

Simulating Enhanced Vertiport Management in a Multimodal Transportation Ecosystem

Christopher Conrad, Yan Xu, Deepak Panda, Antonios Tsourdos
Centre for Autonomous and Cyberphysical Systems
SATM, Cranfield University
Cranfield, UK, MK43 0AL

{christopher.conrad; yanxu; deepak.panda; a.tsourdos}@cranfield.ac.uk

Abstract—The advanced air mobility (AAM) industry envisions a transformative transportation ecosystem for passengers and cargo deliveries. Nonetheless, coordinating large volumes of new aerial vehicles necessitates innovative unmanned aircraft system (UAS) traffic management (UTM) solutions, supported by a robust vertiport infrastructure. Moreover, AAM will form part of a broader multimodal ecosystem, posing additional technical, procedural and operational challenges. This work thereby presents a simulation tool in AnyLogic for deploying, training and testing collaborative and intelligent AAM decision-making frameworks within a multimodal transportation system. The platform integrates multiple vertiports with diverse resource constraints, and offers a flexible solution to investigate the impact of different vertiport designs, layouts and procedures. AAM-specific influences are also introduced, including electric vehicle batteries, heterogeneous vehicle specifications, stricter flight envelopes, and hyper-local micro-weather variations. The model further acknowledges the complex inter-dependencies within a multimodal environment to capture fluctuating travel demands and dynamic passenger flows within transportation terminals. This scalable simulation tool thereby enables the development of enhanced vertiport management and AAM traffic coordination solutions, and facilitates exploratory research on multimodal coordination amongst air, ground, rail and sea transportation systems.

The European Commission Sustainable and Smart Mobility Strategy [2] strongly supports the drive towards carbon neutrality, and envisions a multimodal Trans-European Transport Network (TEN-T) for sustainable and intelligent transportation by 2050. This strategy underscores several pivotal factors, including carbon-neutral travel hubs and vehicles, a marked increase in freight rail activity, and a unified transportation market. Similarly, the US Department of Transport [3] promotes the use of a multimodal strategy to address chronic diseases, increase access to health-supportive resources, and improve equity in transportation.

Research findings from UKPMG and RFG [4] confirm that intermodal freight transportation yields substantial economic, societal and environmental benefits. Furthermore, the concept of mobility as a service (MaaS) emerges as an essential service to meet sustainability objectives, involving the seamless transitioning between different transportation media. Multimodal MaaS solutions are thereby poised to cultivate healthier urban environments by curbing pollution, alleviating traffic congestion and engendering greater social equity in mobility access. A unified transportation system further promises reduced wait times, expedited travel journeys, simplified cross-domain ticket reservations and a more streamlined travel experience.

TABLE OF CONTENTS

1. INTRODUCTION.....	1
2. MULTIMODAL TRANSPORTATION SYSTEMS.....	2
3. SYSTEM MODELLING	4
4. SIMULATION PLATFORM.....	4
5. SIMULATION FRAMEWORK	4
6. AGENT MODELS.....	6
7. DEMONSTRATIVE USE-CASE	9
8. PROTOTYPE AND RESULTS.....	10
9. CONCLUSIONS.....	12
ACKNOWLEDGMENTS	12
REFERENCES	12
BIOGRAPHY	14

1. INTRODUCTION

Multimodality

The existing transportation ecosystem cannot sustainably cater for the projected increase in transportation demand. Consequently, the European Green Deal [1] targets a 90% cut in emissions by 2050, achieved through the implementation of a smart and accessible transportation system.

Advanced Air Mobility

The integration of advanced air mobility (AAM) stands to make a substantial contribution to multimodal transportation by introducing innovative and sustainable aircraft for both freight and passenger transportation. Specifically, urban air mobility (UAM) envisions the use of electric vehicles for low-altitude operations in urban areas. This will usher in a new era of sustainable metropolitan aerial activities, characterised by increased autonomy and reduced noise levels.

NASA [5] suggests that AAM will work cohesively with ground-based modes of transport to enable quicker journeys and reduce ground traffic congestion. Similarly, the Civil Aviation Authority (CAA) [6] affirms that AAM inherently forms part of an emerging interconnected, intelligent and multimodal transportation network. The European Union Aviation Safety Agency (EASA) [7] further projects that UAM could reduce standard urban travel times by 15 to 40 minutes, and offer time savings of up to 70% for emergency and medical deliveries. Zero-emission electric aerial vehicles will also contribute to a healthier and more sustainable urban environment, and the safety quotient of air taxi operations is expected to surpass that of conventional road transport. Furthermore, the construction of a vertiport is significantly cheaper and quicker than that of a comprehensive road or rail network, enabling AAM to connect remote rural areas previously underserved by conventional aviation.

Contributions

Despite the benefits of an intelligent and interconnected multimodal ecosystem, further regulatory and technical development is still required to realise an integrated transportation network. Additionally, innovative algorithms are needed to manage federated business contracts, handle traffic disruptions and environmental uncertainty, and predict or coordinate stochastic fluctuations in mobility demand. AAM operations also face numerous distinct challenges, demanding significant regulatory and infrastructural development to enable safe, secure and efficient aerial operations. Notably, innovative scheduling algorithms, prioritisation schemes and slot reservation models become imperative to manage the limited resources of emerging vertiports and low-altitude airspace structures. Similarly, AAM operations are susceptible to disruptions by hyper-local micro-weather patterns and environmental variations, potentially resulting in travel bottlenecks unless these challenges are appropriately managed.

Considerable research is underway to overcome the challenges associated with emerging AAM operations. Straubinger et al. [8] systematically review recent developments in AAM, and Bauranov et al. [9] summarise airspace structure proposals for low-altitude aerial operations. Additionally, Schweiger et al. [10] comprehensively review the existing vertiport landscape. Existing work, however, tends to focus on specific elements of AAM, and does not adequately consider the intricacies of a complete transportation system. Moreover, little work has investigated practical solutions to incorporate AAM within a broader multimodal ecosystem.

This work thereby presents a simulation platform to effectively model the unique requirements of UAM and AAM within a multimodal transportation system. Such a tool will enable the analysis and optimisation of multimodal decision-making frameworks, facilitating the seamless integration of UAM services within smart cities. The main contributions of this work are as follows:

- The intricacies of a complex multimodal environment incorporating AAM and UAM operations are summarised;
- A high-level methodology is proposed to realise an agent-based simulation model for deploying, training and evaluating AAM and UAM solutions within a multimodal transportation system;
- A sandbox test environment is prototyped in AnyLogic to enable the development and analysis of multimodal and multi-agent AAM algorithms.

Paper Structure

Section 1 of this paper introduced AAM in the context of multimodality, and highlighted the need for a simulation tool to enable exploratory research in this emerging field. Section 2 subsequently discusses the benefits, challenges and enabling technologies of multimodal transportation systems, and presents existing work on MaaS within an intelligent transportation system (ITS). Additionally, Section 3 discusses simulation modelling as a crucial technique to investigate complex multimodal AAM ecosystems, and Section 4 identifies AnyLogic as a promising platform to build such a comprehensive simulation platform. Sections 5 and 6 further detail a methodology to realise the proposed simulation framework, and Section 7 lists the demonstrative use-case employed to test the developed solution. Finally, Section 8 presents and analyses the platform prototype, and Section 9 concludes the paper by summarising the findings of this research and highlighting potential avenues for further research.

2. MULTIMODAL TRANSPORTATION SYSTEMS

Intelligent Transportation Systems

Intelligent vehicles and advanced traffic management solutions pave the way for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) connectivity, enabling greater autonomy and efficiency in smart cities [11]. Paiva et al. [12] systematically review enabling technologies for urban smart mobility and emphasise the critical role of artificial intelligence (AI), big data and smart Internet of Things (IoT) sensors in realising autonomous urban mobility. The authors also acknowledge the importance of electrification, sustainability, geospatial technologies and Blockchain systems in the development of an interconnected mobility ecosystem. Similarly, Seuwou et al. [13] and Pressas et al. [14] propose connected autonomous vehicles (CAVs) as a potential solution to address major concerns related to traffic congestion, environmental sustainability, public health and transportation safety in urban settings, as summarised in Figure 1.

While CAVs and ITSs offer numerous benefits, Stephanedes et al. [15] highlight several challenges and risks associated with increased connectivity and autonomy, which are summarised in Figure 1. These include safety concerns arising from both intentional and non-intentional incidents and attacks, uncertainties stemming from stochastic environmental conditions, and apprehensions surrounding data privacy. Additionally, Barron [16] confirms that cybersecurity threats and the reliability of AI systems pose significant risks to emerging ITSs. Ethical considerations associated with increased autonomy must also be appropriately addressed.

Cascaded Multimodal Risk

A multimodal transportation system can be conceptualised as a network of transportation nodes interconnected by edges representing transportation routes. Owing to the unpredictable and chaotic nature of the environment in which an ITS operates, however, modelling travel times and failure risks remains a challenging task. These factors encompass hyper-local micro-weather fluctuations, actions taken by human drivers or pedestrians, disruptions caused by nearby wildlife, and potential failures of vehicles or infrastructure. Furthermore, as the complexity of the network grows, the correlation and interdependence between nodes and edges intensifies, leading to the rapid spread of risks amongst correlated and associated nodes and edges. This suggests that coordination amongst all stakeholders becomes crucial for ensuring efficient information sharing, collaborative responses to disruptions, and overall system reliability.

