Challenges for UAVs Logistics in Urban Skies

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In this study the development of a design method for the definition of a network of corridors to operate flows of **Unmanned Flying Devices** (UFDs) devoted to urban logistics is considered. The main objectives which are considered while designing this network are traffic safety, network capacity, environment impact and efficiency. The proposed method generates a source graph to connect the main generators and attractors of UFDs traffic. Once this source graph is built, the predicted origin-destination demand (mean flights/day) is loaded in this network so that traffic corridors are characterized. The proposed approach is discussed and illustrated.

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Introduction (1)

These last years, unmanned aerial vehicles (UAVs) have caught the attention of media with impressive applications in different fields such as military, security and rescue, agriculture and forestry.

Urban applications of UAVs started already in the fields of urban security, land use control, traffic surveillance and the inspection of urban infrastructure (electric lines, bridges, etc).

However, new applications considering urban logistics are expected to develop in the next years resulting in an increasing traffic of UAVs devoted to urban logistics in urban skies.

. **Introduction (2)**

These special flying devices are called here **unmanned flying devices** (UFDs) to distinguish them from current UAVs.

They will be able to take profit of until now unused urban airspace and so alleviate ground traffic by diminishing the needs for ground-based logistic transportation which is one of the main contributor to ground urban traffic congestion.

Mobile base for UFDs deliveries

Introduction (3)

The only UAVs networks which have been considered in the recent literature are related either with **mobile communication networks**, based on fleets of UAVs or **route generation for delivery services** with UAVs. The current problem appears to present peculiarities with respect to traditional urban ground transportation network design problems or with respect to air transportation network design problems, so a new approach should be developed. Then, in this study the development of a genuine design method for the definition of a network of corridors to operate flows of unmanned flying devices (UFDs) devoted to urban logistics is considered. The main objectives which are considered while designing this network are traffic safety, network capacity, environment impact and efficiency.

Technology (1)

The fast technological development (electrical engines, navigation systems and communication devices) and increased availability of commercial UAVs has boosted the use of UAVs to perform many tasks which were until recently, either impossible, or difficult or too costly.

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.

Technology (2)

Today, civil 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.

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 GPS signals are hidden.

Technology (3)

On-board task scheduling (defining the sequence and timing of assigned tasks), path planning (defining the optimal segments of flight satisfying some constraint such as obstacles), 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**.

	Advantage	Disadvantage	Visual
Fixed-Wing	• Long range • Endurance	• Horizontal take-off, requiring substantial space (or support, e.g., catapult) • Inferior maneuverability compared to VTOL (Vertical Take-Off and Landing)	 **Source:** Indra Company
Tilt-Wing	• Combination of fixed-wing and VTOL advantages	• Technologically complex • Expensive	 **Source:** sUAS News
Unmanned Helicopter	• VTOL • Maneuverability • High payloads possible	• Expensive • Comparably high maintenance requirements	 **Source:** Swiss UAV
Multicopter	• Inexpensive • Easy to launch • Low weight	• Limited payloads • Susceptible to wind due to low weight	 **Source:** Microdrones

Examples of available UFDs

Regulations (1)

Civil aviation authorities around the world are editing regulations to integrate UAVs traffic into civil airspace.

Each authority develops its own regulations but general rules (EASA) 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, in general safety parameters).

Regulations (2)

There has been many reports concerning UAVs crashes on populated areas resulting in general in property damage and sometime in human or animal injuring.

Also a significant number of near collisions of UAVs with commercial airplanes have been happened even if until today no collision has been reported.

Also, there is some concerns by population about the possible loss of privacy which can result from surveillance applications of UAVs.

Then, there is a pressure on governments from media and civil associations to better regulate the use of UAVs in public airspace.

Urban logistics applications (1)

Today, different urban logistics applications are under study: general purchase delivery, general mail, drugs delivery, urban equipment inspection.

Then, many private and public companies have considered to use UFDs as **delivery and collection vehicles** in the urban airspace.

This solution may appear cheaper, faster and more reliable than ground based delivery:

- It is exempt of ground traffic accidents and congestion hazards;
- It d**oes not contribute to ground traffic congestion** as it is the case, significantly, by ground delivery/collection vehicles.

Urban logistics applications (2)

Pioneer in this sector is the **Amazon company** which considers to use rotorcraft UFDs to deliver small packages (up to five pounds) from its centers (up to ten miles). Other applications consider the use of UFDs taxiing to deliver package directly between particulars.

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 UFDs as it is the case already for traffic surveillance applications.

