DOI: 10.7251/JTTTP2202053M
UDC: 623.746-519:658.286

ORIGINAL SCIENTIFIC PAPER

Time based separation model in high density U-space traffic environment

Vladimir Milošević
Master of Science degree of Aeronautical Engineering from the Faculty of the Transport and Traffic Engineering of the University of Belgrade, Serbian; vladimir_milosevic@hotmail.rs

Mirjana Vasiljević
B.Sc. Engineer in Business and Informatics, Singidunum University, Faculty of Informatics and Computing, Belgrade, Serbia; mirjana.vasiljevic@ymail.com

Received: October 29, 2022
Accepted: December 19, 2022

Abstract: This paper is based on actual U-space regulatory framework defined by the international regulators like EASA, JARUS, FAA and connected actors like AIRBUS, EUROCONTROL or AMAZON. The aim of the work is to analyze requirements for the most complex use cases and define possible deficits in time, capacity and safety. The result should define possible more efficient methods, technologies and procedures and emphasize main development directions for efficient and robust traffic management system.

Keywords: drones, UTM, U-space, CORUS, ATM, UAV, BVLOS, VTOL, time-based separation.

INTRODUCTION

Modern time of 21st Century has brought technological advancement in many areas, but expansion of air and space industry is the most remarkable one. The revolution in communications and IT technology requires more efficient transport of people and goods to the destination all over the world. Large cities are looking for more efficient way of commuter transportation, with easier and more efficient way to construct and maintain transportation system in their areas of responsibilities.

The Unmanned Aerial Vehicles (UAV), well known as "drones", showed as very useful and efficient tools with many applications, from personal entertainment up to the large scale of business cases in many areas. Low price, flexibility of use, vertical takeoff and landing (VTOL), with no need for large infrastructural systems like airport or road network, which have to be constructed and maintained, are the main advantages which put the UAVs development on a very fast lane.

Expansion of UAVs, and air safety sensitive use cases like transportation of humans or goods, initiated the need for development of specific U-space system based on principles of the ATM system which is developed for the General Aviation. The ICAO, and regulators from different part of the world, initially identified risks for the General Air Traffic (GAT) and started regulatory processes [1].

Today, with support of different UAV organizations like Joint Authorities on Rulemaking for Unmanned Systems (JARUS), basics for further development of U-space system include classification of UAVs, Air Space Classification of UAV operations, types and phases of UAV operations, list of services which will be provided in U-space environment, U-space development phases from U0 to U4 with projected services for every phase [2].

MAIN CHARACTERISTIC OF UAVS AND U-SPACE SYSTEM

Main configuration of UAVs or drones is quadcopter configuration with four or more rotors and with weak or no aerodynamic performance. This allows motions in 3D environment in all directions with slow speed and hovering or landing over the point. Also, the future of UAVs is mainly perceived as personal transportation, at short routes, beyond the visual line of sight (BVLOS), fully automated in business cases or remotely piloted in emergency operations, like Firefighting or Rescue missions in urban or suburban areas.

Characteristics of U-space system, in their most developed and most demanding U-4 phase, includes high level of automation, augmented GNSS navigation, intensive 6G based exchange of information in many layers for long list of services, no human in loop decision making processes [3], personalized and automated vehicles as basic traffic units, on demand transportation of humans and goods, high density traffic operations, strong information security environment.

Summarizing all characteristic there are two use cases which are technically and procedural most demanding, and they cover all aspect of the U-space system which have to be developed for safe, smooth and efficient environment for whole list of operations and use cases [4], and those are:

- "Beyond the skyline" or "Delivery operations" which are settled in modern cities at very low level (VLL) where corridors are defined among the buildings, and it is used for delivery of goods.
- "Above the skyline" or "Air taxi" for the on request and short routes transportation of small groups of people in large cities [5].

DEFICIT OF TIME, ENERGY AND INFORMATION MANAGEMENT CAPABILITIES

Density of some traffic system is connected to the number of traffic units and number of traffic participants, where traffic units are transportation vehicles and traffic participants are number of persons who are transported or number of persons that certain delivery covers. Relation among those elements can be described with simple equitation:

$$\text{Traffic Density} = \frac{\text{Traffic Units}}{\text{Traffic Participants}} \times 100\%$$

In situation where personalization of traffic is ongoing process the number of traffic units will be increased closer to the number of traffic participants (e.g., one car for one person) which will result of higher traffic density.

