# Structuring Air Logistics Networks in the Urban Space

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*Abstract*— **The paper considers the rather unexplored problem of designing a network that can be associated with an urban airspace so that Unmanned Air Vehicle (UAV) based logistics can be performed efficiently. This problem is important to guarantee mobility and accessibility for all operators. First, a structure for the lower layers of the urban airspace is proposed, then an optimal network design problem is formulated, and a heuristic solution approach is developed. The paper is related to the subjects of the Smart Cities and the Smart Mobility of the SMART2021 Conference.**

**Keywords:** ***UAV; Urban Air Mobility (UAM); Logistics; Graph theory; Optimization and Heuristics.***

## I. INTRODUCTION

UAV networks have been considered in the recent literature and are mainly related to either mobile communication networks, based on fleets of UAVs or with route generation for delivery services with UAVs. Important perspectives for the development of urban logistics based on the operation of UAVs are consolidating according to recent publications [1], [2], [3], [4] and [5]. They will be able to take profit of the until now unused urban airspace and so to alleviate ground traffic by diminishing the needs for ground-based logistic transportation which is one of the main contributors to ground urban traffic congestion and pollution.

Previously, many studies have been devoted to the design of efficient UAVs based urban logistics systems, see for example [6], [7] and [8], where in general, traffic volumes and capacities are not taken as issues. However, other studies [9] expect, in few decades, high traffic densities of drones operating in the common urban airspace, making imperative and urgent its effective design and organization.

In this study, the development of a design method for the definition of a network of air links to operate traffic flows of UAVs devoted to urban logistics is considered. While designing this network, the main considered design objectives are: to ensure mobility, accessibility and safety, to master traffic safety, network capacity and environmental impacts. The considered problem presents specific characteristics with respect to traditional urban ground transportation network design problems or with respect to air transportation network design problems, so new solution approaches should be developed. Then, the network structure can be optimized so that equipment and operational costs for end-users are minimized in an efficient way.

This paper is organized as follows: First, an overview of recent UAV systems technology of interest in urban logistics operations is displayed, then assumptions about operational objectives for UAV based logistics in the urban airspace are proposed, leading to a structuring proposal for the whole urban airspace. Then the optimization problem of the operated network inside the urban airspace is formulated and a solution approach is developed and illustrated.

## II. OVERVIEW OF UAVS SYSTEMS TECHNOLOGY

The fast technological development (electrical engines, navigation systems and communication devices) and increased availability of commercial UAVs have boosted the use of UAVs to perform many tasks which were until recently, either impossible, or difficult or too costly [10]. Today, commercial UAVs which can be acquired at low cost, when comparing with manned rotorcraft, are used in many different fields, such as surveillance of ground traffic, inspection of buildings and works, agriculture monitoring and resource preservation, search and rescue, meteorology, mapping and photography. Recent UAV technology is offering a large range of fully autonomous rotorcraft, admitting payloads from 1.5kg to 350kg, and mission endurance from half an hour to up to a full working day [11]. Autonomous navigation is available through data fusion which combines information from different sensors for use on board the aircraft. Now on-board computer vision provides on-line localization and mapping, allowing autonomous navigation even when Global Positioning System (GPS) signals are hidden or jammed [12].

On-board task scheduling (defining the sequence and timing of assigned tasks), path planning (defining the optimal segments of flight satisfying some constraints such as obstacles and no-flight zones), flight parameters trajectory generation (built from the selected path), autonomous control (actions to control UAV angular attitude, including stabilization and robustness with respect to wind perturbations) and autonomous guidance (actions to control center of gravity motion) are already available. Communication with the ground allows trajectory monitoring while communication with other UAVs allows coordination and collision avoidance [13].

The Civil Aviation Authorities around the world are editing regulations to integrate UAVs traffic into the civil airspace (see [14], [15], [16] and [17]). Each authority develops its own regulations but general rules (EASA or FAA) are already established with respect to maximum flight level (flights below 400 feet above ground level), daytime operation or visual flight rules, minimum distance to airports (5 miles). According to the type of activity, specific restrictions will be in use (authorized paths and locations, time of day, operational conditions and in general safety parameters).

