \end{aligned}$$

Where $D[i][j]$ is the distance realized by the drone to travel from i to j . (see table 1)) Since in this work we deal a minimization problem. Thus, the solution with lowest objective function value is selected as the best solution.

4.4 Neighborhood solution

In order to improve the solution quality, a search in the neighborhood of the current best solution is applied. Both swap and insertion techniques are used and the choice between them is based on a uniform probability. The swap operation consists basically in a swap between the position of two delivery points with the objective to change the drone's path (see figure 5 and figure 6) while the insertion operation consists in replace a truck position by another (see figure 7). After the application of the swap technique, we probably need a correction of the solution to avoid the unfeasible solution (figure 8)

Fig. 5: Example of swap1 technique

Fig. 6: Example of swap2 technique

Fig. 7: Example of insertion technique

4.5 The proposed Simulated annealing procedure

The proposed SA start at temperature T_i . Then, the VMP heuristic is applied to generate an initial solution and which is considered as the best current solution (x^*). F_{best} presents the value of the best current solution which is set to $F(X^*)$. The neighborhood solu-

Fig. 8: Example of a correction after swap operation

tion Y is generated at each iteration k and it is evaluated by the value of the objective function $F(Y)$. Y became the new solution X if $F(Y)$ is less than $F(X)$ or if $r < e^{\frac{-(F(Y)-F(X))}{T}}$ where r is a number generated randomly between $[0, 1]$ and $F(Y) - F(X) > 0$. In addition if the new solution X is less than the best current solution (X^*) So X became the best current solution. After K_{max} iteration, the temperature T_i is reduced to $c \cdot T$ where c is a constant number in interval $[0, 1]$. This procedure, is repeated until $T_i < T_f$, where T_f is the final temperature which is not able to be reduced or until the best solution is not improved by successive number of temperature reductions In_{max} . The proposed SA algorithm is presented clearly in figure 2.

4.6 Parameter Setting Selection

Parameter-setting is a primordial factor to improve the performance of a metaheuristic. The initial temperature (T_i), the cooling rate (c), the number of iteration at each temperature (k_{max}) and the final temperature (T_f) are the four primordial parameters in our approach.

To find a suitable combination of the four parameters, different preliminary experiments are realized. Four different problem instances are randomly selected and tested. Each problem instance is solved with four different value for each parameter namely ($T_i = 500, 400, 450, 350, c = 0.99, 0.98, 0.97, 0.96, k_{max} = 100, 90, 80, 85, T_f = 0.0025, 0.001, 0.01, 0.025$). Therefore, for each problem instance, 256 solutions are obtained for 256 combinations possible of all parameters. We calculated the average value of each combination of parameters in four problem instances used. Based on the 625 average values obtained, we can conclude that the ideal combination of parameters which guarantee good results for preliminary experiments are $T_i = 450$, $C = 0.99$, $k_{max} = 100$ and $T_f = 0.0025$.

5 Computational experiments

To evaluate how SA performs on the DDPDP, we compare our SA with the solutions obtained by solving the

proposed model in section 3 with CPLEX optimizer (CPLEX version 12.7) and with a maximum running time of two hours. The SA proposed was coded in Java and executed on a dell computer with a 2.30 Ghz i5-5300U CPU. The set of instances tested in our experiments are randomly generated but are inspired by a real case of a quarantine zone caused by the corona virus in Nador city (Morocco).

5.1 Instances generation

On April 4th 2020, a Coronavirus disease outbreak has been detected in Nador city in Morocco. Faced with this emergency situation, the kingdom of Morocco decides to mandate coronavirus quarantine on an area of 0.5 km radius which is the origin of outbreak (figure 1). The set of testing data used in our experiments are generated randomly in accord with the case of the quarantine zone applied in Nador city. The numbers of residents trapped in a quarantine zone R to be visited by the drone were set to 10, 15, 20, 25 and the numbers of possible truck position (depot) P were set to 2 and 3. We are assuming that our drone can delivery up to three packages at a time. The weight limit of each package is 1 kg and the range that the drone can cover before the battery runs out is 10 km. We combining the values of $R = 10, 15, 20, 25$ and $P = 2, 3$ we create 8 different size of problem instances where $R \cdot P = 10 \cdot 2, 10 \cdot 3, 15 \cdot 2$ and $15 \cdot 3$ are considered as the small problem instances and $R \cdot P = 20 \cdot 2, 20 \cdot 3, 25 \cdot 2$ and $25 \cdot 3$ are considered as the medium problem instances. For each problem size, we randomly generate 10 problem instances leading to 80 instances tested. The distance that separate two locations and the distance between each location and the depot are randomly generated based on a uniform distribution with a maximum and a minimum value of 40 and 20 meter consecutively. We should note that the total size of the quarantine area in our case of study is relatively small (a radius of 0.5 km). Therefore, the constraints regarding the runs out of battery are satisfied automatically. Indeed according to data generated above, the maximum distance that the drone can cover without the possibility to change the battery is $4 \cdot 40$ meter. For this reason and for expand our study on the other cases with large areas, we randomly generate a large problem instances with $R = 40, P = 3$ and the distance that separate the locations and the depot is range between 4km and 1 km.

