International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:11, No:10, 2017

Risk Assessment for Aerial Package Delivery

Haluk Eren, Ümit Çelik

***Abstract*—**Recent developments in unmanned aerial vehicles (UAVs) have begun to attract intense interest. UAVs started to use for many different applications from military to civilian use. Some online retailer and logistics companies are testing the UAV delivery. UAVs have great potentials to reduce cost and time of deliveries and responding to emergencies in a short time. Despite these great positive sides, just a few works have been done for routing of UAVs for package deliveries. As known, transportation of goods from one place to another may have many hazards on delivery route due to falling hazards that can be exemplified as ground objects or air obstacles. This situation refers to wide-range insurance concept. For this reason, deliveries that are made with drones get into the scope of shipping insurance. On the other hand, air traffic was taken into account in the absence of unmanned aerial vehicle. But now, it has been a reality for aerial fields. In this study, the main goal is to conduct risk analysis of package delivery services using drone, based on delivery routes.

***Keywords*—**Drone risk assessment, drone package delivery

I. Introduction

UNMANNED aerial vehicles (UAVs) have commenced to get involved into service of humanity as convenience means. This attempts gained momentum in the shipping industry with the help of world-wide massive companies such as Amazon, UPS etc. Today, shipping companies have been getting ready to provide delivery of the customers' orders with drones that are kind of unmanned aerial vehicle, and also this is a safe, efficient, and quick delivery option. To their capabilities and performances, there are three types of unmanned aerial vehicles that are tactical, strategic, and mini UAV. Multicopter Drone is a kind of mini UAV. Thus, drones can be ranked as the lowest grade in accordance with their flight performances. Flight level of drones is at low altitudes. Also, they are not durable under different meteorological conditions. They commonly don't have stabile battery system whose charge may not be supplied by a traditional plane motor. This situation negatively affects the flight time of drones. Consequently, these fragile specifications of drones may influence a reliable shipping delivery system.

Drones have a great potential to reduce the cost and the time of delivery. UAV cost is cheaper than the traditional delivery systems such as trucks. It is also good candidate for autonomous package delivery. Drones are not limited by established infrastructure such as roads. There are many application areas for UAVs such as emergency situation deliveries to package or book deliveries. Developments in low cost lightweight materials, batteries, motors, GPS, LIDAR, and control technologies have made feasible to use the drones for delivery.

Haluk Eren, Ümit Çelik are with the School of Aviation, Dept. of Air Traffic Management, Firat University, 23180, Elazig, Turkey (e-mail: haluker@gmail.com, umitcelik.edu@gmail.com).

The terrain structure, the risks on the route, weather conditions and instant air traffic play key roles in a successful parcel delivery. Real-time risk analysis of drone flights will be very important for insurance agents. In this work, we propose a method for risk assessment to help insurers set premiums or drone operators to decide whether the flight should be made or not.

A. Problem Statement

There are many big companies made drone delivery show off already, including UPS, DHL and Amazon. Drone delivery actually will be feasible to use in near future at least for specific scenarios. High accident rates may cause the cancelation of drone delivery project. Thus, risk factors should be minimized for the real world applications. Drones are not durable for many conditions. Hence, the route must be optimized for a successful delivery task. This is very important for insurance companies and drone operators. Insurance companies should know the risk of the drone delivery for a specific target to determine the insurance premium.

In this study, the main goal is to conduct risk analysis of package delivery services using drone, based on delivery routes. At this point, many problems may come to agenda especially for insurance agents, which deserve to get risk information about on-site package deliveries. For that reason, package delivery services could collect information for their daily activities using drones. To achieve this mission, they need a system to measure risks on delivery routes such as air obstacles and ground hazards that may be residential areas, people on streets, factories, shopping centers, high buildings, trees, or structures, etc. As an outcome of the problem, overall risk will be determined and this information will be shared with insurance agents in secure way, online or offline.

B. Proposed Approach

We propose an approach to determining the shipping insurance premium for drone based parcel delivery. The first step of this work is to obtain risk map considering land and aerial obstacles on delivery route, which is segmented into suitable portions considering natural and man-made structures on it. Then, risk rates for each portion are estimated. Therefore, overall risk on the delivery route will be determined. This method leads us to get transportation risk amount for delivery goods during a specified period.

We produced some scenarios for risk analysis. Some alternative routes are determined, and each route is segmented according to risk classes. Historic data that we collect over a given period of time needs to be analyzed to estimate risk probability and suggest alternative routes for logistics purposes and risk assessment purposes.

