Droneways: Definition of Unmanned Aircraft Vehicles Airways and Traffic Management for Urban and Interurban Environments – A Survey

Rafael Marinho de Andrade[1,2], Elcio Hideiti Shiguemori[1,2], and Rafael Duarte Coelho dos Santos[1(✉)]

[1] National Institute for Space Research, São José dos Campos, SP, Brazil
rafael.santos@inpe.br

[2] Advanced Studies Institute, São José dos Campos SP, Brazil

Abstract. In the 20th century aviation has proven itself as one of the most important techno-social revolutions of modern human history. Now, Unmanned Aerial Vehicles (UAVs) are on the verge of leading the next techno-social revolution, remodeling several areas such as logistics, passengers and cargo transport, surveillance, etc., moving a global market that does not stop growing. The establishment of UAV traffic management systems (UTM) is necessary to make this revolution happen. Ten years after the establishment of the UTM concept, it has been expanded around the world and moves more and more interested parties to develop research to define, optimize and implement technologies and legal apparatuses to make UTMs something practical, real, and effective. Despite all the advances so far, the development of UTM still depends to be maturated for it to be finally implemented: it is an area rich in discoveries and definitions to be made, with problems that await solutions from all sides. In this article, a historical recapitulation and composition of the current state of development were carried out.

Keywords: UAS Traffic Management · Unmanned Aerial Vehicles · Dynamic Environmental Modeling · Artificial Intelligence

1 Introduction

In the 20th century, aviation has proven itself as one of the most important techno-social revolutions of modern human history, allowing better mobility of people and goods and being a key component in defense [5]. By the middle of that century, the remotely piloted aircraft systems (RPAS) appeared [27], also known as "unmanned aerial vehicles" (UAV), but it was only in the 21st century that remotely piloted aircraft technologies advanced and became miniaturized to the point of becoming an affordable technological trend, especially during the 2010s [13]. Then, UAVs began to draw attention to the most diverse areas as a promising and often relatively simple tool to be applied in scenarios ranging

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O. Gervasi et al. (Eds.): ICCSA 2023 Workshops, LNCS 14107, pp. 179–197, 2023.
https://doi.org/10.1007/978-3-031-37114-1_13

from logistics and remote sensing to surveillance and search and rescue missions [20]; the possibilities are so wide that they can be considered in the solution of practically any conceivable problem [13].

There is research for the development of UAVs to meet the most diverse needs, establishing and moving a market that doesn't stop growing, impacting all the markets involved – it is estimated that by the end of 2022 the global UAV market was worth around USD 43 billion, and this value is expected to rise to somewhere around USD 600 billions by the year of 2030 [11]. In 2017, there were more than one million UAVs registered in the USA, of which more than 80% were registered for recreational purposes [9].

Today, just like conventional aircraft in the past, UAVs are leading a techno-social revolution by being increasingly applied as a solution to an increasingly diverse range of problems. The existence of UAVs in contemporary society is a striking reality, but the legislation and rules for the control and management of these aircraft are still incipient [2]. In fact, to date, no system for controlling and managing UAV traffic has been established in most parts of the world.

A factor that determined the success of conventional aircraft since the 20th century is its serious and efficient set of international rules since the operation of aircraft is considered a critical operation given its destructive potential [20]. It lead to the establishment of Air Traffic Management systems (ATM), and their operation with the highest rigor consolidated civil aviation as one of the safest and most efficient systems ever made. UAV systems, however, cannot follow the same rules since they have different flight capabilities due to their usually smaller sizes that allow them to fly and reach the most difficult and critical places, such as between buildings or even indoor environments. Even being used all around the world, there are currently no operational traffic monitoring systems available for UAVs.

Even though no UAV management system hasn't been implemented, there are initiatives under development so that airlines for managing activities with UAVs become something real and practical. In the USA, there is the pioneer UTM (UAS Traffic Management) from the FAA and NASA, the UAM (Urban Air Mobility), also from the FAA, and the UTFC (UAS Traffic Flow Control) from NASA, in addition to MITRE initiatives. In Europe, there is the U-Space from the European Commission, the DLR U-SPACE from the German Aerospace Center, METROPOLIS, and the LLRTM (Low-Level RPAS Traffic Management) from ONERA. In Asia, there is the UTM concept from Nanyang Technological University (Singapore), UOMS (UAS Aviation Operation Management System) from China, JAXA's UTM (Japanese Aerospace Exploration Agency) [2].

The establishment of traffic management systems for such aircraft is a latent contemporary society need, which is currently experiencing a techno-social revolution around aerial vehicles popularly known as "drones", which can assume different proportions and aerodynamic capacities, as well as operating in different regimes and for different purposes. With the establishment of such systems, mainly known as "UTM", society will be able to safely and efficiently enjoy the inherent advantages and resources of these aircraft, making society more efficient in several areas and positively moving the economy.

In this article, a historical recapitulation and composition of the current state of development are carried out by the bibliographies involving the lines of research involved in the development of traffic management systems for UAS, which can be important for the development of upcoming projects.