Algorithm 2 Simulated annealing algorithmInput: all parameters of the algorithm (T_i , K_{max} , c , T_f) and solution initial (VMP(X))Output: best local solution X^* found so far $X^* = VMP(X)$ **while** $T_i > T_f \parallel I_{nmax} == 10$ **do**   **for** $i = 1$ to K_{max} **do**   Generate a neighbor Y to X

▷ See section Neighborhood solution

if $F(Y) < F(X)$ **then** $X = Y$;   **if** $F(X^*) < F(X)$ **then** $X^* = X$;   **else**   **if** $r < e^{-(F(Y)-F(X))/T}$ **then**▷ $r \in [0,1]$ $X = Y$; $T_i = c * T_i$

Table 2: Comparison of the results found with CPLEX and simulated annealing algorithm for small problem instances

Problem instances (R*P)	CPLEX			Simulated annealing algorithm		
	Optimal Value	Running Time (sec)	Gap% ^a	Best Value	Average value	Average running time
10*2	343	123.77	00.00	343	343	02.35
10*2	356	100.14	00.00	356	356	02.21
10*2	356	158.33	00.00	356	356	02.43
10*3	346	103.66	00.00	346	346	03.45
10*3	353	126.14	00.00	353	353	03.21
10*3	330	68.67	00.00	330	330	02.20
15*2	500	488.39	00.00	500	500	04.56
15*2	507	716.94	00.00	507	507	04.50
15*2	500	854.36	00.00	500	500	04.75
15*3	495	3560.06	00.00	495	495	03.21
15*3	489	23.34	00.00	489	489	05.33
15*3	482	1665.89	00.00	482	482	05.10

^a is calculated as (feasible solution value - lower bound)*100/lower bound

Table 3: Comparison of the results found with CPLEX and simulated annealing algorithm for medium problem instances

Problem instances (R*P)	CPLEX			Simulated annealing algorithm		
	Optimal Value	Running Time (sec)	Gap%	Best Value	Average value	Average running time
20*2	678	7200	33.02	664	664	05.23
20*2	683	7200	24.12	681	681	06.45
20*2	637	7200	05.12	637	637	05.33
20*3	671	7200	10.14	672	672	06.89
20*3	666	7200	05.67	666	666	06.44
20*3	696	7200	20.55	691	691	05.89
25*2	857	7200	33.90	842	842	06.75
25*2	886	7200	37.02	851	851	06.67
25*2	870	7200	36.12	843	843	06.09
25*3	863	7200	32.76	827	827	05.34
25*3	838	7200	25.56	820	820	06.23
25*3	865	7200	34.04	846	846	07.44

5.2 Computational results

In the tables 2, 3 and 4 we reports the results of the comparisons between the performance of our SA and the optimal solution found by solving the proposed model in section 3 with CPLEX optimizer. In all tables mentioned above, the first column present the size of problem instances, while the second , the third and the

fourth columns present the optimal value, the running time and the gap obtained by CPLEX consecutively. Finally, the last three columns shows the best value, the average value and the average running time found by the proposed SA after 10 runs for each instance tested. According to the table 2, the small problem instances are effortless solved at the optimality by CPLEX as well as by our SA. However, for the medium and the

Table 4: Comparison of the results found with CPLEX and simulated annealing algorithm for large problem instances

Problem instances (R*P)	CPLEX			Simulated annealing algorithm		
	Optimal Value	Running Time (sec)	Gap%	Best Value	Average value	Average running time
40*3	96085	7200	60.33	91758	94357.79	110.56
40*3	92172	7200	34.12	86346	89017.32	158.67
40*3	96487	7200	54.57	92173	94463.62	165.80
40*3	97677	7200	67.89	92288	96072.43	145.22
40*3	99346	7200	70.87	89916	92899.26	147.30
40*3	90887	7200	54.79	89338	90165	149.63
40*3	90242	7200	60.90	88556	91375.66	170.09
40*3	91250	7200	45.90	90512	91180.41	140.32
40*3	98347	7200	66.89	90881	93533.85	178.01
40*3	93761	7200	63.89	84221	87154.29	184.89
40*3	95117	7200	72.78	85924	88211.82	176.45
40*3	94358	7200	56.78	88338	92122	160.45

large problem instances, the tables 2 and 3 indicate that the CPLEX failed to be finding an optimal solution in a time limit of two hours for the majority of the instances tested. We thus considered the feasible solution obtained after two hours as the best value obtained by CPLEX. In contrast, our SA was capable to outperform all value obtained by CPLEX easily and in a shortest running time. Regarding the running time of CPLEX and SA. All tables of results show clearly that SA spent very short time to find optimal or feasible value than CPLEX. Hence, we can conclude that our proposed meta-heuristic outperform the CPLEX whether in running time or in solution quality.