There have been some reports concerning UAV crashes on populated areas resulting in property damages as well as in human or animal injuries. Moreover, a significant number of proximities of UAVs with commercial airplanes have happened, even if until today no collision has been reported (see [18] and [19]). Also, there are some concerns by population about the possible loss of privacy which can result from surveillance applications of UAVs. Hence, there is a pressure on governments from media and civil associations to better regulate the use of UAVs in public airspace. Today, different urban logistics applications are under study: general purchase delivery, general mail, pharmaceutical and medical equipment delivery, urban equipment inspection, ground traffic control; it is worth to mention that today, many private and public companies have considered using UAVs as delivery and collection vehicles in the urban airspace. This solution may appear cheaper, faster and more reliable alternative solution than ground-based delivery:

- It is exempt of ground traffic accidents and congestion hazards;

- It does not contribute to the ground traffic congestion as it is the case, significantly, with the ground delivery/collection vehicles.

Pioneer in this sector is the Amazon company that started using rotorcraft UAVs to deliver small packages (up to five pounds) from its logistics centers (up to ten miles to the delivery point). Other applications consider the use of UAVs taxiing to deliver packages directly between particulars. The current regulations do not permit such use, but the increased public acceptance of this new technology and the strong interest and pressure of economic sectors should lead to new regulations enabling urban use of UAVs as it is already the case for traffic surveillance applications. More recently, the Unmanned Aircraft System (UAS) Traffic Management (UTM), a concept developed by the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA), and the U-space, a concept developed by the European Union Aviation Safety Agency (EASA), Eurocontrol and the Single European Sky ATM Research (SESAR) Consortium (ATM standing for Air Traffic Management), aims to enable the operation of drones both in the airspace already controlled by Air Traffic Control (ATC) and in uncontrolled airspace today (airspace G), see [20], [21] and [22]. This sector of the airspace that goes outside airport areas and other restricted areas, from the ground level up to 1200 feet in height, generally includes the urban airspace that is the target of this research.

After the COVID19 crisis, a rapid resumption and sustained growth in air transport are expected, and the component relating to urban air transport, which is practically nonexistent today, is foreseen to grow enormously. Eurocontrol's air traffic expectations (total hours flown and total kilometers traveled) for the situation in 2050 in the urban space of Europe, is of about 250 million flights and 15 billion kilometers traveled [23].

## III. ADOPTED ASSUMPTIONS AND OBJECTIVES

In this section, we will detail our assumptions, the logistics demand characteristics and the main objectives and constraints of our study.

### A. *UAVs assumed characteristics for logistics operations*

The main predictable operational characteristics of UAVs to be used in urban areas should be:

- Medium to low flying speed (less than 50 m/s) according to propulsion and flying technology (in general rotorcraft);
- Adoption of a common speed $V_L$ inside the movement slice;
- High maneuverability allowing to perform tight turns and vertical flight level changes;
- Full navigation coverage of urban area through onboard integration of vision, ground references and GPS segments;
- Autonomy in guidance along planned trajectories with centimeter accuracy;
- Autonomous collision avoidance capability;
- Small/medium payload capability;
- On board loading/offloading interfaces;
- Soft landing capability in case of failure or damage.

### B. *Demand characteristics*

It corresponds to a mix of point-to-point deliveries and hub and spoke system of deliveries. The point-to-point deliveries correspond mainly to the deliveries between two entities and their volume is expected to be much smaller than the one relative to the hub and spoke system of deliveries which correspond to collective urban services, either public or private. It is supposed that the goods delivered by air from a hub are either produced there or brought by ground bulk transportation to the hubs. It is also considered that with the currently existing technology, the ground bulk transportation to large distribution centers will remain attractive from the economic and environmental points of view. The demand has a stochastic nature and is distributed spatially and temporally. For planning purposes, it will be considered origin-destination matrices representative of the demand over a given period of time, typically one hour.

### C. *Main objectives and constraints*

When designing the urban air logistic traffic network (L-network), the main constraints to be taken into consideration are the following:

- The designed L-network should provide reachability for any origin-destination pair associated with a demand for logistic UAVs services. In the case of compact urban areas this will imply connectivity of the graph underlying the traffic network.
- The designed L-network is a capacitated network where each link capacity is supposed to be able to cope with its planned traffic.

