A Feasibility Study for the Development of Air Mobility Operations within an Airport City (Aerotropolis)

Xi Wang[1], Michael Balchanos[2], and Dimitri Mavris[3]
Georgia Institute of Technology, Atlanta, Georgia, 30332, Unites States

This study aims to create a simulation environment to study the feasibility of an Advanced Air Mobility (AAM) system in an airport-centric infrastructure or aerotropolis area. The environment and the study are to confirm the effectiveness of the AAM system in terms of reducing traffic congestion for road networks and the reduction in carbon emissions for transportation methods. The traffic simulation will run a baseline simulation with the currently available mobility methods and an alternative simulation with a proposed small network with close distance flights AAM system of 9 vertiports. The traffic modeling utilizes Agent-Based Modeling (ABM) to accurately models the two cases and compare trip times of the two cases. The emission modeling models the emission of carbon per mile of travel for different mobility methods and use the miles traveled from the traffic simulation to calculate the emission. The conclusion was drawn based on the two comparisons of the change in travel time and the change in emission. A small AAM system servicing a small area with short flight legs is found to be effective in both decreasing trip times and decreasing emissions and is significantly more effective when the ground mobility network is congested and not accessible.

I. Introduction

An Advanced Air Mobility (AAM) system is an emerging concept of mobility method. The method utilizes electrical Vertical Take-off and Landing (eVTOL) aircraft as a public transportation method to reduce travel time and greenhouse gas emissions. The results are made possible as the electric-powered aircraft have zero direct emission, and road load is reduced as a portion of the traffic is redirected to the air. It experienced a dramatic increase in interest during the past decade as traffic congestion in urban areas surged. An aerotropolis, or an airport city, is a new urban form evolving around many major airports. It includes the airport and its surrounding areas, including businesses and living districts. It is a heavy traffic hub and an air mobility center with a complex, multidimensional transportation network.

Congested traffic has been a rising issue for metropolises around the United States, forcing commuting drivers to spend a significant amount of extra time on the roads. According to INRIX Global Traffic Scorecard [1], some of the most congested cities are located in the United States, including New York City (ranked 5th), Chicago (ranked 7th), and Atlanta (ranked 59th). Being the 10th most congested city in the U.S., an average commuter in Atlanta would waste more than 53 hours and more than $800 a year in traffic jams. The congestion on the road traps not only average commuters but also commercial vehicles, causing damage to the economy. Even though there are available alternative public transportation methods such as ride-share and metro public transport systems such as buses, they are all vulnerable to congestion in the road network.

Slow-moving traffic also increases carbon and greenhouse gas emissions as the engines idle more in congestion, according to the Department of Energy [2]. Despite the increase in traffic congestion, cities around the states aim to reduce emissions. The city of Atlanta plans to reduce transportation-related emissions by 40% by 2030 while reducing single-occupancy vehicle travel [3]. These motivations showed a demand for a renewable public transportation method for the city. The AAM system could address both issues as the use of electrical Vertical Take-off and Landing (eVTOL) aircraft results in no direct emission and reduces the load on the ground mobility network as a portion of the

---

[1] Graduate Research Assistant, School of Aerospace Engineering, AIAA member.
[2] Research Engineer II, School of Aerospace Engineering, AIAA member.
[3] Regents Professor, School of Aerospace Engineering, AIAA Fellow.

traffic is taken to the air. These aircraft take off and land on vertiports – a specialized infrastructure similar to a heliport – scattered around the city.

AAM could affect the recent rise of interest in smart cities and smart infrastructures. Smart cities and infrastructures are urban areas and buildings that use different types of data collected to manage assets and resources efficiently. Those types of assets could use their collected data for rapid solution implementation to address the issue more efficiently, whether it is congested traffic or a surge in electricity usage. With the AAM system implemented, a smart city could utilize this next-generation mobility method as a new solution. For example, the city could decrease ticket prices and increase the frequency of flights during rush hours to prevent traffic congestion on the ground mobility network.

Due to the complexity of multidimensional traffic from ground to air, an aerotropolis is very likely to be a smart city in terms of traffic management. Implementing an AAM system in an aerotropolis not only could benefit the city, but it could utilize the already available Air Traffic Control (ATC) system during the early stages of operation before the system matures. Therefore, the Atlanta Aerotropolis was selected as the case study area due to its characteristic of it being a central hub of ground traffic (passenger cars, buses, and cargo trucks) and air traffic. By selecting the complex study area, the simulation environment could be used in other complex areas.

Multiple stakeholders were identified as relevant to the project, including aviation administrative agencies, vehicle manufacturers, city planners, and infrastructure providers. Their shared interest in the area is simulation analysis to identify the feasibility of the new mobility method. This study focused on simulating the feasibility of AAM operating on a specific route. Therefore, it is catering to the city planners more than the other stakeholders. Figure 1 shows the overlapping interest of potential stakeholders.