6 Conclusion

This paper has addressed the drone delivery problem in disaster and pandemics. This problem is a variant of the vehicle routing problem with drones where the delivery is made in quarantine areas and only with drone. Both a mathematical formulation coded with OPL-CPLEX and a simulated annealing algorithm were proposed to solve the problem. Computation experiments based on a real case affected by the Covid-19 has been realized. Computational results showed that the formulation proposed is capable to find optimal solution in reasonable running time for only small to medium sized instances, whereas, the SA guarantee optimal or best near-optimal solution within reasonable computation time for all sized instances tested. In the future, we could extend this study by the consideration of delivery with several drones or truck positions simultaneously. The development of others optimization methods, exact or approximate, to solve the DDPPD is another interesting point that can be investigated.

References

- Abdeljaouad MA, Bahroun Z, Saadani NEH, Zouari B (2020) A simulated annealing for a daily operating room scheduling problem under constraints of uncertainty and setup. *INFOR: Information Systems and Operational Research*, 58(3), 456–477. <https://doi.org/10.1080/03155986.2020.1734901>
- Agatz N, Bouman P, Schmidt M (2018) Optimization Approaches for the Traveling Salesman Problem with Drone. *Transportation Science*. <https://doi.org/10.1287/trsc.2017.0791> 40.
- Alex H (2016) Amazon claims first successful Prime Air drone delivery. *The guardian newspaper online edition*. <https://www.theguardian.com/technology/drones-non-military?page=8>. Accessed 14 december 2016
- Carlsson JG, Song S (2018) Coordinated Logistics with a Truck and a Drone. *Management Science*. <https://doi.org/10.1287/mnsc.2017.2824>
- Chang YS, Lee HJ (2018). Optimal delivery routing with wider drone-delivery areas along a shorter truck-route. *Expert Systems with Applications*, 104, 307–317. <https://doi.org/10.1016/j.eswa.2018.03.032>
- DHL Parcelcopter (2018) Rapid response from the air: medicines successfully delivered using a parcel drone in East Africa. <https://www.dpdhl.com/en/media-relations/specials/dhl-parcelcopter.html>. Accessed 04 octobre 2018
- Ha QM, Deville Y, Pham QD, Hà MH (2018) A hybrid genetic algorithm for the traveling salesman problem with drone. *Journal of Heuristics*, 26(2), 219–247. <https://doi.org/10.1007/s10732-019-09431-y>
- Kirkpatrick S, Gelatt CD, Vecchi MP (1983) Optimization by Simulated Annealing. *Science*, 220(4598), 671–680. <https://doi.org/10.1126/science.220.4598.671>
- Lin SW, Ting CJ (2014) Solving the dynamic berth allocation problem by simulated annealing. *Engineering Optimization*, 46(3), 308–327. <https://doi.org/10.1080/0305215X.2013.768241>
- Mathew N, Smith SL, Waslander SL (2015) Planning Paths for Package Delivery in Heterogeneous Multirobot Teams. *IEEE Transactions on Automation Science and Engineering*, 12(4), 1298–1308. <https://doi.org/10.1109/TASE.2015.2461213>
- Murray CC, Chu AG (2015) The flying sidekick traveling salesman problem: Optimization of

- drone-assisted parcel delivery. *Transportation Research Part C: Emerging Technologies*, 54, 86–109. <https://doi.org/10.1016/j.trc.2015.03.005>
12. Poikonen S, Golden B (2020) Multi-visit drone routing problem. *Computers and Operations Research*, 113, 104802. <https://doi.org/10.1016/j.cor.2019.104802>
13. Ponza A (2016) Optimization of drone-assisted parcel delivery. Dissertation, UNIVERSITA DEGLI STUDI DI PADOVA
14. Rabbouch B, Saâdaoui F, Mraïhi R (2020) Empirical-type simulated annealing for solving the capacitated vehicle routing problem. *Journal of Experimental and Theoretical Artificial Intelligence*, 32(3), 437–452. <https://doi.org/10.1080/0952813X.2019.1652356>
15. Sacramento D, Pisinger D, Ropke S (2019) An adaptive large neighborhood search metaheuristic for the vehicle routing problem with drones. *Transportation Research Part C: Emerging Technologies*, 102, 289–315. <https://doi.org/10.1016/j.trc.2019.02.018>
16. Sohrabi C et al (2019) World Health Organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19. *Int. J. Surg* . <https://doi.org/10.1016/j.ijssu.2020.02.034>
17. Wang X, Poikonen S, Golden B (2017) The vehicle routing problem with drones: Several worst-case results. *Optimization Letters*, 11(4), 679–697. <https://doi.org/10.1007/s11590-016-1035-3>
18. Wang Z, Sheu JB (2019) Vehicle routing problem with drones. *Transportation Research Part B: Methodological*, 122, 350–364. <https://doi.org/10.1016/j.trb.2019.03.005>

Figures

Figure 1

a Parcelcopte

Figure 2

Quarantine zone affected by Covid-19 in Nador (Morocco)

(a) The value of the total path realized by a drone is 256

(b) The value of the path realized by a drone is 277

(c) The value of the path realized by a drone is 258

Figure 3

Three solutions possible for a problem with 8 delivery points and 2 possible positions for a truck

Figure 4

Representation of a solution for the drone delivery problem

Figure 5

Example of swap1 technique

Figure 6

Example of swap2 technique

Figure 7

Example of insertion technique

Figure 8

Example of a correction after swap operation