Complexity of traffic management is referred to the amount of information that has to be processed in real time for decision making process. If we compare actual way of transportation (Air, Road, Rails …) we can conclude that problem of complexity is solved with decentralization of the traffic management so the amount of data that should be processed in decision making process is significantly low. Car driving is personalized, relatively self-sustainable, with high traffic density but quite low data load in decision making processes, which is based on traffic participant.

As the flying is quite complex activity based on many precaution activities in pre-flight, and later inflight phase, number of services and demanding data exchange is relatively high and centralized what increases complexity of the U-space traffic data exchange system. Data filtration and management in decision making process will be main problem in future of U-space design.

Volume of certain area where traffic is organized directly influence the available reaction time for the conflict resolutions and decision-making processes. Volumes of the U-space areas, settled over the large cities, are significantly smaller than the areas of ATM systems what will increase the possibility of conflict situations and cause the reaction time deficit.

Deficit of fuel or energy that is capable to overcome gravity for the certain mass requires highly efficient U-space traffic system, capable to provide shortest and synchronized routes without stops and unnecessary hovering over certain points, and lower altitude levels, having in mind that the lack of aero-dynamical capabilities.

A requirement of the high level of data security, like Blockchain technology has promoted, combined with large amount of data processing in real time requires provision of the significant computational force, and can cause longer latencies, and many communicational problems.

If we translate everything mentioned to the U-space traffic management, high density on demand traffic operations will inevitably require decentralization of decision-making processes, simplification of procedures and techniques and higher level of automation based on Artificial Intelligence.

U-SPACE CONFLICT RECOGNITION AND RESOLUTION

All mentioned deficits have opened many airs safety issues. Basic safety regulation for U-space divided UAVs operations in three phases: Strategic (Pre-flight) separation, Tactical (In-flight) separation, Collision avoidance with Detect and Avoid (DAA) equipment [2].

Based on tradeoffs between operations safety and freedom of actual aircraft U-space structures can be composed by one of four proposed strategic concepts [2] [5]:

1. Basic flight (Layers),
2. Free route (Full Mix),
3. Corridors (Tubes),
4. Fixed Route (Zones).

Large cities already have intensive air traffic with helicopters in police, rescue and firefighting operations and high-end business use cases, open drone operations in Visual Line of Sight (VLOS) for commercial and personal use [6]. This does not leave much possibilities and space to stack many layers over large cities to accommodate intensive U-space traffic, and to construct complex approaching areas to many landing zones and sectors [7] [8].

Everything implies that all traffic should be accommodated in one or a few layers, and the horizontal separation and conflict resolutions method will be primary one, as difference to the regular ATM systems. Longitudinal procedures related to the time-based separation will be core of preflight and in-flight phases of operations, while lateral separations will be main method for collision sense and avoid procedures.

With all mentioned deficits, the future U-space structures will be hybrid, with combinations of those strategic concepts with higher level of precision in positioning and navigation, time-based separation, time gates on crossings and block-chained flight plans, network centric data broadcasting and exchange.

SPEED CORRECTIONS IN TIME-BASED ENVIRONMENT

The time-based separations are based on exact time of arrival targeting over the certain point. This requires precise navigation in all three dimensions plus precise speed-time control as a tool for longitudinal position manipulation. Time based separation provides avoidance of traffic fluctuation and cut delays and holdings, and provide savings in needed energy for flight, spare fuel and protect nature in many ways.

Future hybrid network centric U-space structure should be defined as dense network of lanes which can provide routes "as close as it is possible" to direct fly-to routes with many crossings which will have opened and closed time gates. The UAVs as traffic units in preflight phase will define exact combination time gates up to the destination, and during the flight will manipulate with small speed corrections to target dedicated time gate on every crossing. The density of network should provide automated in-flight avoidance re-routing procedures, as second level of conflict resolution.

