A Strategy for Drone Traffic Planning

Dynamic Flight-paths for Drones in Smart Cities

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***Abstract*—This paper presents a solution for creating dynamic flight plans for drones. The number of drones is expected to increase dramatically, and there will be a demand for drone traffic planning solutions. The approach used here is based on a multidimensional grid with fixed top-level paths and lower-level paths used for local traffic between the departure and arrival points and the top-level paths. Flight plans may change dynamically if disruptions happen. The proposed solution includes the establishment of temporary no-fly zones and priority traffic.**

Keywords-unmanned aerial vehicles; drones; flight planning; smart cities; routing algorithms; scheduling algorithms.

I. INTRODUCTION

“Smart cities” is a concept that uses information and communication technology to improve the quality of life for its citizens by delivering better services, reducing environmental footprint and improving citizen participation. One aspect of smart cities is to make transport smarter [1]. This paper focuses on how to meet the challenges of drone traffic for delivery and other applications.

Some of the leading information and communication technology companies (Google and Amazon) are currently exploring new delivery services using unmanned aerial vehicles (drones). Drone technology has also attracted the attention of traditional logistics companies like DHL, UPS and Deutsche Post AG, as well as big retailers like Walmart.

Drones are becoming increasingly important in agriculture, medical sector, civil engineering, insurance, security, and energy. According to Goldman Sachs, the future drone market is predicted to be $100 billion by the year 2020 [2] where the defense sector remains the largest consumer with around 70%. However, Business Insider Intelligence researchers are less optimistic and expect sales of drones to surpass $12 billion in 2021 [3]. The lift capacity and operating distance are improving, mainly due to advances in battery technology.

Drones are particularly of great interest for last mile delivery applications in smart cities. Last mile delivery is the end part of the delivery chain, which deals with the distribution of goods from long haul to the end user, being the most expensive part of the delivery chain. As part of the upcoming Industry 4.0 revolution, the autonomy of drones plays an essential role in the evolution of logistics. Drones are becoming commonly used in the early stages of logistics (commonly called first-mile) as well as in its last stages.

Intralogistics operations deal with the optimization, integration, automatization, and management of data flow and goods inside a distribution center. Drones can be smartly used for transportation inside factories, spare parts delivery, goods storing and delivering.

Use of drones for city infrastructures surveillance is of great interest as they can be used for building inspections and maintenance.

In 2013, Amazon announced Prime Air [4], a service that utilizes multirotor drones to deliver packages from Amazon to customers. The German logistics company Deutsche Post DHL started its Parcelcopter project in 2014. One application of the Parcelcopter [5] has been to transport medicine to the German island of Juist in the North Sea.

Google revealed Project Wing [6] in 2014 to produce drones that can deliver larger items than Prime Air and Parcelcopter. Recently, in April 2019, Project Wing has received regulatory approval to start making last-mile commercial drone deliveries in Australia, according to the American technology news channel - The Verge [7].

In 2014, the US company PINC launched the PINC Air service, using its drones to follow goods in transports, vehicles and more. These drones are equipped with cameras, Radio-Frequency Identification (RFID) and barcode readers, and have software for real-time 3D mapping, navigation, goods identification and localization [8].

In 2014, the United Arab Emirates announced its plan to use drones to distribute official government documents such as permits and identification cards [9].

A startup company, Matternet has partnered with Swiss Post to test a lightweight package delivery drone [10].

Recently, the UNICEF Innovation labs [11] explored the use of drones for search and rescue operations. The drones could be useful in emergency situations, such as rescuing victims of natural disasters (floods, extreme temperature events, earthquakes, mudslides, storms and wildfires) when roads are no longer usable. Drones may be used to transport life-saving materials in both humanitarian and development contexts [12]. Deliveries of emergency medical supplies and kits can reduce the response time in multiple humanitarian contexts that require the provision of life-saving immunization materials, biological samples, transfusion plasma or organs. UNICEF has used drones for such operation in African countries and Vanuatu isle in the Pacific Ocean [13].