The two main objectives are:

- The designed L-network should minimize investment, this can be assessed by its total weighted length, where the weight is related to the installed capacity.
- The designed L-network should also propose for each demand a minimum “length” connection as a path of the underlying graph. Length here is a generalized length which can consider either distance, delay or a mix of them. The links constituting this network should be published, dimensioned, delimited and secured with respect to aircraft failures and landing sites and equipped with docking facilities, navigation guides and electrical charge stations. To minimize the costs related to the equipment of the network a set of corridors, fed by secondary links, will be defined.

These two objectives are antagonists, since the second objective should lead to a multiplication of the links of the network and then to an increased investment. Other objectives are relative to safety and environmental impacts which should be minimized. Safety will be the result of the required functional characteristics of the UAVs and of protections installed along with the network (for example when a link crosses a street).

## IV. STRUCTURING THE URBAN AIRSPACE

The decision problem considered here is relative to the design of the traffic management system for UAVs devoted to logistics in urban areas. A basic assumption of this study is that urban logistic air traffic is organized along with the communication links of the urban area (avenues and streets) while the urban passenger traffic is organized between the top of buildings (public and private) and open areas such as parks, cemeteries, outdoor parking areas.

Some reasons in pro of this organization are the following:

- The demand of the end users for urban logistics services is distributed along with the streets network of the cities.
- The introduction of UAVs for logistics should reduce the pollution level in the streets due to ground delivery/collecting vehicles and it can be expected that they will be able to accommodate this new source of disturbance.
- The physical interface of many buildings is through their front, right in the street, and it is doubtful that any historical city may accept to modify notably its architecture.
- The main objectives of passenger air transportation services are to offer a faster and safer means of transportation between origins and destinations inside and outside towns, so it will take place in the open airspace with few obstacles (only the highest buildings).
- The urban passenger air traffic flows will be completely segregated from other means of transportation and from logistics traffic flows, avoiding collision risks with other aircraft.
- The integration of urban passenger air traffic inside the UTM or the U-space will appear to be natural and will be performed more easily.

When the logistic air traffic occupies the lower levels of traffic, two slices can be considered: one for movement along the streets and one for local loading/unloading maneuvers. Here it is supposed that urban passenger traffic occupies the upper levels of the urban airspace with exceptions in open areas which are forbidden for the logistic air traffic. Figure 1 gives a view of the possible organization of a section of the vertical space of a two ways street where air logistics and air passenger traffic are completely segregated. It is supposed that this design remains constant all along a street section. There the two ways are distinguished by the + and – signs. Areas NL+/- represent the two spaces assigned to normal movement at speed $V_L$, they can contain one or more lanes. Areas UL+/- represent the two spaces assigned to upper crossing maneuvers while LL+/- represent the two spaces assigned to lower crossing maneuvers. These spaces are only present at the proximity of a crossing where conflicts are planned to be avoided by level change maneuvers (Figure 2 displays such a situation). These areas also allow to adapt the flight levels when two successive street sections have different dimensions in their vertical sections. Narrow lateral spaces along the previous areas allow changes of levels without interacting with the level traffic. The areas LUML+/- are dedicated to UAVs maneuvers towards and from logistics terminals or UAVs refueling/maintenance stations. Some areas, in general at the tops of the buildings, are dedicated to Passenger UAVs take-off and landing (PTOL).

In Figure 1, $HLOP_{min}$ and $HLOP_{max}$ are the minimum and maximum AGL levels (AGL: Above Ground Level) for logistics UAVs manoeuvers for docking/undocking, $HLMV_{min}$ and $HLMV_{max}$ are the minimum and maximum AGL levels for logistics UAVs flight progression, $HPMV_{min}$ and $HPMV_{max}$ are the minimum and maximum AGL levels for Passengers UAVs flight progression.

Let $H_{max}$ be the maximum height of the buildings adjacent to a given street section and let $h$ = min {$H_{max}$, 150ft}, possible values for the different levels can be such as:

$HPMV_{max}$= 400ft, if $h$=150ft then: $HLMV_{max}$= $HPMV_{min}$= 150ft, if 90ft< $h \leq 150ft$ then: $HLMV_{max}$= $HPMV_{min}$= $h$ , if

$h \leq 90ft$ then: $HLMV_{max} = HPMV_{min} = 90ft$, $HLOP_{max} = HLMV_{min} = 30ft$, $HLOP_{min} = 10ft$.