Urban First and Last Mile

PROBLEM DEFINITION

The decision problem considered here is relative to the design of the network to be operated by UFDs. 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 with the equipment of the network a set of corridors, fed by secondary links, will be defined.

UFDs assumed characteristics (1)

The main predictable operational characteristics of UFDs employed in urban areas should be:

- Medium to low flying speed (less than 50 m/s) according to propulsion technology (in general rotorcraft);
- 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;

UFDs assumed characteristics (2)

- autonomy in guidance along planned trajectories with centimeter accuracy;
- autonomous collision avoidance capability;
- small/medium payload capability;
- on board loading/delivering interfaces;
- soft landing capability in case of failure or damage.


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Demand characteristics

It corresponds to a **mix** of **point to point deliveries** with **hubs to/from points** deliveries. Point to point deliveries correspond mainly to deliveries between particulars and they volume is expected to be much smaller than the one relative to the hubs to points deliveries which correspond to collective urban services, either public or private. Demand has a stochastic nature and is distributed spatially and temporally. For planning purpose it will be considered to be given by origin-destination matrices representative of demand over a given period of time, typically an hour.

Main objectives and constraints (1)

The main constraints are the following:

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

Main objectives and constraints (12)

The two main objectives are:

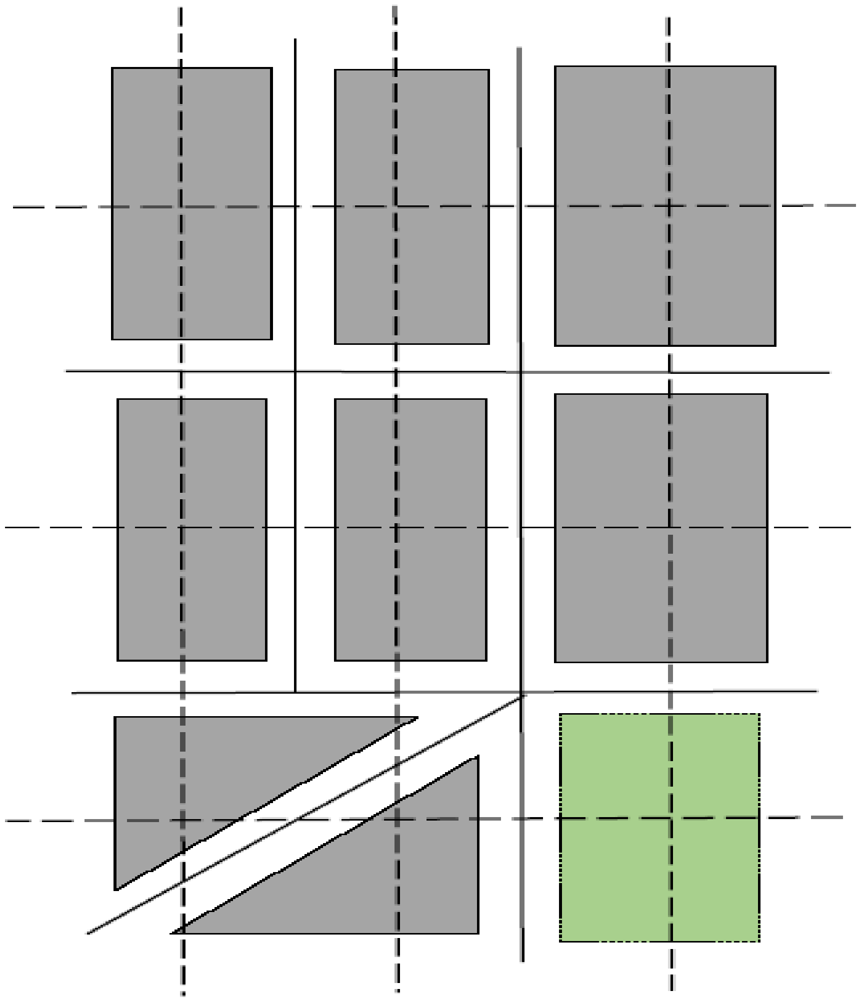
- The designed network should **minimize investment**, this can be assessed by its total weighted length, where the weight is related with the installed capacity.
- The designed network should also propose for each demand a **minimum length connection** as a path of the underlying graph.

These two objectives are antagonists, since the second objective should lead to a multiplication of the links of the network and then to 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 UFDs and of protections installed along the network (for example when a link crosses a street).

