Urban Air Mobility (UAM): A Model Proposal based on Agents using Netlogo

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Abstract: Netlogo is a tool for creating MAS (Multi-Agent Simulations), and it is used to create simulations for multiple areas and scenarios. With the advent of the use of manned and unmanned aerial vehicles, considering electric vehicles known as eVTOL (electric Vertical Take-Off and Landing), multiple problems in the urban environment appear. Also, as multiple vehicles are expected to be used to obtain urban mobility in dense metropolitan regions around the world, the concept of UAM (Urban Air Mobility) emerges as a way to assure environment air control. To not compromise the future of UAM, researchers were faced with the challenge of structuring the airspace with specific air traffic rules, with separations between vehicles lower than those currently applied, without reducing the aviation required safety levels. As testing in a real scenario is not practical, simulation is a form to gather data and define parameters for this new system. This work aims to present a computational tool that uses multiple agents to generate different UAM scenarios, being possible to analyse the impact that simulation input parameters variation will cause in the safety indicators proposed in the model.

1 INTRODUCTION

Every day, many hours are wasted by people on roads around the world. People spend a considerable part of their time commuting between work and home, resulting in millions of unproductive hours every day (Holden; Goel, 2016).

One of the biggest challenges for authorities around the world is urban mobility. Over the years, to make it possible to reduce travel time, especially in metropolitan regions where congestion has become a major problem, considerable investments have been made in inland transport infrastructure (Patterson; Antcliff; Kohlman, 2018).

However, with the constant increase in population and the consequent increase in demand for transport, in recent years the industry and scientific communities have invested resources to create new ideas to improve the performance of urban transport (Neto et al., 2019). As a consequence, the conception of an intelligent air transport system (UAM) (Thipphavong et al., 2018) has the objective to provide air transport services within a metropolitan area to overcome the increase in surface congestion.

Types of operations include emergency medical evacuations, rescue, humanitarian missions, newsgathering, land flow assessment, weather monitoring, cash deliveries, and passenger transportation (Thipphavong et al., 2018).

Several projects are under development for application at UAM. An example is eVTOL (electric Vertical Take-Off and Landing), considerably cheaper when compared to helicopters, which can be used for inspection, transportation of valuables and people, with a market potential of US$ 74 billion and 23,000 units by 2035 (PORSCHE, 2018). The forecasts are that, with the use of 4,000 eVTOL,

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55,000 air taxi flights will take place every day in the United States (Booz Allen Hamilton, 2018).

To this market not be compromised in the future, some barriers must be overcome. Some examples are aircraft certification, noise impacts caused in urban areas, cybersecurity protection, and the creation of an air traffic system with characteristics different from those displayed on conventional airspace.

The air traffic system required by UAM should be able to handle aircraft demands far superior to those currently existing in general aviation. Landings and take-offs will be possible in most varied places, increasing the complexity of managing this type of traffic. It is evident that there is a need for new criteria for separation between aircraft and for new vehicle performance both in landing and on take-off procedures and in cruising (level) procedures. In order not to compromise the required safety indices, new models of airspace complexity and airspace capacity should be presented.

As the scenarios using only one or a few coordinated eVTOLs are a majority in the literature, this works, however, not covers real case scenarios where we have multiple eVTOLs, not from the same organization.

An organization that tries to be competitive and operating multiple vehicles in the limited air space needs to try to create the best rules to ensure fair use of the resources in a safe way.

In this work, to simulate different UAM scenarios, a model developed using a computational tool based on agents (Multi-Agent System – MAS), called Netlogo, will be presented. During the execution of this model, based on the several parameters used, it is possible to change the behaviour of the system. The outputs generated, including the number of conflicts and possible collisions between vehicles, represent the safety indicators for each scenario, making it possible to establish a relationship between the inputs and the outputs in UAM scenarios. In this modelling, all vehicles will be considered unmanned.

Netlogo is used in a way that has a stable and powerful simulation tool, then it is possible in an easy way to develop the model and obtain the problem solution and results. The system will receive inputs (parameters) from the user and the model developed will execute the simulation and show the results.