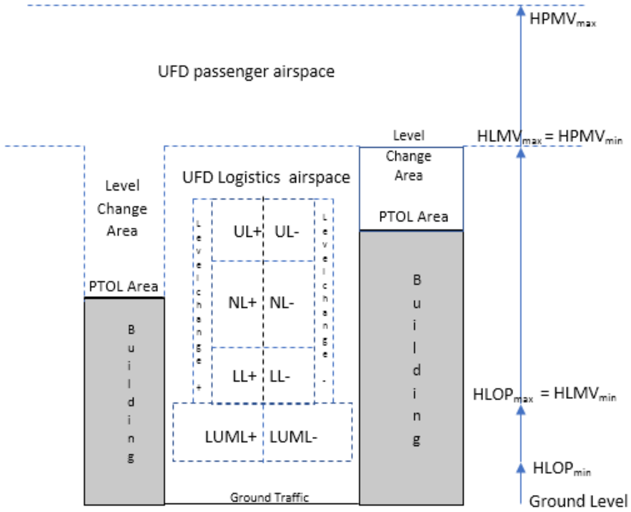

Figure 1: Proposed organization of the street airspace.

In the case of ground traffic, crossings and connections between different street segments create hard crossing conflicts and the adopted solution for nearly a century has been to install traffic lights systems which are costly to install, maintain and operate and which generate traffic queues and waiting times, increasing the direct cost of travel. To avoid this situation in highways with large volumes of traffic operated at high speed, costly civil constructions must be built to avoid cross conflicts. In the case of UAVs traffic, a simple solution is to pre-assign a different flight level to some movements to allow them to cross without any conflict. For example, as shown in Figure 2, any cross conflicts can be avoided by performing no level change for the blue movements, a climb to an upper level for the red movements and a descent to a lower level for the green movements. Note that four convergence conflicts remain, but they can be solved easily by implementing some priority or metering rule.

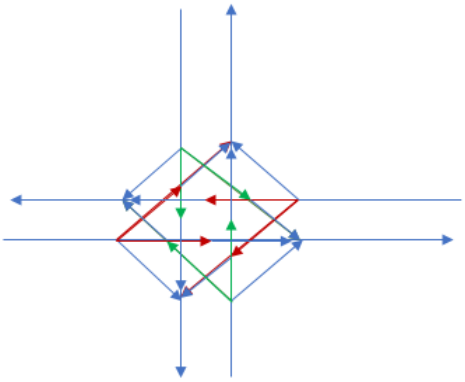

Figure 2: A 3D zero crossing conflict solution at a two ways streets intersection (blue: fly level, red: fly over, green: fly below).

## A. Modelling and structuring urban airspace

The map of the streets with their intersections with other as well as the position of every building and its connections with the street system are basic data for this study. From the street network is generated a non-oriented graph (it is supposed that every UAV link is two ways) where the set of nodes $X_0$ corresponds to the street intersections and the set of edges $U_0$ is associated with the set of sections of streets between two intersections.

From this graph are removed the nodes and edges associated with areas where logistic air traffic is not allowed for any reason such as those related with safety or environment issues, giving way to the graph $[X_1, U_1]$ which is representative of the air street network. The borders of these forbidden areas could be protected by geofencing if necessary.

Considering each building in the urban area, most of them will be connected to the air links of the air logistic network. Each possible connection of the buildings to the air logistic network will represent a user's point connected at both ends of each adjacent edge as shown in Figure 3.a and Figure 3.b. There, the polyhedrons represent the buildings (origin and destination of logistics trips) and the double arrows represent the connection points for logistics.

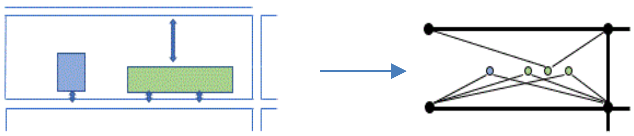

Figure 3a: Graphical representation of connection of end-users with several street sections.