A kidney scheduled for transplant was delivered by a drone for the first time on April 19th, 2019, in Baltimore, United States [14]. A specially tailored drone having the size of a washing machine carried a healthy human kidney to hospital. The doctors successfully transplanted the organ. The operation took place at night, and the drone traveled 4.5 km in 10 minutes. The whole operation was the result of a three-year collaboration of a team of doctors, researchers, engineers and plane experts who worked together at the Maryland Medical Center and the Living Legacy Foundation. The transport of transplant organs using the drones reduces costs, reduces transport time and improves the quality of medical services. Conventional transport methods, including the use of cars, helicopters and planes, have significant drawbacks: airplanes are too expensive, commercial flights take too long, and small aircraft are dangerous to medical teams.

The increase in drone traffic calls for a traffic management system to make sure that drones operate in a regulated environment to avoid collisions and improve the safety of drone operations. The aim of this paper is to present an idea for how drone flight management can be implemented in urban areas.

The rest of the paper is organized as follows: The next section addresses some current challenges related to the commercial use of drones. Section III provides an overview of related work. Section IV discusses drone flight planning. Section V presents an idea for an algorithm. Section VI concludes and provides ideas for further research.

II. CURRENT CHALLENGES

The use of drones for professional purposes introduces a set of challenges that must be observed and addressed:

- Most drones use electrical motors. The battery capacity is proportional to the weight of the battery. The capacity of the batteries becomes a limiting factor in how far a drone can travel before needing to be recharged. Battery technology is improving and will increase both travel distance and payload weight.
- Flying distance and payload weight depends on battery capacity. A larger battery will increase flying distance, but also decrease the payload capacity. Balancing payload weight, battery weight, and flight time are important considerations when attempting to minimize the cost or the delivery time for drone deliveries [15].
- The flight planning for drones is a multi-objective optimization problem. The solution needs to take into account the existence of no-fly zones and dedicated paths for drones to follow.
- Drones may be difficult to maneuver in tight spaces.
- Scalability: How does a fleet of drivable drones might be organized so that they do not crash into one another implemented in the complex reality of real city streets and the surrounding airspace. This calls for implementation of traffic planning and collision avoidance systems as more and more drones enter the airspace.
- Algorithmic path-planning taking into account of urban-like landscape with buildings, roads, parking areas, landing pads and no-fly zones.
- Since the law regarding the use of drones is still not fully developed, other challenges or restrictions are currently being regulated by the European Union [16], e.g., drone weight, maximum possible flying altitude, no-fly zones over "crowds", minimum safe distance, etc.

III. RELATED WORK

Mok [17] presents the prototypes of drones developed at MIT´s Computer Science and Artificial Intelligence Laboratory (CSAIL), located in Cambridge, Massachusetts, USA. These drones, equipped with wheels, represent a mix between a drone and a tiny car that can not only fly but are capable of driving on the ground, making a tradeoff related to energy consumption and speed (time of delivery). Their tests included eight drones deployed at the same time and following autonomously their own path revealed the machines could fly for 90 meters or drive for 252 meters before needing to recharge their batteries, a relatively short distance.

Schermer et al. [18] used a heuristic algorithm to extend the original Vehicle Routing Problem (VRP) [18] to the Vehicle Routing Problem with Drones (VRPD), where a drone works in tandem with a vehicle to reduce delivery times. The authors emphasize qualitative differences between trucks and drones and highlight the usefulness of incorporating drones in last-mile logistics.

The limitations of existing VRP solutions applied for planning drone deliveries are illustrated by Dorling, Heinrichs, Messier and Magierowski [15]: multiple trips to the depot are not permitted leading to solutions with excess drones, or the effect of battery and payload weight on energy consumption is not considered, leading to costly or infeasible routes. The authors solve drone delivery problems with a Multi-Trip VRP (MTVRP) that compensates for each drone’s limited carrying capacity by reusing drones when possible. The authors used a model based on the approximately linear relationship between power consumption and battery and payload weight. The main drawback of their solution is their local optimization algorithm based on simulated annealing and not a global optimization algorithm. Furthermore, the authors also admit that the simulated annealing algorithm does not take advantage of characteristics inherent to a VRP such as it does not use geographical information to reduce the likelihood of trying infeasible routes between two locations at opposite ends of the area of operations.

The researchers from MIT [20], using extra hardware (video camera and processing power for image recognition) developed an obstacle-detection system that allows autonomous drones to zip through trees at 48 km/h in different delivery scenarios.