2 UAV Laws Around the World

All sovereign nations with an international airport follow an international statute defined by the International Civil Aviation Organization (ICAO), which means that international civil aviation follows, in general, always the same rules. For now, however, this only applies to conventional civil aviation and ICAO doesn't have a statute with centralized rules for all sovereign nations to follow when is about UAVs – however much the general recommendation is that these aircraft do not interfere with the operations of conventional aircraft, or otherwise operate just like them. As a consequence, at least for now, each nation is free to define the rules for the operation of UAVs and the like within their territories.

Although there are some standards in the establishment of legislation for UAVs – which consequently impact on the rules defined for the operation of eventual UTMs –, the influence of two agents in defining these laws and rules is somewhat clear: 1) the civil aviation local laws that already existed and was in force before the popularization of UAVs, and 2) the ideals defined by already conceptually established UTMs (such as the FAA-NASA UTM and the U-Space).

International laws and regulations – whose access links are centralized in [12] – tend to vary considerably, even though they show some standards. These standards have some consistency among sovereign nations in Europe, in addition to a certain influence from the FAA-NASA UTM (which simply limits UAV airspace to up to 120 m high and establishes concerns for meteorological and social conditions) and the U-Space. Table 1 presents general restrictions for several nations in Europe, and Table 2 for nations elsewhere [1,6,19,26].

3 The Evolution of UAV Traffic Management

Since UAVs are allowed to operate in several distance ranges (depending on their capabilities), they depend on legislation and technological resources to control their traffic, ensuring that their operations are safe and efficient.

3.1 Dawn of UTM: Early-2010

Until the mid-2010s, while UAVs were becoming popular, the laws were still incipient and also unclean [14]: an aircraft could be legally considered a toy, a model airplane, or an aircraft of conventional use. The growing popularization of UAVs made the need for definitions of laws and rules more evident, to avoid accidents and assign legal responsibilities. In general, the first organizations assigned to deal with this type of responsibility and control were the regulatory bodies linked to aeronautics.

Table 1. General restrictions for UAV in European sovereign nations [19].

Sovereign nation	Minimum distance	Constraint element
Belgium	2778 m	Airports
	926 m	Heliports
	50 m	Building, people, animals
Croatia	3 km	Airport and approach/departure zone
	150 m	Group of people
	30 m	People and structures
Czech Republic	150 m	Congested areas
	100 m	Person not directly associated with the operation
Germany	1,5 km	Airports
		Above people, accident and disaster
	No fly zone	areas, prisons, military installations, industrial areas and power stations
Ireland	8 km	Airports
	2 km	Aircraft in flight
	150 m	People, vessel, vehicle and structures
Italy	5 km	Airports
	150 m	Congested areas
	50 m	People and properties
Poland	5 km	Airports
Slovenia	300 m	Crowds
	50 m	Power lines, roads, railways, etc.
Spain	8 km	Airports
Sweden	50 m	People, animals and properties
Switzerland	5 km	Airfields
	100 m	Crowds
United Kingdom	150 m	Congested areas
	50 m	People, objects and vehicles

Since 1981, remotely controlled model airplanes could occupy the American airspace as long as they were at safe distances from the civilian population, airports, or areas insensitive to noise, at a height of up to 120 m [10]. This same legislation was faced with the need for updates, and by 2013 this became even more latent with research on drones for transport and logistics operations already conducted by notable companies such as Amazon, DHL, Google, etc.

By 2014, UAVs were classified into three types: high-capacity (somewhat similar to conventional aircraft), small-sized (which weighs less than 1 kg) and medium-sized (the most common classification nowadays) [14].

3.2 First Steps: Mid-2010s

As shown in Fig. 1, American legislation (defined by the FAA) divides airspace into seven classes, where A, B, C, D, and E are ATM-dependent controlled spaces, F is unused and the G is uncontrolled [8]. Class G is the low-flying height airspace that matters to whatever is immediately below (such as properties).

Table 2. General restrictions for UAV in Asian, Oceanian and Latin-American sovereign nations [19].

Sovereign nation	Minimum distance	Constraint element
Australia	30 m	People not involved in operation, buildings, properties, structures and animals.
Brazil	5,6 km	Registered aerodromes, operating on approach/takeoff zones
	2 km	Registered helipads and agricultural aviation areas
	1,9 km	Registered aerodromes, operating outside of approach/takeoff zones
	30 m	People not involved in operation, buildings, properties, structures and animals
	No fly zone	Above crowds and populated areas.
China	5 km	National boundary lines, radio observations
	2 km	Landing points for manned aircraft, borderlines, satellite earth stations
	1 km	Military reservation, thunderhead, buildings, tall towers, power grids, wind power
	500 m	High-speed railway
	200 m	Warehouses with inflammable and explosive objects, petrol stations, electric power facilities, mountains.
Japan	30 m	People and properties
	No fly zone	Over event sites with group of people
United Arab Emirates	5 km	Airports, heliports, airfields and controlled airspace
	150 m	Crowds, public and private properties

The "thin" UTM, by Foina *et al.*: [10] presented a solution based on the ideas described by NASA and operation of systems applied in autonomous cars, relying more on sensors than third-parties information. This solution considered three components: 1) electronic identification, 2) route planning system, and 3) ground identification devices. The electronic identification consists of sequences of colored light signals. The route planning system (main component) consists of a communication protocol between the aircraft and the UTM, where the starting and ending points of the routes are communicated. The UTM manages the airspace based on airspace concurrency restrictions and other particularities, thus determining the definitive route that is sent to the aircraft.

