Human Mobility 2049 - It's Time to "ACTT"
(*Aeronautical Conceptualization for Tomorrow's Transportation*)

Authors: Kevin F. Hulme, Ph.D., CMSP[1], Rachel Su Ann Lim[1], Panagiotis Ch. Anastasopoulos, Ph.D.[1], Sheikh Shahriar Ahmed[1], Daniel B. Hess, Ph.D.[3], Meredith Finn[2], Cameron LaCourse[5]

Author Contacts: hulme@buffalo.edu, rlim2@buffalo.edu, panastas@buffalo.edu, sheikhsh@buffalo.edu, dbhess@buffalo.edu, mkfinn@buffalo.edu, camlacourse71@gmail.com

1: The Stephen Still Institute for Sustainable Transportation and Logistics; **2**: Department of Mechanical and Aerospace Engineering; **3**: Department of Urban and Regional Planning; **4**: Engineering Science (Data Science)
University at Buffalo (UB), Buffalo, NY 14202

5: School of Engineering, Department of Human Factors
Embry Riddle Aeronautical University, Daytona Beach, FL 32114

Supporting research team: Irina Benedyk, Ph.D.[1], Stephen E. Still, Ph.D.[1], Aaron Estes, Ph.D.[2], Matthew Klein[2], Rajyavardhan Karra[4], Prajit Kumar[2], Rizve Chowdhury[2], Toan Le[2], Salvatore Guadagna[2], Achira Boonrath[2]

ABSTRACT

Mobility (of people, goods, services) is an urgent, cross-disciplinary, bipartisan concern that impacts all humans on this planet. As our surface infrastructure continues to devolve (e.g., through overuse, congestion, and disrepair), intermodal Transportation has become a matter of extreme National priority. Recent emphasis is so pervasive that Federal policymakers are mandating widespread change, including the recent "Build Back Better" initiative. Near-term technological pathways towards improving human mobility include connected and autonomous vehicles (CAV's) and unmanned aerial vehicles (UAV's). Longer-term, domain experts are already investigating disruptive, bleeding edge prospects, including extreme advances with High-speed Rail, the Hyperloop, and even "flying car" technologies – formally referred to as Advanced Air Mobility (AAM). For such technologies, Modeling & Simulation (M&S) will be essential both to demonstrate baseline technological viability and to achieve long-term sustainability.

The 2022 I/ITSEC edict to ACTT! (Accelerate Change by Transforming Training!) is timely -- to enable humankind to revolutionize innovations that will overcome the varied Mobility challenges we face in the near future. This paper presents a notional examination of planned and ongoing Simulation developments towards realization of AAM on a broader scale. The proposed strategic vision is to urgently "ACTT": *Aeronautical Conceptualization for Tomorrow's Transportation* - through the rigorous and integrated application of M&S, and the Live-Virtual-Constructive-Autonomous (LVCA) taxonomy. Our implementation includes: a) Live prototyping, using drones and quadcopters within a large testing enclosure; b) Virtual simulation, by way of a custom-designed, parameterizable "human-in-the-loop" Mixed Reality Flying Car simulator; c) Constructive modeling, to enable vehicle traffic simulation into the third dimension through emulation of organic system behavior, including particle swarm theory; and d) Autonomous system implementations, for prioritizing network safety and efficiency. Critically, the paper concludes with an examination of candidate AAM Use Cases that will both: a) impact near-term human-machine interactions with next-generation mobility vehicles, and b) influence longer-term future urban development and planning.

ABOUT THE AUTHORS

Kevin F. Hulme, Ph.D., CMSP is the Operations Director for the Stephen Still Institute for Sustainable Transportation and Logistics (SSISTL) at the University at Buffalo. His areas of research and teaching interests include: vehicle simulation, game-based learning, game engines, and virtual/augmented/mixed-reality technologies, and M&S for current/future transportation systems. He is a Certified Modeling & Simulation Professional (CMSP).

Rachel Su Ann Lim received her B.S and M.S. degrees from the Department of Biomedical Engineering at the University at Buffalo. Her research interests involve the novel application of Modeling & Simulation (M&S) for public health advancement and game-based training, simulation, and analysis.