The risk factor can be derived by hazard identification, risk assessment and documentation. The hazard sources can be classified in 4 groups. The hazards can be vehicle, operator, territory or weather conditions. Severity of risk factors is classified in five groups as in Table I [5]. Possibility of risk factor also needs to be considered. It can be classified in 5 groups as in Table II.

TABLE I
SEVERITY OF RISK FACTOR

Severity	*Detail*	*Rf*
Catastrophic	Death of people; drone or building destroyed (Orange)	80-100
Hazardous	Serious injury; major drone or building damage (Red)	60-80
Major	Injury to person; further operation not possible (Yellow)	40-60
Minor	Minor injury to person; minor effect on system performance (Green)	20-40
Negligible	No injury to person; Negligible effect on system performance (Blue)	0-20

TABLE II
POSSIBILITY OF RISK FACTOR

Possibility		Value
Frequently	Occurred frequently	5
Occasional	Occurred infrequently	4
Rarely	Occurred rarely	3
Improbable	Very unlikely to occur	2
Extremely improbable	Never happened	1

In this paper, we will explore hypothetical cases to illustrate the proposed system. An illustrative map is given in Fig. 1. The map is segmented according to severity of risk factor. The route risk for each segment is given in Table III.

C. Contributions

Drone parcel delivery can significantly reduce the shipping time and cost. This is why, it is expected that the drone parcel delivery will be quite common. Currently, there are many drone startup companies. Logistics companies such as DHL, Fedex, and UPS invest in drone parcel delivery. Also, retailers such as Amazon, Walmart also fund drone parcel delivery projects. All these signs give us some idea about future drone traffic. Thus, there needs to be many considerations that need to be worked on it in parallel such as risk map and route suggestion systems for insurance companies. We proposed a method to estimate the amount of insurance for companies. This method can help insurers to set premiums or drone operators to decide best risk-minimized routes.

D.Related Works

There are many projects based on UAVs such as parcel delivery, agriculture and forestry control, environmental protection, emergency response, surveying, inspection, search and rescue, etc. This situation refers to wide-range insurance concept. Risk analyses of drone flights will be one of the most important issues. There are some works on VRPs for drone delivery, but these works are not considered the risk assessment.

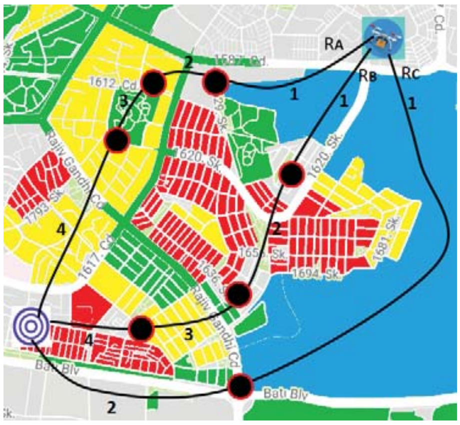

Fig. 1 Risk map for a territory

TABLE III
SEGMENT AND ROUTE RISK FACTORS

Route	1	2	3	4	Route Risk
Route A	10	40	20	40	110
Route B	10	70	40	60	180
Route C	10	20	-	-	30

There are many works on vehicle routing problems (VRP) but it is quite poor for UAVs. Doling et al. proposed a method to two multi-trip VRPs for drone delivery that considers the effect of battery and payload weight [1]. Murray et al developed mathematical programming models aimed at optimal routing and scheduling of unmanned aircraft, and delivery trucks for parcel delivery [2]. Sundar et al. focused on a single Unmanned Aerial Vehicle (UAV) routing problem where there are multiple depots and the vehicle is allowed to refuel at any depot [3]. Wang et al. introduce the vehicle routing problem with drones (VRPD). A truck is equipped with drones delivering packages to customers [4]. Ferrandez et al. investigated the notion of the reduced overall delivery time and energy for a truck-drone network by comparing the in-tandem system with a stand-alone delivery effort [6].

The UAV route planning problem has been tried to be solved with by many methods, such as artificial potential field (APF) method, A* algorithm, and genetic algorithm [7]. The APF method is commonly used in path planning because of the simple algorithm structure, the concise mathematical description and the convenience for real-time control [8]. Srikanthakumar et al. used the APF method as a path planning and obstacle avoidance technique for verification study [9]. Oland et al. applied the APF method to solve the problem of collision and terrain avoidance for multiple UAVs [10]. However, APF method has some defects such as the local minimum problem and the method cannot guarantee planning result is optimal [11]. There are some efforts to solve these problems. Chen et al. improved the model based on the UAV particle dynamics system, uses the APF method and takes the additional control force as an independent variable [12].