The system relies on simplicity, not requiring continuous communication between the aircraft and the UTM, where the UTM would be "thin". The identification system would be a system based on computer vision to read the aforementioned electronic identification (working similarly to a traffic radar) and thus perform the necessary validations regarding the aircraft, its route, etc.

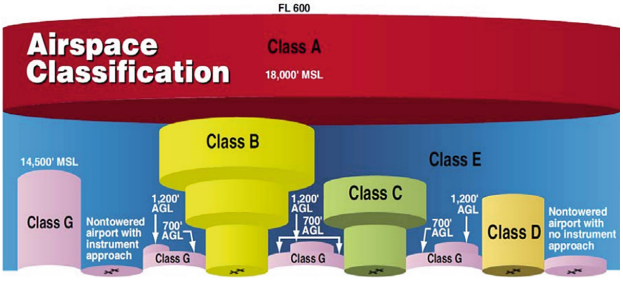


Fig. 1. Classification of the American airspace, from [8].

The Zhu and Wei Geofences: In the literature, among the approaches that are mainly concerned with safety, those that consider the geofence approach stand out, a concept that was proposed by the European Organization for Civil Aviation Equipment (EURO-CAE) together with NASA [2]. Consist of virtually delimited geographic zones following specific rules within their volume; geofences are defined as areas restricted to the flight of controlled amounts of aircraft, or even no aircraft at all, reserving them only for specific aircraft.

[28] defined that geofences are a way to ensure the use of airspace with the lowest collision probabilities and that dynamic geofences, in turn, should guarantee greater flexibility and security to the UTM, where its 3D spaces are lean and follow aircraft throughout their operations, like bubbles; the main advantage of this is to prevent geofences from becoming too complex, without becoming rudimentary like a huge bubble that envelops all presumed operational space.

This kind of solution depends on planning and high stability of the aircraft and/or continuous communication between them and the UTM, but the geofences themselves are modelled taking into account the most agile displacements. In any case, [28] consider that the only communication between the aircraft and the UTM is in the planning and deliberation for operations, with less communications as possible.

For environment modeling, everything is modeled as a graph, where the geofences are dynamically generated from the graph's vertices.

3.3 Expansion: Late-2010s

By the end of the 2010s, the UTM concept and its needs were already clear after the efforts to establish them, mainly by NASA, and so a period of research mainly to improve and optimize technologies and approaches for the implementation of UTMs begun. The concept has also expanded around the world.

A Framework for Singapore: Applying evolutionary algorithms, [23] proposed a framework with three main components: 1) traffic network construction, 2) route planning, and 3) takeoff scheduling.

The traffic network consists of the urban topography defined as a graph, where the nodes must be in safe places in relation to physical structures such as buildings, for example, and must present the greatest possible connectivity.

The routing algorithm defines both routes with intersections and without intersections, where the latter aims to minimize the chances of conflicts and, therefore, collisions. Basically, it consists of applying Dijkstra's algorithm or similar algorithms like A*; also uses tabu searches to avoid restricted areas, depth and breadth searches to define flexibility. [23] also consider the application of other linear programming resources in the algorithm.

The scheduling based on an evolutionary algorithm consists of defining the ideal takeoff and landing points and time, in order to avoid conflicts. For proof of concept purposes, they assumed that all aircraft would move at constant speed.

The validation took into account the city of Singapore and the tests were conducted with delivery activities, with previously defined take-off and landing points. On average, there were no waits of more than a few seconds for takeoff.

Not long after, [17] claimed that, although many approaches applied to define routes in UTMs have been presented, few show concern about the risks involved in the urban air environment inherent to UTM operations. They also noted that probabilistic roadmaps (PRM) and random rapid exploration trees (RRT) have improved route planning for UAVs.

Resuming the work presented by [23], [17] proposed and investigated an interesting model of risk-based UAV route planning, aiming to be safe and efficient in urban environments and low flight, considering attributes such as signal strength and population density as risk blocks.

With regard to risks, four types are considered: 1) physical obstacles (such as buildings), 2) meteorological adversities (such as wind, fog, rain, among others), 3) operational restrictions (such as GPS signal) and 4) regulatory and social constraints (socially defined, such as militarized areas and the like). These risks were also scaled in five levels, based on probability and severity.

To actually define the routes, the Dijkstra, A* and ant colony algorithms were tested, where the displacements between the nodes would have 7 directional degrees of freedom.

As well as in [17,23] simulated tests with the urban environment of Singapore. The results indicate that Dijkstra's algorithm is slightly more secure than A*, but much more expensive; the ant colony algorithm didn't perform well.

The Taiwanese UTM: [15] based their work on the legislation defined by the CAA, with rules for flights up to or above 120 m in height [3] and taking into account, in particular, suburban regions. They idealized an architecture very similar to a smart city, but having as main inspiration the ATM systems.