The UTM (Unmanned Aircraft Systems Traffic Management) project [21] enters in the fourth stage where NASA will test drone traffic management systems in six field test sites of U.S. cities – Alaska, Nevada, Texas, North Dakota, Virginia, and New York. The project aims developing technologies, responsibilities and procedures for safely managing the airspace that includes autonomous aircraft operations in populated areas. Structured in four levels entitled technical capabilities, and focused first on agriculture, firefighting and infrastructure monitoring, the operators of drones are enabled to set flight plans reserving airspace for their operations and provide situational awareness about other operations planned in the area. The second stage explores the space beyond visual line of sight of the operator in sparsely populated areas and contingency management. The third involves tracking capabilities of drone operations over moderately populated areas. Perhaps the most complex, the fourth stage, aims to extend the operations defined in the third stage by sending correspondence and delivering packages in high populated areas. Also, testing the technologies that could be used to manage large-scale contingencies aims this last stage.

Dukowitz [22] revealed other important Urban Aerial Mobility (UAM) projects supported by more than 500 European stakeholders and by European Commission funds that intend to bring urban mobility to the third dimension bridging the Unmanned Traffic Management with Urban Traffic Management. The goal of such projects is to develop a cloud-based software platform to integrate low-flying unmanned aircraft systems into the airspace safely.

Since scientific literature is mostly limited to the physical implementation of the flying devices and to the control methods, not to the integrated solutions, maybe the most useful and with open content related work from software point of view, about algorithms and information management systems focused on drone traffic management systems is represented by Plaza [21]. The author creates an elaborated model of the system of information for the traffic management of unmanned aircraft systems composed by Users (the human components clustered on 10 groups depending on their role), Functions (22 information management activities according to the temporality of the flight / mission), Datasets (managed data sorted into groups by the content and the temporal validity in order the conformability and the orderliness) and 2 Functional subsystems (Technical infrastructure elements and Operational support systems). The model is implemented like an information structural matrix, which systematically contains the managed data handled by the users connected to the execution of the functions. The activities described are related only to civil operations, not military, which must follow other rules. Besides collecting data covering UAV position and movement data, UAV status data, UAV type related data (static data), mission-related flight plan data, the author also considers environment-related data, which is relevant for the safe operations. Operation of the information structural model provides comprehensive data sharing among the industrial partners, deliverables companies, user communities, about the UAVs and their operations. Another merit of [23] is that it provides a clear separation of notions like UAV (Unmanned Aerial Vehicles), which is the flying object (technical parts), and the UAS (Unmanned Aircraft Systems), which is a greater technical solution, that includes the UAV plus the sum of the control infrastructure (the human operator).

These related works do not handle the increasing number of drones and the need for traffic planning, including the dynamic establishment of no-fly zones and noise reduction. Our solution addresses these problems, but does not concern itself with battery time. We expect the development of battery technology to increase both distances traveled and lift capacity.

The solution is based on two well-known areas from computer science: scheduling and routing. To allocate time slots, a scheduling algorithm is used. The scheduling algorithm makes sure that the drone gets operating space throughout the flight. The routing algorithm calculates an efficient route through the airspace. Scheduling algorithms are heavily used in operating systems. Routing algorithms are found in both computer networks and the design of printed circuit boards and integrated circuits.

IV. DRONE FLIGHT PLANNING

An increase in drone traffic will require a traffic management system to control the airspace.

Land-based transport is basically handled by paths in a two-dimensional grid, but with possibilities to make intersections multi-level to avoid roundabouts or single-level intersections. The infrastructure for land-based transport is expensive and inflexible. A road or a train line normally has a life-span of hundreds of years.

A. *A layered model of the airspace*

The difference between land-based transport and air-based transport is that paths may be established in three dimensions since it is possible to divide the airspace into several horizontal layers. This is already done for conventional air transport. Drones will use the airspace below that used by conventional air transport. Another advantage is that airspace is not fixed. The paths may be dynamically established and removed based on needs.