The intricate and interlinked nature of a multimodal transportation system thereby results in a cascading effect of risk and failure propagation. Vulnerabilities in a single node or edge can disrupt or paralyse substantial portions of the transportation system, resulting in considerable delays, costs, and environmental impacts. Consequently, numerous studies have delved into the complexities of multimodal risk propagation. Guo et al. [17], for instance, conduct research on modelling multimodal risk propagation and suggest employing percolation theory for simulating dynamic risk propagation under system uncertainty. He et al. [18] apply cascade failure theory to propose a model for multimodal risk propagation in transportation systems, and simulate the model to illustrate the impact of different node distributions on system performance. Similarly, Liao et al. [19] explore essential factors for enhancing the resilience of multimodal transport logistics.

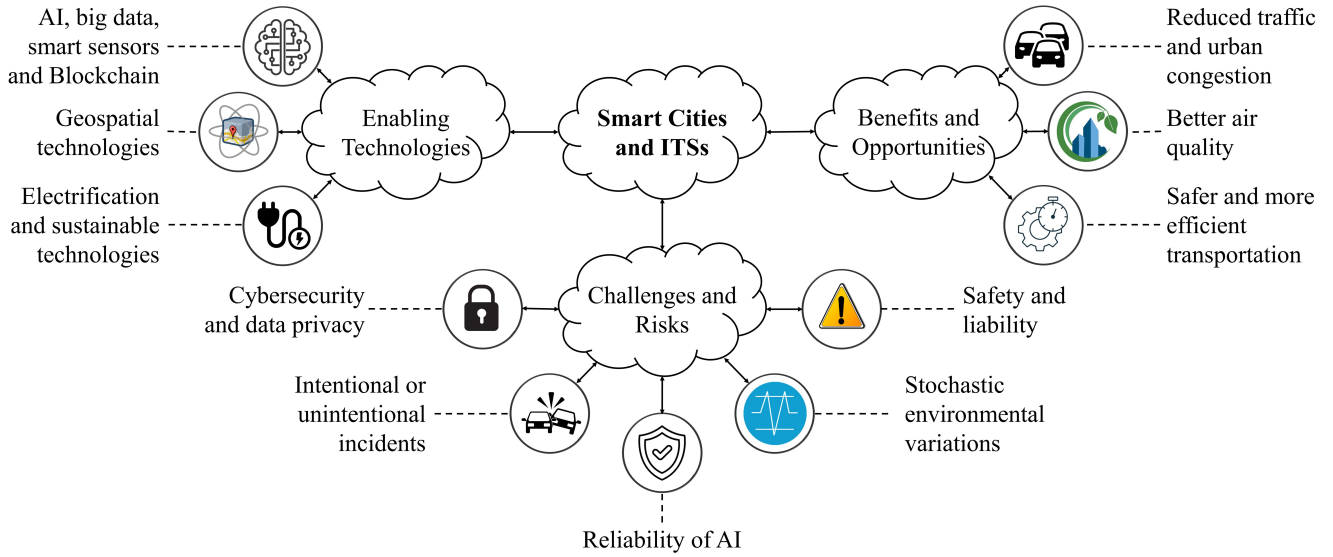


Figure 1. Benefits, challenges and enabling technologies of ITSs and smart cities.

Existing research on cascaded multimodal risk focuses on cargo deliveries across extensive geographic regions employing traditional transportation modes. A research gap therefore exists in investigating how AAM and UAM operations affect such a cascading risk model. Notably, AAM is envisioned to play a central role in regional mobility for services like MaaS and last-mile cargo deliveries. Consequently, risk propagation analysis for this emerging transportation system must increasingly concentrate on short-distance influences and risk factors that are more challenging to model and predict than broader conditions over a larger geographic area. Predicting the direction of a major storm, for example, is significantly less challenging than anticipating hyper-local wind speed variations impacting UAM flight times and delays. Consequently, this work establishes the groundwork for a robust simulation platform facilitating the assessment, analysis and mitigation of risk propagation in a multimodal transportation system encompassing UAM and AAM operations.

Mobility as a Service

A multimodal transportation system enables MaaS within smart cities, whereby transportation is centred around the service of mobility, rather than the transportation medium used [20]. This optimises cargo and passenger mobility by efficiently integrating ground, sea, air and rail systems into point-to-point services. Furthermore, multimodal transport can be characterised as a subset of intermodal transport, where a single multimodal transport operator orchestrates diverse intermodal carriers for end-to-end freight movement.

Extending this concept to public transport, Hensher [21] envisions a hybrid multimodal system that combines pre-scheduled routes and MaaS, potentially yielding the most favourable overall transportation solution for smart cities. Ceder [22] further explores the potential of cross-domain public transport, integrating various modes such as metro, bus, light rail, tram, ridesharing services, taxis and personal rapid transit. In such applications, AI emerges as a crucial enabler for MaaS within a multimodal ecosystem [23], and Maity et al. [24] delve into intelligent solutions to tackle the challenges of multimodal transportation.

Despite the potential benefits of MaaS, AAM and UAM have not been extensively explored in existing multimodal algorithms. Janic [25] and Toet et al. [26] propose a transformative model to establish airports as multimodal transport nodes, leveraging rail, air and ground systems to optimise efficiency, sustainability, profitability and customer satisfaction. While airports play a significant role in multimodal systems, however, smaller vertiports may offer a more promising solution for establishing a distributed network of multimodal transportation nodes. In fact, several companies have acknowledged the potential of vertiports and vertistops to serve as distributed multimodal nodes.

Consider, for instance, a tourist staying in a remote rural holiday home. The passenger could take a train from the destination airport to an urban vertihub and then use an air taxi to reach a rural vertistop before completing the journey with a conventional taxi, as depicted in Figure 2. This integrated approach is likely to reduce overall travel time and costs compared to a single ground taxi journey, while improving the overall operation sustainability.

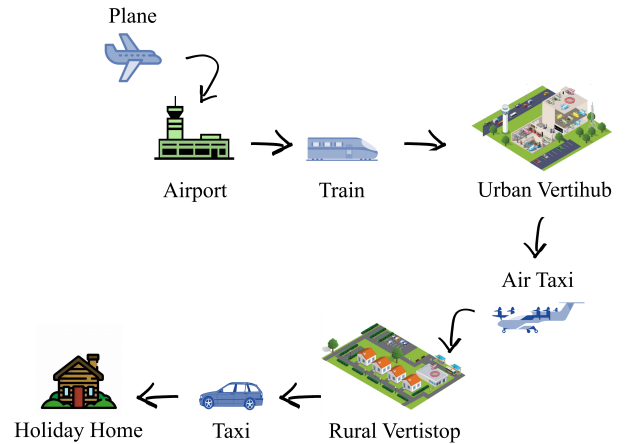


Figure 2. Example of MaaS for tourist transportation to a rural holiday home.

3. SYSTEM MODELLING

Effective testing of multimodal solutions necessitates robust models that capture the complexities of the underlying transportation ecosystem. Travel demands in different regions, for instance, may exhibit seasonal, weekly and diurnal patterns, while socio-economic trends and environmental variations can influence consumer behaviours and transportation preferences [27]. Various factors such as rail strikes, road accidents, traffic congestion, weather conditions and airspace restrictions can also impact the demand for UAM services. Similarly, disruptions to the electric power grid, vertiport availability and aircraft status may reduce the efficiency of UAM operations during specific time periods. Moreover, public acceptance and perceptions of new technologies play a significant role in shaping UAM passenger demands.

The dynamic, heterogeneous, uncertain and interconnected nature of an ITS, coupled with non-linear, spatio-temporal and causal relationships, make it challenging to identify and model cross-domain dependencies using traditional analytical techniques. Simulation modelling thereby emerges as a promising approach to test and visualise multimodal algorithms in a safe representative environment [28]. In fact, several studies employ simulation modelling to investigate novel solutions in diverse industrial fields. Moon [29], for instance, reviews the use of simulation models for sustainability, while Young et al. [30] highlight their application in road safety analysis. Few works, however, have used simulation modelling in the context of AAM. Rothfield et al. [31] suggest the importance of modelling and evaluating UAM solutions, and Brittain et al. [32] propose an AI test bed for AAM. Similarly, Yang et al. [33] employ simulation modelling for the stress testing of UTM decision-making frameworks, and Rimjha et al. [34] utilise discrete-event modelling to investigate factors affecting vertiport capacity. Furthermore, Schweiger et al. [35] employ a discrete-event simulation model to generate airside traffic and develop a level of service concept for vertidrome operations. Similarly, Preis et al. [36] use agent-based modelling to present a refined vertiport model with the most crucial simulation parameters. Digital twins can also offer enhanced realism when modelling AAM ecosystems, by enabling real-time bidirectional data flow between the physical and digital worlds [37], [38], [39].

Existing simulation models, however, do not consider all the unique requirements of UAM, and fail to incorporate the multimodal elements of a transportation system. Moreover, a comprehensive digital twin is often unnecessary for initial exploratory research, particularly in complex environments for which the underlying models do not yet exist. Consequently, a literature gap exists for a simple yet complete simulation environment that enables effective research on AAM solutions within a collaborative multimodal ecosystem.

4. SIMULATION PLATFORM

A multimodal experimentation platform must remain compatible with a variety of research endeavours and satisfy the core requirements summarised in Table 1. Various software platforms offer the ability to create 3D models and simulation environments. Notably, NVIDIA OmniverseTM [40] focuses on the scalable and collaborative development of metaverse environments, and rendering engines like Unreal or Unity may be coupled with external simulators to realise comprehensive digital twins. Such solutions, however, require substantial development and are not conducive to platforms for exploratory research.