[15] proposed their own communication protocol and well-defined workflows for all UAV flight stages (pre-takeoff, flight and post-landing), prioritizing UTM operation with prior mission planning (ideally at least 30 min before takeoff). It also proposes circular surveillance for each aircraft for an area of about 600 m that surrounds it.

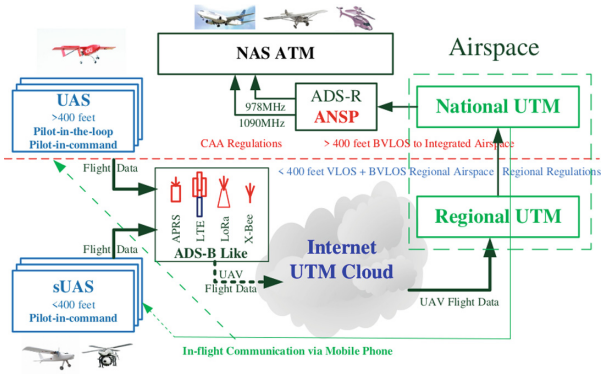


Fig. 2. UTM for Taiwan airspace control, from [16].

[15] have developed a prototype and considered that plans changes in flight time can be very chaotic for the UTM. Because of this, they suggest that such changes are not allowed.

Anticipating that as soon as UAVs would ordinarily operate below 120 m high in urban and interurban environments to fulfill their tasks, and that, depending on the capabilities and assignments of the aircraft in question, they may still be subject to occupying the conventional aircraft space, [16] noticed in communication and infrastructure the foundations for the development of UTMs, including the appropriate frequency spectrum for this type of communication.

[16] proposed a hierarchical UTM, composed of regional UTMs that sums in a larger UTM where communication is the key point, as shown in the diagram in Fig. 2 as "Regional UTM" and "National UTM", respectively, or "RUTM" and "NUTM".

A proof-of-concept test was conducted in Tainan (which comprises its own RUTM). The results indicate that the hierarchical division helps to relieve the computational cost in the realization of deconflictions, making them more agile, and without any problems in the operational safety of the system.

3.4 Maturation: Early-2020s

Entering the 2020s, UTM research was already present in several world powers and the concept was already established *de facto*. There were still no operational UTMs in operation, but studies on specific optimization applications with the aim of being employed in UTM systems became more frequent.

The Pötter Neto, Bertolli and Saotome Simulations: The A* algorithm was also addressed by [18] for route planning, in order to find optimal routes between two points. In particular, they extracted 2D and 3D maps from simulated environments, and compared the A* algorithm between 2D and 3D environments for UTMs.

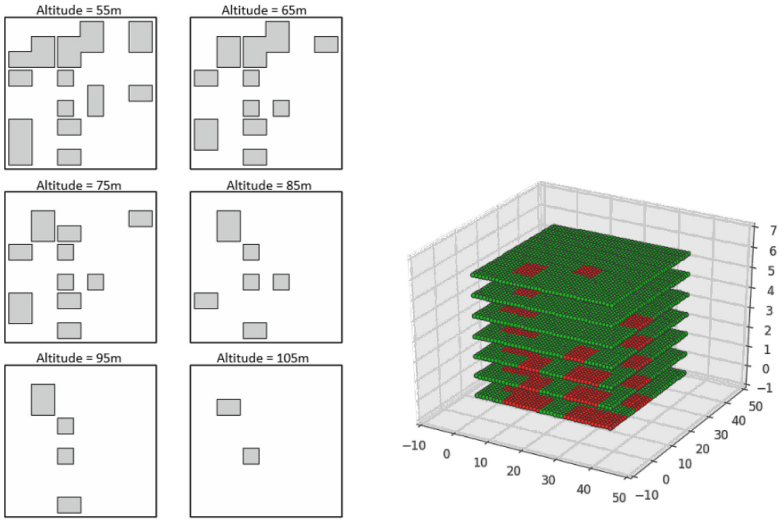


Fig. 3. Simulation environment modeling as a tensor of order 3, from [18].

First, [18] modeled the environment with buildings that occupy homogeneous areas and with varying heights. The maps are defined as a tensor of order 3, where each voxel represents $1\,m^3$, as graphically abstracted as in Fig. 3. The maps are then vectors with matrices of dimension 200×200, where the altitudes have been more discreetly separated.

To reduce the computational cost, the matrices were then simplified and grouped into sets of 5×5.

The experimentation process included the definition of a pair of voxels as a takeoff and landing points. As a practical verdict, the A* algorithm covered more space for the displacements when executed restricted to 2D displacements, while the 3D algorithms are more spatially efficient (however requiring a considerably higher computational cost); therefore, displacements in mostly horizontal traffic lines would be slower, while traffic lines with more vertical freedom would be more agile (but more complex).

In the following year, [19] returned with a update, presenting the same details but in a more elaborate form and accompanied by additional details, such as the application both Euclidean and Manhattan distance in the simulations.

An UTM Optimised by Artificial Intelligence: [25] identified both the FAA-NASA UTM and U-Space as Air Traffic Flow Management (ATFM) extensions, and declared that none of them can currently meet the needs and tactics that will be needed in the coming years in intense low-height flight operations. They proposed then an approach that combines tabu search and A* algorithm to support the UTM decision process, providing dynamic route re-planning in complex environments, achieving better results for NP-complex problems. The solution is based on four-dimensional trajectory functionalities, being resilient to uncertainties, and seeks to be safe and efficient, while reducing uncertainties. A diagram of this UTM is shown in Fig. 4.

