ANALYSIS OF THE POSSIBILITY OF USING AUTONOMOUS AIRCRAFT TO DELIVER PARCELS - ROUTE OPTIMIZATION

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Abstract: Nowadays, the popularity and interest in courier services among customers is constantly growing. This is the reason for introducing new or improving current services by courier companies to the market.
The main idea of the courier service has been the same for many years - fast picking up the parcel from the sender and delivering it to the recipient in the shortest possible time. In these days, information systems for shipment tracking are not enough, now the latest trend is the implementation of autonomous aircraft carrying out the delivery process itself.
In the last few years, the costs of electronic components and their minimization have resulted in a significant increase in the use of so-called drones or UAV (unmanned aerial vehicle). The production of more efficient batteries with shorter charging times and less mass increased the flight time and enabled the transport of more shipments.
In this article, the authors will present current trends related to the automation of the delivery of courier parcels by applying autonomous aircraft. Optimization of the operating parameters of such a system, consisting in shortening the delivery time by planning a collision-free path, choosing a safe height or minimizing energy consumption are key parameters that should be subjected to detailed analysis.
Key words: autonomous aircraft, route optimalization, unmanned aerial vehicle, drones

1. INTRODUCTION

Numerous scientific works and research are currently underway on the development of drone use for civilian applications. Works concerning the identification of objects are carried out by numerous scientific and research units around the world. Particularly noteworthy are the work of Professor Ivan Gostev [3, 4], scientist of the National Research University Higher School of Economics, Faculty of Business Informatics, from Moscow.
At the largest Polish technical universities, there continue works and projects related to the modernization and optimization of technical parameters of the unmanned airships. The Silesian University of Technology present in this group can boast of great achievements in this field: there was constructed, among others, a drone for search and rescue missions. At the Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Faculty of Mechanical Engineering, the Silesian University of Technology undertakes research related to the automation of industrial systems and intelligent systems [1, 2, 5, 8, 10]. The Institute's researchers also cooperate in other foreign centers [3, 4]. This article is part of the work carried out by the authors on the study of the autonomous airships working as a parcel delivery system in an urban environment.

2. PROJECT ASSUMPTIONS

The main assumption of the project is to have one warehouse with many locations in the area.
Perhaps using several warehouses instead of one could shorten delivery times and save money, but this would require a different approach and would significantly increase the difficulty of the problem.
It is better to focus on this problem in another work [6], taking into account the optimization of their quantity, their distribution in the field and the allocation of an appropriate number of batteries in each of them, as well as the distribution of goods.
As for the batteries, they are not charged during the flight, or even after the mission. It is proposed to do this at night when the goods are not being transfered. Therefore the life of the battery will be extended as it will be charged regularly, always at the same time.
It is assumed that the total delivery to each point must be made with one UAV. In a situation where the load to a given point exceeds the capacity of UAVs, the algorithm does not allow the use of several drones and optimal delivery to that point. In order to solve this problem, locations items can be indistinctly aggregated on one another. An interesting feature is that by optimizing the weight of the drone battery, the scenario is restricted to a certain upper limit. This ensures that the

weight of the battery is not exceeded, and leaving room for cargo. This prevents the danger of losing energy to fly, and worse, losing control and falling. The average speed of UAV which performs deliveries is assumed to 15 m/s what is independent of the weight of the payload and the size of the battery. The energy taken from drones battery during flight is relatively the same as during hover. Energy consumed from the battery while flying is marginally lower while in hover possibly because of translational lift forces. The cruising speed can be therefore increased in a reasonable manner taking into account external factors. The disadvantage of this approach is that the impact of weather conditions is rejected. It is evident that when flying in the wind, the energy demand will increase and during the flight with the wind the energy will be saved. For example, high humidity and low air temperature can significantly reduce the battery performance, which can make it more quickly degrade. In order to generalise the case, the impact of weather conditions effect is not taken into account. To figure out what the exact influence on the speed and energy has the weather, there is a need to perform additional tests in particular atmospheric conditions. Another assumption while performing deliveries is the use of multiple UAVs. The use of a more substantial number of flying units allows to shorten the delivery time and thus to handle more locations at the same time. However, the use of more of them results in more significant financial contribution and energy consumption. Therefore their number should be limited depending on the operations carried out. Furthermore, the designed system allows carrying several packages at one UAV during deliveries. This approach allows delivering from a few to a dozen shipments to different customers depending on the size.
Some companies may want priority delivery to individual customers. In this case, the delivery time is very important. There is a possibility to make priorities concerning performing deliveries to the first location. The solution that was achieved in this topic allows performing priority number of deliveries less or equal to the number of drones used for specific mission.
In the further part of the article, the main assumptions of drones deliveries are described by mathematical equations used later to carry out simulations in a computer program