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Fixed high-level path 1
Fixed high-level path 2
Endpoint layer 1
Endpoint layer 2
Endpoint layer 3

Figure 1. Layer design

The dynamic flight planning system presented here is using five levels (Figure 1), but the number of levels can be increased if necessary. On the upper levels, a number of fixed paths are established. These will be the "highways" for the drone traffic. When the drone needs to go from a location to the highway entry point or from the highway exit point to a specific location, separate paths will be established on endpoint layers 1, 2 or 3. The algorithm will start with endpoint level 1, and check for conflicts. If a conflict is detected, it will move on to endpoint layer 2, and so on. These paths are allocated dynamically. The algorithm proposed for channel routing is based on a multi-layer algorithm for printed circuit board design. The modification is to make it dynamic. A set of fixed channels is established. Then, from the nearest point in an existing channel, the dynamic path is established from the source to the destination.

The rationale for using fixed upper levels ("drone highways") is considerations about noise. This is important for urban areas, where the main corridors for drone traffic may be located away from noise sensitive areas.

B. The algorithm

Figure 2 shows the establishment of the flight path from the point of departure (S) to the point of arrival (E). The yellow path shows a part of fixed high-level path ("drone highway"). The orange paths show the path from the point of departure (S) to the entry point of the fixed path, and from the exit point of the fixed path to the point of arrival (E). The algorithm will include the following steps:

1. Based on departure location, find the nearest entry point to the higher-level fixed path ("drone highway")
2. Based on arrival location, find the nearest exit point from the higher-level path ("drone highway")
3. Calculate distance and air time between departure point and entry point
4. Calculate distance and air time between the exit point and the arrival point
5. Search for next available slot time taking distance to the higher-level path into consideration
6. Reserve slot time
7. Check for collisions in the departure area, if collision move to next endpoint layer
8. Check for collisions in the arrival area, if collision move to next endpoint layer
9. Submit flight plan

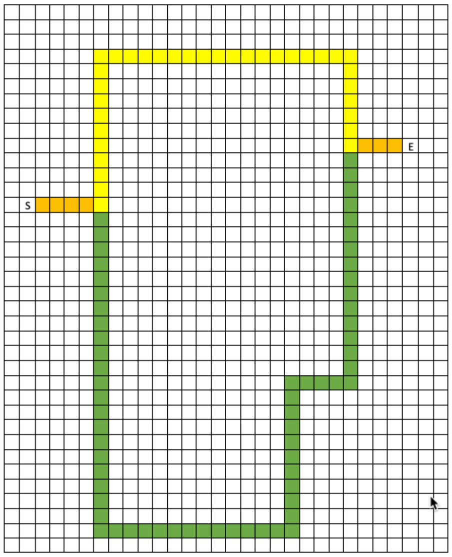

Figure 2. Submitted flight plan

A more formalized version of the algorithm using a single higher-level path ("drone highway") is shown in Figure 3.

```
Input:
HWay_ID, DR_ID_, DR_ID_Velocity,
Start_Loc, Arrival_loc;  Entry_SET, Exit_SET;
Output:
DR_ID_Flight_Plan ;
Start:
Chosen_HWay_Entrance :
   If  ( ∀ HWay_Entrance  ∊ Entry_SET )
     Dist (Start_Loc, Chosen_HWay_Entrance)   ≤
     Dist(Start_Loc, HWay_Entrance) ,
Chosen_HWay_Exit  :
   If ( ∀ HWay_Exit  ∊ Exit_SET )
     Dist (Arrival_Loc, Chosen_HWay-Exit)   ≤
     Dist(Arrival_Loc, HWay_Exit) ,
  Calculate Time (Start_Loc,  Chosen_HWay_Entrance);
  Calculate Time ( Arrival_Loc,Chosen_HWay_Exit) ;
  Assign Slot_Time;
  Return( Drone_ID_Flight_Plan);
End
```

Figure 3. Single-level path flight planning

At the scheduled time, the drone will take off and follow the calculated path to its destination. Figure 4 shows how multiple fixed paths can coexist. In this case, the paths will be on different levels, with intersections where drones can shift from one fixed path to another. This increases the complexity of the algorithm, since slot times for each path must be taken care of. The green fixed path is on one of the upper levels, the two blue paths are on another upper level. The drones will shift from one level to another at the interchanges (grey color).