Panagiotis Ch. Anastasopoulos, Ph.D. is an Associate Professor in the Department of Civil, Structural and Environmental Engineering at the University at Buffalo. His research interests include statistical and econometric modeling, infrastructure systems, transportation safety, integration of human behavior with advanced air vehicles, urban air mobility, sustainable engineering, and transportation economics.

Sheikh Shahriar Ahmed is a Ph.D. candidate in Transportation Systems Engineering. His research involves statistical and probabilistic analysis of public willingness to use emerging air mobility services and the impact assessment of such services on our existing transportation network.

Daniel B. Hess, Ph.D. is a Professor and Chair of the Department of Urban and Regional Planning at the University at Buffalo. His research addresses interactions between housing, transportation, land use, and the development of pathways for understanding the complex socio-economic and ethnic landscape of cities and spatial inequalities.

Meredith Finn is pursuing her Bachelor's Degree in Mechanical Engineering at the University at Buffalo. She is currently developing a Mixed Reality human-machine interface for Urban Air Mobility vehicle simulation.

Cameron LaCourse is a graduate student at Embry-Riddle Aeronautical University pursuing his Master's Degree in Human Factors. He is currently forecasting next-generation cooperative traffic egress models for Urban Air Mobility. His career interests include the design and optimization of novel forms of aircraft.

Human Mobility 2049 - It's Time to "ACTT"
(*Aeronautical Conceptualization for Tomorrow's Transportation*)

Authors: Kevin F. Hulme, Ph.D., CMSP[1], Rachel Su Ann Lim[1], Panagiotis Ch. Anastasopoulos, Ph.D.[1], Sheikh Shahriar Ahmed[1], Daniel B. Hess, Ph.D.[3], Meredith Finn[2], Cameron LaCourse[5]

Author Contacts: hulme@buffalo.edu, rlim2@buffalo.edu, panastas@buffalo.edu, sheikhsh@buffalo.edu, dbhess@buffalo.edu, mkfinn@buffalo.edu, camlacourse71@gmail.com

1: The Stephen Still Institute for Sustainable Transportation and Logistics; **2**: Department of Mechanical and Aerospace Engineering; **3**: Department of Urban and Regional Planning; **4**: Engineering Science (Data Science)
University at Buffalo (UB), Buffalo, NY 14202

5: School of Engineering, Department of Human Factors
Embry Riddle Aeronautical University, Daytona Beach, FL 32114

Supporting research team: Irina Benedyk, Ph.D.[1], Stephen E. Still, Ph.D.[1], Aaron Estes, Ph.D.[2], Matthew Klein[2], Rajyavardhan Karra[4], Prajit Kumar[2], Rizve Chowdhury[2], Toan Le[2], Salvatore Guadagna[2], Achira Boonrath[2]

INTRODUCTION

Mobility (of people, goods, services) is an urgent, cross-disciplinary, bipartisan concern that impacts all humans on this planet. Recent data (e.g., Federal Highway Administration, 2017), suggests that daily travel in the United States averages 11 billion miles per day (i.e., almost 40 miles per person), and Americans take 411 billion trips per year, for purposes primarily attributed to shopping (45%), recreation (27%), and daily commute (15%). Given this increasing reliance, the "Transportation Network of Tomorrow" has long been a topic of discussion and debate, with the potential for forward-thinking possibilities (e.g., ultra-high-speed rail; The Hyperloop) seeming limitless (Sarkar and Jain, 2017; Hansen, 2020). Near-term pathways towards improving personalized human mobility include connected and autonomous vehicles (CAV's) - for which ongoing technical, logistical, and legal challenges (Singh and Saini, 2021) will inform future prospects related to sustainable/automated ground transportation. Likewise, in the aeronautical workspace, humankind has witnessed exciting recent advancements related to drone technologies, and other applications of unmanned aerial vehicles (UAV's) for surveillance, package deliveries, and agriculture, but whose practical realization includes profound challenges (e.g., operation, acceptance, safety) (Jeelani and Gheisari, 2021).