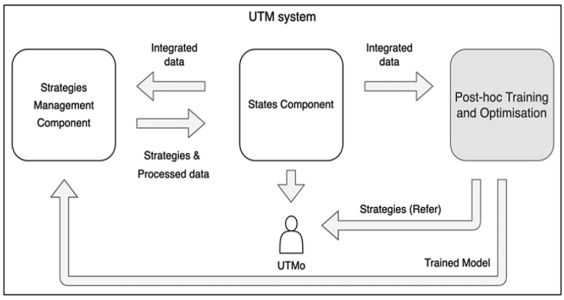


Fig. 4. IA-optimized UTM structure, from [25].

In previous works [24], they proposed a GRU recurrent network architecture for Deep Q Learning, which has components to deal with the multidimensional states of the environment and components for strategies management, as well as components for post-training optimization; in [25], the focus was on post-training optimization, with a component for generating training sets based on genetic algorithms and tabu search; the training data is stored in the strategy management component and the training data is the actual states.

The components may not always immediately achieve optimal solutions, but the data may be reintroduced into machine learning training algorithms.

Throughout the system operation, there is a continuous data exchange between the database and the route re-planning system, always integrating the data: the A* algorithm enters as a tabu search *pipeline* process, aiming always avoiding route conflicts or otherwise minimizing their effects. It also has its complexity increased as the system deal with more routes under these objectives.

[25] also conducted a case study simulating high-density operations. Finally, the tabu search presented, in comparison with the genetic algorithm, larger amounts of collision cases and a slightly smaller number of steps in the paths, also requiring time around 15% to 20% greater (roughly speaking), using modest *hardware* and *software* configurations.

The Bauranov and Rakas Review: Within this expanding universe, while several works (such as those already summarized here) make contributions to its development, [2] stand out for bringing together the most complete UTM research to date, listing, summarizing and synthesizing relevant studies grouped by factors that impact aerospace modeling.

Among the various points addressed, [2] research led them to gather knowledge to define the least problematic airspace possible, taking into account in a synthetic way problems that go beyond collision with structures and objects (including other aircraft).

The research also exposes important information, such as 1) the fact that the restriction that aircraft cannot be less than 5 nautical miles from another while in flight (or 90 s of range in cruising speed) does not aligns with the idea of small aircraft and in urban areas with low flight height; 2) the considerably high noise produced by UAVs tends to be a particularly difficult problem to deal with, and it is observed that this is becoming one of the most annoying sounds in

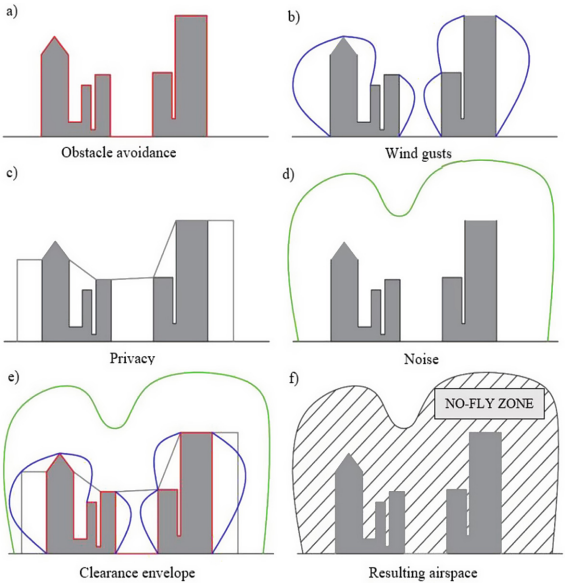


Fig. 5. Flight zones delimitation according to different constraints, from [2].

the modern world according to recent research [4]; and 3) visual pollution is also a popular concern, indicating that traffic over less populated regions (including over water) is a sensible idea for this problem.

The problems also come up against the issue of privacy and its moral, ethical and legal issues, as also observed by [19], given the fact that UAVs are usually equipped with imaging sensors (whether for recording images or for its avionics).

Other issues were also noted with regards to communication and sensors, including unreliability and errors that may be inappropriate for a system like UTM (like the ones associated with GPS).

But the most worrying problem exposed by [2] is the issue of wind gusts and weather conditions, presented as the main risk agents for UAV operations as well to any other aircraft.

More than just exposing relevant details about UTMs, [2] also suggest and support some assumptions such as the idea of avoiding regions and building critical infrastructure such as hospitals, militarized zones, schools and the like.

In summary, one of the contributions of [2] is the conservative airspace delimitation approach demonstrated in Fig. 5. This approach, however, practically eliminates the presence of UAVs in an environment where many of them must be used to fulfill their operational objectives: in the nearby urban environment, in direct or close contact with customers of their respective business models.

Additionally, [2] also summarized relationships between the amount of structure needed to establish the observed concepts, as well as plotted curves that describe the relationship between the amount of structure and various performance metrics; these relationships are shown in Fig. 6.