Modelling and structuring urban airspace

It is assumed here that the available airspace to operate UFDs is built from two components: the airspace over ground traffic links (streets, roads and railways) operated at low speed and the airspace over buildings (in grey on figure) and green areas (parks, rivers, squares) operated at higher speed. This constitutes two inter-related networks as shown in figure. The lower network is devoted to local traffic with arrival and departure procedures while the higher network is devoted to travel from one place to another.



The interrelated networks in urban airspace

Modelling and structuring urban airspace

The set of nodes X of the higher network correspond to different components such as blocks of buildings X_B and green areas X_G. Many of these blocs are associated with UFDs individual customers X_C and some of them, set X_H, are associated with hubs generating or attracting payload. Then:

$$X = X_B \cup X_G = X_{\mathrm{H}} \cup X_C \cup X_G$$

Modelling demand

The considered demand is represented by an origin-destination matrix which is composed of two symmetrical sub-matrices corresponding to the two types of traffic (from hubs to and from particulars, between particulars):

$$M = M_H + M_P \text{ with } M_H = \begin{bmatrix} O & H \\ H' & O \end{bmatrix} \text{ and } M_P = \begin{bmatrix} O & O \\ O & P \end{bmatrix}$$

where H is the origin-destination matrix representing demand from hubs to particulars and P is the origin-destination matrix between particulars with are grouped by urban blocs.

SOLUTION APPROACH

The solution approach is composed of three steps to get trade-off solutions between the two main objectives:

- First, the underlying graph which is the backbone of the network is defined.
- Then demand is assigned to this graph according to minimum length paths.
- Finally, according to the flows in each link, a set of spanning trees is defined.

Defining the supporting network

The proposed design method generates first a source graph representing the connections between the traffic generators and attractors of the considered urban area as well as connections with outside centers. To each arc is associated a weight which can be the length of the arc plus a penalty related with environmental impact.

Network loading

- Once this source graph is built, the predicted **origin-destination demand** (flights/day/hour) for a given daily time period. From each node of the network corresponding to a point inside the region under study, the shortest path connecting it with all possible destination centers is found using a minimum length path search algorithm. Then, demand from that center to the other ones is assigned along the edges of the computed shortest paths.

- The **addition of the resulting flows** in each edge for the different time periods will represent the final weights used for choosing a **maximum weight spanning tree**.

Defining spanning trees

Considering these weights, a maximum weight spanning tree is constructed over the source network. This will allow to concentrate on this spanning tree as many UFDs connections as possible.

Therefore, **a trade-off is performed between higher traffic density in edges and directness of connections** through this spanning tree.

When the use of the spanning tree for a connection produces an increase of travelled length over a given threshold value τ which in the case study was chosen to a percentage over the length of the path, the corresponding demand will be deleted from the origin-destination matrix used to compute the weights of the edges.

A new maximum weight spanning tree will be computed from the remaining demand with the rest of connections. The whole process is repeated until all demand is satisfied.

Finally, a reduced set of spanning trees through which all connections will be processed is obtained. It will configure the selected network structure that will be operated to cope mainly with high levels of traffic demand in the considered urban region.

Successive links with large flows will then configure air corridors fed by secondary links.