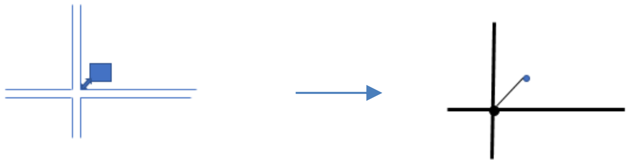

Figure 3b: Graphical representation of connection of end-users with a crossing.

When a distribution or collecting center is located outside the limits of the urban area under consideration, this center and its connections with the urban street systems must be considered too. Then, adding the connection points and the connecting edges as new nodes and edges we get the graph $[X_2, U_2]$. Let also, $X_{OD} = X_2 - X_1$ be the set of origin and destination nodes associated with providers and end-users of the air logistic system.

To each edge $(i, j)$ of $[X_1, U_1]$ can be attached an instant capacity $cap_{ij}$ which is equal to the maximum number of UAVs which can be present in each direction of the street link at a given time. Then the total capacity of link $(i, j)$, $CT_{ij}$, during a period of time $T$ is given by:

$$CT_{ij} = cap_{ij} \cdot V_L \cdot T / L_{ij} \quad (1)$$

where $L_{ij}$ is the length of the link $(i, j)$. The cost $C_{ij}$ associated with an edge $(i, j)$ of $[X_1, U_1]$ is taken proportional to its length $L_{ij}$, while the cost of connection of end-users to $[X_1,U_1]$ is proportional to their position in the street section (see Figure 3a).

### B. *Modelling demand*

The considered demand for logistic transportation is represented by a set of origin-destination matrices giving the volumes of trips for different periods of the day between nodes of $X_{OD}$. Origins and destination of trips can be logistic centers, public offices, shops and restaurants, client positions (for return trips or transfer trips within a distribution tour or a dial-a-ride delivery service). Round trips are broken down into several trips. These origin-destination matrices, written $M_T$, when covering a short period of time T are asymmetric, but for longer time periods, they tend to symmetrize. Then, they can be written as the sum of symmetric and asymmetric matrices $M_T = MS_T + MA_T$.

## V. UAVS NETWORK OPTIMIZATION

To further reduce the number of air links which have to be equipped, it appears necessary to foresee how the air logistic network will be used, then the air links who are not origin or destination of demand as well as not used by any path between an origin and a destination, can be removed. Also, the flows of air links with very low traffic can be reassigned to other paths so that these air links can be deleted, however, global connectivity of the air logistic network must remain.

### A. *Formulation of the Optimal Design Problem*

First here is considered the optimization problem for users from a central point of view:

- Let $P_{ij}$ be the set of elementary paths linking the origin i and the destination j in the air logistic network of graph $[X_2, U_2]$.

- Let $U_{ij}^k$ be the set of edges composing the kth path between i and j.

- Let $CP_{ij}^k$ be the cost of the kth path between i and j in $X_{OD}$:

$$CP_{ij}^k = \sum_{(h,l)\in U_{ij}^k} C_{hl} \quad (2)$$

- Let $[a_{ij}^{khl}]$ be the incidence matrix between the $k^{th}$ path between pair (i, j) and air link (h,l): $a_{ij}^{khl} = 1$ if (h,l) belongs to the kth path between *i* and *j*, otherwise, $a_{ij}^{khl}=0$.

Here, no saturation effect is considered and the total cost to be minimized is given by:

$$\sum_{i\in X_{OD}} \sum_{j\in X_{OD}, j\neq i} \sum_{k\in P_{ij}} CP_{ij}^k \cdot x_{ij}^k \quad (3)$$

under the constraints of capacity of the edges of $U_1$:

$$\sum_{i\in X_{OD}} \sum_{j\in X_{OD}, j\neq i} a_{ij}^{khl} \cdot MT_{ij} \cdot x_{ij}^k \leq CT_{h,l} \quad (h,l) \in U_1, h \neq l \quad (4)$$

and

$$\sum_{k\in P_{ij}} x_{ij}^k = 1 \quad i,j \in X_{OD}, i \neq j \quad (5)$$

with

$$x_{ij}^k \in \{0,1\} \quad k \in P_{ij},\ \ i,j \in X_{OD}, i \neq j \quad (6)$$

Here constraints (4) are capacity constraints for all the edges of the air logistic network, constraint (5) assumes that all the demands between the pairs *i, j* of $X_{OD}$ use only one path and constraints (6) recall the binary nature of the considered decision variables.

