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EVALUATING THIRD-PARTY IMPACTS IN URBAN AIR MOBILITY COMMUNITY INTEGRATION: A DIGITAL TWIN APPROACH

Alexander Ireland[1] and Chun Wang[1]

[1]Concordia Institute for Information Systems Engineering, Concordia University, Montreal, QC, CANADA

ABSTRACT

Urban Air Mobility presents unique community impacts. UAM vehicles mostly operate above populated areas while traditional aviation typically operates point-to-point between populated areas, so impacts on third parties are increasingly important. This paper explores the approach of using a Digital Twin to optimize EVTOL vehicle flight planning by using accurate live population data to minimize third-party safety and privacy impacts. Live population density data is translated into an equivalent agent-based simulation and used to calculate safety and privacy metrics. A Montreal vertiport case study compares a baseline EVTOL approach suggested by the FAA to 128 alternate approach scenarios to find generalizations and prove the usefulness of Digital Twin technology for UAM operational optimization. It was found that flight path characteristics suggested by regulators are not necessarily optimal when considering third-party impacts, and by extension that Digital Twins are promising technology that will play a significant role in making UAM safer.

1 INTRODUCTION

The future of Urban Air Mobility (UAM) has many unknowns. Unlike traditional aviation that has benefited from over 100 years of continuous improvements to become statistically the safest form of travel (Stoop and Kahan 2005), how EVTOL vehicles will integrate into our communities is still an open question with many active research areas (NASA 2023). Fundamental questions such as where EVTOL vehicles will be allowed to operate, what the rules of the sky will be, or how UAM will integrate into the airspace shared with traditional aviation, remain unanswered. In any nation that is a signatory to the Chicago Convention, civil aviation Standards and Recommended Practices (SARPs) originate from the International Civil Aviation Organization (ICAO). These SARPs are then adapted into regulations written by National Aviation Authorities (NAAs) such as the Federal Aviation Administration (FAA), The European Union Aviation Safety Agency (EASA), or Transport Canada (TC).

In traditional aviation, where commercial aircraft generally fly point-to-point between airports, it is easy to imagine that only a small portion of most commercial flight time is spent flying over urban areas, so when there is an incident or accident, the people at risk are predominantly those on-board the aircraft. The risk to these users is known as first-party risk when referring to the impact that the aviation system has on them. By contrast, UAM vehicles will spend most of the operational time directly above populated areas. This paradigm shift highlights the importance of considering impacts to UAM third-parties, which are non-users of UAM. Many sources have explored the concepts and ideas of Urban Air Mobility community integration and have conceptually identified third-party impacts.

Existing research has explored third-party safety and privacy impacts for UAM as well as for similar systems such as Unmanned Aerial Systems (UAS) operations, or traditional aviation. Because UAVs are generally small and maneuverable, but with limited range, path planning while considering third-party impacts for Unmanned Aerial Vehicles (UAVs) is a research area with some interesting results. Many strategies segment their study areas into 2-dimension or 3-dimensional grids in cartesian space, calculate a risk cost value for each segment and optimize the path accordingly. Some recent examples include Tang et al. (2023) who used a min-cost A* algorithm approach to optimize 3-dimensional UAV flight paths considering injury to ground personnel, and damage to buildings. Similarly Celdran Martinez et al. (2024) used an A* algorithm combined with machine learning to optimize 3-dimensional UAV flight paths considering first-party safety and third-party privacy, safety and noise. Both of these prior works as well as others like them rely on complex flight planning to generate an optimized solution for UAV operations. In the world of UAM where EVTOL vehicle designs are not currently as maneuverable as small UAVs, and many use aerodynamic fixed-wing lift to achieve some of their flight modes (Johnson and Silva 2022), complex flight paths may not be desirable or even feasible. For this reason, investigating optimized final approaches in polar coordinates (heading, descent rate, distance) is more like the operational paradigm of traditional aviation. That being said, many of the concepts for measuring third-party safety and privacy presented in previous studies on third-party impacts are relevant and are used as inspiration for the metrics presented in this research.

Agent-based modeling and Digital Twins are powerful tools for creating realistic representations of the real world that can be used for a variety of purposes. Agent-based modeling allows the creation of independent agents that can be given a unique task, are aware of their environment, and can interact and communicate with other agents. Modeling human mobility using agent-based modeling has been extensively studied (Divasson-J. et al. 2025). Digital Twins integrate bidirectional real-time or near-real-time data transfer from the physical twin to the virtual twin which then provides insights into the physical twin that can then be communicated back to the physical twin to modify the physical situation (Singh et al. 2021). Agent-based modeling is complementary to Digital Twins when data for an entire system is not available. In this data maturity state, the Digital Twin can be called an Augmented Digital Twin (Raj and Surianarayanan 2020). Digital Twins can be used to aid in system design prior to the physical twin being fully capable or existing in its final state. This type of Digital Twin can be used for predicting behaviors and is known as a Digital Twin Prototype (Grieves and Vickers 2017:95).