AnyLogic thereby emerges as a promising solution to meet the identified platform requirements. The software supports the integration of geographic information system (GIS) maps [41], enabling simulated agents to be defined within a real-world geographical context. Multiple diverse agents can be modelled within this environment by leveraging existing AnyLogic packages and libraries. AnyLogic also facilitates data imports from external databases, enabling the introduction of pre-defined vehicle schedules, real weather data and other contextual information. To enhance the visualisation and analysis capabilities of the model, AnyLogic further supports 2D and 3D visualisations, coupled with robust statistical computations and displays.

5. SIMULATION FRAMEWORK

An agent-based simulation model is proposed as the foundation for a comprehensive multimodal and multi-agent experimentation platform, as illustrated in Figure 3. The model encompasses strategically distributed travel hubs positioned within an external GIS map, tailored to a specific use-case or operating scenario. Each hub contains a set of transportation facilities, including any combination of vertiports, bus stops, train stations, airports and seaports. Passenger mobility demand is subsequently simulated throughout the selected region, incorporating specific probabilistic distributions or demand models.

Table 1. Core requirements of a multimodal simulation platform

Requirement	Overview
Interoperability	The platform should remain compatible with multiple platforms and software packages to ensure easy integration of external data and tools.
Flexibility	The environment must accommodate a wide variety of agents, operational scenarios and parameters.
Reliability	For a given set of parameters, the simulation model must return consistent results in the absence of stochastic variations.
Functionality	The model must support the implementation of sequential multi-agent decision-making frameworks within a multimodal transportation environment. It should offer the capability to deploy and train intelligent solutions, while supporting 2D and 3D visualisations, performance monitoring and results analysis.
Scalability	The simulation must be able to accommodate large geographic regions with numerous vehicles and passengers across various transportation domains.
Efficiency	Computational burden must be minimised for ease of deployment.
Accuracy	The environment should accurately represent the real-world, striking an appropriate level of abstraction.

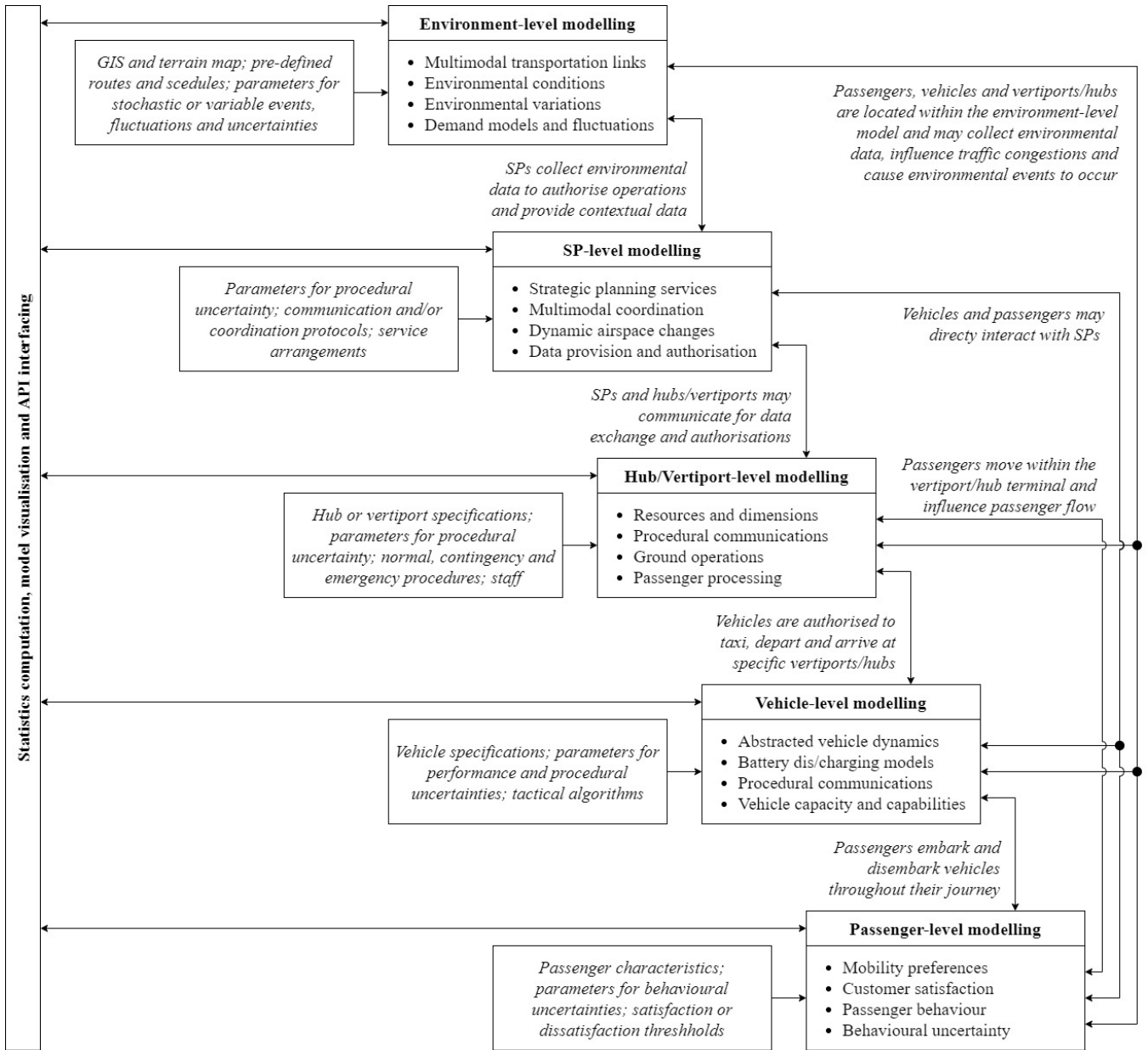


Figure 3. Overview of the proposed simulation modelling framework to realise an experimentation platform for multi-agent and multimodal AAM algorithms.

Environmental conditions can be readily modified through user-defined parameters, including micro-weather variations, maintenance works and uncooperative transportation entities. Model uncertainty can also be tailored to specific operating conditions. Within this environment, various types of agents are realised, representing diverse customers, vehicles, vertiports and service providers (SPs). Pre-defined schedules for public transport may also be included for a more realistic environment. Moreover, contextual data may be imported from external databases, enabling increased overall connectivity.

Since the focus of this research lies on UAM operations, the internal workings of bus stops, train stations, airports and seaports are not rigorously modelled. Nonetheless, their operational impacts on the broader mobility ecosystem are simulated as delays following specific probabilistic distributions. Conversely, vertiport operations are extensively

modelled, including the vertiport layout, configuration and underlying resources. Ground operations, terminal passenger flow and communication with other AAM stakeholders are simulated to ensure a more realistic scenario in which all UAM components can be evaluated. Similarly, ground, rail and sea vehicle models are not comprehensively modelled, apart from the factors that impact the entire transportation ecosystem. Conversely, UASs and eVTOL vehicles are more robustly modelled, to better understand their impact on UAM operations. Each aircraft can be defined with unique dynamics, battery models, procedural algorithms and performance specifications, to reflect the heterogeneity of AAM and UAM vehicles. All vehicles are also equipped to make tactical decisions, using on-board sensing capabilities. Nonetheless, cooperative aircraft are still guided by vertiports and other SPs, and should follow relevant instructions and authorisations throughout mission execution.

The simulation platform manages communications and data distribution among all constituent agent models, facilitating seamless information exchange. It further computes and presents essential statistics while providing relevant interfaces for connecting to external software packages. The entire environment is subsequently visualised as a dynamic 2D map, offering a comprehensive overview of the positions, movements and actions of all involved agents. Advanced Any-Logic visualisation capabilities are also leveraged, whereby users can selectively zoom in on specific vertiports to explore the internal passenger flow, ground operations and vertiport layout within a 3D simulation.

Optimisation or RL-based decision-making algorithms can be deployed, trained and tested within this simulation model. Notably, each algorithm can determine the actions of one or more agents, including individual vehicles, vertiports and SPs, enabling the deployment of multi-agent and hierarchical RL solutions. These can be evaluated within a realistic and repeatable test environment, to enable the development of effective and robust AAM and UAM solutions under diverse operating conditions and performance objectives.

6. AGENT MODELS

Environment-level Model

Various socio-economic, geographic, contextual and environmental factors must be modelled in the target environment, as summarised in Figure 4. Firstly, the geographic positions of each travel hub must be defined within a GIS map, accompanied by a clear delineation of the transportation services available at each location. Route structures between these nodes must also be established, which may be dynamically modified throughout the simulation.

Travel demands at each node must be modelled for each transportation medium. Individuals residing near a vertiport in an affluent neighbourhood, for instance, are more likely to afford expensive air taxi fares. Areas with a higher acceptance of UAM are also likely to generate more travel demand compared to locations where air taxis face societal resistance. Furthermore, passenger demand near airports and seaports will vary depending on the schedules of flights or ships. Similarly, mobility demands in residential, office and school areas are likely to spike during specific rush hours throughout the day, and special events such as sports and music gatherings can lead to occasional surges in transportation requirements.

The simulation environment must also account for events that can impede or restrict mobility services. UAM operations, for instance, might be adversely affected by factors such as poor weather conditions, micro-weather variations, dynamic geofences, uncooperative aerial entities, malicious cyberattacks and damage to electric charging infrastructure. On the ground, traffic congestion can arise due to road accidents, unforeseen bottlenecks or ongoing roadworks. Similarly, disruptions like maintenance works or labour strikes could restrict rail and road transportation links.

The environment must therefore be initialised for the use-case under investigation, as illustrated in Figure 5. Throughout the simulation, this model must be updated to reflect the dynamic transportation environment, external data sources and decisions made by agents within the environment. Furthermore, it must regularly update the movements and locations of all deployed agents until the simulation concludes.