Speed corrections are core of longitudinal position manipulation and exact understanding of the nature of speed can provide engineering of methods and tools which will be capable to instantly detect delays or overtimes. Correlating the value of speed correction with rest of time till the destination point in function the resulting speed correction has tendency to the infinity as the time for the correction goes toward zero, and vice versa if correction time goes toward infinity. In

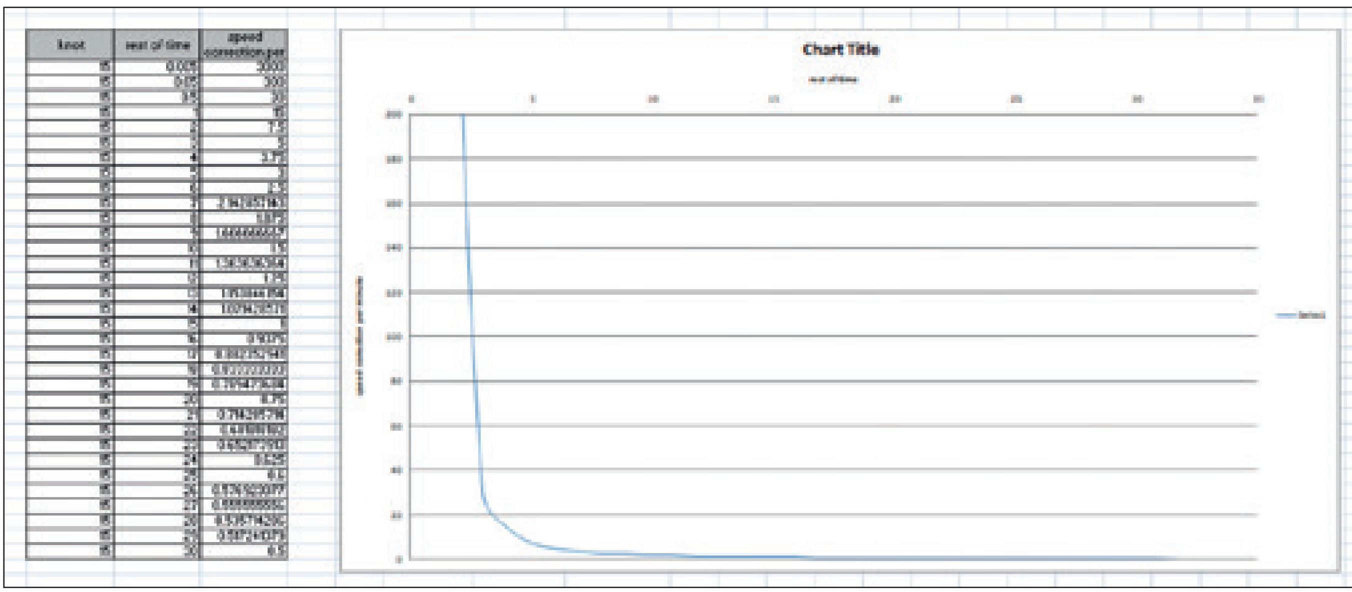

Fig. 1. The value of speed correction in correlation with rest of time till the destination