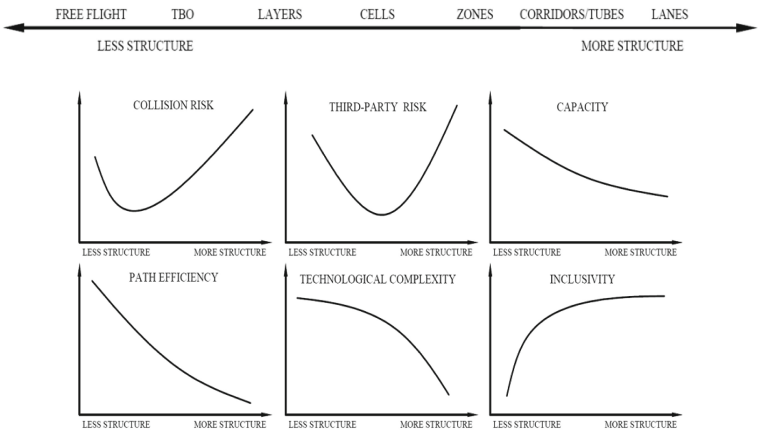


Fig. 6. Relations between the amount of structure needed for different concepts and their performances, from [2].

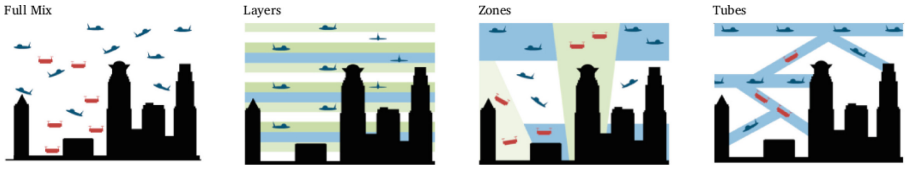


Fig. 7. Different airspace structures considered for METROPOLIS UTM, from [22].

Table 3. Comparison between considered structures for the METROPOLIS UTM [2].

Comparison attribute	Full mix	Layers	Zones	Tubes
Safety	2	1	3	4
Third party risk	2	1	3	4
Capacity	1	2	3	4
Efficiency	1	2	3	4
Noise	2	1	4	3

Finally, also in a comparative way, [2] addressed the concept of a UTM for the European Union called METROPOLIS [22] and its four different airspace structures: 1) free flight, 2) layers, 3) zones and 4) tubes, which are best graphically represented in Fig. 7 and whose comparison is summarized in Table 3.

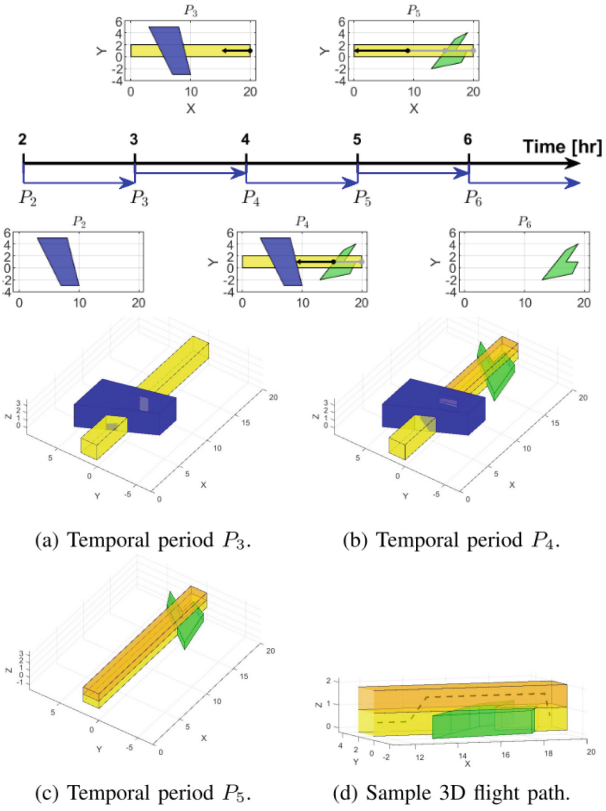
In summary, taking into account the work of [22] when comparing these four structures, the layers approach takes 1st place in the search for the best structure, followed by the free flight approach, while the 3rd place goes to zones structure and 4th (and last) place goes to tube structure.

Dynamic Four-Dimensional Geofences: [21] considers that, with the pace of growth in the number of UAVs in circulation, it should not take long before

the airspace where they travel becomes congested, either spatially or logically. To deal with such conditions, they proposed a UTM based on geofences that can be added, adjusted and removed from static and temporal definitions, with means for merging, partitioning and performing deconflictions of geofences.

In this UTM, the approved geofences would therefore be temporally organized and spatially processed to have non-conflicting boundaries. Hence, every conceivable airspace position is reserved for none or a single one geofence. They explored the theory and implementation of a geofences management system in UTMs and related algorithms, standing out for being apparently the first to offer deconfliction capabilities in three-dimensional geofences.

In practice, the geofence is an aerospace volume with spatial, temporal and permissive constraints. If a geofence conflicts with some airspace of higher priority (an airport, for example), the geofence must be defined in a way that excludes this region of higher operational priority. There may also be time restrictions on when users could define and make use of their own geofences, and the priority



(a) Temporal period P_3. (b) Temporal period P_4.