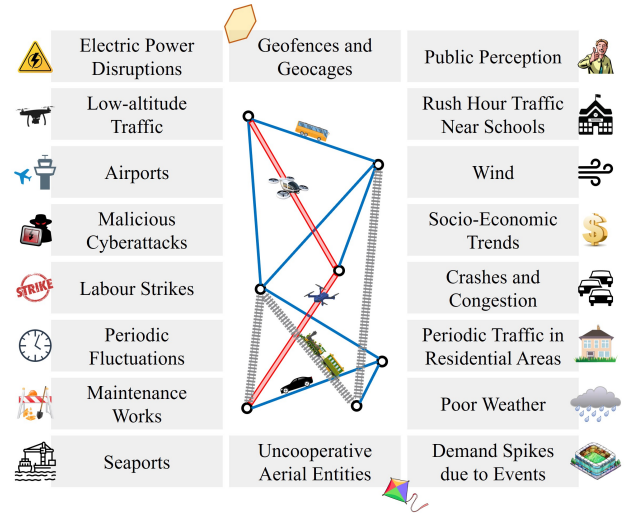


Figure 4. Elements of a multimodal environment model.

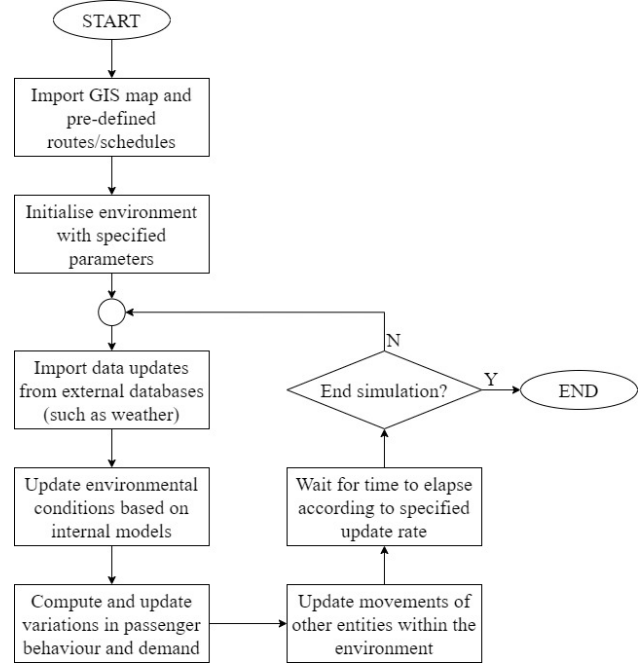


Figure 5. High-level overview of the proposed simulation flow for the environment-level model within the multimodal framework.

Passenger-level Model

The simulated environment may be divided into distinct geographic zones experiencing unique fluctuations in mobility demand. Passengers are dynamically spawned within each zone based on a predetermined rate or distribution, and events such as concerts or sports events can introduce spikes in demand during specific time periods. Each passenger is modelled with unique characteristics, including average walking speed, behavioural traits and transportation preferences. Passengers can also be categorised into sub-populations with similar traits, randomised over a specified probability distribution. This provides insights into how different passengers interact with the transportation framework under investigation.

After initialisation at a specific location with designated destination coordinates, start time and mobility preferences, each passenger requests a route to a mobility SP after some delay. The SP may propose a route to the passenger after coordinating with relevant stakeholders, which is either accepted or rejected with a certain probability. In case of rejection, the customer may resubmit a request or cease using the SP, resulting in a dissatisfied passenger. If the route is accepted, the passenger begins moving to the first transportation hub at the booked time slot. Upon reaching a transportation hub, the customer goes through terminal queues and processes before waiting at the gate or platform until the vehicle is ready to board. If a significant delay occurs, however, a passenger may cancel the remainder of the journey, leaving dissatisfied.

Upon landing or arrival, the passenger undergoes a disembarking processes, modelled as a series of delays following tuned probabilistic distributions. The passenger subsequently walks to the next transportation hub or gate, with the speed possibly affected by heavy luggage or poor weather conditions, as summarised in Figure 6. Upon reaching the final destination, customer satisfaction can be computed based on the door-to-door delay and adherence to the customer mobility preferences. This serves as a crucial customer-centric metric for evaluating the transportation framework under investigation.

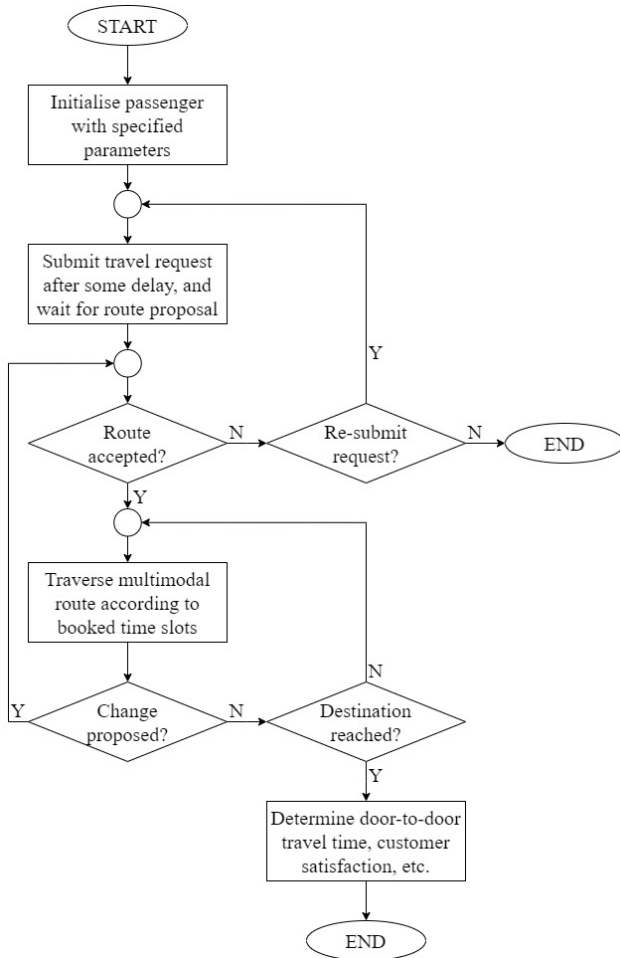


Figure 6. High-level overview of the proposed simulation flow for the passenger-level model within the multimodal framework.

Vertiport-level Model

Each vertiport must be modelled according to specific design criteria, encompassing unique final approach and take-off area (FATO) locations, parking bay arrangements and charging facilities. The number and type of pads available, for instance, determine which and how many aircraft can be supported. Similarly, the number and type of vehicle chargers impact how quickly electric vehicles may be charged. The location of the vertiport also influences whether air traffic control (ATC) approval is required when authorising take-offs and landings, and pre-defined procedures determine how contingency and emergency scenarios are managed. Taxiway lengths and taxiing vehicles impact the taxiing duration, while the vertiport design impacts ground operations. The passenger area design impacts passenger throughput and waiting time, and sensing infrastructure enables nearby aerial entities or phenomena to be detected with a specified level of uncertainty. The airspace structure surrounding the vertiport must also be defined, and significantly influences take-off and landing procedures.

Comprehensive modelling of the vertiport passenger terminal is particularly important, as exemplified in Figure 7. On arrival at a vertiport, a passenger must navigate the terminal, pass any security checks and embark or disembark UAM vehicles. This approach facilitates future research exploring different vertiport configurations and the impact of security checks on vertiport throughput and the average passenger waiting time. Similarly, queues may be introduced for passengers leaving the terminal after disembarking an aircraft.

Ground-based vehicle operations within the vertiport are also modelled, as summarised in Figure 8. Notably, the vertiport assumes the responsibility of authorising vehicle take-offs and landings, allocating resources to specific aircraft, coordinating taxiing operations and managing embarking or disembarking procedures. Contingency procedures can also be defined, enabling the vertiport to request counter-UAS support or issue emergency notices to nearby authorities.

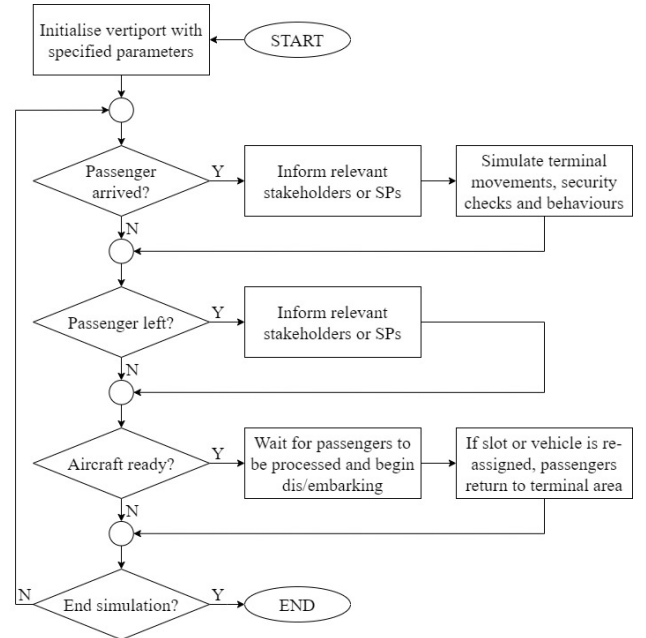


Figure 7. High-level overview of the proposed simulation flow for terminal passenger movement.