Longer-term, at the intersection of these technologies, domain experts are already investigating disruptive prospects for human mobility, including so-called "Flying Cars" – formally referred to as Advanced Air Mobility (AAM) - defined as an air transportation system that moves people and cargo using revolutionary new forms of aircraft (e.g., Johnson and Silva, 2021). The surmised advantages of AAM are many. Vehicle types currently in development effectively combine the ideal characteristics of both planes and cars; are generally more maneuverable; and would be less susceptible to surface constraints (e.g., traffic jams, construction delays, adverse weather events) while traversing 3D airspace as compared to 2D roadways (Ahmed et al., 2020). As with any emerging technology, there will be many technical, practical, logistical, and regulatory obstacles (e.g., Pan and Alouini, 2021) for which Modeling & Simulation (M&S) will be essential to: a) demonstrate baseline technological viability; b) achieve long-term sustainability; and c) provide a framework to conceptualize future aeronautical advancements to improve human mobility.

In this paper, we present an overview of recent and ongoing M&S developments towards the advancement of human mobility challenges over the next quarter century. The proposed strategic vision is to urgently "ACTT": *Aeronautical Conceptualization for Tomorrow's Transportation* - through the integrated application of M&S, and the Live-Virtual-Constructive-Autonomous (LVCA) taxonomy. Refer to Figure 1 for a notional depiction of our strategic vision, which includes key aspects of relationships (i.e., real/simulated) between operators and systems that comprise our AAM framework. The next section presents additional theoretical background and a compelling justification for these timely advancements. Subsequently, we will discuss requirements and challenges towards demonstrating the viability of AAM more broadly. Thereafter, we will suggest a series of downstream Use Cases to demonstrate how models (and accompanying simulations) are essential towards quantifying the evolving AAM value proposition. Finally, we will outline current and next steps, and forecast how the novelties of this work serve as a preamble towards downstream challenges related to other key I/ITSEC subcommittees, including human performance and human-machine interaction, education and STEM, and training (e.g., engineering vehicle design, pilot certification, and maintenance).