3. MODEL VARIABLES

This chapter presents the variables used in further calculations:
N: number of locations {0,1…10};
N_0: number of locations excluding depot {1,2…10};
M: number of used UAVs;
K: cona stant large value representing and upper bound for constraints;
v: velocity of UAV performing deliveries in (m/s);
τ: delay time of descending, delivering and ascending in (s);
ξ: battery energy density in (kJ/kg);
B: maximum budget for one mission (£);
F: cost othe f one UAV (£);
s: financial units of energy in (£/kJ);
α: power used per kilogram of battery and payload weight m in (kW/kg);
β: power needed to sustain the UAV in the air (kW);
m: constant weight of battery in (kg);
d_ij: distances between locations in (m);
x_ij: edge binary decision variable (0 or 1). When the UAV flies from point i to j x_ij=1 and in other case x_ij=0;
σ_ij: edge binary reuse decision variable. The σ_ij=1 if the UAV flies from location i to the depot then gather new batteries and new parcels and then flies to location j staring new route. In other case σ_ij=0;
y_ij: edge decision variable which represents payload weight between locations i and j in (kg);
q_ij: edge decision variable which represents battery weight between locations i and j in (kg);
ζ_i: decision variable which tracks the battery weight in location i in (kg);
f_i: decision variable which symbolize the energy taken from present UAV battery after reaching the location i ∈ N0 in (kJ);
〖**qmin**〗 **_i:** decision va ariable which represents the minimum battery for reaching each point in (kg);
t_i: decision variable which represents the time in which the particular location is visited by UAV in (s);
l: decision variable which represents the overall delivery time in (s);
c: decision variable which represents the overall delivery time performed by UAVs in (s)
z_i: decision variable which represents the energy taken from a UAV battery when it reaches the depot on the route end, straight after flying out of the last route location i in (kJ).
a_i: decision variable which represents the time that a UAV comes back to the depot straight after flying back from location i in (s).
E: decision variable each represents the total energy summary in (kJ)

4. MATHEMATICAL MODEL

This chapter presents the mathematical model used to minimize delivery times, assuming a variable battery during delivery. The model is inspired by [7] Kevin Dorling article. Restrictions are classified regarding routes, reusability, demand, timing, capacity, energy and cost constraints however for article purposes only some of them are presented.

$$\min l + 0.001 * E \qquad (1)$$

The equation (1) is an objective function used in order to minimise the overall time of performed deliveries. It consists of main l parameter which is the total time of performed deliveries expressed in seconds. The E is an energy sumed from the battery in kJ. While minimising the time the energy is also taken into consideration and is being minimalised only small part (0.001) of E what is aprox. 2% of time part. Such a solution is used to force Cplex to use the second function parameter E while the solution of the main optimisation value l is not affected.
The road parameter was described using equations presented in [7]:

$$\sum_{\substack{j \in N \\ i \neq j}} x_{ij} = 1 \quad \forall \mathrm{i} \in \mathrm{N}_0 \qquad (2)$$

Constraint (2) makes sure that each UAV visits every delivery point only once.

$$\sum_{\substack{j \in N \\ i \neq j}} x_{ij} - \sum_{\substack{j \in N \\ i \neq j}} x_{ji} = 0 \quad \forall \mathrm{i} \in \mathrm{N} \qquad (3)$$