Then if a solution is obtained, those links composing a used path (path $k^*$ between $i$ and $j$ when $x_{ij}^{k^*} = 1$) will be retained for proper equipment in the air logistic network.

However serious difficulties appear:

- The above optimization problem may not have a feasible solution when considering the capacity constraints and the demand levels. A necessary condition to ensure the satisfaction of the capacity constraints (4) is the following:

$$\exists k \in P_{ij} : \max MT_{ij} \leq \min CT_{kl},\ (k,l) \in P_{ij}^k,\ i,j \in X_{OD} \quad (7)$$

- Problem (3)-(4)-(5)-(6) will be, even for a rather medium size town, a very large Boolean linear program with hundreds of thousands of variables whose numerical application will be extremely expensive in terms of computing time, and this is bad news when different scenarios of demand may have to be tested. So, another approach must be found to efficiently design the air logistic network.

### B. *Heuristic Solution Approach*

Here a greedy heuristic is considered (see [24]) where the larger logistics demands are treated first and assigned to their minimum cost paths taking into account their capacity. So, the steps are the following:

- a) Compute the minimum cost paths between the pairs $(i, j)$ of $X_{OD}$, the Floyd algorithm can be used here even if its complexity is in $O(n^3)$ where $n$ is the cardinal of $X_1$, the computational burden can be also diminished by considering some peculiarities of the structure of the considered graph (for instance the presence of sub-trees).

- b) Rank by decreasing logistics demand levels the pairs $(i, j)$ of $X_{OD}$.

- c) Assign according to this ranking demand $MT_{ij}$ to the minimum cost path between *i* and *j*. If there is a capacity overflow at some edges of the minimum path, reallocate on this path a portion of demand equal to the minimum capacity of the edges of this path, then reassign the rest of demand between *i* and *j* on the air logistics network without the already saturated edges, repeat the process until all pairs *i, j* have been treated.

- d) Compute for each edge in the air logistics network its resulting flow $F_{kl}$, $(k, l) \in U_1$ by adding up the flows in the paths which contain that edge. In this case it can be easily shown that this procedure has a polynomial complexity which is compatible with the computation of real size problems.

- e) A threshold $F_{min}$ can be considered so that the edges such as $F_{kl} < F_{min}$ are deleted from the air logistic network unless they insure connectivity. An algorithm which detects if an edge is a bridge in a graph can be used to point out which edges, satisfying the above condition, will not be deleted. Then deletion must be done edge by edge while checking current connectivity.

If no edge is removed, the process ends, otherwise, update $U_1$ and restart the steps from *a* to *e* but only for the pairs $(i, j)$ which made use of the deleted edges.

Then, once this structure is established, when a new demand for a logistics flight is requested with the urban air traffic management system, a time window and minimum cost path computed within this air logistics network whose loading state should have been updated, will be assigned to the UAV.

### C. *Illustration of the Heuristic on a Small Scale Case*

Here a small size street network represented by a graph of 22 nodes (circles in blue) and 34 edges (blue segments), is considered as given in Figure 4. Table 1 provides the length of the different street sections in meters and the air trips demand matrix *MT*, between 8 origin-destination nodes (the green squares), is given in Table 2.

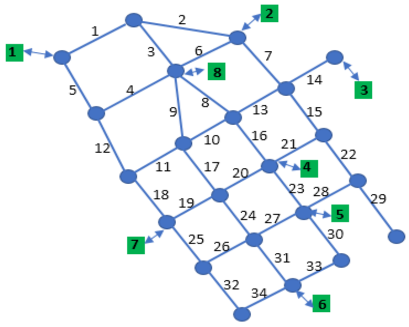

Figure 4: The considered street network.