(c) Temporal period P_5. (d) Sample 3D flight path.

Fig. 8. Example of spatiotemporal evolution of geofences, from [21].

tiebreaker between two geofences may be in favor of the one defined first, so that the geofences created afterwards must adapt to the existing airspace.

For operational safety reasons, minimum vertical heights and widths must be established for the definition of geofences, and they can be also vertically partitioned to create deconflictions trends in the definition of new geofences. These partitions generated from the original geofence would be assigned for the same purpose, as two or more "subgeofences" of it, and which in practice compose a whole geofences, as can be seen in Fig. 8.

Fluid-Inspired Aerial Traffic Lines: At the same time that Ella Atkins was researching dynamic four-dimensional geofences, featured in [21], she was also busy collaborating with other innovative approaches. In one these approaches, [7] adopted continuous Eulerian mechanics as a way of coordinating spatiotemporal planning, such as an ideal fluid flow governed by Laplace partial differential equations (PDE). The solution seeks to be temporally invariant, and it's inspired by physical concepts rather than just mathematics.

Assuming that 1) the design and allocation of air corridors are centralized and 2) each UTM is connected to a single local UTM cloud that manages such airspace (mainly at low flight heights), the solution seeks to define smooth aerial traffic lines between obstacles (like buildings), as shown in Fig. 9, where the direction of these streamlines rotating clockwise every 5 m.

The approach ensures that traffic lines maintain safety margins away from obstacles. The operation of the traffic lines is in order of requests, and are optimized using Markov decision processes (MDP) which, according to hierarchically organized terminal and non-terminal states, optimizes the traffic lines; these MDP have a reasonable computational cost but take into account the optimization for a single aircraft at a time – check the diagram in Fig. 10.

For experimentation, simulations were conducted based on Downtown Tucson, extracting the coordinates of the region and converting them to Euclidean space, and model the 3D buildings in the simulation environment. In this environment, building areas were defined as obstacles, as shown in Fig. 11, and very close buildings were grouped into convex envelopes.

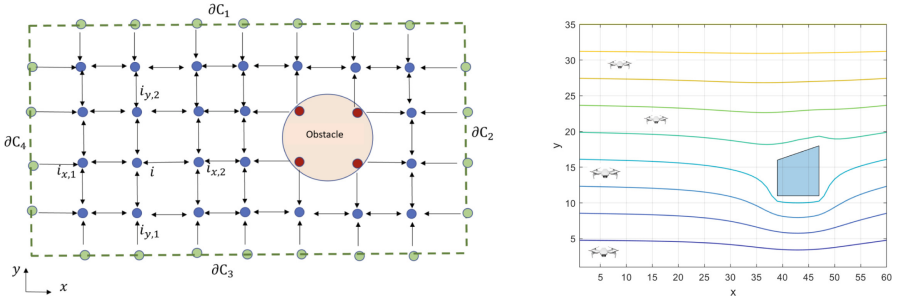


Fig. 9. Air corridors' streamline definition, from [7].

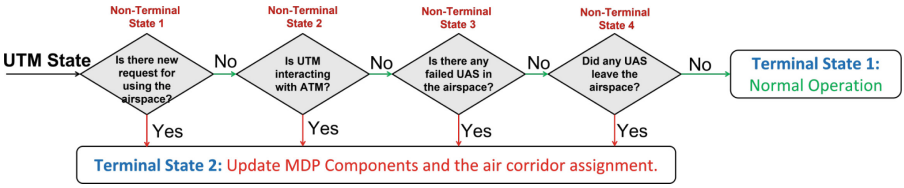


Fig. 10. MDP state machine for UAV allocation into the air corridors, from [7].

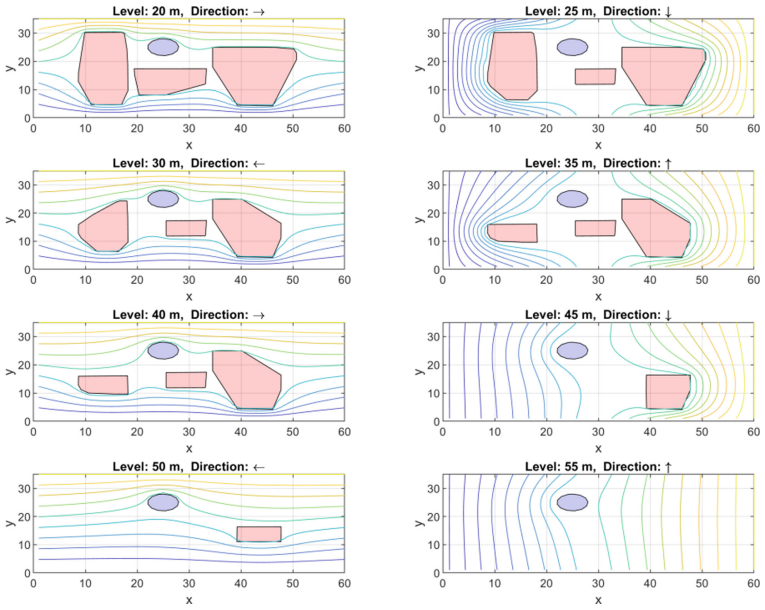


Fig. 11. Streamlines definition on layers, from [7].