Constraint (3) guarantees that a UAV flying to point i continues its route also from point i.

$$\sum_{\substack{j \in N \\ j > 0}} x_{0j} \geq 1 \qquad (4)$$

Constraint (4) ensures at least one departure from the depot, so the sum of departures must be equal to or greater than one.

$$\sum_{\substack{j \in N \\ i > 0}} x_{i0} \geq 1 \qquad (5)$$

Constraint (5) guarantees at least one arrival to the depot, so the sum of arrivals must be equal to or greater than one.

$$x_{0i} \geq P_i \qquad (6)$$

Equation (6) is a priority constraint. The first visited location can be set before another. So the UAV starts from the depot and firstly flies to the chosen location. The number of priority location is equal to a number of used drones for operations.
Equations (7) are equation limiting equations for route routes as in (4).
This equation ensures at least one departure from the depot, so the sum of departures must be equal to or greater than one.

$$\sum_{\substack{j \in N \\ i > 0}} x_{0i} \geq 1 \qquad (7)$$

Constraint (7) guarantees at least one arrival to the depot, so the sum of arrivals must be equal to or greater than one.

$$x_{0i} \geq P_i \qquad (8)$$

Equation (8) is a priority constraint. The first visited location can be set pbeforeother. So the UAV starts from dthe epot and firstly flies to cthe hosen location. The number of priority location is equal to a number of used drones for operations.
The following equations describe the restrictions on multiple use.

$$\begin{aligned} \sigma_{ij} &\leq x_{i0} \\ \sigma_{ji} &\leq x_{0i} \end{aligned} \qquad (9)$$

Constraints (9) describe that if a drone is reused, so arrived from point i and next flies to point j, so σ_ij=1. If σ_ij=0 there was no reuse, so there was performed no route to depot and again to athe nother location by the same UAV.

$$\sum_{\substack{i \in N_0 \\ j \in N_0 \\ j \neq i}} \sigma_{ji} + 1 \leq \sum_{i \in N_0} x_{0i} \qquad (10)$$

Constraint (10) guarantees that the sum of departures from the warehouse is higher by at least one than the sum of the reused UAVs.

$$\sum_{\substack{i \in N_0 \\ j \in N_0 \\ j \neq i}} \sigma_{ij} + 1 \leq \sum_{i \in N_0} x_{i0} \qquad (11)$$

Similarly, equation (11) implies that the sum of warehouse arrivals is greater by at least one than the sum of the reused UAVs.
The following equations describe the restrictions on the demand for delivery at a given point.

$$\sum_{i \in N_0} y_{0i} \geq D_i \quad \forall i \in N_0 \qquad (12)$$

Constraint (12) ensures that a sum of payloads weight departing from the depot is more significant or equal than each demand in kg.

$$\sum_{i \in N_0} y_{i0} = 0 \quad \forall i \in N_0 \qquad (13)$$

Constraint (4-16) guarantees that a drone which is coming back to depot has an empty payload, so all the routes payloads have been delivered to routes locations.
Subsequently constraints regarding timing were introduced - (limiting equations regarding time, order of flights)

$$d_{ij} = d_{ji} \quad \forall (i,j) \in N \times N_0, j \neq i \tag{14}$$

The constraint (14) ensures that a distance between points i to j and j to i are the same.

$$t_i \geq (d_{0i}/v) + \tau + K(1 - P_i) \quad \forall \mathrm{i} \in \mathrm{N}_0 \tag{15}$$

Constraint (15) is a very important restriction. It assumes the convexity of the road, e.g. driving along the triangle will always be longer than a direct connection between points, unless 3 points are on one straight. Hence it is greater or equal. Here it is assumed that a time needed to reach any point must be higher than a direct flight from the depot to it. It also has a priority regarding time so if P_i=1 then time must be shorter t_i=(d_i/v)+τ.