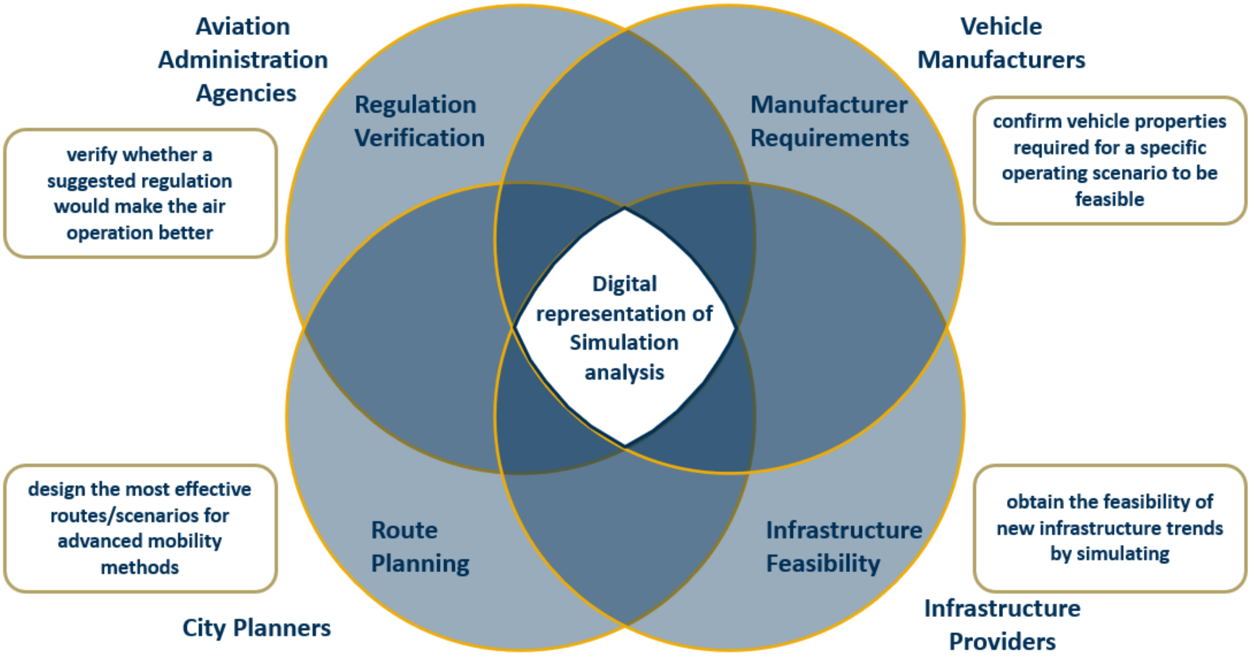

Fig. 1 Potential stakeholder interest

The study aims to analyze whether introducing a limited AAM service of a small network with close-distance flights in the Atlanta Aerotropolis will reduce traffic congestion and emission. The model in this study prioritizes reducing travel time for commuters and calculates the emission based on the result. Certain challenges in the study include the requirement of a large-scale traffic simulation capable of simulating commuter interaction; the uncertainty of future battery technology that influences the performance of eVTOL aircraft; the complexity of the airspace and related FAA regulations. By overcoming these challenges and creating the simulation environment used in this study, the stakeholders will be able to simulate their proposed AAM corridors and routes to check the feasibility of such routes before investing millions of dollars into the infrastructures.

II. Literature Review

There are no existing studies that simulate how an AAM system performs in a simulated traffic system with all other possible methods of transportation. Past AAM studies this study looked at include optimization of siting the vertiports by solving a Facility Location Problem [4], study for AAM operating environment [5], demand estimation for AAM commuters with a focus on cost [6], challenges of battery-powered flights [7], and the impact of AAM in the vicinity of an airport [8]. Taking the conclusion and takeaways from these previous studies into account is to make the simulation of this study closer to reality.

Chitale, Y of the Aerospace Systems Design Lab (ASDL) of Georgia Institute of Technology studied the optimization of siting vertiport locations by formulating and solving it as a Facility Location Problem [4]. The study applied the optimization model to South Florida and used U.S. census data to obtain commuter demand. An additional constraint of cost and residential and workspace demand is used. The study compared the result of 2010 and 2019 and found that the change in commuter demand profile across nine years is sufficient to alter the solution of optimal vertiport placement [4]. This study suggested that in order to obtain a sustainable vertiport placement, demand data across some time period should be studied, and a change in demand trend concluded. The study placed vertiports at the center of Census Tract (CT) blocks to simplify the model, which would not be applicable in the new model.

A team of researchers at ASDL evaluated different Concepts of Operations (ConOps) and produced a dashboard with a surrogate model [5]. The study evaluated how the impact of an operating AAM system changes during certain scenarios: weather conditions, evolving environmental constraints, and improvements in technologies. The study concluded that with the improvement in battery technology, bigger eVTOL aircraft with heavier loads would benefit more. It also concluded that an on-demand service would result in less environmental impact than scheduled service. These aspects were implemented in the new model.

Researchers from Virginia Polytechnic Institute and State University evaluated the commuter demand for an AAM system in Northern California, focusing on cost. The study included several available public transportation methods as alternatives to AAM for comparison. The study used Open-Source Routing Machine (OSRM) to find the shortest path for commuters. The study showed that the AAM system would suffer issues such as peak hours and deadheading, just like any other public transport method. Special pricing may be used to reduce the number of travelers at peak hours to avoid overbuilding the system resulting in empty aircraft during non-peak hours. A unique issue to the AAM system is the regulation of land use. As high-demand areas are mostly city centers, the government will play a significant role in the siting and building of vertiports in the future [6]. The model based on OSRM in this study cannot simulate the interaction of different traffic systems, and the vertiports were simply placed in the center of the Census Tract block without any detailed siting. The new model is capable of simulating all mobility methods so the commuters can choose which to take based on their priorities, and have vertiports sited based on not only demand but also government land use data to find vacant exempt land to avoid the risk of regulations.