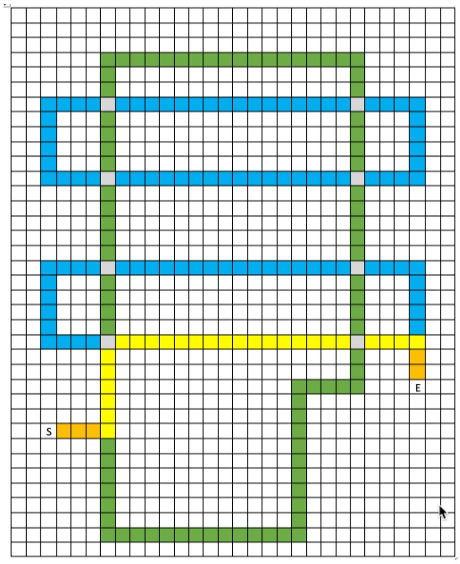

Figure 4. Multiple fixed paths on the upper levels

The enhanced algorithm is shown in Figure 5.

```
Input:
HWay_ID[I], DR_ID[J]_, DR_ID[J]_Velocity,
I ∈ {1…….K} /* number of highways */
J ∈ {1……..M} /* number of drones */
Start_Loc[J], Arrival_loc[J];  Entry_SET[I], Exit_SET[I];
Departure_Collision[J] = False;
Arrival _Collision[J] = False ;
Output:
Flight plan for all drones;
Start:
Stop = False;
While (Not  Stop) {
  For all drones: J: 1 to M:
    Chosen_HWay_Entrance [J] :
      If  ( ∀ HWay_Entrance [I] ∈ Entry_SET[I] )
        Dist(Start_Loc[J], Chosen_HWay_Entrance[J]) ≤
        Dist(Start_Loc[J], HWay_Entrance[I]) ,
    Chosen_HWay_Exit [J] :
      If ( ∀ HWay_Exit [I] ∈ Exit_SET[I] )
        Dist (Arrival_Loc[J], Chosen_HWay-Exit[J])   ≤
        Dist(Arrival_Loc[J], HWay_Exit[I]) ,
    Calculate Time [J] (Start_Loc[J],
Chosen_HWay_Entrance[J]);
    Calculate Time [J] ( Arrival_Loc[J],Chosen_HWay_Exit[J]) ;
    Assign Slot_Time[J];
  If ( ∀ x ∈ {1…..M} , Departure-Collision[x] = False and
    Arrival_Collision[x] = False)
    Stop = True;
  Else
    If ( ∀ x ∈ {1…..M} , Departure-Collision[x] = True OR
      Arrival_Collision[x] = True)
       Remove collision by moving to next endpoint layer ;
       Stop = True;
}
Return( Drone_ID_Flight_Plan[J]);
End;
```

Figure 5. Multiple level paths flight planning

C. *Disruptions*

Disruptions may happen. In particular, disruptions may be caused by the establishment of temporary no-fly zones. This can be above areas that either represents a danger for people on the ground, like large gatherings, or accidents where drone traffic could disrupt emergency service operations.

Disruptions may also be caused by priority traffic, e.g., for delivering a heart defibrillator.

If drones have communication capabilities, it is possible to upload new flight instructions if something happens. Figure 6 shows the establishment of a no-fly zone marked in red. The top-level path needs to be reconfigured.

In this case, it is possible to change the path to not conflict with the no-fly zone. The distance will be one grid unit larger, so original slots can be reused.