An important enabler of constructing a digital twin for assessing third-party impacts is the urban population density data. In general, census data can be used. On top of that, a case of using live population density information is also reported (Choi et al. 2024). While, for researchers, accessing high resolution live population density information is not likely due to security and privacy concerns of data providers, such as mobile-phone carriers, device manufacturers or software companies, The mix of census data and aggregated live population density data can be very useful, especially when combined with simulation. For example, in Pinto Neto et al. (2022), discrete event simulation is used to create a UAM trajectory simulator that can evaluate hundreds of possible trajectories for efficiency and safety in UAM planning.

The purpose of this research is to show the utility of using a Digital Twin approach for UAM that can evaluate the third-party impacts of various UAM flight scenarios. The digital twin is built to leverage Agent-based Modeling while paving the way for real-time data in various forms to be used. We show that policy decisions can affect outcomes, and we provide quantitative measures that can be used to assess and choose EVTOL operations that minimize third-party impacts. Various organizations, including NAAs, have published concepts of operations, blueprints, and playbooks for how UAM may function. This paper uses the guidance for vertiport design and EVTOL approach characteristics provided in FAA Engineering Brief No. 105A, Vertiport Design (Federal Aviation Administration 2024) as a baseline to compare against alternate scenarios with various approach headings and descent profiles. More complex paths such as road following or area avoidance were not examined. This paper proposes metrics for third-party safety and privacy. Noise and other nuisance metrics are significantly dependent on vehicle design so while they are important considerations for community acceptance (NASA 2023:6), it is not explored in this study.

2 THIRD-PARTY IMPACT METRICS

As opposed to first-party risks, where the users of a system have accepted the personal cost-benefit tradeoffs, third-party risks are imposed upon non-users by users or operators (Ren and Cheng 2020). This touches on the topic of equity (fairness). Equity is important for community integration and acceptance

(NASA 2023:28). Transportation equity is a broad topic that covers many outcomes such as accessibility and affordability, but also covers external costs (Litman 2022). These so-called external costs are negative outcomes imposed on others and are equivalent to the concept of third-party impacts when talking about safety or privacy outcomes. Unlike previous attempts at third-party impact assessment, this study uses agent-based simulation to capture the user-level third-party risk with the intent to minimize these metrics. As such, the metrics proposed, while based on previous studies, are created in a way that assumes an incident will occur somewhere during the flight as opposed to using the more common method of calculating a Target Level of Safety (TLOS) and comparing it to aviation industry standards.

2.1 Third-Party Safety Metrics

Previous research has explored third-party safety risks which can be generally classified into two types: vehicle crash risk and falling object risk. Metrics for safety of non-users of UAM (pedestrians, buildings, road vehicle occupants) were modelled using aviation crash models and the geometric proximity of EVTOL vehicles with buildings and people in 3-dimensional space. Two possible operational or failure conditions were studied: complete loss of power resulting in a ballistic crash trajectory, and simulation of a falling object originating from the EVTOL vehicle.

2.1.1 Aircraft Crash Metrics

Aircraft crash area modeling and prediction have been extensively studied and analyzed. There are various approaches that have been used, including multiple different geometric and weight-based approaches. Melnyk et al. (2014) provided a thorough review and analysis and concluded that the most accurate approach was the weight-based approach proposed by Ale and Piers (2000) where linear relationships between estimated impact area and aircraft weight exist for built up areas and for open areas where the former is a smaller estimate than the latter. The chosen formula (in metric units) using the maximum takeoff weight (MTOW) is:

$$A_{debris} = 0.275 * MTOW[kg] \tag{1}$$

Due to the advantages of this 3D simulation approach where individual buildings are modelled, the open area formula was chosen to model impact area of an EVTOL and the effects of interactions with buildings are considered. The crash impact area is modelled as a circle. Figure 1 is an illustrative diagram of the crash trajectory overlaid over a 3d scene. Figure 2 is the 2d visualization showing; the EVTOL aircraft, the impact area (positioned based on a ballistic free-fall path from the current EVTOL position), road traffic, and pedestrians.