Lee et al. proposed an optimization method for the operation management of a fleet of modular delivery drones [13]. They

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:11, No:10, 2017

applied a forward-looking fleet operation management strategy to improve the performance of drone delivery. Another study proposes a mixed-integer linear programming formulation for a drone delivery fleet to minimize operation costs by optimizing the delivery routes [14].

II. Theoretical Approach

Occurrences of hazardous events can be identified and classified for segments or zones. Some hazards can be high loss of altitude, loss of control, collusions, climatic events, and rotor failure. Identified hazards can be assessed according the importance of the risk. Past events also need to be considered for risk assessments.

External risk sources can be drone operator fault, collusions (another UAV, tree, a power line, a bird, or a bullet), hacking attacks or weather effect. Risk factor (*Rf*) of each segment can be calculated using risk severity and frequency as:

$$Rf = Severity.Frequency \quad (1)$$

Average Risk Factor (*ARF*) for each segment caused by external effects or drone operator given by:

$$Avarage\ Risc\ Factor = \frac{\sum_{i=1}^{n} Rf_n}{n} \quad (2)$$

where Rf_n is the risk factor of each segment and n is the number of segment for a target route.

Drone internal risk factor also changes with quality. Drone internal risk sources can be sensor failure, motor failure, logic failure, battery exhaustion, battery charging fault leading to fire, and malicious attack to remote control system. Internal risk factor (*IRf*) should be considered as a parameter to calculate total average risk factor.

Weather-related risk can be classified in 2 classes. Some segment specific weather events can be occurred very frequently. For example, coastal areas are generally windy. This should be considered as a segment property. Also, weather conditions (*Wc*) for a parcel delivery time needs to be considered as a parameter for total average risk factor. Delivery time needs to be considered as a parameter as well. Daytime and night delivery risk factor will be different. Assume delivery time risk factor for a segment is *Dt*, average risk factor for the route (*ARFR*) is provided by

$$ARFR = \frac{\sum_{i=1}^{n} (Rf_n * IRf * Wc_n * Dt_n)}{n} \quad (3)$$

Another important point is to select the shortest path to destination or the route which has lowest risk factor. Package delivery companies prefer faster delivery, shorter route, and lower insurance premium. Insurance companies prefer the route which has the lowest risk factor. Hence, there needs to be made an optimization. A risk factor and delivery time threshold can be applied to the routes data to eliminate the routes which has high risk factor and high delivery time.

III. Simulated Results

The territory for a delivery can be classified in three groups as urban area, mixed area and rural area. We generated a parcel delivery scenario for a specific target address in Fig 2. Two routes are generated for the same target. Red and green paths are segmented in 3 pieces. Red route is shorter but risk factor is higher.

Fig. 2 Risk map for an urban area

External risk factor for the each segment in Fig. 2 is given in Table IV. *ARF* for the red route and green route are calculated 43.3 and 23.3, accordingly. Red route is 1.5 times longer than green path but the risk factor is almost twice as much. Thus, green route should be selected.

TABLE IV
Urban Area Risk Factors for The Segments

Segment No	*1*	*2*	*3*	*ARF*
Red Route	30	80	20	43.3
Green Route	30	20	20	23.3

We produced a scenario for a mixed area in Fig. 3. There are two alternative routes to the target. The risk in urban area is higher than the rural areas. There are many risk sources for rural regions such as long buildings, electric poles, electric lines, and people. Also hazard importance and cost for the urban area is higher. Hence, rural segments would be better to select even the route is longer, because of the low risk factor according to urban area. It needs to be decided according to average risk factor. The risk sources for a rural area can be trees, hills, and homes. Human and building density is much more less according to urban area.

External risk factor for each segment in Fig. 3 is given in Table V. *ARF* for the red route and green route are calculated 23.3 and 33.3, accordingly. Red route is 1.25 times longer than green path, but the risk factor is almost 1.5 times higher. The insurance companies should quote both routes according to average risk factors. Assume there are 6 routes for a delivery target. The risk factor and delivery time is given in Table VI. Shipment companies prefer shortest delivery time for customer satisfaction. Also, the insurance premium needs to be less as possible. If we look at the perspective of the insurance company, they prefer the route which has the lowest risk factor. We can apply threshold to risk factor and delivery time to classify the routes and select the best route easier.