Viswanathan. V published a *nature* article on battery-powered flights [7]. In the article, he summarized the battery cell-specific energy and maximum powers of different types of aircraft and compared them to the usable energy density of available batteries in aviation. In conclusion, batteries having 300-400 watthour per kilogram is sufficient for intracity flights. During a seminar he gave at the Georgia Institute of Technology, he summarized the energy required for available eVTOL aircraft on the market. This study will use the average number of 300 watthours per passenger per mile in the ABM model. However, Dr. Viswanathan also stated that the battery currently certified by the administrative agency has a lower energy density than the required 300-400 watthour per kilogram.

The German Aerospace Center (DLR) published a study on the effect of an AAM system in the vicinity of an airport on commercial air traffics [8]. The study simulated an AAM shuttle service at Hamburg airport approaching the runway in different directions. It also simulated both an approach to a runway and an approach to a designated vertiport. The result showed that the AAM service only did not affect the commercial air traffic when it is operating to designated vertiports and approaching at a large angle to the runway. This will be implemented when planning AAM routes at Atlanta Aerotropolis for the model.

III. Methodology

The study will follow a road map shown in Figure 2. The solution consists of two simulations: traffic simulation and emission simulation. Geospatial analyses were performed along the development of the simulation models to provide them with the necessary shapefiles and to visualize the data obtained for decision-making on key features such as the eVTOL route planning. The outcome was drawn by comparing the change in travel times by implementing the new AAM system in the simulation model.

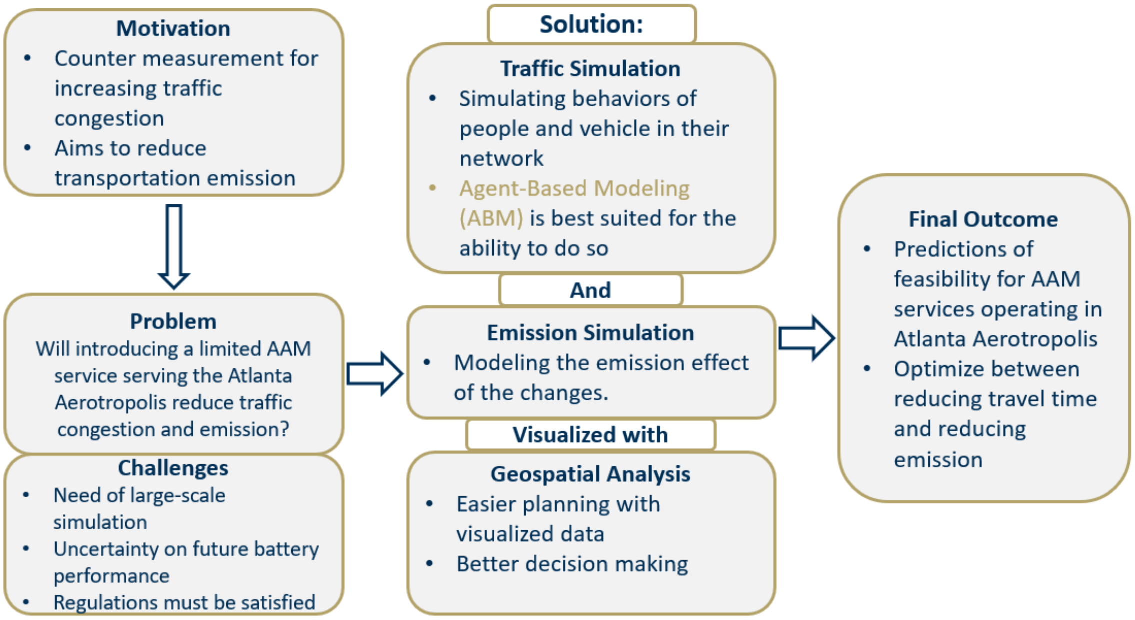

Fig. 2 Master road map outlining the course of this study.

The traffic simulation requires a simulation of the decision process of commuters to choose a mobility method based on their priorities. Agent-Based Modeling (ABM) method was chosen for its ability to simulate each commuter as an individual agent commuting through the Atlanta Aerotropolis. GAMA [9] was chosen due to its advanced driving simulation ability to simulate driver's characteristics on the road, such as rapid acceleration and constant lane changing, and correctly representing the characteristic of public transportation methods.

A. Data Collection

The study started with collecting data for the population flow to build the commuter demand. Researchers from the University of Wisconsin-Madison published a set of human mobility flow datasets [10] that used SafeGraph data which tracked cell phone signals from the originating CT block to the destination CT block in a day from January 2019 to April 2021. The study summarized the human flow for both the local population and visitors visiting the area on a daily and weekly basis.

The study requires the daily commuter demand for the Atlanta Aerotropolis. Therefore, only the population flow data was collected. Since the original data covered a total timespan of two years and was for the entire United States, it was filtered to the C. blocks within the Atlanta Aerotropolis. Average and medium population flow was calculated to use in this study. An Origin-Destination (O.D.) matrix was created using the filtered data for ABM modeling. O.D. pairs with a distance of fewer than 5 miles were filtered out from the visualization as the distance was too close for AAM service to be effective [6].