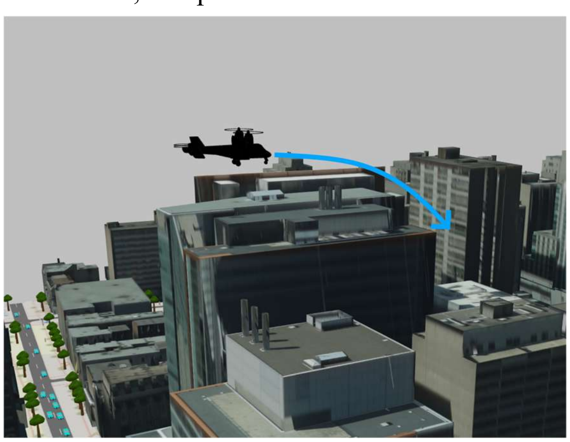
Figure 1 – ballistic crash trajectory in 3D


Figure 2 – Crash Zone in 2D

Based on the free-fall characteristics and impact area, two crash safety metrics are generated that include the total number of agents and buildings that would have been affected if a crash had occurred anywhere along the flight path. The safety metric for ground crash impacts is a simple sum for the time that each affected pedestrian and vehicle agents are within the crash area during the EVTOL approach, divided by the total number of agents. Dividing by the total number of agents gives a relative metric. The ground crash safety metric is as follows:

$$Safety_{gc} = \frac{\sum t_{agentInCrashZ}}{N_{totalAgents}} \tag{2}$$

The safety metric for building crash impacts is conceptually inspired by prior studies that attempt to determine the third-party risks when aircrafts impact buildings. For example Choi et al. (2024) used ground coverage area percentage for open areas vs buildings, inferring the number of impacted individuals by using building height data to model the fraction of people exposed to harm, which when combined with their hourly population density data, created an overall metric for crash risk to third-parties. The building crash safety metric shown below uses a different approach to achieve the same objective. Estimating building occupancy is a challenging task with many different approaches possible based on the available data (Caballero-Peña et al. 2024). The method chosen for this study is to use standardized building occupancy measures that use floor area to calculate a maximum occupancy level. The 3d-building dataset used for this study has all data required to make this calculation. The metric is a relative metric of affected buildings to all buildings in the case-study area, so calculating the occupancy is not relevant at this stage because it will be canceled out. Instead, the occupant load is used in Section 2.3 to calculate the weight of this metric in the final integrated metric.

Based on the ballistic trajectory of the falling EVTOL vehicle, the sum of the volumes of all buildings that could be impacted is divided by the total volume of buildings in the case study area to create a relative metric that can be used for minimization purposes. The building crash safety metric is as follows:

$$Safety_{bc} = \frac{\sum(Volume_{buildingInDanger})}{Volume_{allBuildings}} \tag{3}$$

2.1.2 Falling Object Model

There are various reasons for objects originating from the EVTOL vehicle and falling that can cause a third-party risk, including: birds (Cardoso et al. 2022), in-air collision with a small UAV (Che Man and Low 2021), ice shedding while flying in icing conditions (McKillip et al. 2020), or simply loss of cargo or other equipment. A probabilistic distribution approach was taken to model the probability of an UAM non-user agent being hit by an object originating from the EVTOL. Every specific EVTOL design will have differences, including propeller arrangement, tip speed, and other considerations such as de-icing system dynamics, or even whether windows can be opened in-flight. For this reason, the model used is a simple ballistic model where the maximum distance from the EVTOL is based on an object leaving a propeller horizontally at a realistic speed and following a ballistic trajectory to the ground. Figure 3 is an illustrative diagram showing the modelling of the possible paths an object can follow after originating from the EVTOL vehicle. Figure 4 visually depicts the output in 2d of the impact location distribution zone (shown in yellow), which is used to identify affected agents.