We will make the development of this text as follows. Section 2 presents the tools used in this work: MAS and Netlogo. In Section 3 the UAM is conceptualized. Section 4 presents the model developed for the simulations and the criteria used and some example results. And finally, in Sections 5 and 6, the conclusions and future work are presented, respectively.

2 MAS AND NETLOGO

Some problems existing in the current approaches are the difficulty to validate scenarios with more than one vehicle and put more than one variable in an experiment and analyse the impact of individual variables in the whole system. And as there is no real system in operation, the simulation is the only feasible alternative to gather data before a real system could be implemented.

The approach that we used, in this case, is to provide a simulation that includes multiple intelligent vehicles, create a model using the characteristics that we want in a way that we could collect data close to the real. Then, for the reasons described, it is possible to see why this approach has been considered the best way to tackle this problem.

MAS (Multi-Agent System) is a paradigm for the development of intelligent systems, being a subarea of distributed artificial intelligence, widely used in several areas to solve complex problems in a decentralized manner, with or without coordination between agents. The agent-oriented paradigm is one of the main ones used in artificial intelligence, with the ability for multiple agents to act autonomously in a defined environment. Several applications are presented in the literature, including those that require high reliability, such as aviation (Wooldridge, 2002).

In MAS multiple agents are interacting, requiring the exchange of information between all, collaborating to achieve, together, the same objective. In other cases, they will work, with a certain collaboration, to achieve individual goals, which can sometimes even be conflicting (Wooldridge, 2002).

Netlogo is an agent-based language developed by Wilensky (1999) that presents simple structures to facilitate its use. Nevertheless, it is a language that makes it possible to build several programs, with results of different levels of complexity.

Netlogo, with its ability to be multi-agent, adds even more simulation features while maintaining the simplicity of the Logo with versions with 2D and 3D simulation capabilities. Also, Netlogo has been used in several academic works in the construction of MAS models for different areas such as Physics and Social Sciences (Wilensky, 2015).

However, we can find some relevant works with agent-based approaches applied to UAM, as is the case with eVTOLs. Most use an agent-based approach, forming a group (swarm) in which several agents coordinate for the execution of a task (Cooley; Wolf; Borowczak, 2019).

In some examples in the literature more complex problems are presented, where the agents are not used to achieve the objective in a coordinated way, with each agent having different objectives, often conflicting with each other. An example of this approach is found in Liao et al. (2017), where eVTOLs must maintain their separations in-flight using MAS.

Alvarez-Munoz et al. (2019) use MAS to decide whether an aircraft should use the collaboration of other vehicles to determine its trajectories. Despite this, it also considers the decision process based on consensus between the aircraft and not in a competitive scenario,

Postorino; Sarné (2020) proposed the use of MAS to measure the impact of mobility of people, simulating transport by air and land vehicles. This simulation was used to measure the impacts on urban mobility and the capacity to transport people.

Kitajima et al. (2019) use MAS to simulate the integration between autonomous and non-autonomous land vehicles with a focus on validating reliability in certain scenarios, considering cases of conflicts, cases of accidents, as well as other parameters. It is a proposal similar to the one presented in this work but applied to other types of autonomous vehicles.

3 URBAN AIR MOBILITY (UAM)

Due to concerns about the time spent by people travelling by land, mainly in places with high population density, researchers, industry, and authorities are looking for innovative solutions to this problem. Therefore, in recent years there has been a growing interest in the integration of urban air mobility (UAM) operations around the world, leveraging the development of new technologies and types of aircraft and thus requiring changes in the way of using and managing airspace (Bosson; Lauderdale, 2018; Lascara et al., 2019).

Urban Air Mobility (UAM) is a term used to describe a system that allows air transport services on demand, with a high level of automation, for the transport of passengers or cargo. The predominant vehicle in the UAM environment is the VTOL, enabling vertical landings and take-offs in small areas, called “vertiports”. Among the direct benefits of replacing, when possible, land transport employing air transport is the possibility of more direct routes and the increase in vehicle speed. These benefits can reduce the travel time of passengers in the current transport system, considering the door-to-door displacement (Patterson; Antcliff; Kohlman, 2018).