Income was then looked at to determine the ability of the local residents to afford the AAM service. Due to the high cost of building vertiports and eVTOL aircraft, the system cannot be affordable without government subsidies. Medium household income data for each CT block from the Atlanta Regional Committee (ARC) [14] was visualized with the demand. Some tracks have endpoints outside of the Atlanta Aerotropolis boundary due to a part of its associated CT blocks being in the boundary, as seen on the left part of Figure 3.

AAM data for traffic and emission modeling required are the speed of the eVTOL and the energy consumption of the eVTOL. By averaging the available models of eVTOL on the market, a cruise speed of 120 mph was concluded. From Dr. Viswanathan, the average energy consumption rate of available eVTOL aircraft at full occupancy is around 300 watthour per passenger per mile [11].

B. AAM corridor planning

With the demand and affordability visualized, the AAM corridors could be proposed according to FAA regulations. FAA AAM ConOps [12] stated that operations within an AAM corridor do not vary with airspace class, granting the permission to plan AAM corridors within KATL Class Bravo airspace. ATC tactical separation services are also not provided within AAM corridors and are allocated to AAM operators and PICs. These statements gave freedom to plan AAM corridors. Aviation obstacles data were provided by Beavers, M. from ESRI. These data were overlayed on top of the commuter demand and income for a better visual to plan the corridors.

The AAM corridors were proposed and shown in Figure 3. eVTOL aircraft travels through the corridors on a demand-based service to minimize environmental impact [8]. 9 vertiports scattered around the higher income side of the Atlanta Aerotropolis are connected based on the commuter demand. The vertiport at the airport is proposed to be on top of the main terminal for easier access to the airport. As shown in Figure 3, AAM corridors into the airport vertiport are combined into two approaches and depart routes. At a vertical angle to the adjacent runways, the proposal is to minimize the impact on commercial airliner traffic at the Atlanta airport [11].

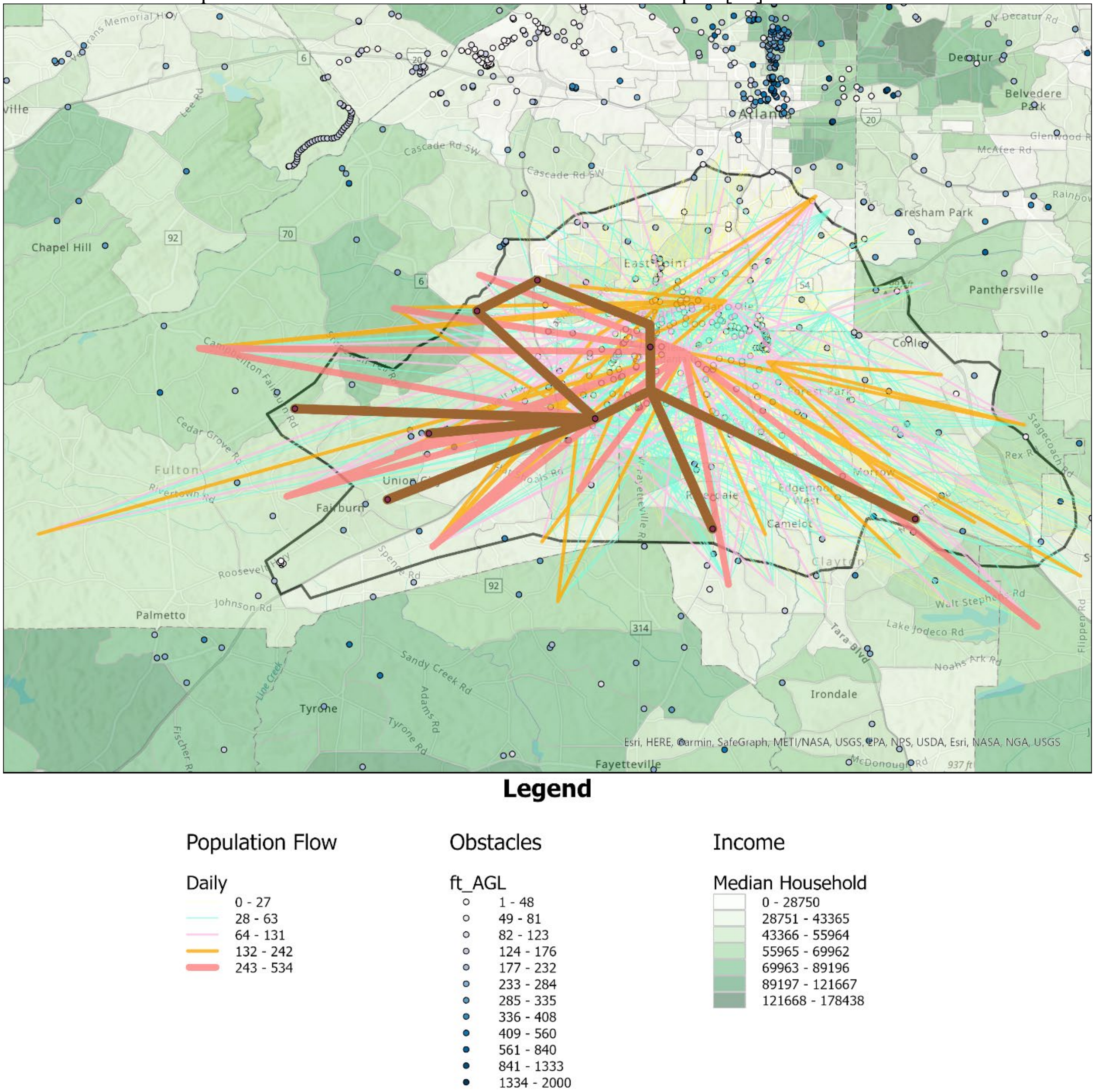

Fig. 3 Completed geospatial analysis model.