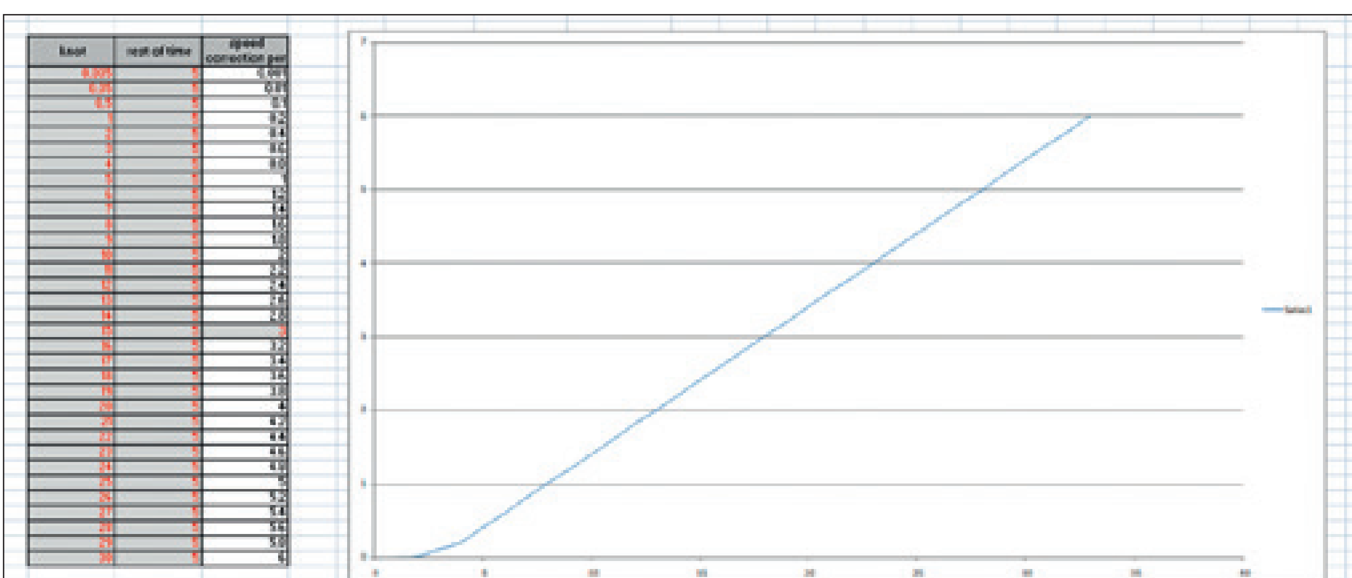

Fig. 2. The speed corrections in correlation with corrections per minute.

another hand, small speed corrections require smaller corrections per minute.

Combining dose two principles the longitudinal maneuver could be shaped with list of requirements as a basis of future methods for time-speed-distance manipulation tools. Those requirements are:

1. Delay or overtime early warning and reaction provide small speed corrections which can be divided in smaller portions over longer time period for speed/time corrections.
2. Smaller portions of speed correction provide seamless and synchronized flight.
3. Every, even shortest period of time in flight could be used as time gate, or check point, with precise passing time as unique code and capability to alert smallest deviations in longitudinal navigation.
4. Graphically if every point or time unit on route has unique time code which mathematically could be calculated:

$$\Delta Vcorr = Vplan - \frac{\text{S plan}-\text{Sflown}}{\text{Tarr}-\text{Tact}},$$

As we plan routes without delays,

$$Vplan = \frac{\text{S plan}-\text{Sflown}}{\text{Tarr}-\text{Tact}},$$

and time on any point could be expressed as,

$$Tact = Tarr - \frac{\text{S plan} - \text{Sflown}}{\text{V plan}}$$

Using this equitation, we can project navigational time marker for every point of route as a tool for precise longitudinal position and speed manipulation.

CONCLUSION

U-space is much smaller volume which should settle very intensive and demanding traffic system based on high density, high level of automation, on demand operations and totally new safety cases. It is very hard to copy actual ATM system on U-space without deep reconstructions and accommodation. Actual level of

U-space development established basic regulations for UAVs and U-space classification, list of services divided by the phases of development, phases of U-space operations based on safety issues and possible traffic structures for aircraft separations and collision avoidance.

Due to many factors and characteristics of U-space system this work determined crucial deficits of time, capacity and energy which led us up to the new list of requirements which most demanding U-space operations and use cases will need. Basically, future U-space structure will be hybrid, very close to "direct fly to capability", based on time gates and horizontal navigation and separation. Tools which will provide precise longitudinal position manipulation, continuous time control and seamless speed corrections will be crucial for future development of U-space structures.

Future traffic structures will need to be energy efficient for all and every traffic unit, especially because the UAVs are without or with very weak aerodynamics and any kind of power loss will initiate emergency situation. Compared to the ground traffic, synchronized U-space should provide a drive through the city always on green light.

REFERENCES:

[1] Eurocontrol Corus, "U-space Concept of operations," vol. VOL1, 2019.

[2] Airbus, Blueprint for the sky - The road map for the safe integration of autonomous aircraft, Airbus LLC, 2018.

[3] R. Shrestha, R. Bajracharya and S. Kim, 6G Enabled Unmanned Aerial Vehicle Traffic Management: A Perspective, IEEE Acess, 2021.

[4] E. Sunil, J. Hoekstra, J. Ellerbroek, F. Bussink, D. Nieuwenhuisen, A. Vidosavljevic and S. Kern, Metropolis: Relating Airspace Structure and Capacity for Extreme Traffic Densities, Eleventh USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), 2015.

[5] N. Pongsakornsathien, S. Bijjahalli, A. Gardi, A. Symons, Y. Xi, R. Sabatini and T. Kistan, "A Performance-Based Airspace Model for Unmanned Aircraft Systems Traffic Management," *MDPI Aerospace*, 2020.

[6] H. González-Jorge, J. Martínez-Sánchez and M. Buen, Unmanned Aerial Systems for Civil Applications:, MDPI drones, 2017.

[7] V. Duchamp, L. Sedov and V. Polishchuk, Density-Adapting Layers towards PBN for UTM, Thirteenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2019), 2019.

[8] Amazon, Revising the Airspace Model for the SafeIntegration of Small Unmanned Aircraft Systems, Amazon, 2015.