$$a_i \leq K x_{i0} \quad \forall \mathrm{i} \in \mathrm{N}_0 \tag{16}$$

Constraint (16) establishes that if there is no return to the depot. So if x_i0=0 then a_i=0.

$$l \leq \sum_{i \in N_0} t_i \quad \forall \mathrm{i} \in \mathrm{N}_0 \tag{17}$$

Equation (17) ensures that a sum of increasing times t_i in each point is greater than an overall delivery time l. It's a trivial equation but the more constraints are put into Cplex the faster it calculates the result due to better start values.
Further restrictions apply to battery capacity:

$$\zeta_i \geq \frac{(2\beta + \alpha D_i)\left(\frac{d_{0i}}{v} + \tau\right)}{\xi - 2\alpha\left(\frac{d_{0i}}{v} + \tau\right)} \quad \forall i \in N_0, \;\; \xi - 2\alpha\left(\frac{d_{0i}}{v} + \tau\right) > 0 \tag{18}$$

$$q\min_i = \frac{(2\beta + \alpha D_i)\left(\frac{d_{0i}}{v} + \tau\right)}{\xi - 2\alpha\left(\frac{d_{0i}}{v} + \tau\right)} \quad \forall i \in N_0, \;\; \xi - 2\alpha\left(\frac{d_{0i}}{v} + \tau\right) > 0 \tag{19}$$

Constraints (18) and (19) ensures that each chosen battery is equal or greater than minimum calculated battery qmin_i.

$$q_{i0} \leq \zeta_i + K(1 - x_{i0}) \quad \forall i \in N_0 \tag{20}$$

Moreover, similarly the q_i0≥ζ_i is set by equation (20). So if x_i0=1 then q_i0=ζ_i.
Restrictions on energy restrictions are written as follows:

$$\frac{z_i}{\xi} - \zeta_i \leq K(1 - x_{i0}) \tag{21}$$

Constraint (21) sets the battery tracking weight ζ_(i) from summary routes energy. If x_i0=1 then ζ_(i =) z_i/ξ.

$$\zeta_i \leq mbat\,\mathrm{max} \tag{22}$$

Furthermore, constraint (22) ensures that capacity of the battery is smaller than maximum capacity. This protects against the selection of an excessively heavy battery.

$$y_{i0} = 0 \quad \forall i \in N_0 \tag{23}$$

Constraint (23) ensures that each return to the depot by UAV has to be performed without any payload.
Calculation of costs related to the use of drones to send packages - constraint regarding costs are as follows:

$$c = F * l * M + s * E \tag{24}$$

Expression (24) is known as a cost equation which can be treated as a cost amortisation and consists of F: financial units of each UAV purchased in (£), l: total time of performed deliveries expressed in seconds, M: the number of drones used, s: financial units of energy of 1 (£/kJ) used and E: summary of energy consumption expressed in kJ.
Time optimization with a fixed battery is defined as is showed in equation (1). Once again the objective time function (1) is used as in order to minimise the overall time of performed deliveries but this time with regards to constant battery applied.

5. MODEL IMPROVEMENTS

While working with the algorithm, various improvements have been made to the model. Most of the improvements concern the capacity section and energy consumption where new limiting restrictions have been introduced, and the existing ones have been changed to a certain extent. The improvements made concern the following issues:

- First of all the use of double equation restrictions (greater than or equal to and smaller or equal to) for equations with variable K have been introduced. Such a solution forces the constraint to be equal to 0 while it was necessary for Cplex model implementation.

Given example: while x≥0≤x thus x=0;

- Furthermore the use of double target indicators with appropriate weights ensure correctness of calculations for both values of l and E simultaneously;
- What is more, the calculation time is significantly shortened while combining these two elements;
- Another feature is an application of supply order priorities. Generally there is a possibility to visit the first chosen location by UAV an, the number of performed priorities is equal the number of used UAVs in particular case.
- Next, the calculation of the minimum qmin battery has been done in order to ensure routes at least to the first location.
- Assurance that at least one outlet from the warehouse and arrival will always be carried out and that the number of departures and arrivals will be equal.
- Finally, the model with constant carrying battery has been presented which is a standard solution when it comes to the delivering shipments by drones and although it has as many advantages as disadvantages. Constant batteries in most cases cause prolonged delivery time and increased energy, however, are practical in the physical execution of flights. The computing time of the optimisation is several times shorter due to the lack of recursion of the battery calculation.