Fig. 3 Risk map for a mixed area

TABLE V
MIXED AREA RISK FACTORS FOR THE SEGMENTS

Segment No	*1*	*2*	*3*	*ARF*
Red Route	20	30	20	23.3
Green Route	20	60	20	33.3

TABLE VI
RISK FACTORS AND DELIVERY TIMES FOR THE ROUTES

Route ID	*ARFR*	*Delivery Time (minutes)*
RA	120	10
RB	40	14
RC	60	12
RD	25	25
RE	150	12

If we apply a threshold for the risk factors less than 60, and delivery time less than 15 minutes, the intersection cluster will be including *RB* and *RC*. Venn diagram is given in Fig. 4. Insurance company can quote for both routes.

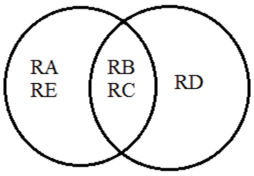

Fig. 4 Risk map for a territory

IV. CONCLUSIONS

We propose a risk assessment method for drone package delivery. Drone parcel delivery will be quite common, thus risk factor for a delivery is important to determine shipping insurance. Also, risk factor is important for drone operator to decide best and secure route. High accident rates can cause the cancelation of drone delivery projects. In fact, the low risk drone flights are important for shipment and insurance companies, but it is much more important when we look social perspective. People must trust the reliability of the drone delivery. Route risk assessment and optimization is very important at this point. We classified drone flight risk sources as operator, vehicle, weather, and terrain depended. The route for a target is segmented according to risk classes. We generated a parcel delivery scenario for a specific target to examine the risk assessment parameters. The proposed approach can be used for future route risk assessment system.

REFERENCES

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

[2] C. C. Murray and A. G. Chu, “The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery,” Transp. Res. Emerging Technol., vol. 54, pp. 86–109, May 2015.

[3] K. Sundar and S. Rathinam, “Algorithms for routing an unmanned aerial vehicle in the presence of refueling depots,” IEEE Trans. Autom. Sci.Eng., vol. 11, no. 1, pp. 287–294, Jan. 2014.

[4] Wang, Xingyin, Stefan Poikonen, and Bruce Golden. "The vehicle routing problem with drones: Several worst-case results." Optimization Letters 11.4 (2017): 679-697.

[5] Wackwitz, Kay, and Hendrick Boedecker. "Safety Risk Assessment for UAV Operation." Drone Industry Insights, Safe Airspace Integration Project, Part One, Hamburg, Germany (2015).

[6] Ferrandez, Sergio Mourelo, et al. "Optimization of a truck-drone in tandem delivery network using k-means and genetic algorithm." Journal of Industrial Engineering and Management 9.2 (2016): 374.

[7] Chen, Chen, Y., Zhao, X., & Han, J. (2010). Review of 3D path planning methods for mobile robot. Robot, 32, 568–576.

[8] Berry, A., Howitt, J., Gu, D.-W., & Postlethwaite, I. (2010). Enabling the operation of multiple micro-air-vehicles in increasingly complex obstacle-rich environments. In J. Rankin (Ed.), AIAA Infotech@ Aerospace 2010, Atlanta, Georgia (p. 1–14). Reston, VA: American Institute of Aeronautics and Astronautics Inc..

[9] Srikanthakumar, S., Liu, C., & Chen, W.H. (2012). Optimizationbased safety analysis of obstacle avoidance systems for unmanned aerial vehicles. Journal of Intelligent & Robotic Systems, 65(1–4), 219–231.

[10] Oland, Espen, & Kristiansen, Raymond. (2013). Collision and terrain avoidance for UAVs using the potential field method. In IEEE Aerospace Conference (pp. 1–7). Washington, DC: IEEE Computer Society.

[11] Koren, Y., & Borenstein, J. (1991). Potential field methods and their inherent limitations for mobile robot navigation. In Proceedings of the IEEE International Conference on Robotics and Automation (pp. 1398–1404). Piscataway, NJ: IEEE.

[12] Y.-b. Chen, G.-c. Luo, Y.-s. Mei, J.-q. Yu, and X.-l. Su, “UAV path planning using artificial potential field method updated by optimal control theory,” International Journal of Systems Science. Principles and Applications of Systems and Integration, vol. 47, no. 6, pp. 1407–1420, 2016

[13] Lee, Jaihyun. "Optimization of a modular drone delivery system." Systems Conference (SysCon), 2017 Annual IEEE International. IEEE, 2017.

[14] K. Dorling, J. Heinrichs, G. G. Messier, and S. Magierowski, “Vehicle Routing Problem for Drone Delivery”, IEEE Transactions on System Man and Cybernetic: Systems, 2016.