Considering the advantages presented for UAM (traffic decongestion, improved mobility, reduced travel time, reduced accidents, etc.), it is expected that there will be a considerable increase in demand for this type of service. However, for this to be possible, in the UAM environment vehicles with different ascending, descending, and cruising performances are required, as well as new parameters for separation between aircraft, new air traffic rules, and a new air traffic control system that does not compromise current security levels.

Companies like UBER, interested in this market and partnership with industry and researchers, have made vehicles with differentiated performance possible, in addition to noise reduction and lower fuel consumption expenses. These vehicles are called eVTOL.

Due to the density of traffic in the UAM environment, current ATC (Air Traffic Control) procedures are expected to be insufficient to deal with a large number of new UAM aircraft. This is due to the limitations of the air traffic controllers´ workload and the minimum necessary separation distances between the aircraft. Likewise, the design of airspace and current flight routes restricts UAM's access to significant parts of airspace above metropolitan areas (Vascik; Hansman, 2018).

Thus, some needs so that the future of UAM is not compromised are the availability of land infrastructure geographically distributed in areas where there is demand from customers, the integration of urban air transport operations with Air Traffic Control (ATC), and the potential need for a new automated ATC system to manage airspace below 3,000 feet (Vascik; Hansman, 2017), integrating airspace in a UAM environment with other existing airspaces.

This integration should under no circumstances compromise the levels of security expected in aviation as a whole.

Researchers around the world are aware of the challenges presented by UAM. The characteristics of the aircraft, the landing and take-off locations, as well as the demand projections, which create highly dense air spaces, compel the aeronautical community, in particular researchers and air traffic authorities in all countries, to propose new separation criteria, new air traffic rules and new models of complexity and airspace capacity.

In Neto et al. (2019) a computer simulation tool was presented to measure the safety and effectiveness of trajectory-based UAM operations, considering the presence of manned and unmanned eVTOL vehicles. In Baum et al. (2018) it was presented the concept called TML (Technology Maturity Level) related to the familiarization of ATCo (Air Traffic Controller) with unmanned aerial vehicles. From the simulation of different scenarios with the gradual increase of unmanned aircraft, it was proposed to gradually increase the ATCo's familiarity with these unmanned aircraft. Although the VTOL can be manned or unmanned, all concepts presented in this work will be based on unmanned aircraft.

The airspace where the UAM takes place in particular, and the concepts currently applied in air traffic can compromise the future of this market, such as, for example, the minimum separation applied between the aircraft can make it not viable. But knowing the relationship between the demand for eVTOL, its performances, and the safety indexes applied in aviation, we can try to define the number of aircraft that will be able to fly simultaneously safely, which is still a desire and a challenge for all researchers.

4 DEVELOPED MODEL

For the development of the model, Netlogo 3D version 6.1.1 was used. The proposal was to enable the creation of numerous UAM scenarios with the possibility of varying many proposed inputs. Thus, it will be possible to establish the relationship between the variation of a given "input" with the "outputs" resulting in the simulation.

4.1 Model Description

Aircraft generation and landing and take-off locations occur stochastically within the limits of the proposed scenarios. Considering that 1 NM (Nautical Mile) equals 1.852 km and 1 ft (feet) equals 0.3048 m, the dimensions shown are 30 NM x 30 NM or 15 NM x 15 NM, from 1000 ft to 3200 ft above the landing and take-off location. Each scenario is divided into 0.5NM x 0.5NM squares horizontally and 200 ft vertically.

This difference in the feet and Nautical Mile is because these are the most common distances in the aeronautical field and is necessary a smaller distance vertically to make the system secure, because of that the area is not a cube with equal sides and have different distances horizontally and vertically. We can see this division in Figure 1.