6. GENERAL DATA USED

This section presents used data while optimising delivery routes. There are assumed ten different delivery points separated at some distance at each other. The number of points was chosen in order to find the most optimal solutions using a mathematical model and show the results for the real delivery scenarios. However the more significant the number of customers was generated the problem with computer computing power occurred. The same applies to more considerable distances between the depot and delivery points. The loading volume and the size of the battery used also influences extending the duration of the optimisation conversion in Cplex program. During some calculations, it happened that the simulation lasted forever and the solver could not find the optimal solution. A good solution would be to use a computing unit with more computing power. The maximum allowed distance that UAV can fly while delivering is 25km from the depot, and it can be increased in the future. The depot location is set in (0.0), so every UAV starts its route from this point and finish as well. Every case uses the delivery map 50 km x 50 km to be able to perform last mile deliveries for a bigger scale. The methods used by different companies so far in other analysis performed provided a smaller range of activities.

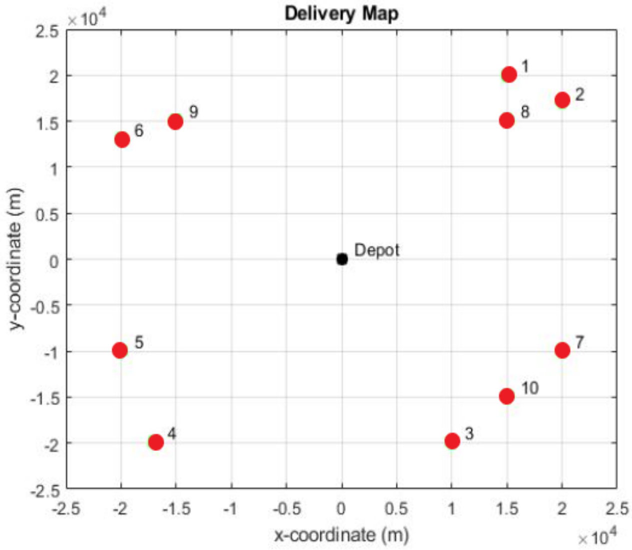

Fig. 1. Delivery locations and warehouse map centred

Table situated below presents the variable Di which symbolises the weight in kilograms of the goods required to deliver at i location. Demand at each point has to be satisfied so during delivering while departing from point i it must be less than upon arrival and when reaches the depot the UAVs payload has to be equal to zero. It ensures that each point got a suitable amount of goods.

Payload(D_i)	input (kg)
D_0	-
D_1	30.00
D_2	10.00
D_3	40.00
D_4	10.00
D_5	13.00
D_6	7.00
D_7	16.00
D_8	15.00
D_9	20.00
D_{10}	70.00
	y
sum	231.00

D points	Coordinates (m)	
	x	y
i=0	0	0
i=1	15000	20000
i=2	20000	17000
i=3	10000	-20000
i=4	-17000	-20000
i=5	-20000	-10000
i=6	-20000	13000
i=7	20000	-10000
i=8	15000	15000
i=9	-15000	15000
i=10	15000	-15000

Fig. 2. Tables Delivery demand at each point in kg(left) and deliveries locations coordinates in meters (rights)

It ensures that each point was visited only once and the parcel was delivered to the exact location. The values of desired payloads vary from (7 to 70)kg at different locations, and the total sum of delivering goods is 231kg in this scenario.

Proposed delivery coordinates shown in table were randomly generated and are only used examples so can be easily changed in the future for other delivery purposes. However, for this particular case, their number (10) was restricted because of computing problems due to power limitations of the used hardware. While the calculating minimisation in case of regular batteries lasted shortly (up to couple minutes), the minimisation about variable battery lasted up to several hours in some cases. Cplex while computing actively overloads the CPU and RAM what significantly increases the computation time. It is recommended to use cloud computing for more prominent instances in the future.