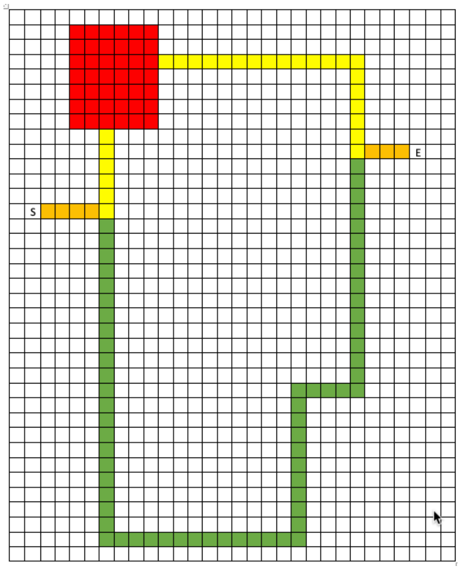

Figure 6. Temporary no-fly zone established

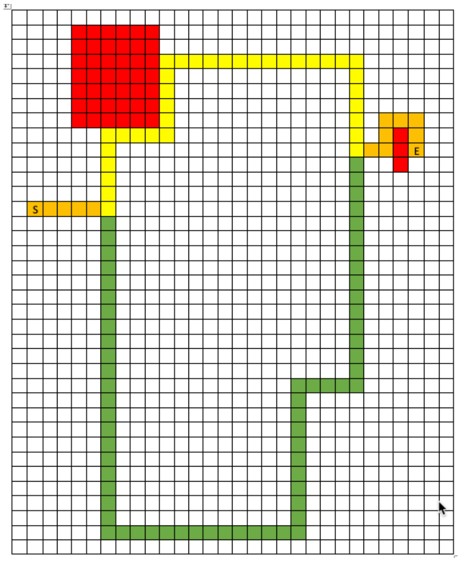

Figure 7. Dynamic rerouting

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Figure 7 shows the reconfigured high-level path, and also introduces a no-fly zone close to the arrival point. The last stretch is recalculated to not interfere with the no-fly zone.

Since drones always have a limitation on flying distance, it is necessary to plan for situations where the drone will run out of battery before accomplishing its mission, e.g., due to the establishment of no-fly zones or priority traffic. The problem can be solved by establishing some locations where drones can land and later be picked up by the operator.

V. CONCLUSIONS AND FUTURE WORK

As drone lift capacity is growing and travel distance increases, drones will be used for commercial purposes. Drone traffic, especially in cities, will increase dramatically. This calls for a drone traffic management solution to keep the air space safe. In this paper, we have shown one possible solution to drone traffic management using multiple layers where some layers contain fixed paths ("drone highways") and other layers are used for traffic from departure points to the highways and from the highways to the arrival point. A flight plan is submitted before the flight, and the system will find the best possible schedule.

However, an important issue regarding drones refers to governing laws of flying. According to [24], every country has specific laws. Thus, our algorithm would not be applied in regions like the State of Alabama, USA, where a city ordinance ban flight over city properties, parks and recreational areas or any other area specified by the police.

Future research includes developing a simulator for the flight scheduling system. The simulator should allow for a large number of submitted flight plans in order to prove the concept. The simulator should have a visualization module to show drones moving in the airspace.

Since, as far as we know, no fully functional and available UTM solution is known, the business model and operating methods of the system are not known at present. Future research should find answers to these questions and address the development of such measures. In this sense we will also include developing a business model for the flight planning system.

Blockchain is an immutable distributed ledger. Cryptographic techniques make sure that it is not possible to change the content of an entry when it is put on the blockchain. All entries are recorded in blocks that are distributed to many computers. If one or more computers fail, the data is still obtainable from the network. If there should be an inconstancy, the majority will win. Essentially, blockchain makes it possible to do transactions without an intermediary. Since a traffic planning system will handle many different actors, the use of blockchain technology and smart contracts may be explored as a possible repository for flight plans.

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REFERENCES

[1] U. Fiore, A. Florea, and L. G. Pérez, "An Interdisciplinary Review of Smart Vehicular Traffic and Its Applications and Challenges," Journal of Sensor and Actuator Networks, vol. 8(13), pp. 1-19, 2019.

[2] Goldman Sachs Research, "Drones Reporting for Work," [Online]. Available from: https://www.goldmansachs.com/insights/technology-driving-innovation/drones/, 2019.06.10

[3] A. Meola, "Drone market shows positive outlook with strong industry growth and trends," Business Insider, 2017.07.13, [Online]. Available from: https://www.businessinsider.com/drone-industry-analysis-market-trends-growth-forecasts-2017-7, 2019.06.10

[4] Amazon, "Amazon Prime Air," [Online]. Available from: https://www.amazon.com/b?node=8037720011, 2019.06.10

[5] Aircargo News, "DHL Parcelcopter launches initial operations for research purposes," 2015.02.27 [Online]. Available from: https://www.aircargonews.net/sectors/express/dhl-parcelcopter-launches-initial-operations-for-research-purpose/ 2019.06.10

[6] J. Stewart, "Google tests drone deliveries in Project Wing trials," BBC, 2014.08.28, [Online]. Available from: http://www.bbc.com/news/technology-28964260, 2019.06.10

[7] J. Porter, "Google's Wing drones approved to make public deliveries in Australia," The Verge, 2019.04.09, [Online]. Available from: https://www.theverge.com/2019/4/9/18301782/wing-drone-delivery-google-alphabet-canberra-australia-public-launch 2019.06.10