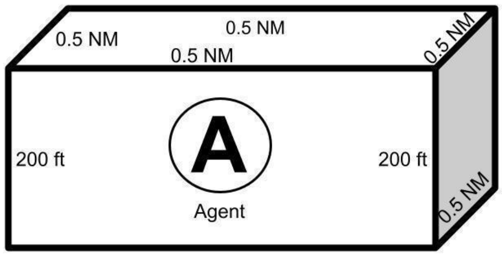

Figure 1: Illustration of the agent environment.

The air traffic rules included in the model, such as minimum horizontal and vertical separation, rate of climb and descent, speed when the aircraft is on a level (cruising speed) and altitude that it can maintain depending on the magnetic course it will use on the flight, as shown in Figure 2, that are presented in Neto et al. (2019). A new rule proposed in this work is the interdiction of the squares above the aircraft landing and take-off location, preventing other aircraft from crossing this air space whenever an aircraft is performing an approach or take-off procedure.

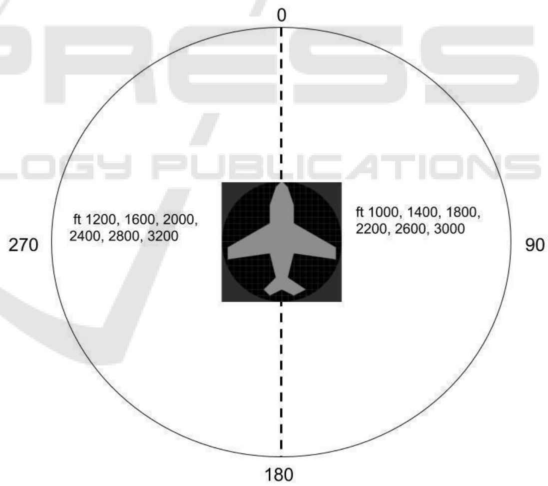

Figure 2: Division of altitude ranges by heading.

Figure 3 presents the graphical interface developed in Netlogo, where the green “buttons” are all the “inputs” that may be affected, making it possible to create numerous UAM scenarios.

Figures 4 and 5 show in more detail how the input interfaces look like. And Figure 6 shows in detail the output interface with text items and the graphs that show the variation during each iteration of the simulation.

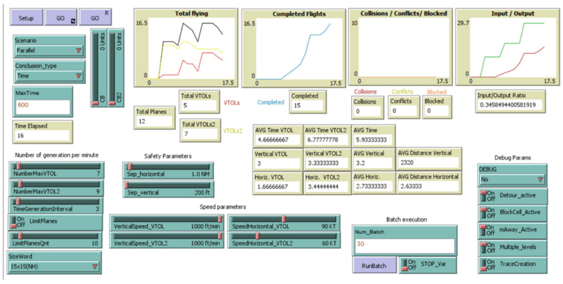

Figure 3: Netlogo graphical interface.

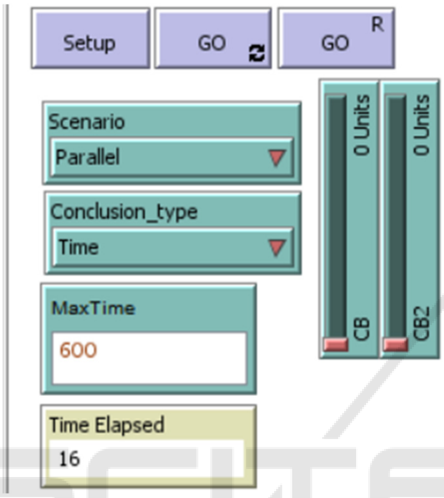

Figure 4: Netlogo controls interface detail.

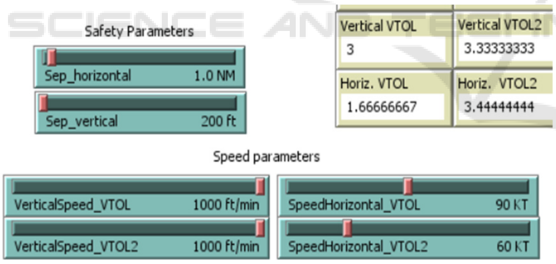

Figure 5: Netlogo velocity controls interface detail.