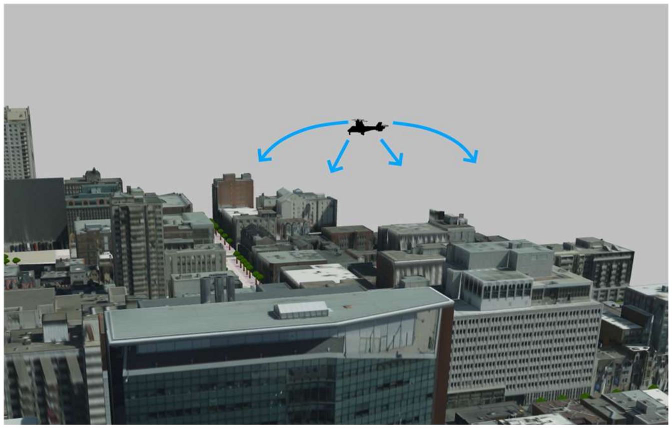

Figure 3 - Possible falling object paths in 3D

Figure 4 – Falling object "danger zone" in 2D

Based on the ballistic characteristics of the ejection model and assuming an equal probability distribution, a metric is generated using; the area that each agent occupies (A_{agent}, assumed to be 1m2 for pedestrians), the danger zone area $A_{dangerZone}$ (based on EVTOL altitude), the total number of agents in the case study area $N_{totalAgent}$, the time that each agent is located within the danger zone as the EVTOL follows its flight path $t_{inDangerZone}$, and the total time of the EVOL flight approach ($t_{approach}$ using the following formula. The falling object safety metric is as follows:

$$Safety_{fo} = \frac{\sum(\frac{A_{agent}}{A_{dangerZone}} * t_{inDangerzone})}{N_{totalAgents} * t_{approach}} \quad (4)$$

2.2 Privacy Model

Neither the FAA (Federal Aviation Administration 2025) nor Transport Canada (Transport Canada 2021) regulate drone-related privacy and instead defer to local laws. EVTOL operations will no doubt be treated similarly. Past studies have proposed methods for measuring and ultimately minimizing third-party privacy concerns for drone operations. Drones are unmanned so the privacy concerns are related to cameras and other recording devices which has guided the direction of past research. For instance Celdran Martinez et al. (2024) used the resolution of a camera and distance to determine whether an object or person could be recognized. By contrast, research into the third-party privacy risk caused by EVTOL passengers viewing scenes that are not otherwise possible, such as seeing into private gardens, window angles, or rooftops that are not visible from existing public and private areas, has not been thoroughly investigated. For a thorough impact analysis, highly detailed data such as 3d Photogrammetry or LiDAR that include natural items such as trees and foliage would need to be combined with specific building and land information to provide an in-depth privacy metric, so a simplified approach is proposed where the number of buildings within a given proximity and direct line of sight to the EVTOL are recorded. This acts as a measure of privacy incident opportunities. The quantity is then made relative by dividing by the total number of buildings in the case-study area. The privacy metric is as follows:

$$Privacy = \frac{\sum Building_{inObservationZone}}{N_{totalBuildings}} \quad (5)$$

2.3 Integrated Third-Party Metric

To create a single integrated third-party impact metric, a weighted sum is used where the weights k_{gc}, k_{bc}, k_{fo}, and k_p are scaled according to their severity and potential impact. We set the ground crash metric weight

(k_{gc}) as our reference with a value of 1 as it is a measure of fatalities. The building crash metric weight(k_{bc}) is based on the mortality rate when an aircraft crashes into a building, which can be estimated as 0.1-0.2 (0.1 used) for a small aircraft impacting buildings of various types and sizes (Brady and Hillestad 1995:49). In order to relate k_{gc} to k_{bc}, we use building occupant load to get a rough estimate of the maximum number of people in the affected buildings and compare that number to the number of pedestrian and vehicle agents in the simulation. The building dataset contains the building volumes, so by dividing them by a standard height of 3m/storey, we estimate the equivalent floor space area. Using this and dividing by a reasonable average occupant load of $10m^2$/person (NCR 2015:3–36) gives us an upper-end bound estimate. Because buildings rarely operate at their occupancy limits, further dividing by a factor of 25 will give a more reasonable estimate for the actual number of occupants at any given time. To use this with the safety metric which is a relative measure of building volumes, the total building volume in the case-study area is required, as is the total number of pedestrian and vehicle agents. For the two metrics that are not guaranteed death, the falling object metric weight (k_{fo}) is set to 0.25 and the privacy metric weight (k_p) to 0.1.

$$k_{gc} = 1.0 \qquad k_{bc} = \frac{\left(\frac{Volume_{allbuildings}}{3*10*25}\right)*0.1}{N_{totalagents}} \qquad k_{fo} = 0.25 \qquad k_{p} = 0.1$$

Each of the metrics inherently have a scaling different factor due to how each is measured, so to allow the weights to fully determine the amount of impact each metric has on the Integrated Third-Party Metric $Thirdparty_{int}$, each metric is divided by its max value prior to multiplying its weight.

$$ThirdParty_{Int} = k_{bc} * \frac{safety_{bc}}{safety_{MAXbc}} + k_{gc} * \frac{safety_{gc}}{safety_{MAXgc}} + k_{fo} * \frac{safety_{fo}}{safety_{MAXfo}} + k_p * \frac{privacy}{privacy_{MAX}}$$