C. ABM Modeling

The ABM model consists of a baseline layer with the currently available mobility methods in the Atlanta Aerotropolis and an AAM system layer. The baseline layer consists of three types of mobility methods: privately owned vehicles, MARTA trains, and MARTA buses.

Privately owned vehicles are simulated as agents moving on a road network. The shapefile for the road network was obtained from ARC [13] and was cropped to the Atlanta Aerotropolis. MARTA trains and buses are simulated as public transportation. Figure 4 shows the baseline mobility network of the Atlanta Aerotropolis with road segments in green and the MARTA bus stops and rail stations in dark blue dots.

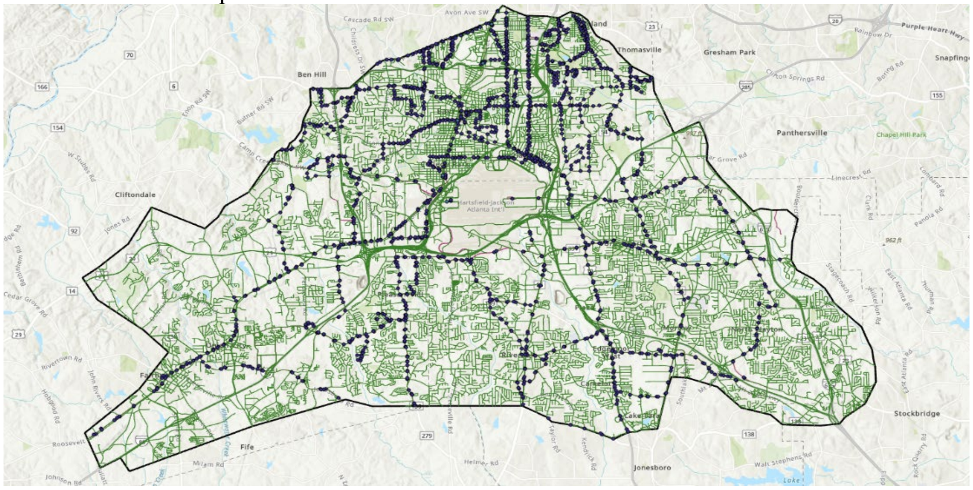

Fig. 4 Baseline mobility network for the Atlanta Aerotropolis.

Each road segment was assigned a speed limit based on Georgia Code Title 40, Chapter 6, Article 9, § 40-6-181 - Maximum limits. The agents were assigned random driving parameters if they chose to travel by personally owned vehicles. The advanced driving simulation ability of GAMA is able to simulate the driving style of drivers by randomly assigning parameters such as the probability of changing to a fast lane or the maximum acceleration and deceleration to the driver. With the advanced driving feature, if a driver is too aggressive and keeps shifting lanes, the driver may cause congestion on an otherwise clear road for a simulation closer to reality.

The ABM simulation logic works as follows. The travel demand was modeled following the four-step method. People agents were spawned based on the input from the commuter demand data. Those people agents were spawned in an origination CT block and were assigned a destination CT block. They will be spawned in a residential building and will travel to a commercial or industrial building in the morning and reverse the process in the evening. They will choose a mobility method based on their assigned priority. Then they move to the destination using their mobility method of choice. With agents on the road, the model will calculate the new congestion parameter on each road segment, so the newer spawned agents will take the congestion into account when choosing their mobility method. Shown in Figure 5 is the simulation logic for the GAMA model.

The simulation was run with a set of different inputs to obtain the effect of varying eVTOL energy consumption rate and price to travel on the AAM system to the traffic congestion and emission in the Atlanta Aerotropolis. These inputs were selected as variables due to the uncertainty of future eVTOL technology and the infrastructure cost of AAM systems. The energy consumption rate of eVTOL aircraft will be changed from 150 watthours per passenger per mile to 450 based on the referenced 300 watthours per passenger per mile [10]. The price to travel on the AAM system will be changed from $2 per passenger per mile to $4 based on the referenced $3 per passenger per mile [6]. Due to the AAM operation consisting of electric-operated eVTOL aircraft, charging times for those aircraft were considered. However, with the eVTOLs having high-performance batteries and charging times as low as 15 minutes to charge to 80% of the capacity from empty [15], the action of downing an aircraft to charge is ignored in the model as the charging could be completed during the time it takes to unload and reload passengers for short flights within small networks in the study.

A high-demand case of an air travel demand peak will also be run as a comparison. The case is set to simulate a holiday where the demand for traveling to the airport to take a flight significantly increased compared to the average daily demand. The difference in demand for the traffic network will cause a significant difference in the result.

To account for the stochasticity nature of the ABM model, the study will be looking to produce trendlines by running the model at small increments instead of exact numbers as a result.