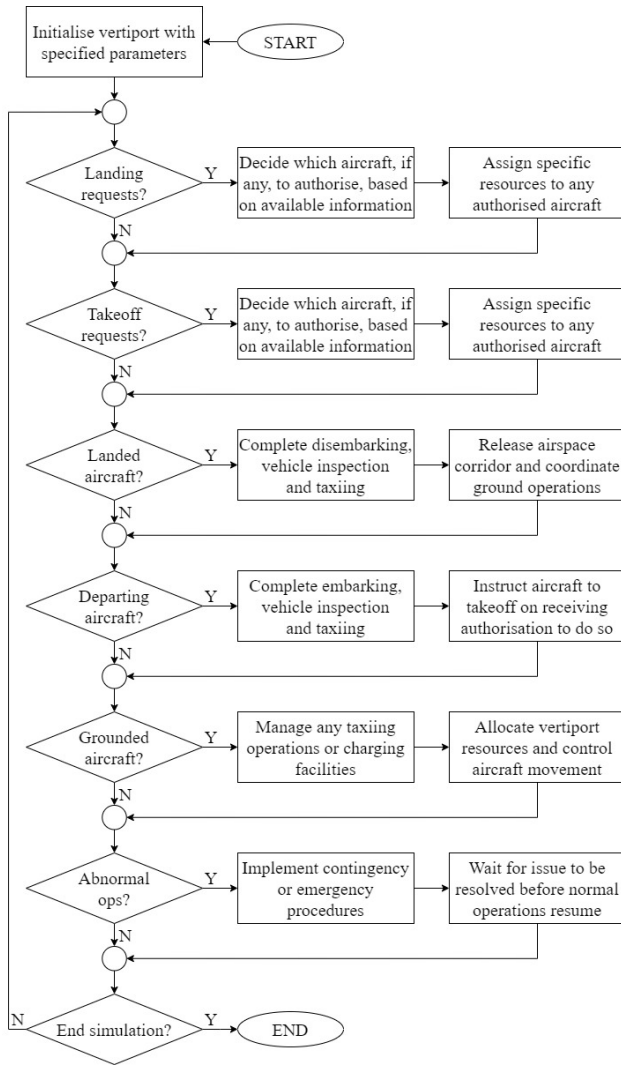


Figure 8. High-level overview of the proposed simulation flow for vehicle-based ground operations.

Vehicle-level Model

Each UAM vehicle model is characterised by distinct aircraft specifications, battery models, flight dynamics and vehicle dimensions. Specifically, battery charging and discharging models should be modelled under varying environmental conditions and the flight envelope of each aircraft must be defined. Additionally, vehicle specifications may impose manoeuvrability constraints and restrict the number of vertiports in which the vehicle can land. Such specifications also impact the safe flight envelope, minimum cool-down times, rotor start/stop times, environmental sensitivity, pad sequence requirements and cargo capacity.

The simulation must also account for on-board sensors, enabling the aircraft to detect entities in its vicinity with varying degrees of accuracy and uncertainty. Pre-determined algorithms may subsequently use such information to manage contingency, emergency, and mission execution procedures. Communication systems can also be modelled to simulate data transmission uncertainties between vehicles, vertiports and other SPs. Throughout the simulation, each vehicle thereby traverses a pre-defined state sequence, as summarised in Figure 9.

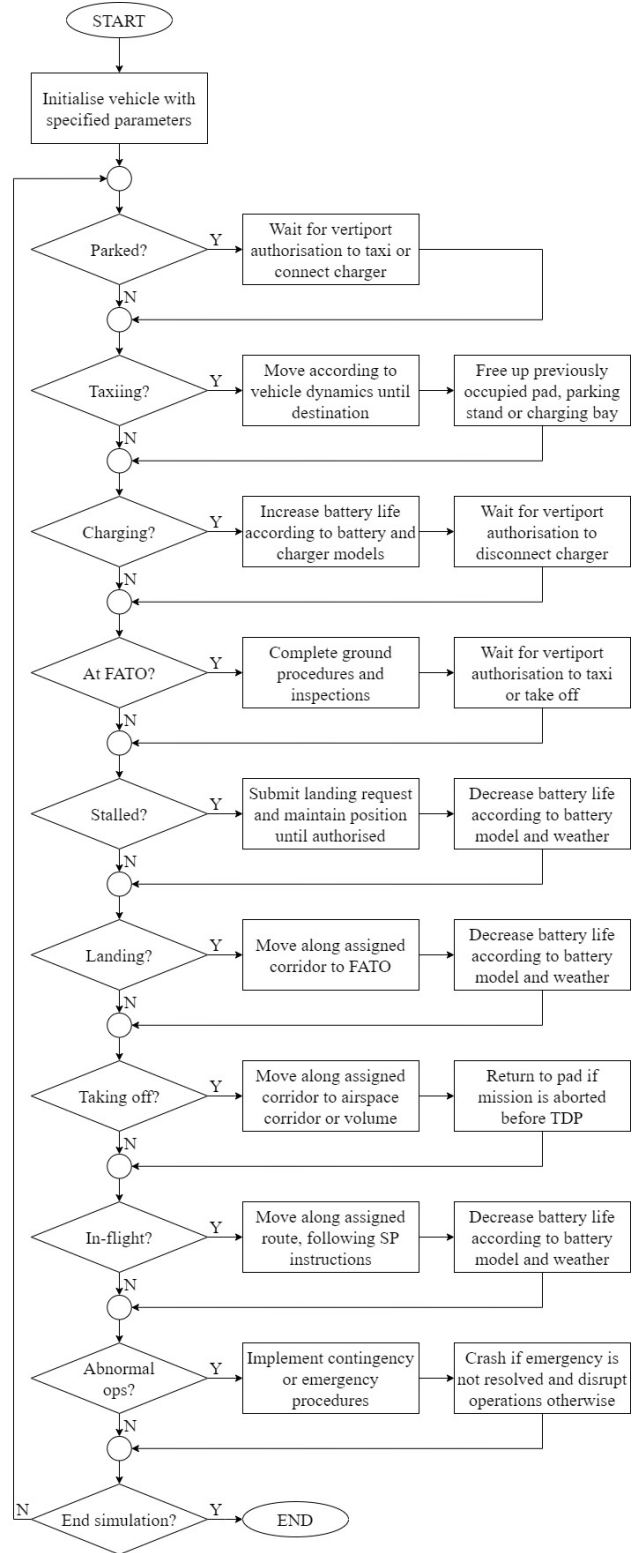


Figure 9. High-level overview of the proposed simulation flow for UAM vehicles.

While parked, the aircraft awaits vertiport instructions to initiate taxiing operations. If the vehicle is connected to a charging bay, its battery status is also updated. The aircraft may subsequently submit a take-off request after completing its taxiing operation. Upon receiving take-off authorisation, the vehicle should execute its planned mission and follow its assigned trajectory, executing any pre-programmed tactical detect and avoid (DAA) algorithms. Finally, the vehicle should submit a landing request at its arrival vertiport and remain in a holding position until authorisation is granted. The landing process, passenger disembarking and subsequent taxiing manoeuvres must also be simulated, according to the instructions issued by the respective vertiport. Contingency or emergency procedures may also be defined to address abnormal operations.

Ground, rail and sea vehicles are modelled to a higher level of abstraction. These vehicles adhere to pre-defined schedules or depart when there is a substantial surge in passenger demand at the relevant travel hub location. Once in motion, each vehicle follows its assigned route, potentially incurring delays caused by diverse environmental conditions. Upon reaching its destination, the vehicle allows passengers to disembark before preparing for the next cycle of operations.

Service Provider-level Model

SP agents are modelled to provide advisory and data provision services to vehicles and vertiports within the environment. Pre-defined parameters dictate what service is provided and how each SP interacts with other agents. The simulation can also specify the timeliness and accuracy of any communication, navigation and surveillance (CNS)-related data provision. Moreover, the maturity of security and recovery protocols may be defined, determining the speed at which an SP can recover from a fault or malicious attack. Throughout the simulation, SP agents continually monitor and process relevant environmental data, promptly issuing necessary commands or transmitting data packets to other agents, as illustrated in Figure 10. Any simulated faults or cyberattacks could corrupt this data, requiring a certain amount of time to elapse before service provision can continue.

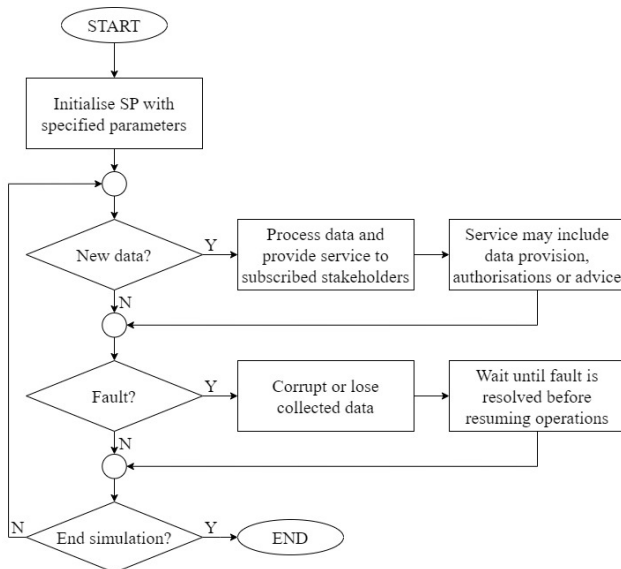


Figure 10. High-level overview of the proposed simulation flow for SP models.