3 DIGITAL TWIN PROTOTYPE CONSTRUCTION AND METRIC INTEGRATION

Because UAM as a transportation system is not yet operational, the intent of this research is to create a prototype to highlight the future potential for use of digital twin technology in urban flight management. The prototype uses a mix of available data sources with various update frequencies. Some unknowns exist related to the future availability and nature of real-time mobility or person-centric data, so the Augmented Digital Twin Prototype is constructed to be flexible with its data sources. By converting the source data to an analogous representation (leveraging the power of person-centric agent-based simulation), we can decouple the input data characteristics from the generated metrics to enable the possibility of using different data sources while maintaining the same metrics. Figure 5 shows where the agent generation algorithm that creates the analogous representation fits in the architecture of the Digital Twin.

3.1 Digital Twin Construction

A general-purpose COTS modeling and simulation program (Anylogic) was used to create a virtual world consisting of accurate 3d building models, road network, and pedestrian areas. The 3D world was constructed using accurate 3D building data provided by the City of Montreal (City of Montreal n.d.) converted from CityGML format to the natively supported COLLADA format (AnyLogic n.d.). The road network and pedestrian areas were created using OpenStreetMap data (OpenStreetMap n.d.).

The study used multiple simulation and modeling techniques to achieve the objectives. The program supports both agent-based modeling techniques and discrete event simulation as well as standard libraries for pedestrian and road traffic agents. These libraries were leveraged to create realistic representations of the distribution and movements of people within the case study area.

Creating agent-based pedestrian and vehicle patterns and density that match inputs from the data source requires a 2-step approach: creating agents in the right location and with the right task to perform then waiting until the system reaches a steady-state configuration that matches the input. To accomplish this, a simple source-sink (start location-end location) technique was utilized where road traffic was created at the periphery of the simulated area and instructed to drive to other locations at the periphery to create the appropriate traffic characteristics and density that match given scenarios. Similarly, pedestrian traffic was created from specific points throughout the simulated area and instructed to travel to other areas to create the required pedestrian densities throughout the simulated area. These key behaviors were achieved using a model where the source and sink locations of the agents are set statistically for each individual agent. When coupled with control over the agent creation rate, steady-state representations of the expected traffic patterns and pedestrian densities can be created. Figure 5 shows the architecture.

The vertiport specifications chosen were based on suggestions from the FAA Engineering brief 105A (Federal Aviation Administration 2024). The size of the vertiport TLOF, FATO, and safety areas are based on the vehicle dimensions the vertiport was designed for. The engineering brief describes ground level as well as elevated/rooftop vertiports. The engineering brief also specifies suggested flight paths for approach and departure based on the prevailing wind direction, and traditional heliport operations.

3.2 Case Study Architectures

To eliminate random differences due to the dynamic nature of the Digital Twin and the stochastic nature of the agent generation routine used to create the expected agent distributions, the architecture was adapted for case study use, as shown in Figure 6, to enhance the repeatability of the results. For each setting the agent generation algorithm used fixed and representative input data (not live data), and for each setting, the metrics for all 64 flight path scenarios were calculated simultaneously.

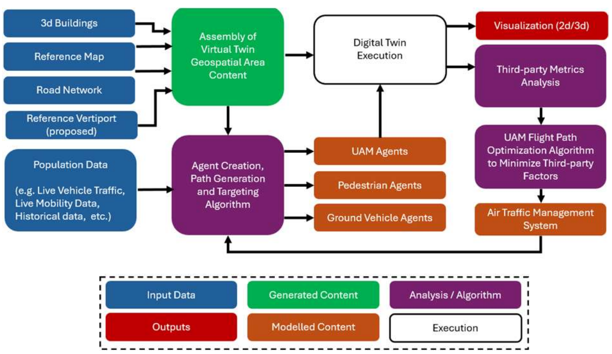

Figure 5 – Augmented Digital Twin Prototype Architecture

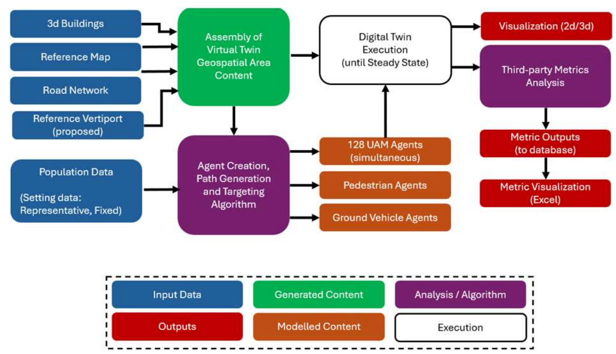

Figure 6 – Case study Architecture

4 MONTREAL CASE STUDY

A 425m diameter geospatial study area was modelled with a vertiport in the middle. The circular study area was selected in downtown Montreal centered around WGS 84 coordinates 45.49732, -73.57888. The case study area, shown in figures 7 and 8, has a mix of residential, business, low-rise and high-rise buildings.