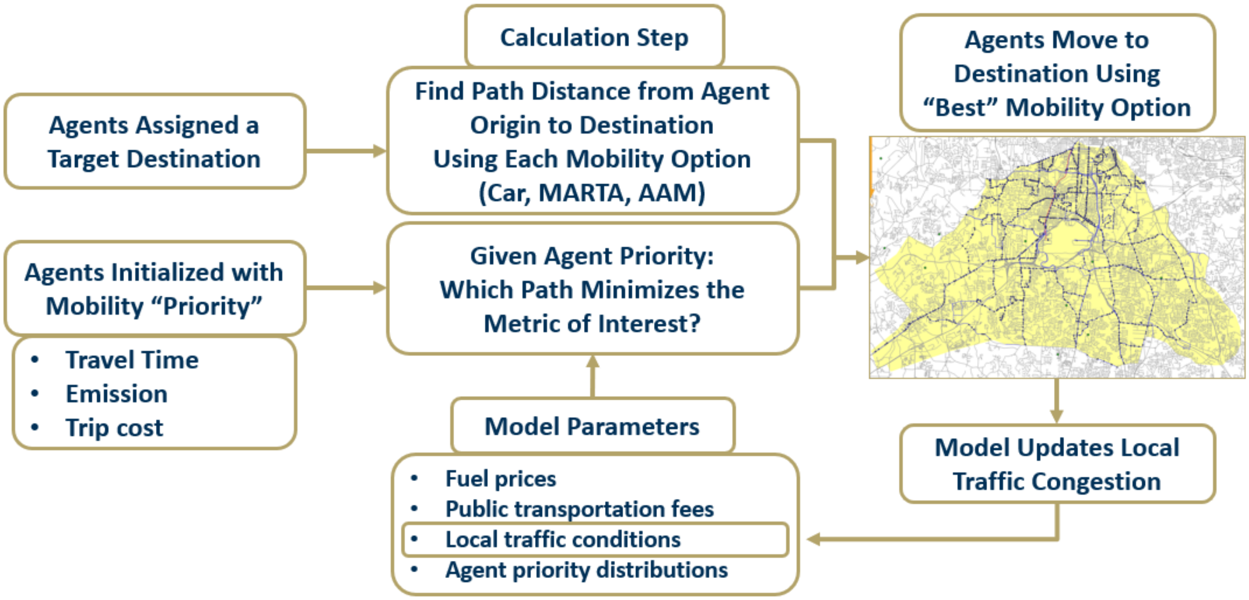

Fig. 5 ABM model logic

D. Emission Calculation

With the energy consumption data for eVTOL collected, the study used the Georgia Power electricity cost data to obtain the amount of emission per kWh of electricity produced.

As shown in Equation 1, the total emission of the eVTOL aircraft can be calculated:

$$Emission = Energy\ Consmuption\ Rate \times Distance \times Emission\ Rate \tag{1}$$

where the emission is in $kg\ CO^2$, the energy consumption tare is in $kWh/pax/mile$, distance is in miles, and emission rate is in $kg\ CO^2/mile$.

The same logic was used for other methods of mobility that were powered by electricity. The emission of gas-powered vehicles was calculated by assuming the vehicles on the road are all the same type of vehicle with an averaged fuel consumption rate and the same emission per gallon rate to simplify the calculation.

IV. Results

The simulation was run for sensitivity studies to study the dependency of average trip time on the price of AAM service and the average trip emission of the traffic networks to the eVTOL energy consumption. Three plots were generated, average trip time versus the cost to ride in the AAM network for normal demand (Figure 6), high demand (Figure 7), and average trip emission versus eVTOL aircraft energy consumption rate (Figure 8).

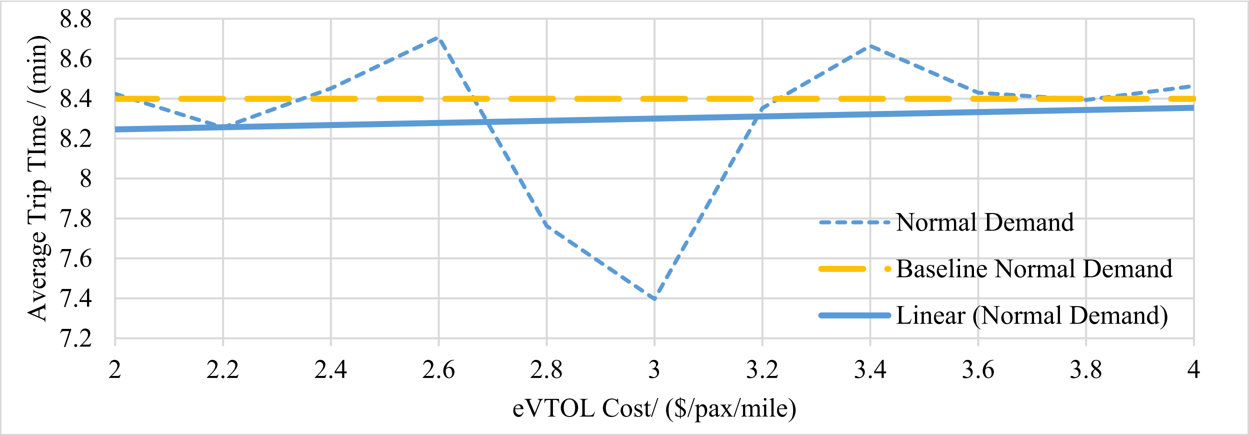

Fig. 6 Average trip time to eVTOL cost for normal travel demand

Both demand cases showed a decrease in the trip time from the baseline scenario, showing that the AAM system effectively reduced traffic congestion. The high-demand case showed a more significant decrease, showing that the AAM system is more effective in congested road networks.