7. COMPUTER AIDED ROUTE ANALYSIS

Analysis of the performance of the MILP model was performed for different delivery scenarios. All the tests are performed using IBM ILOG CPLEX Optimization Studio (COS) [9] which is a mathematical programming tool created to solve high-level mixed integer programming and quadratic programming problems. It allows performing optimisation of decisions, rapid development and implementation of optimisation models, as well as the creation of applications that finds practical applications and have a positive impact on obtained results. COS improves fast development and implementation of decision optimisation models using mathematical programming and constrained programming techniques. COS is a combination of an integrated development environment (IDE) that supports the language of Optimization Programming Language (OPL), and highly efficient solvers CPLEX and CP Optimizer. In this case the free version of IBM ILOG CPLEX Optimisation Studio was used limited up to 1000 decision variables and 1000 constraints.

8. TIME OPTIMISATION

This section presents the results obtained for drones delivery scenarios regarding time optimisation with constant and variable battery. Additionally, to each case, the forced priority was included in order to confirm the validity of the results. The number of drones is also set to two as the most reliable amount in these type of iterations. Each UAV starts its missions at depot and finishes as well after performed routes.

8.1. Constant battery

Fixed battery weight is set to 80 kilograms in both no-priority and priority delivery cases for time minimisation. Next two sections present non-priority and priority cases. The input data used are shown in Table 1.

Table 1. Input data

M	2
$mbat_{max}$[kg]	80
Q[kg]	150
T[s]	20000

The maximum UAV capacity is limited to 150 kilograms, so the payload and battery weight is forced to be less in total. Total delivery time cannot exceed 20 000s for both UAVs.

No priority applied. In the Figure 3 the tests performed for overall delivery time minimisation with constant battery and no delivery priority applied were presented.

The generated routes are shown in Table 2 which corresponds to the order of visited points.

Table 2. Visited points order 5

First UAV	0	3	0	10	0	8	0	7	0	
Second UAV	0	5	4	0	1	2	0	9	6	0

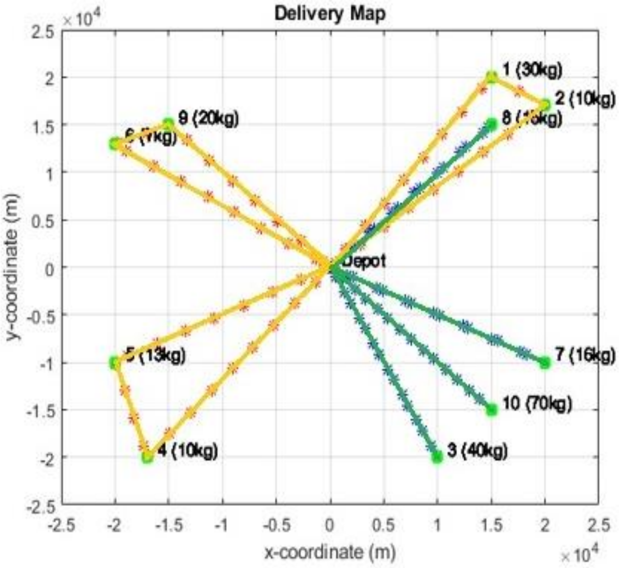

Fig. 3. Routes optimisation map

Table 3. Objective function results 5

l[s]	10548.99
E[kJ]	299244.8

In Table 3 provided results are shown and no significant changes occurred comparing to constant battery weight for energy minimisation. It is also as mentioned before due to the same weight of fixed battery size.

Priority applied. In this point tests performed for overall delivery time minimisation with constant battery and delivery priority applied are presented.