Figure 7 – Case Study Area in 3D

Figure 8 – Case Study Area in 2D

Multiple settings were created using agent-based simulations for vehicles and pedestrians to provide the basis for the UAM non-users representation in the study. Different traffic densities and pedestrian densities were modelled to approximate times such as a regular business day, special events, etc. Figures 9 and 10 show 2 settings visualizing the road traffic slowdowns, and pedestrian heat maps. Setting 1 represents typical evenly distributed traffic and pedestrian patterns. Setting 2 represents a special event or festival, located on Sainte-Catherines Street with a substantial number of pedestrians.

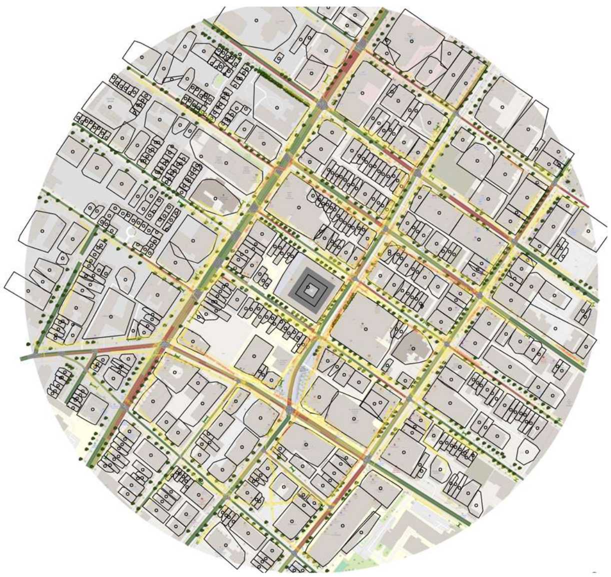

Figure 9 – Setting 1 - Normal Day

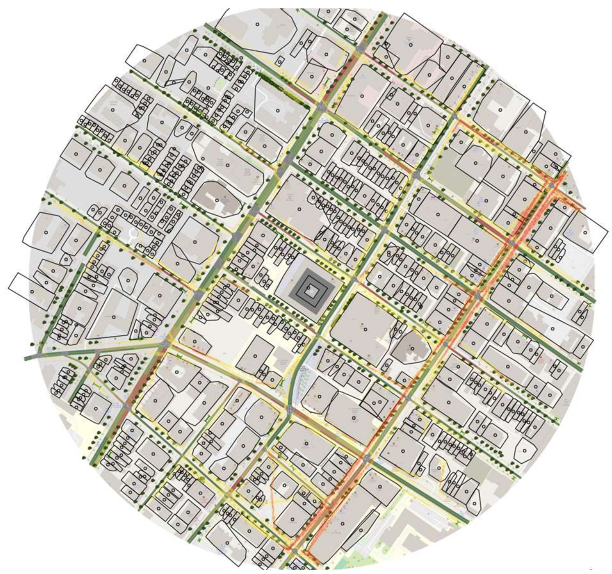

Figure 10 – Setting 2 - Special Event

The flight approach path was varied and compared to the baseline approach described in the FAA Engineering Brief (Federal Aviation Administration 2024). The baseline approach descent is shown in Figure 11 scaled to the case study area. It consists of a 1:8 descent profile with a preferred approach heading consistent with the prevailing winds in the area. In Montreal, the historical prevailing winds generally come from the WSW (247.5deg) (meteoblue.com n.d.) so the preferred approach heading would be 67.5deg from North.

Figure 11 – Implementation of Baseline Approach from FAA Engineering Brief No. 105A

Due to the size of the case study area, representing the final 425m of flight (horizontally), each approach uses a fixed heading from the periphery of the case study area to the vertiport. The selection of approaches covers the full 360degree approach headings (every 22.5deg) with 4 different descent profiles. Figure 12 represents the 64 approach scenarios used for this study. Complex paths involving multiple waypoints were not investigated. For larger scale studies, such as at the scale of the entire city, complex flight paths would become interesting to investigate.