The emission results also show the AAM system is more effective in the high-demand case. With little to no decrease in emissions for the normal-demand case shown, the effect of the AAM system on the aerotropolis in this condition requires further study.

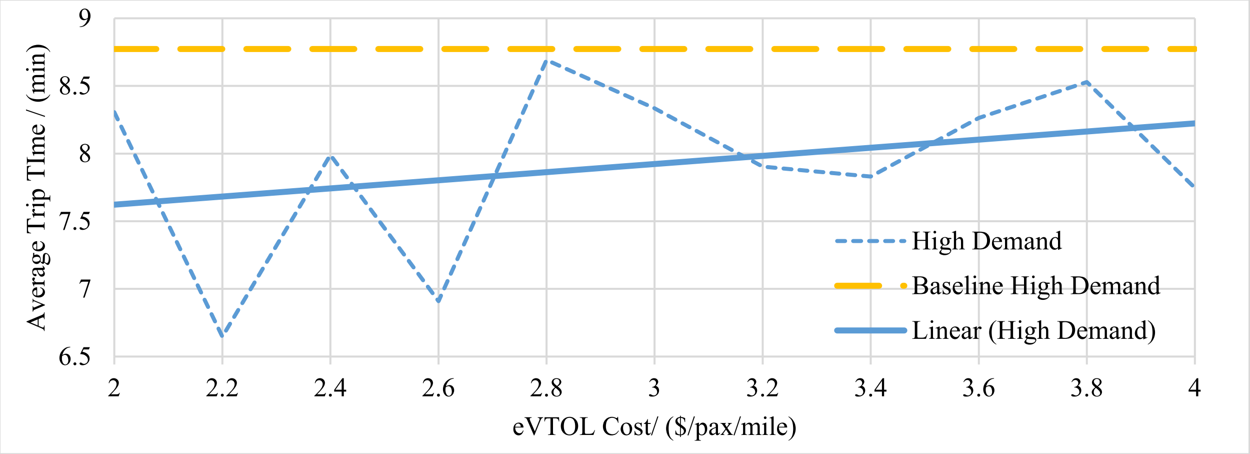

Fig. 7 Average trip time to eVTOL cost for high travel demand

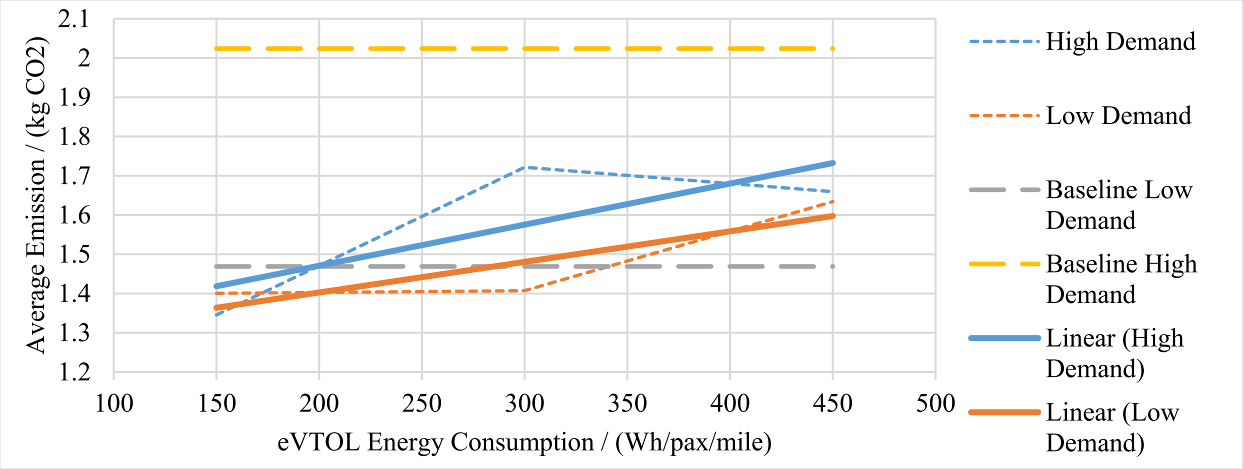

Fig. 8 Average emission per trip to eVTOL energy consumption rate

V.Conclusion

The study successfully produced a simulation environment using ABM modeling to simulate the traffic flow in the Atlanta Aerotropolis. Based on the demand data, agents moved to their destinations using their preferred way of travel. Trip time and emissions were calculated to determine the feasibility of the proposed AAM service.

The model produces a similar trendline with the anomaly of traffic being more congested as the cost of AAM rides decreases, as shown in Figure 6 and Figure 7. The result predicts that the average trip emission and trip time would decrease with reduced eVTOL energy consumption and AAM travel cost.

In conclusion, for the AAM system to be efficient and feasible in a small network with close-distance flights, there direct route in the road network between the origin and the destination must be congested or not accessible. With an already developed road network, the AAM system will only be effective in reducing trip time for commuters during peak traffic hours. The AAM system would be considered overbuilt during a long day of low commuter demand.

Some factors were not considered yet in the study. The study did not consider the possible eVTOL choice for a small network is most likely going to be single or double occupancy eVTOLs which have a lot lower energy consumption than the ones used in the calculation in this study. With small eVTOLs having energy consumption rates as low as 100 watthours per passenger per mile [10], the service could be even more beneficial to reducing carbon emissions. The effect of MARTA buses on road congestion was not considered as the buses are now modeled on a separate network without interference with the privately owned cars' network.