Finally, from the streamlines with directions defined by height (with a 90 ° clockwise change every 5 m), the Euclidean space can be summarized as a set of graphs organized as a three-dimensional mesh that can generate routes from any linear programming algorithm.

4 Discussion

In view of the analyzed references, some patterns and preferences in technological approaches are notable, thus forming some specific lines of research that contribute directly or indirectly to the development of the UTM concept.

It is observed that several geometric abstractions were approached for modeling the environment, as well as different abstractions for defining the airspace. Figure 6 and Fig. 7 (with Table 3) summarized these abstractions in a synthetic and comparative way, showing that no approach meet all the needs of an UTM:

although the structures most recommended by [2] are free flight zones and layers. These structures stands out amongst the others with regard to safety, risk to third parties, traffic capacity, route efficiency and noise levels, but demand greater technological complexity both from the UTM and from the aircraft to work out, consequently being less inclusive.

Despite this diversity and the varied advantages and disadvantages associated with each structural abstraction, practically all approaches fall back onto the abstraction of the environment as a graph, either immediately (where the environment is in fact already modeled as a graph) or discrete (where the graph is defined after excluding obstacles and defining waypoints, among other processes). Consequently, approaches to routing and optimization are, in general, based on operation research algorithms and linear programming such as Dijkstra's algorithm, A* and ant colony algorithm.

The A* algorithm, for example, was the most common approach in both 2D and 3D abstractions, explicitly addressed in [17,18,23] and [25]. These first two also addressed Dijkstra's algorithm.

More than just generating optimal routes, however, there were concerns about the complexity of the system, with the computational cost distribution between the UTM and the aircraft, as well as the communication between them. The solutions presented by [10] stand out for considering a "thin" UTM system, where most of the computational processing cost would be outside the actual management system, distributing duties between other involved devices. [28], in turn, present a solution that relies on ideally minimal amounts of communication between the aircraft and the UTM. In contrast, [15] relied almost completely on connectivity for the efficiency of their approach, reinforced in [16]; even so, both have in common the proposal of their own communication protocol.

The need for changes in flight itineraries during flight was also a common concern in virtually every work that addressed the dynamism of air environments, considering both meteorological and systematic particularities. During prototyping exercises, [15] even assumed that this dynamism is so chaotic that they thought it best to prevent changes in itineraries from being made once the aircraft takes off, in addition to requiring the itineraries scheduling with at least half hour in advance; this more radical perception is somewhat in line with the contemporary work of [15], who argues that deconflictions do should be carried out in flight time, while making it clear that proactive deconflictions are much more desirable than reactive deconflictions. To better distribute the communication, making the problem more computationally manageable, [16] presented proposals that divide a larger UTM (linked to the ATM) into several subsystems that manage the zones in which they are responsible and establish contact with a superior centralizing unit.

For optimisation, the use of metaheuristics such as tabu search [23,25] and genetic algorithms [25] were addressed, presenting promising results. The use of more advanced artificial intelligence techniques in [24] has also applied recurrent neural networks and reinforcement learning for the definition and continuous optimization of routes, as well as Markov Decision Process [7].

Finally, since current aircraft do not necessarily follow the standards and technical approvals to be able to operate in the airspace governed by UTMs with considerable technological needs, and the very technological complexities of UTMs efficient enough to be implemented would be high, it is fair to believe that this type of service will not be implemented in the near future. Even after a decade of conceptual and theoretical development by several government institutions, research institutes and private initiative corporations, this is an area of research and development that still needs to mature.

5 Conclusion

The research and development of UAV traffic management systems comprises a relatively young area that mainly gathers around the term *UAV Traffic Management*, generally reduced to the acronym UTM. The first initiatives to establish concepts and theories about this area emerged in the early 2010s in efforts conducted mainly by the FAA in conjunction with NASA, with room for collaboration with other government agencies, academic and independent research groups, and private initiatives.

About 10 years later, the FAA-NASA UTM concept has expanded around the world and moves more and more interested parties to develop research to define, optimize and implement technologies and legal apparatuses to make UTMs something practical, real and effective, in order to insert UAVs and similar vehicles into modern society, with all their benefits that promise leading the world into the next techno-social revolution.

Despite all the advances established so far by the various research centers involved in the area (which also have the remarkable collaboration between key researchers), the development of UTM still depends to be maturated for it to be finally implemented: it is an area rich in discoveries and definitions to be made, with problems that await solutions from all sides.

We can speculate that the technologies that will allow the implementation of UTMs are already established, and that a set of them will be legally required for UAVs to operate in urban and interurban environments, as happened with conventional aircraft in the 20^{th} century. The requirement for these technologies, which ensure the safe and efficient operation of UTMs, will also push the development of the area, while make it more expensive and therefore less accessible.

It is then concluded that the research area explored in the bibliographic review is a fertile ground for the development of several research with the proposition of new approaches on, for example: 1) definitions of routes, 2) optimization of routes, 3) techniques of airspace modeling, 4) UTM system architecture modeling, 5) establishment of communication technologies and protocols.

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