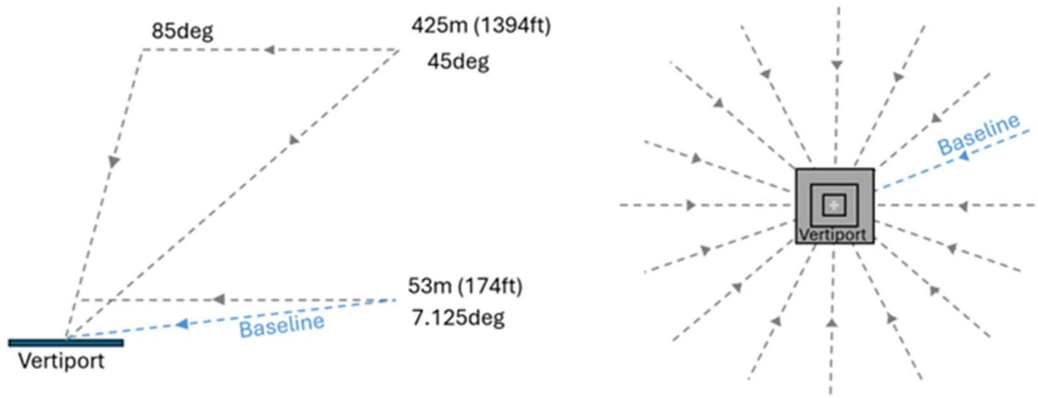

Figure 12 – 64 approach scenarios modelled: 4 descent profiles and 16 approach headings

The Vertiport design and crash area model require the specifications of the EVTOL. A representative collection of some past, present, and future VTOL/EVTOL vehicles is presented in Table 1. The Canadair CL-84 was a development project from the 1960s and was one of the first Tilt-wing VTOL aircraft created (Canada Aviation and Space Museum n.d.). It was chosen for this case study due to its Canadian historical significance as well as its size being representative of modern VTOL vehicles. The length and width were used for Vertiport sizing as per the FAA Engineering brief (Federal Aviation Administration 2024) and the associated crash radius, is calculated using Equation 1 as 22.4m.

Table 1 –VTOL/EVTOL vehicles past, present, and future

Aircraft	MTOW [kg]	length [m]	Width [m]	Configuration
Joby S4	2404	7.3	10.7	tilt rotor
Canadair CL-84	5710	16.3	10.6	Tilt wing
Archer Midnight	3175	15	15	Lift+cruise
Volocopter Volocity	1000	11.3	11.3	Multi-rotor
Wisk Aero Gen 6	unknown	15	15	Lift+cruise
Eve Air Mobility Eve	unknown	15	15	Lift+cruise
Lillium Jet (7-seater)	3175	14	14	vectored thrust
Ehang AAV	620	5.73	5.73	Multi-rotor
Bell V-280 Valor	14000	15.4	24.9	tilt rotor
Bell V-22 Raptor	21546	17.48	25.8	Tilt wing
Beta Alia 250	3175	15	15	Lift+cruise
Bell 429	3402	12.7	11	Helicopter

5 SIMULATION RESULTS

Both case study settings were run. The agent-based simulation converged on the expected distributions, the results for 128 EVTOL approach scenarios were collected, and the impact metrics were calculated. Figure 13 displays the resulting radar charts that are used to visualize the results in an intuitive way. The approach bearings are shown as the arms of the radar chart, which visually match the 2D setting visualizations from Figures 9 and 10. Each radar chart shows all 64 approaches with the 4 approach descents represented as the data series and the 16 approach bearings shown annularly forming a ring. The metrics for building crash and privacy are independent of the agent settings so the results were therefore identical for Normal day and Special Event and only one instance is shown.

Figure 13 – Metrics visualized as radar charts, each showing 64 scenarios.

The falling-object safety metric for Normal Day and for Special Event show some of the same trends. In both cases, the metric was larger when the EVTOL is higher above the ground indicating an overall higher falling object risk factor. Additionally, the directionality decreased when the EVTOL was higher above ground, although the special event setting shows that optimizing the flight path can still yield a significant decrease in falling-object risk factor, especially at lower altitude

The ground crash safety metric for Normal Day and for Special Event predictably do not show the same variation with altitude as was seen with falling object safety metric. The same ground crash area that will occur for each approach will occur at a different time due to the fall distance so the agent locations are slightly different for each approach. In both scenarios, there is a strong directionality effect so the ground crash safety risk can be significantly reduced with an optimized flight path.

The building crash safety metric shows that optimized flight paths will reduce the risk to occupants of buildings. It should be noted that other strategies such as road-following would eliminate the building crash risk as measured in this study.