There are future works that could be done for the study. The baseline model could be validated using traffic data from the Georgia Department of Transportation (GDOT) [14]. Traffic count data for roads could be used to compare with the traffic in the simulation. As the model does not simulate the thorough traffic flow on interstates that passes through the Atlanta Aerotropolis without stopping, only traffic flows on the local road segments should be compared. To better model the through traffic, changes to the model must be made.

There is a lot of potentials to develop this study further in the future. The logic for the ABM simulation could be integrated into a simulation environment with an easy-to-use Graphical User Interface (GUI) for use by the stakeholders of the AAM system themselves. With surrogate modeling built into the simulation environment, only a small number of simulations are needed to be run. Decision makers could easily navigate through the environment and decide between different proposed AAM corridors.

The simulation environment could then be elaborated further to have the simulation based on Trajectory Based Operation (TBO). This method of simulation takes into account many more input parameters and is able to be turned into a digital twin of AAM operation if the input parameters are updated in real-time. Potential input layers include weather information, air traffic data (ADS-B), FAA System Wide Information Management (SWIM) data, and airspace data. The said digital twin is able to simplify AAM traffic management, make the operation more compliant to schedule, and is necessary for Human Over the Loop (HOTL) operations. This enables the simulation environment to be used in both the planning and operating stages of the AAM operation, catering to one more stakeholder, the infrastructure providers.

This study could be elaborated to create a said digital twin for the AAM fleet using TBO. The said fleet digital twin will be able to monitor the heading, airspeed, altitude, and energy remaining of each eVTOL aircraft and take into account the weather, other air traffic, and FAA SWIM data to update the trajectory for the remaining of the flight, estimated time of arrival, and future schedule. Operators of AAM services will be able to use the fleet digital twin to manage air traffic inside the AAM corridors when FAA ATC services are no longer provided [16]. The digital environment should also be able to estimate the demand for travel by monitoring the mobility trends and the current population flow data in vertiports to schedule in advance maintenance events such as charging to minimize eVTOL downtime.

References

[1] INRIX., "Atlanta," INRIX 2020 Global Traffic Scorecard, URL: https://inrix.com/scorecard [retrieved 15 April 2022].

[2] U.S. Department of Energy, "Idling Reduction for Personal Vehicles," Alternative Fuel Data Center, URL: https://afdc.energy.gov/files/u/publication/idling_personal_vehicles.pdf. [retrieved 12 November 2021].

[3] American Society for an Energy Efficient Economy, "Atlanta, GA," State and Local Policy Database, URL: https://database.aceee.org/city/atlanta-ga/. [retrieved 16 April 2022].

[4] Chitale, Y., "Optimal Siting of Ground Infrastructure for Urban Air Mobility Operations," ASDL, Georgia Institute of Technology, Atlanta, GA, 2021 (unpublished).

[5] Chitale, Y., Introne, S., and Sotiropoulos, E., "ConOps Evaluation with Scenario Integration for Urban Air Mobility," ASDL, Georgia Institute of Technology, Atlanta, GA, 2021 (unpublished).

[6] Rimjha, M., Hotle, S., Trani, A., and Hinze, N., "Commuter demand estimation and feasibility assessment for Urban Air Mobility in Northern California," Transportation Research, 6 May 2021, https://doi.org/10.1016/j.tra.2021.03.020.

[7] Viswanathan, V. et al., "The Challenges and Opportunities of Battery-Powered Flights," Nature, Vol 601, 27 January 2022, pp. 519-525. https://doi.org/10.1038/s41586-021-04139-1.

[8] Ahrenhold, N.; Pohling, O.; Schier-Morgenthal, S., "Impact of Air Taxis on Air Traffic in the Vicinity of Airports," Infrastructures, 2021, 6, 140. https://doi.org/10.3390/infrastructures6100140.

[9] Taillandier, P., Gaudou, B., Grignard, A.,Huynh, Q.-N., Marilleau, N., P. Caillou, P., Philippon, D., & Drogoul, A. (2019). Building, composing and experimenting complex spatial models with the GAMA platform. Geoinformatica, (2019), 23 (2), pp. 299-322, [doi:10.1007/s10707-018-00339-6]

[10] Kang, Y., Gao, S., Liang, Y. Li, M., Rao, J. and Kruse, J., "Multiscale dynamic human mobility flow dataset in the U.S. during the COVID-19 epidemic," Scientific Data, Vol. 7, No. 390, 2020, pp. 1–13.

[11] Sripad, S., Viswanathan, V., "Energy Efficiency of eVTOLs," Proceedings of the National Academy of Science, 2021, 118 (45) e2111164118

[12] Office of NextGen, "FAA UAM ConOps v 1.0," Federal Aviation Administration, Washington, DC., 2020.

[13] Atlanta Regional Committee, “Streets TIGER 2010,” Open Data [online database], URL: https://opendata.atlantaregional.com/datasets/7b912e0f04274e11904db57876e585a9/explore?location=33.843950%2C-84.425300%2C9.74 [retrieved 6 March 2022].

[14] Georgia Department of Transportation, “Traffic Analysis and Data Application,” https://gdottrafficdata.drakewell.com/publicmultinodemap.asp

[15] Head, E. “What we know about Lilium’s eVTOL batteries so far”, Verticalmag, URLhttps://verticalmag.com/features/lilium-evtol-batteries-what-we-know/ [retrieved 23 November 2022]