7. DEMONSTRATIVE USE-CASE

A regional mobility use-case around London is considered to demonstrate the capabilities of AnyLogic to realise a multimodal simulation environment. This use-case involves travel hubs at Heathrow, Luton and Stansted Airports, each equipped with a railway station, vertiport and bus terminus. A travel hub at Cranfield Airport is also assumed. This airport, however, is only assumed to contain a vertiport and bus stop, since no nearby train tracks exist. Nonetheless, travel hubs with a bus terminus and railway station are introduced in adjacent cities like Bedford and Milton Keynes. Similarly, Euston serves as another travel hub with a train station and bus terminus in central London. For safety reasons, other urban vertiports are positioned on the outskirts of London. Promising locations, such as Lambourne and Norman Park, offer ample space for developing urban vertiports while maintaining conservative safety buffers. Since these locations are less densely populated, however, they only feature nearby bus stops and no train stations. These travel hub locations demonstrate a representative use-case of UAM, showcasing a complex multimodal infrastructure connecting airports, city centres and neighbouring towns. The quantity and characteristics of travel hubs, however, can be readily modified.

Each travel hub location is linked to a GIS map, and a fixed number of bus, train, and eVTOL agents represent the multimodal transportation fleet. These agents are distributed among the travel hubs during startup, with all initialisation data loaded from a customisable external database. Passengers with randomised characteristics are subsequently created within specified geographic regions, according to a pre-defined rate. Each passenger submits a request to reach a random destination to a mobility SP, who proposes a random route for the passenger to take. The passenger then accepts or rejects the route with a certain probability, depending on how closely the proposal adheres to the specified mobility preferences. If rejected, the consumer may resubmit a request with a certain probability or leave dissatisfied. If accepted, the customer will begin traversing the route at the specified start time with some uncertainty. This involves walking to a node when required, before moving through the terminal until instructed to board the assigned vehicle. Upon arriving at the next transportation hub, the passenger disembarks the vehicle and continues to the next leg of the journey.

Within vertiports, passenger terminal behaviour can be monitored, controlled, and viewed in 2D or 3D. Specifically, a passenger may request help from a help desk or use the available vending machines with a certain probability. Each passenger must then pass a security check before waiting at the assigned gate for embarking. When an eVTOL is taxied to the appropriate parking slot, the necessary inspections are carried out, and passengers are authorised to embark the aircraft, according to a pre-defined queue model. The vertiport can also authorise the charging of a vehicle for a specified duration when required. After loading passengers or cargo, the vertiport coordinates eVTOL taxiing to an available FATO. Before authorising a vehicle to take off or land, however, the vertiport must submit an authorisation request to a competent authority, which must in turn issue the authorisation or rejection accordingly. Each vertiport may also accept or reject requests by a mobility SP to book a FATO or parking slot at a future time slot. Other modes of transport are modelled to a higher level of abstraction, with queues and processes simulated using pseudo-random temporal delays. Additionally, bus and train agents respectively move along roads and train tracks embedded within the GIS map, while UAM vehicles follow predefined AAM routes and corridors.

8. PROTOTYPE AND RESULTS

The implementation of specific decision-making frameworks is not within the scope of this research. Conversely, the prototype aims to demonstrate the flexibility and functionality of the simulation platform for investigating UAM within a multimodal context. This section thereby showcases the actions taken by each agent during a single multimodal passenger journey within the use-case described in Section 7.

New passengers successfully and randomly spawned within defined geographic regions, featuring randomised destinations and preferences. Each passenger requested a route from a mobility SP, exemplified in Figure 11, and accepted or rejected the route with a predetermined probability. The mobility SP could in turn request the necessary airspace authorisations and company confirmations for a particular route, as highlighted in Figure 12, before proposing a multimodal route to the user, as shown in Figure 13. Such actions could be readily automated by connecting custom Java applications or Python scripts to the simulation model, wherein animations could also be disabled. This ensures that the platform remains suitable for RL training and fast Monte Carlo simulations. Additionally, hundreds of passengers were successfully simulated within the environment, confirming its suitability for realistic simulations of high mobility demand in urban areas.

Upon accepting a sample route involving walking, air taxi travel, and other modes of transport, the passenger initiated the journey by walking to the first vertiport at the specified start time. At the vertiport, the passenger successfully entered a high-fidelity micro-level simulation, viewable in 2D or 3D as demonstrated in Figure 14 and Figure 15. After traversing all necessary queues and processes, modelled using established AnyLogic pedestrian flow models, the passenger correctly waited at the assigned gate until boarding commenced. Specifically, the terminal area was assumed to comprise two security checkpoints for incoming passengers, a help desk and several ticket vending machines that passengers could use with some probability, with appropriate queues modelled to access or pass each service.

Throughout this prototype, a simple vertiport design was considered, with two FATOs, two ground taxi vehicles and eight parking bays, each equipped with a vehicle charger. The vertiport could therefore manage slot reservations, as well as control ground and air operations, as illustrated in Figure 16 and Figure 17, respectively. Each vertiport was also assumed to support all eVTOLs within the simulation. After taxiing the vehicle to the required slot, the boarding gates were opened, allowing waiting passengers to board the aircraft. Following boarding completion, the aircraft was successfully taxied to an available FATO, as shown in Figure 18.

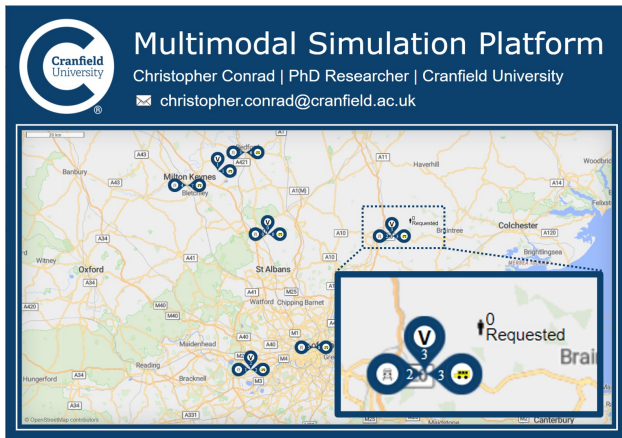


Figure 11. Platform prototype with dynamically loaded hub locations and a new passenger request.

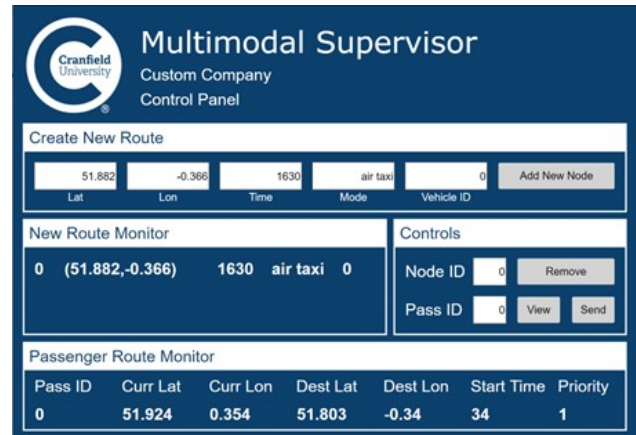


Figure 13. Interface used by a mobility SP to manage customer routes within the platform prototype.

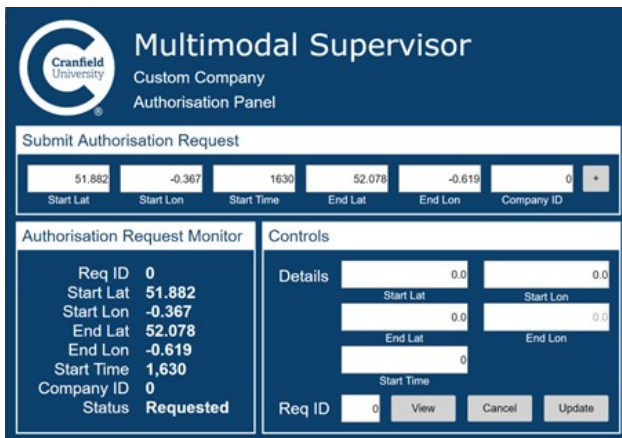


Figure 12. Interface used by a mobility SP to manage airspace authorisations within the platform prototype.

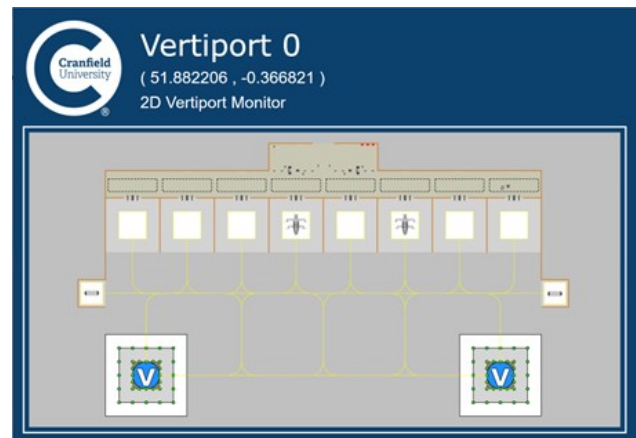


Figure 14. 2D vertiport visualisation within the platform prototype, with a passenger waiting at the final gate.



Figure 15. 3D vertiport visualisation within the platform prototype, with a passenger waiting at the final gate.

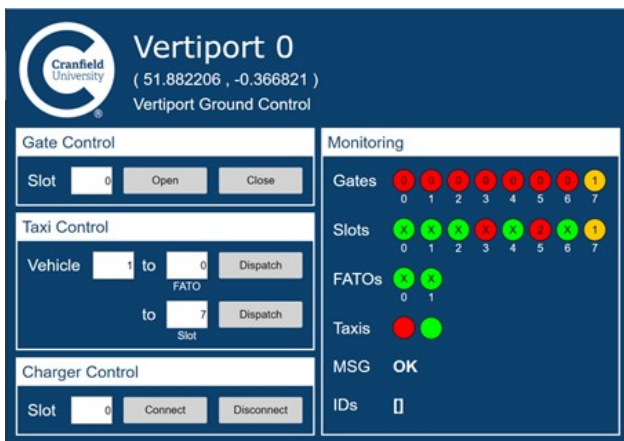


Figure 16. Interface used by a vertiport to manage ground operations within the platform prototype.