As explained previously, the privacy metric is a simple model based on proximity to buildings so there is a strong altitude component. As altitude increases the directionality decreases until only the buildings close to the vertiport impact the metric. At low altitudes, privacy was significantly affected by heading indicating routes that minimize privacy issues are possible.

The integrated metric has directional characteristics consistent with the other metrics showing that when all safety and privacy metrics are considered, an optimal approach can be determined. In the case of the special event, the scenario with the greatest third-party impact is over 3x higher than the scenario with the smallest impact.

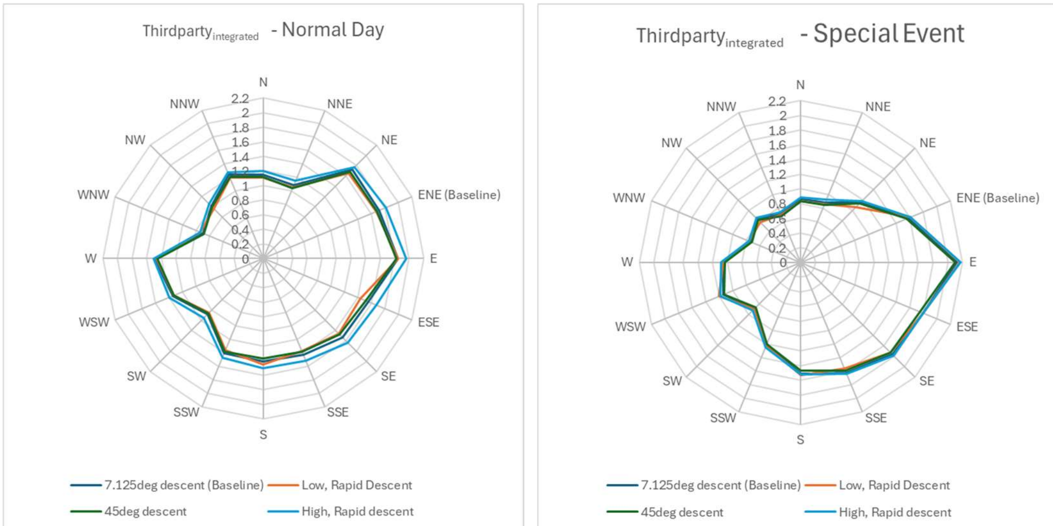

Figure 14 – Integrated third-party metric

6 CONCLUSION

Third-party impacts for UAM operations are more important than for traditional aviation due to the inherent proximity to urban environments. Measuring third-party impacts requires accurate knowledge of the physical environment as well as high fidelity information for where people are located within the environment. These two characteristics match well with the characteristics of a Digital Twin. When regulators make design decisions, such as suggesting an approach heading that matches the prevailing winds of the area, or a descent rate familiar to traditional aviation, it can cause significant impacts for third parties when compared to a flight path optimized for minimizing third-party impacts. This study showed that simple modifications to the final approach of an EVTOL vehicle can have a significant impact on the safety and privacy of third parties. Unlike previous studies that optimize flight paths in cartesian coordinates, by generating paths that may only make sense for UAVs, we showed that good results can be obtained by using polar coordinates (heading, decent profile, distance) that provide a solution that is more aligned with the performance characteristics of current EVTOL aircraft. Third-party privacy and safety are strongly affected by approach heading which can be optimized based on live mobility and population data. A Digital Twin approach shows a lot of promise as an integral part of a future UAM transportation system that minimizes third-party impacts. The created Augmented Digital Twin Prototype provides a mechanism to represent live population density data using agent-based simulation to remain flexible with the nature of available data sources. Future work will add complexity to the virtual world with the intent to improve the accuracy of safety and privacy metrics. Another direction is to scale the Digital Twin geographic area larger and incorporate more complex flight path scenarios such as road-following and area avoidance.

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AUTHOR BIOGRAPHIES

ALEXANDER IRELAND is a graduate student passionate about one-day owning a flying car. His current research focus is on helping to design the future Urban Air Mobility transportation system that not only works, but works for everyone. His email address is alexander.ireland@mail.concordia.ca and his website is https://alexanderireland.ca.

CHUN WANG is a Professor and the Director of the Concordia Institute for Information Systems Engineering. His research areas include: Sustainable, Smart, and Socially-Oriented Mobility Systems, Computational Social Simulation for Electrification and Decarbonization, Scheduling, Two-sided Matching, e-Supply Chain, Community Health Management, Mechanism design, Game Theory, and Multiagent Systems. His email address is chun.wang@concordia.ca and his website is https://chunwang.ca/.