TABLE I. LENGTHS OF THE STREET NETWORK EDGES.

| edges | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| length | 100 | 130 | 100 | 100 | 100 | 100 | 120 | 110 | 110 | 70 | 70 | 100 | 100 | 120 | 90 | 90 | 90 |
| edges | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| length | 90 | 70 | 100 | 100 | 100 | 100 | 100 | 100 | 70 | 100 | 100 | 120 | 90 | 90 | 90 | 100 | 70 |

TABLE II. DEMAND MATRIX.

| O-D | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | - | 10 | 5 | 5 | 0 | 5 | 10 | 0 |
| 2 | 10 | - | 0 | 5 | 0 | 0 | 0 | 5 |
| 3 | 5 | 0 | - | 10 | 5 | 0 | 2 | 5 |
| 4 | 5 | 5 | 10 | - | 10 | 5 | 5 | 5 |
| 5 | 0 | 0 | 5 | 10 | - | 5 | 3 | 2 |
| 6 | 5 | 0 | 0 | 5 | 5 | - | 2 | 2 |
| 7 | 10 | 0 | 2 | 5 | 3 | 2 | - | 2 |
| 8 | 0 | 5 | 5 | 5 | 2 | 2 | 2 | - |

After assignment of air trips to their shorter connection path, it appears (see Table 3) that edges 4, 7, 15, 21, 22, 28, 29, 30, 32, 33 and 34 are not used, so they are retrieved from the air logistics network. The reduced graph is displayed in Figure 5.

TABLE III. DISTRIBUTION OF FLOWS IN THE AIR LOGISTICS NETWORK

| edges | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| flow | 25 | 10 | 15 | 0 | 10 | 10 | 0 | 27 | 9 | 2 | 2 | 10 | 27 | 27 | 0 | 32 | 9 |
| edges | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| flow | 12 | 9 | 10 | 0 | 0 | 17 | 14 | 3 | 3 | 8 | 0 | 0 | 0 | 19 | 0 | 0 | 0 |

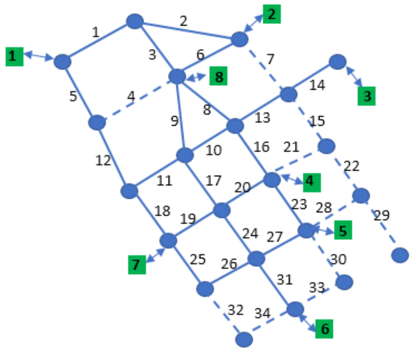

Figure 5: First reduction of the air logistics network.

Then, a minimum flow level $F_{min}$ is chosen, leading to the suppression of low traffic edges. For instance, when $F_{min}$ is taken equal to 9, this leads to the suppression of edges 10, 11, 25, 26 and 27 and the reassignment of their flows along new paths, giving the new flow distribution displayed in Table 4 and Figure 6.

TABLE IV. FINAL DISTRIBUTION OF FLOWS IN THE AIR LOGISTICS NETWORK.

| edges | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| flow | 25 | 10 | 15 | 0 | 10 | 10 | 0 | 27 | 9 | 0 | 0 | 10 | 27 | 27 | 0 | 34 | 9 |
| edges | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| flow | 12 | 17 | 23 | 0 | 0 | 28 | 19 | [illegible] | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 0 |

So, with this heuristic process the number of street sections in the air logistics network is reduced by 44% while less than 5% of total traffic is submitted to an increase of the travel time inferior to 30%.

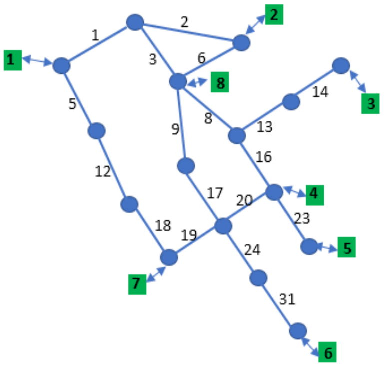

Figure 6: Final air logistics network generated by Heuristic.

## VI. CONCLUSION AND FUTURE WORK

This study has considered the design of a network of urban airways allowing mobility and ensuring accessibility to operate traffic flows of UAVs devoted to general logistics over an urban area. The proposed method makes use of classical concepts and algorithms of graph theory and since the exact optimization problem is in practice intractable for real size problems; a heuristic solution approach that is more computer friendly is developed.

The proposed approach remains preliminary since detailed regulations with respect to the use of UAVs in urban areas are still to be issued. It appears already that a systematic approach such as the one described in this communication leads to a feasible modeling and optimization, it should be completed by custom made rules to make the design more effective and more efficient; also a validation by simulation at the scale of a whole city would be useful to complete this feasibility study.

## ACKNOWLEDGMENT

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