The vertiport subsequently requested take-off approval from a competent authority, and instructed the vehicle to take off on receiving authorisation to do so. This successfully caused the eVTOL and on-board passenger to exit the micro-level simulation and begin their journey in the macro GIS map, as depicted in Figure 19. The vehicle traversed its assigned UAM corridor before arriving and landing at the destination vertiport, on receiving authorisation to do so. The agents then entered the micro-level simulation of the destination vertiport, which successfully taxied the eVTOL to an available parking bay. The on-board passenger could then disembark, exit the vertiport, and walk to the next transportation hub accordingly. Specifically, the passenger could effectively use train and bus agents, correctly traversing existing rail tracks and roads within the dynamically loaded GIS map.

This process simultaneously occurred for all passenger, hub, vehicle, and SP-level agents, each capable of taking distinct actions based on unique observations. This guarantees that the simulation testbed can be readily used to deploy and test decision-making algorithms and frameworks. Additionally, the simulation environment successfully interfaced with Python scripts, facilitating interaction with established optimisation, RL, and decision-making libraries. These outcomes support the assertion that AnyLogic is suitable for realising a multimodal and multi-agent simulation environment tailored to AAM and UAM applications.

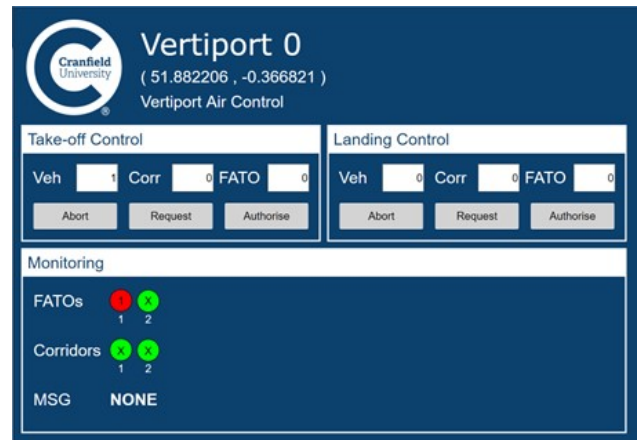


Figure 17. Interface used by a vertiport to manage air operations within the platform prototype.



Figure 18. 3D visualisation of taxiing operation within the platform prototype.

Throughout the simulation, environmental and model parameters were loaded from a custom initialisation file, including agent characteristics, noise or uncertainty specifications, and the initial location of simulated vehicles. This confirmed the ability of the simulation platform to cater for different user requirements, ensuring that agent parameters, queue dynamics, environmental conditions, demand fluctuations and mobility dynamics can be readily customised on simulation startup.

The quantity of simulated agents could also be readily modified, with fleets of 15 eVTOLs, 20 trains and 40 buses considered in the selected use-case. Similarly, a single multimodal supervisor and a single airspace authority were assumed to exist. Nonetheless, increasing the number of simulated agents was observed to have negligible impact on system performance, especially when disabling 3D animations for fast simulation activities. This suggests that the platform is suitable for complex regional simulations comprising multiple transportation SPs and high mobility demands.

In summary, this section highlights the versatility of the developed prototype for exploring UAM in a multimodal context. The simulation successfully models passenger interactions with SPs, the initiation of journeys involving different transportation modes, and the dynamic management of terminal, ground and air operations within vertiports.

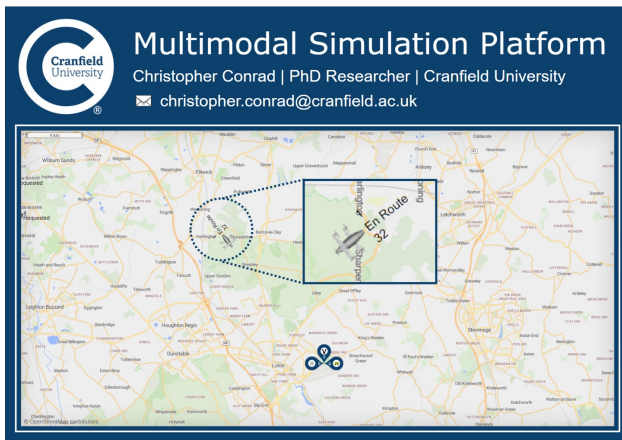


Figure 19. EVTOL journey displayed within the platform prototype.

9. CONCLUSIONS

Summary

This work successfully proposed and prototyped a multi-agent and multimodal simulation tool to enable future research on vertiport configurations, collaborative vertiport strategies and decision-making frameworks for AAM. To the authors' knowledge, this is the first research to propose and prototype a simulation environment that incorporates UAM and AAM within a broader multimodal ecosystem for MaaS operations and enhanced collaborative decision making.

This work thereby establishes a unified platform for both academic and industrial research, fostering the growth of safe and reliable intelligent solutions within a data-centric AAM infrastructure. In the emerging vertiport industry, the proposed simulation platform is indispensable for investigating diverse transportation frameworks, vertiport layouts, operational procedures, design configurations, and scheduling schemes. This has the potential to accelerate the development of sophisticated AAM scheduling and resource management algorithms. Such solutions will yield increased cost savings while ensuring the safety, sustainability and efficiency of nascent UAM operations.

Future Work

Future work will build upon the constructed prototype to refine the simulation platform with higher-fidelity models for each transportation medium, vertiport, SP, and scheduling algorithm. This extension will also involve simulating more intricate models of travel demand and environmental variations, coupled with comprehensive statistical computations and displays. Combining pre-scheduled public transport routes with on-demand MaaS models will pave the way for advanced solutions maximising customer satisfaction, business profitability, environmental sustainability, and transportation efficiency. Additionally, the impact of external traffic not controlled by the collaborative decision-making framework will be considered for a more realistic use-case. Moreover, it will introduce more complex stakeholder communications, cyberattacks, CNS interference, data corruption, contingency scenarios and emergency events within the realised simulation environment. The simulation tool will subsequently be leveraged to investigate the benefits and limitations of different vertiport layouts, vertiport network configurations, operational procedures, decision-making algorithms and prioritisation schemes.

ACKNOWLEDGMENTS

The research work disclosed in this publication is partially funded by the Malta Tertiary Education Scholarships Scheme, and by Innovate UK under grant agreement No.10023201, as part of the Air Mobility Ecosystem Consortium (AMEC) project. The support of Dr. Anthony Rushton and Ms. Elisabeth Chau from NATS is also gratefully acknowledged.

REFERENCES

- [1] "Eu green deal: Make transport greener," European Commission, Tech. Rep., Jul. 2021.
- [2] "Sustainable and smart mobility strategy: Putting european transport on track for the future," European Commission, Tech. Rep., Feb. 2021.
- [3] "Multimodal access to public transportation," U.S. Department of Transportation, Tech. Rep., Aug. 2015.
- [4] "Why the uk needs more intermodal rail freight," UKMPG / RFG, Tech. Rep., Jan. 2021.
- [5] L. A. Garrow, B. J. German, N. T. Schwab, M. D. Patterson, N. L. Mendonca, Y. O. Gawdiak, and J. R. Murphy, "A proposed taxonomy for advanced air mobility," NASA, Tech. Rep., Apr. 2022.
- [6] "Advanced air mobility: Taking a use case approach to develop regulation," UK Civil Aviation Authority, Tech. Rep. CAP 2122, Mar. 2021.
- [7] "Urban air mobility: What are the benefits for the eu?" EASA, Tech. Rep., 2023.
- [8] A. Straubinger, R. Rothfeld, M. Shamiyeh, K.-D. Büchter, J. Kaiser, and K. O. Plötner, "An overview of current research and developments in urban air mobility – setting the scene for uam introduction," *Journal of Air Transport Management*, vol. 87, p. 101852, 2020.
- [9] A. Bauranov and J. Rakas, "Designing airspace for urban air mobility: A review of concepts and approaches," *Progress in Aerospace Sciences*, vol. 125, p. 100726, 2021.
- [10] K. Schweiger and L. Preis, "Urban air mobility: Systematic review of scientific publications and regulations for vertiport design and operations," *Drones*, vol. 6, no. 7, Jul. 2022.
- [11] C. Conrad, S. Al-Rubaye, and A. Tsourdos, "Intelligent embedded systems platform for vehicular cyber-physical systems," *Electronics*, vol. 12, no. 13, 2023.
- [12] S. Paiva, M. A. Ahad, G. Tripathi, N. Feroz, and G. Casalino, "Enabling technologies for urban smart mobility: Recent trends, opportunities and challenges," *Electronics*, vol. 21, no. 6, 2021.
- [13] P. Seuwou, E. Banissi, and G. Ubakanma, "The future of mobility with connected and autonomous vehicles in smart cities," in *Digital Twin Technologies and Smart Cities*, M. Farsi, A. Daneshkhah, A. Hosseinian-Far, and H. Jahankhani, Eds. Cham: Springer International Publishing, 2020, pp. 37–52.
- [14] A. Pressas, Z. Sheng, P. Fussey, and D. Lund, "Connected vehicles in smart cities: Interworking from inside vehicles to outside," in *2016 13th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON)*. 27-30 June 2023, London, UK: IEEE, Jun. 2016, pp. 1–3.