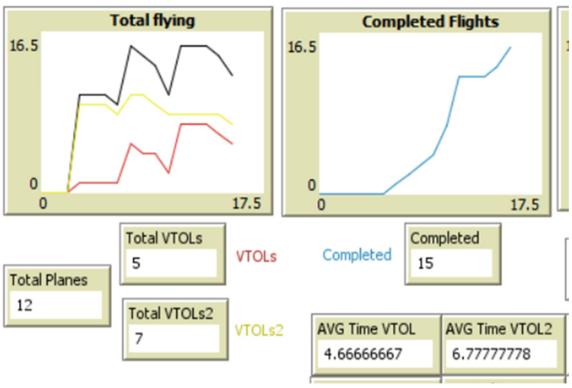

Figure 6: Netlogo execution interface detail.

Figure 7 shows the model in execution, with the agents (aircraft) in 3D. The VTOLs types 1 and 2 are presented by the different colours (yellow and red) in the model. These vehicles could have the same or different parameters as the number of vehicles in the airspace and different velocities (vertical and horizontal), as to simulate vehicles as fast small delivery and slow big passenger vehicles.

The inputs proposed in this model are:

1) Scenarios: the scenarios describe the formats of the trajectories, which can be classified in parallel, perpendicular, and general (in any direction), relative to the other planes in the same level;
2) Simulation time: the time may vary according to the analysis that will need to be performed;
3) The number of VTOL1 and VTOL2: in the simulation two different types of VTOL are possible, being at the discretion of the researcher how the horizontal and vertical speeds will be varied. Thus, it will be possible to maintain aircraft with different performances in the environment so that the impact on the safety indices presented analysed;
4) Aircraft generation interval: it is possible to vary the aircraft entry interval, making air space increasingly dense;
5) Safety parameters: it is possible to vary the minimum horizontal and vertical separation so that the impact on safety indices is analysed. Although the necessary separations between aircraft in UAM airspace are being proposed by different entities, the values used in this investigation consider the reference present in the literature (Neto et al., 2019; Booz Allen Hamilton, 2018), that is, 0.5 NM horizontally and 200 ft vertically;
6) Vertical and horizontal speed: the vertical speeds (rate of ascent and descent) and horizontal of the VTOL1 and VTOL2 may be varied to increase the complexity of the airspace and verify the impacts on the safety indexes.

The "outputs" proposed in this model, which can be called security indexes, are:

1) Completed trips: traffic will be considered complete when it takes off and lands within the simulation time. If the environment becomes more complex, forcing the aircraft to wait to comply with safety parameters, the number of traffic completed may vary;

2) Collisions: traffic should, in principle, always be kept in different squares (0.5 NM x 0.5 NM and 200ft horizontally). However, depending on the level of complexity generated in the scenario, these minimums may be compromised. If two aircraft are in the same grid, a collision is considered;
3) Conflicts: conflicts are considered when the aircraft does not comply with the minimum horizontal and vertical separation presented in the safety parameters;
4) Blocked aircraft: is the computation of the number of aircraft that will maintain their position for more than 10 min in order not to enter restricted airspace.

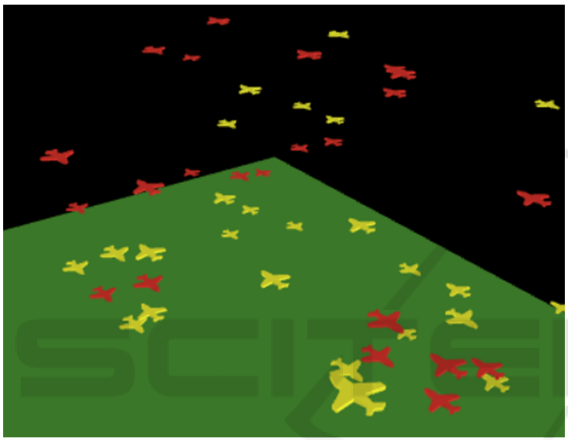

Figure 7: Running Graphical View of the 3D agent model.