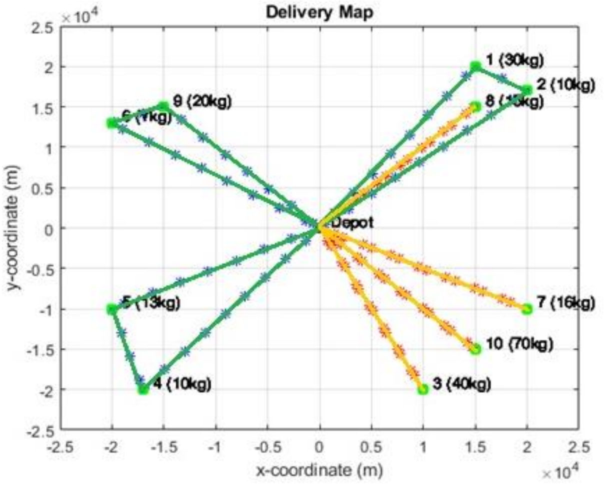

Fig. 4. Routes optimisation map 6

The generated routes are shown in Table 4. Which corresponds to the order of visited points.

Table 4. Visited points order 6

First UAV	0	5	4	0	1	2	0	9	6	0
Second UAV	0	8	0	7	0	10	0	3	0	

While the priority is applied, the first visited locations are respectively 5 for first UAV and 8 for the second one. The number of routes performed in this case is equal to 17, and the UAVs has been changed five times.

Table 5. Objective function results 6

l(s)	10548.99
E(kJ)	299244.8

Table 5 reflects obtained energy and overall time results. No changes occurred in time and energy comparing to the non-priority scenario from the previous subsection. They are precisely the same as for the non-priority scenario as well as for energy minimisation with constant battery scenario presented before. Moreover, this is also correct because the optimisation solver takes into account the same weight of batteries for non-priority and priority scenario. The vehicles move along the same paths even despite the different order of the points visited.

8.2. Variable battery

This section presents minimalisation of time concerning the variable battery while their maximum weight cannot exceed 100 kilograms. The input data are presented in Table 6.

Table 6. Input data 7

M	2
$mbat_{max}$[kg]	100
Q[kg]	150
T[s]	10000

Again the maximum carrying capacity is restricted to 150 kilograms and the overall delivery time is restricted to 10000 seconds. Next two sections present non-priority and priority applied cases.

No Priority applied. On the Figure 5 tests performed for overall delivery time minimisation with variable battery and no delivery priority applied was presented.

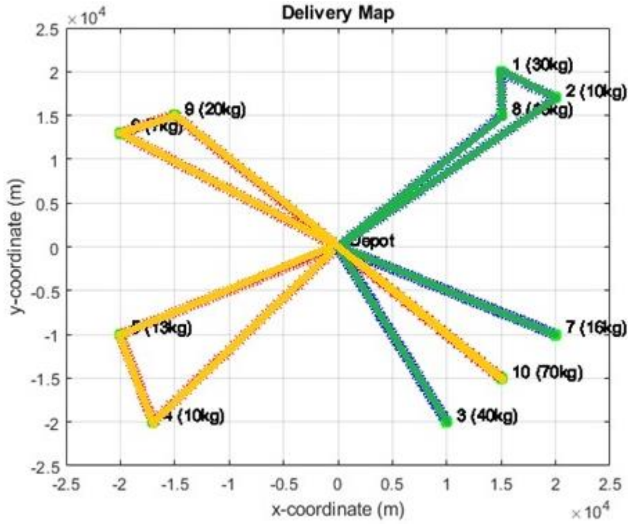

Fig. 5. Routes optimisation map 7

The generated routes are shown in Table 7 which corresponds to the order of visited points.

Table 7. Visited points order 7

First UAV	0	3	0	8	0	1	0	2	0	7
Second UAV	0	9	0	6	0	10	0	5	0	4

As it is presented in Figure 5 and validated in Table 7. The total number of obtained optimised routes is equal to 16 while the UAVs have been reused four times. For the energy minimisation with variable battery, the generated path delivery map looks the same however the order of performing deliveries is different. The first visited location is 3 for first UAV and location 9 for the second one.