- [15] Y. J. S. P.E., M. Golias, G. Dedes, C. Douligeris, and S. Mishra, "Challenges, risks and opportunities for connected vehicle services in smart cities and communities," *IFAC-PapersOnLine*, vol. 51, no. 34, pp. 139–144, 2019.
- [16] L. Barron, "The road to a smarter future: The smart city, connected cars and autonomous mobility," in *2021 26th International Conference on Automation and Computing (ICAC)*. 2–4 September 2021, Portsmouth, UK: IEEE, Oct. 2021, pp. 1–6.
- [17] J. Guo, J. Xu, Z. He, and W. Liao, "Research on risk propagation method of multimodal transport network under uncertainty," *Physica A: Statistical Mechanics and its Applications*, vol. 563, p. 125494, 2021.
- [18] Z. He, J.-N. Guo, and J.-X. Xu, "Cascade failure model in multimodal transport network risk propagation," *Mathematical Problems in Engineering*, pp. 1–7, 2019.
- [19] R. Liao, W. Liu, and Y. Yuan, "Resilience improvement and risk management of multimodal transport logistics in the post-COVID-19 era: The case of TIR-based sea-road multimodal transport logistics," *Sustainability*, vol. 15, no. 7, 2023.
- [20] A. Canale, G. Tesoriere, and T. Campisi, "The MAAS development as a mobility solution based on the individual needs of transport users," *AIP Conference Proceedings*, vol. 2186, no. 1, p. 160005, Dec. 2019.
- [21] D. A. Hensher, "Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: Are they likely to change?" *Transportation Research Part A: Policy and Practice*, vol. 98, pp. 86–96, 2017.
- [22] A. Ceder, "Urban mobility and public transport: future perspectives and review," *International Journal of Urban Sciences*, vol. 25, no. 4, pp. 455–479, 2021.
- [23] I. Sung, M. Buderath, and P. Nielsen, "Unpacking the role of artificial intelligence for a multimodal service system design," *Electronics*, vol. 11, no. 4, 2022.
- [24] G. Maity, S. K. Roy, and J. L. Verdegay, "Analyzing multimodal transportation problem and its application to artificial intelligence," *Neural Computing and Applications*, vol. 32, no. 7, pp. 2243–2256, Apr. 2020.
- [25] M. Janic, "Assessing some social and environmental effects of transforming an airport into a real multimodal transport node," *Transportation Research Part D: Transport and Environment*, vol. 16, no. 2, pp. 137–149, 2011.
- [26] A. Toet, J. van Kuijk, and S. Santema, "Transforming airport hubs into future-proof multimodal transport hubs," in *Relating Systems Thinking and Design 2022 Symposium*. 13–16 October 2022, Brighton, UK: RSDX, Oct. 2022.
- [27] R. A. Zachariah, S. Sharma, and V. Kumar, "Systematic review of passenger demand forecasting in aviation industry," *Multimedia Tools and Applications*, May 2023.
- [28] I. Grigoryev, "Anylogic in three days - a quick course in simulation modelling," AnyLogic, Tech. Rep., 2022.
- [29] Y. B. Moon, "Simulation modelling for sustainability: a review of the literature," *International Journal of Sustainable Engineering*, vol. 10, no. 1, pp. 2–19, 2017.
- [30] W. Young, A. Sobhani, M. G. Lenné, and M. Sarvi, "Simulation of safety: A review of the state of the art in road safety simulation modelling," *Accident Analysis Prevention*, vol. 66, pp. 89–103, 2014.
- [31] R. Rothfeld, M. Balac, and C. Antoniou, "Modelling and evaluating urban air mobility – an early research approach," *Transportation Research Procedia*, vol. 41, pp. 41–44, 2019.
- [32] M. Brittain, L. E. Alvarez, K. Breeden, and I. Jessen, "AAM-Gym: Artificial intelligence testbed for advanced air mobility," *arXiv*, Jun. 2022.
- [33] X. Yang, M. Egorov, A. Evans, S. Munn, and P. Wei, "Stress testing of uas traffic management decision making systems," in *AIAA Aviation 2020 Forum*. 15–19 June 2020, Virtual: AIAA, Oct. 2020.
- [34] M. Rimjha and A. Trani, "Urban air mobility: Factors affecting vertiport capacity," in *2021 Integrated Communications Navigation and Surveillance Conference (ICNS)*. 20–22 April 2021, Dulles, VA: IEEE, Apr. 2021.
- [35] K. Schweiger, F. Knabe, and B. Korn, "Urban air mobility: Vertidrome airside level of service concept," in *AIAA Aviation 2021 Forum*. 7–11 June 2021, Washington, DC: AIAA, Jul. 2021.
- [36] L. Preis and M. Hornung, "Vertiport operations modeling, agent-based simulation and parameter value specification," *Electronics*, vol. 11, no. 7, 2022.
- [37] J. Zhao, C. Conrad, Q. Delezenne, Y. Xu, and A. Tsourdos, "A digital twin mixed-reality system for testing future advanced air mobility concepts: A prototype," in *The 23rd Integrated Communications, Navigation and Surveillance Conference*, 18–20 April 2023, Washington, DC, 2023.
- [38] C. Conrad, Q. Delezenne, A. Mukherjee, A. A. Mhowwala, M. Ahmed, J. Zhao, Y. Xu, and A. Tsourdos, "Developing a digital twin for testing multi-agent systems in advanced air mobility: A case study of Cranfield university and airport," in *2023 IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC)*, 1–5 October 2023, Barcelona, Spain, 2023.
- [39] J. Zhao, C. Conrad, R. Fremont, A. Mukherjee, Q. Delezenne, Y. Su, Y. Xu, and A. Tsourdos, "Co-simulation digital twin framework for testing future advanced air mobility concepts: A study with BlueSky and AirSim," in *2023 IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC)*, 1–5 October 2023, Barcelona, Spain, 2023.
- [40] University of Colorado Boulder, "NVIDIA omniverse - the platform for creating and operating metaverse applications," 2023, (Accessed: 12 July 2023). [Online]. Available: <https://www.nvidia.com/en-gb/omniverse/>
- [41] AnyLogic, "AnyLogic simulation software," 2023, (Accessed: 12 July 2023). [Online]. Available: <https://www.anylogic.com/>

BIOGRAPHY



Christopher Conrad received his Bachelor's degree in Electrical and Electronic Engineering from the University of Malta (UM) in 2022, and his MSc in Advanced Air Mobility Systems from Cranfield University in 2023. His research interests include advanced air mobility, urban air mobility, UAS traffic management, vertiport management, multimodality and intelligent data processing.

Mr. Conrad is a student AIAA and IEEE member, a student member of the Royal Aeronautical Society, and sits on the research council of the Advanced Air Mobility Institute.



Yan Xu is a Senior Lecturer in ATM/CNS, with the Centre for Autonomous and Cyber-Physical Systems in the School of Aerospace, Transport and Manufacturing. Before taking the academic role, he conducted his postdoc research with the Centre for Aeronautics in the same school as a Research Fellow in UTM. Prior to joining Cranfield University, he received his Ph.D.

in Aerospace Science and Technology from the Technical University of Catalonia, and received his M.Sc. and B.Eng. in Traffic Engineering from Nanjing University of Aeronautics and Astronautics. His main research interests include advanced air mobility, air traffic management, UAS traffic management and urban air mobility.



Deepak Panda is a Research and Teaching Fellow in AI and Autonomous Systems, and works at the Centre for Cyber-Physical Systems, School of Aerospace, Transport and Manufacturing (SATM) as a member of Human Machine Intelligence Group. He obtained his PhD from University of Exeter in 2022, focusing on Applied AI and Control of Smart Grids and got his M.Tech in Industrial

Automation and Control from National Institute of Technology, Calicut in 2016, after completing his graduation in Electrical Engineering (Power) from Jadavpur University in 2014. Dr.Panda also worked as Smart Factory Deployment Engineer in Schneider Electric Infrastructure Limited, India from 2016-18.



Antonios Tsourdos obtained an MEng in Electronic, Control and Systems Engineering from the University of Sheffield (1995), an MSc in Systems Engineering from Cardiff University (1996) and a PhD in Nonlinear Robust Autopilot Design and Analysis from Cranfield University (1999). He is the Director of Research and Head of the Autonomous and Cyber-Physical Systems Centre in

the School of Aerospace, Transport and Manufacturing at Cranfield University, United Kingdom. Professor Tsourdos is leading and involved with several projects sponsored by Innovate UK, Research England, EPSRC and H2020. He was a member of Team Stellar, the winning team for the UK MoD Grand Challenge to develop autonomous vehicles

to survey an area in 2008 and the IET Innovation Award (Category Team, 2009). Professor Tsourdos is Chair of the International Federation of Automatic Control (IFAC) Technical Committee on Aerospace Control, and a member of the American Institute of Aeronautics and Astronautics (AIAA) Unmanned Systems Integration and Outreach Committee; the Institute of Electrical and Electronics Engineers (IEEE) Control System Society.



DSPACE

<https://dspace.org/>

Simulating enhanced vertiport management in a multimodal transportation ecosystem

Conrad, Christopher; Xu, Yan; Panda, Deepak Kumar; Tsourdos, Antonios

2024-05-13

Institute of Electrical and Electronics Engineers (IEEE)

<https://doi.org/10.1109/AERO58975.2024.10521373>

Conrad C, Xu Y, Panda D, Tsourdos A. (2024) Simulating enhanced vertiport management in a multimodal transportation ecosystem. In: 2024 IEEE Aerospace Conference, 2-9 March 2024, Big Sky, USA