[8] M. Williams, "PINC Solutions to launch aerial drones for inventory management," Automotive Logistics, 2014.11.18 [Online]. Available from: https://www.automotivelogistics.media/pinc-solutions-to-launch-aerial-drones-for-inventory-management/11871.article 2019.06.10

[9] Aljazeera, "UAE to use drones for citizen services," 2014.02.12, [Online]. Available from: https://www.aljazeera.com/news/middleeast/2014/02/uae-use-drones-government-services-20142121717319272.html 2019.06.10

[10] C. Dillow, "Meet Matternet, the drone delivery startup that´s actually delivering," Fortune, 2015.05.01, [Online]. Available from: http://fortune.com/2015/05/01/matternet-drone-delivery/ 2019.06.10

[11] Unicef, "Unicef and the Government of Kazakhstan Begin Test Flights for Emergency Response. [Online] Available from: https://www.unicef.org/innovation/stories/unicef-and-government-kazakhstan-begin-test-flights-emergency-response 2019.06.10

[12] Unicef, "Drones – Addressing transport, connectivity and better emergency preparedness," 2019.01.23, [Online]. Available from: https://www.unicef.org/innovation/drones 2019.06.10

[13] Unicef, "Drones take to the Vanuatu sky to test 'last mile' vaccine delivery to children," 2019.12.06, [Online]. Available from: https://www.unicef.org/eap/press-releases/drones-take-vanuatu-sky-test-last-mile-vaccine-delivery-children 2019.06.10

[14] B. Molina, "A kidney for transplant was delivered by drone for the first time ever," MSN News. 2019.04.29, [Online] Available from: https://www.msn.com/en-

za/news/techandscience/a-kidney-for-transplant-was-delivered-by-drone-for-the-first-time-ever/ar-BBWp5iP 2019.06.10

[15] K. Dorling, J. Heinrichs, G. Messier, and S. Magierowski, "Vehicle routing problems for drone delivery," IEEE Transactions on Systems, Man, and Cybernetics: Systems, 47(1), pp. 70-85, 2017.

[16] N. Nader and G. Reicher, "Drones in European Airspace, Initial regulatory steps by the EU," cepInput, March 2016. [Online]. Available: https://www.cep.eu/fileadmin/user_upload/cep.eu/Studien/cepInput_Drohnen/cepInput_Drones.pdf

[17] K. Mok, "Drones That Fly and Drive Using Path Planning Algorithms," The New Stack, 2017.07.16, [Online] Available from: https://thenewstack.io/drones-fly-drive-using-path-planning-algorithms/ 2019.10.06

[18] D. Schermer, M. Moeini, and O. Wendt, "Algorithms for solving the vehicle routing problem with drones," 10th Asian Conference on Intelligent Information and Database Systems (ACIIDS), Lecture Notes in Computer Science 10751, pp. 352-361, Springer, 2018.

[19] B. Eksioglu, A. V. Vural and A. Reisman, "The vehicle routing problem: A taxonomic review," Computers & Industrial Engineering, vol. 57, Issue 4, pp. 1472-1483, 2009.

[20] A. Conner-Simons, "Self-flying drone dips, darts and dives through trees at 30 mph," 2015.10.26, [Online]. Available from: https://www.csail.mit.edu/news/self-flying-drone-dips-darts-and-dives-through-trees-30-mph 2019.06.10

[21] Z. Dukowitz, "NASA Will Test Drone Traffic Management Systems in U.S. Cities as Final Phase of UTM Project," UAV Coach, 2019.02.22, [Online]. Available from: https://uavcoach.com/nasa-utm/ 2019.06.10

[22] J. Plaza, Unifly Set to Define the Future of Drone Traffic Management for Europe, Commercial UAV News, 2019.01.28 [Online]. Available from: https://www.expouav.com/news/latest/unifly-future-drone-traffic-management-europe/ 2019.06.10

[23] S. Zsolt, "Model of the System of Information for the Traffic Management of Unmanned Aircraft Systems," Journal of Unmanned Aerial Systems, 4(1), pp. 18-31, 2019.

[24] UAV Coach, "Master List of Drone Laws" [Online] Available from: https://uavcoach.com/drone-laws/ 2019.16.10