Table 8. Objective function results 7

l[s]	8798.632
E[kJ]	235498.7

The objective functions values are presented in Table 8 and are decreased in relation with the results obtained concerning time minimisation for constant battery. It confirms the rule again that while the variable battery is used the total delivery time is decreased as well as the total energy consumption.

Priority applied. On Figure 6 tests performed for overall delivery time minimisation with variable battery and priority applied was presented.

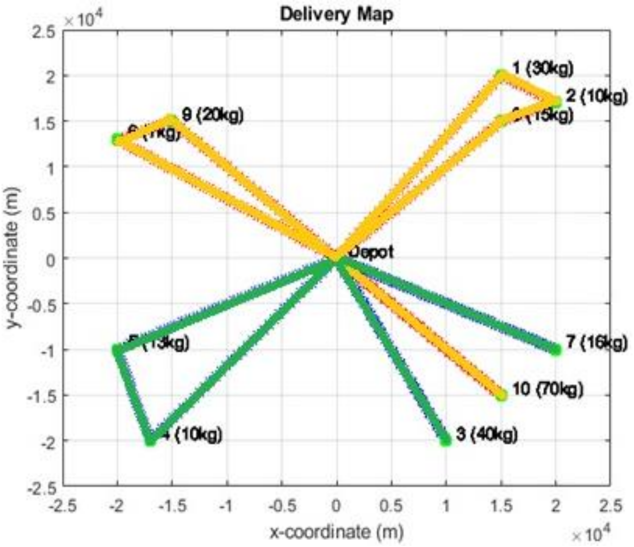

Fig. 6. Routes optimisation map 8

The generated routes are shown in Table 9 which corresponds to the order of visited points.

Table 9. Visited points order 8

First UAV	0	5	4	0	3	0	7			
Second UAV	0	8	2	1	0	10	0	9	6	0

The generated routes have change comparing to the non-priority scenario presented in the previous subsection. As it is presented in Figure 6 and validated in Table 9 the total number of obtained optimised routes is equal to 16 again while the UAVs have also been reused four times. Comparing to the previous section with a constant battery the generated path delivery map looks the same however the order of performing deliveries is different. The first visited location is 5 for first UAV and location 8 for the second one.

Table 10. Objective function results 8

l[s]	8910.273
E[kJ]	235968.9

The small changes occurred in the obtained results of minimised time and energy comparing to the values in subsection without priority. This is due to the occurrence of the priority applied. The starting points have been artificially forced to be different points than optimisation solver would pick by itself. So, in this case, the routes optimisation has been slightly affected.

9. CONCLUSIONS

In this article has been developed an optimal delivery route for unmanned aerial vehicles with consideration of minimizing energy consumption and delivery times. The routes optimisation mathematical model of mixed integer linear programming has been derived concerning: routes, reusability, demands, timing, carrying capacity, energy and cost constraints. Furthermore to solve the multiple UAV delivery scenarios the algorithm has been implemented into the Cplex optimisation solver. The most optimal values have been found while minimising the overall delivery time and energy consumption which meets the desired requirements. The analyzes carried out showed that it was not correct, as it was initially thought, that there was a relationship between energy and the overall reduction in delivery time. Studies have shown that while the main indicator has been minimized, the second auxiliary indicator has also been reduced accordingly. Indicators are understood to mean time or energy in this case. Furthermore, the use of both variable and permanent batteries was considered. Using variable batteries, it was found that during delivery routes the total delivery time and energy consumption decreased. However, when using a fixed battery with a specific function value, the values are much worse. The minimized time and energy values are greater when the battery has been selected according to the specific flight. The use of different battery sizes depending on the situation is better than using a fixed battery size. After analyzing several cases of priority delivery scenarios, it was found that there were no significant changes in the value of the objective function, because only the initial delivery points and the order of deliveries differ, however, the priority applied did not affect the results. In this project the fixed altitude at which drones move during the delivery mission has been assumed. So the time needed for take off and landing was not taken into account, as well as the ability of automatic obstacle avoidance using built-in sensors, what will be the subject of further research.

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