Considering that the generation of the scenarios is stochastic, it is necessary to perform a considerable number of tests per scenario for the analyses to be correctly performed. For this purpose, the “batch” function was created in the model, making it possible to define the number of experiments for the proposed scenario, exporting the data from the multiple simulations to CSV, making posterior analysis possible.

4.2 Model Validation

For model validation, air traffic specialists analysed each proposed scenario by comparing the results obtained with the expected results. Considering that all landing and take-off locations are stochastically defined, to enable the analysis, the following validation outputs were created:

1) Average Vertical Distance: average vertical distance, of all simulation aircraft, between the landing and take-off location and the cruising level;
2) Average horizontal distance: average horizontal distance of all aircraft in the simulation, between landing and destination;
3) Average horizontal flight time: it is the average time used by all aircraft at the cruise level;
4) Average vertical flight time: it is the average time used by all aircraft in the ascent and descent procedures;
5) Total average time: is the sum of the average time used by all aircraft;

The model used was validated and considered ready for the simulation when it was found that the behaviours of the agents (aircraft) and the outputs generated were compatible with the chosen performances, as well as with the other parameters used.

4.3 Example Case

For example, we could have a sample execution using only VTOL1 with 400ft/min and 90KT using simulation, putting between 0 and 3 new vehicles every 3 minutes, running each simulation for 600 minutes. Using a travelling environment of 15 NH x 15 NH. Executing this simulation 100 times, we could take some median values of each execution.

In this sample, we have 220.48 finish planes per run (with a standard deviation of 14.23). These planes run in the median of 2593.15 ft (with a deviation of 83.82) and take 6.99 minutes in the median (with a deviation of 0.20).

Taking this value, we can see that a plane running in a 400ft/min for 6.99 minutes will take a distance of 2794.32 ft. We could see that our median value is 7.2% less than that because the vehicles could not use the full velocity or have to stop and wait, this is the loss of performance by having multiple vehicles sharing the same airspace.

5 CONCLUSIONS

Due to the high population density in several metropolises, researchers, industry, and authorities are faced with the challenge of solving the problem of urban mobility. Thus, the concept of UAM (Urban Air Mobility) emerges and, with it, countless new challenges for the viability of its future.

The vehicles proposed for use at UAM have performance for vertical landings and take-offs, called VTOL, with the electric version called eVTOL. These vehicles have operational conditions to land

and take-off in small areas, called “vertiports” in the literature.

Conventional aviation has well-defined landing and take-off procedures, with separations between aircraft applied without impacting the system's capacity and with a well-defined strategy for traffic and airspace management. However, if we use such concepts, the future of UAM will be compromised. It is a consensus among researchers from all over the world that the parameters and equipment used, for example, in air traffic control of commercial aviation are not applicable at UAM, making all operations unfeasible.

New models of complexity and airspace capacity should be developed based on the operational characteristics of eVTOL. In this work, to simulate UAM scenarios, a model was presented using Netlogo. In the model it is possible to vary several parameters ("inputs"), checking their impact on the simulation results ("outputs"). After an exhaustive process of checks by air traffic specialists and successive calibrations, the model proved to be satisfactory for simulating UAM scenarios.

Using this model, we could validate ideas from the literature of how the system should behave and validate all the parameters and impact in the system.

6 EXPECTED RESULTS AND FUTURE WORK

With the presented model, it is possible to generate several scenarios, checking what is the impact on the results when there is a variation of the input parameters.

The results of the simulations will be used in the future for the development of an airspace complexity model. The studies sought to define the relationship between the variation of "inputs" and the increase in the complexity of airspace and the consequent impact on its capacity.

In the future, it will also be verified what is the appropriate limit of minimum horizontal or vertical separation between eVTOLs without compromising the level of security required for aviation. This is possible since any variation in the proposed safety parameters changes the model's “outputs” and can be considered as safety indicators, presented in this work as “completed”, “collisions”, “conflicts” and “blocked”.

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