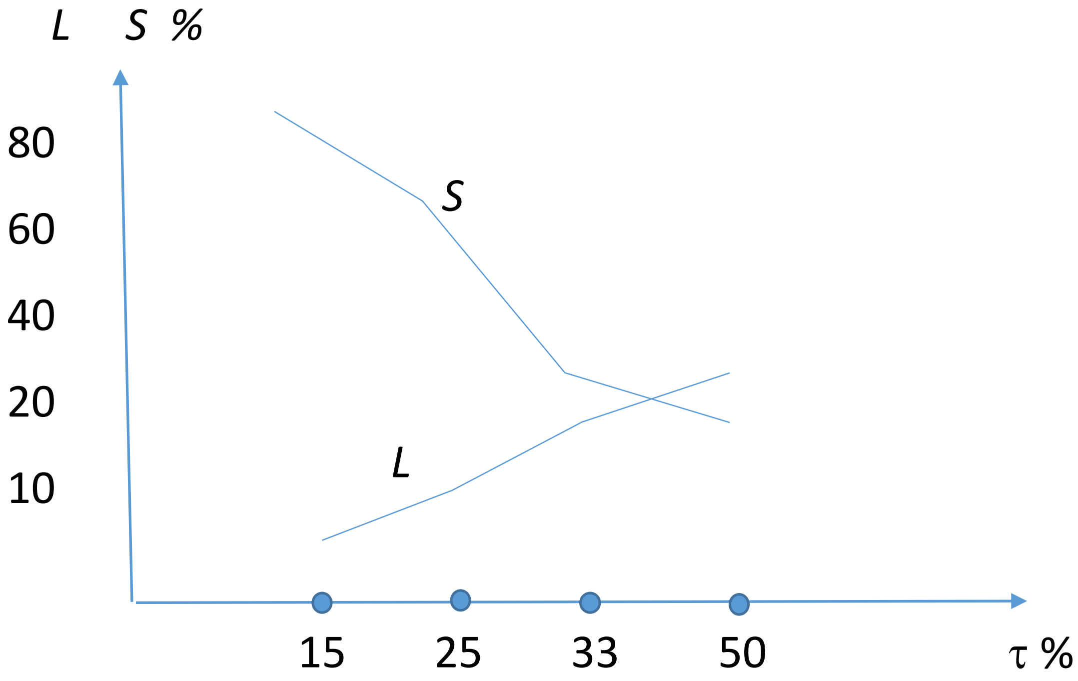
Numerical application

The above approach has been applied to a rectangular grid networks with 150 nodes with 500 links. Three time periods of two hours have been considered with demand at each of the 150 nodes.

The involved algorithms presenting polynomial time complexities, results have been obtained in a very short time. When considering different values for the threshold parameter τ, tradeoffs between the two main objectives appear. Table 1 provide such results.

There L represents the mean increase of the connection length in % with respect to the shorter one on the underlying graph and S represents the total length of the selected network with respect to the total length of the support graph.

threshold τ	L	$\hat{S}$
15%	8%	81%
25%	17%	62%
33.33%	28%	38%
50%	38%	29%



Example of effect of threshold on global performance of UFDs network

CONCLUSION

This study has considered the design of a network of corridors to operate flows of UFDs over an urban area. The proposed method makes use of classical concepts and algorithms of graph theory, leading to a computer friendly solution.

The proposed approach remains preliminary since detailed regulations with respect to the use of UFDs in urban areas are still to be issued.

It appears already that a systematic approach such as the one described should be completed by custom made rules to make the design effective and more smart.

REFERENCES (1)

- S. Niu, J. Zhang, F. Zhang and H. Li (2015) A method of UAVs route optimization based on the structure of the highway network. *International Journal of Distributed Sensor Networks*, Vol. 2015, ID 359657.
- O.K. Saahingoz(2014) Networking Models in Flying Ad-Hoc Networks (FANETs): Concepts and Challenges.Journal of Intelligent and Robotics Systems 74(1-2) · April 2014.
- K. Nonami (2007), Prospect and Recent Research & Development for Civil Use of Autonomous Unmanned Aircraft as UAV and MAV, *Journal of System Design and Dynamics* vol. 1, no.2, pp.120-128.
- K. Máthé and L. Busoniu (2015), Vision and Control for UAVs: A Survey of General Methods and of Inexpensive Platforms for Infrastructure Inspection, *Sensors*, vol. 15, pp.14887-14916.
- Drouin, S. Simões Cunha, A.C. Brandão and F. Mora-Camino (2011), Differential flatness and control of nonlinear systems, *CCC 2011, 30th Chinese Control Conference*, Jul 2011, Yantai, China. pp.643-648.
- N. Gageik, P. Benz and S. Montenegro (2015), Obstacle Detection and Collision Avoidance for a UAV With Complementary Low-Cost Sensors, *IEEE ACESS*.2015.2432455.

REFERENCES (2)

- M.T. de Garmo (2004), Issues Concerning Integration of Unmanned Aerial Vehicles in Civil Airspace. MITRE, Center for Advanced Aviation System development,http://www.mitre.org/work/tech_papers/ tech_papers_04/ 04_1232/04_1232.pdf.
- E. Bart (2016), Unmanned Aircraft Operations in Domestic Airspace: U.S. Policy Perspectives and the Regulatory Landscape, Congressional Research Service 7-5700, https://www.fas. org/sgp/crs /misc/R44352.pdf
- EASA (2015), Proposal to create common rules for operating drones in Europe,http://easa.Europa.eu/drones.
- DHL (2014), Unmanned aerial vehicle in logistics, a DHL perspective on implications and use cases for the logistics industry, http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research / lshc2020.html
- R.L. Mota, L.F. Felizardo, E. H. Shiguemori, A.C. Brandão Ramos and F. Mora-Camino (2013), Expanding Small UAV Capabilities with ANN: A Case Study for Urban Areas Inspection, *IEEE Second International Conference on Image Information Processing*, Dec 2013, Shimla, India. pp.516 – 520.

Thank You very Much

Questions?