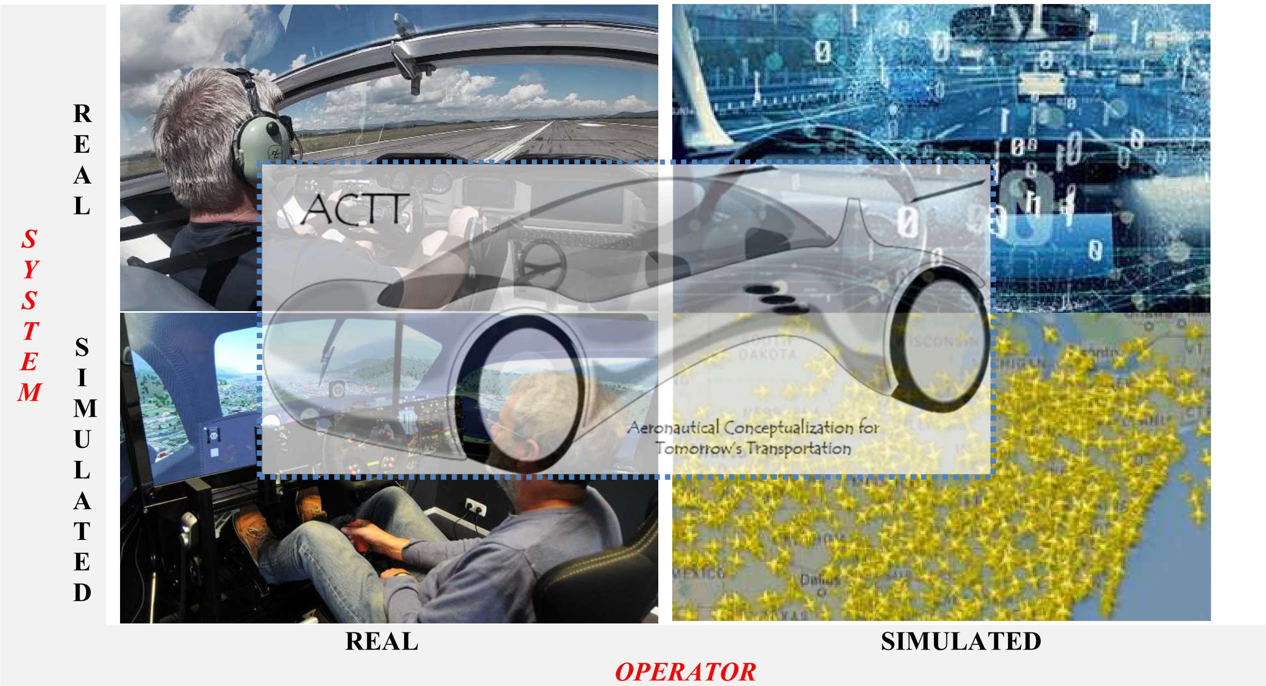


Figure 1 – Aeronautical Conceptualization for Tomorrow's Transportation (ACTT): A conceptual blueprint for *Human Mobility 2049*

BACKGROUND AND MOTIVATION

A sound transportation network is the foundation of any society, and promotes successful commerce by enabling safe and efficient human mobility. The political, social, and economic well-being of a nation is reliant on a well-organized transport system and supporting inter-modal (e.g., ***personal***: bicycles, trucks, cars; ***public***: buses, planes, trains, trams) infrastructure (Impoff.com, 2020). However, increasingly within the modern era, our surface transportation infrastructure is suffering from overuse, extreme traffic congestion, and roadway disrepair (Hulme et al, 2019). Likewise, over the past two years, the COVID-19 pandemic has permanently altered the global supply chain, as well as the national landscape for future urban and regional planning and development (Hulme et al., 2021). For these reasons, transforming human mobility is an ongoing matter of extreme National priority, and remains essential for the drastic improvement of sustainable inter-modal transportation and future supply chain logistics.

Federal policymakers are mandating widespread change towards expanding our infrastructure and improving our environment. The Build Back Better Act (BBBA) (WH.gov, 2022) is a bi-partisan $1.75T legislative framework that includes funding for transportation infrastructure (e.g., highways and roads, railways, public transportation, airports, and electric vehicles and charging stations). The National Association of Counties performed a legislative analysis of the BBBA (NACo, 2022), and identified highlights and key provisions for *low-emission aviation technologies*. Annually-published technology "hype cycles" for connected and smart mobility provide a snapshot of expected future trends related to transportation, and recent trends (e.g., Visnic, 2020) notably include long-term projections for "flying autonomous vehicles" still proximal to its innovation trigger, alongside the observed shortcomings of autonomous (Level 4 and Level 5) ground vehicles. To forecast and overcome complex design challenges associated with the next generation of AAM development, and to effectively convert science fiction to science fact, we must innovate now to mitigate or circumvent similar mistakes from the recent past (Jongen, 2018).

The prevailing and unifying theme at I/ITSEC 2022 is to ***Accelerate Change by Transforming Training! (ACTT!)***; a challenge to enhance, adapt, and accelerate product and process solutions through advanced technology and approaches. In conforming to this theme to address emerging human mobility challenges, this paper posits an *Aeronautical Conceptualization for Tomorrow's Transportation (ACTT)* to provide an AAM Testing & Evaluation (T&E) blueprint for the next quarter century. In the next section, we provide additional details on our implementation-in-progress, which features advanced M&S, and highlights critical application of the Live-Virtual-Constructive-Autonomous (LVCA) taxonomy (e.g., Department of Defense, 2011) for simulation, training and education. These aspects will be essential both to demonstrate baseline technological viability and to achieve long-term sustainability.

ACTT REQUIREMENTS: M&S AND LVCA

Modern technological developments – including key associations with NASA - suggest that AAM (e.g., oversized electric drones; air taxis) may be available for commercial use by 2025 (e.g., Strauss, 2021; Gillespie, 2021). All of **the primary challenges associated with technological sustenance for AAM will necessitate Live-Virtual-Constructive-Autonomous (LVCA) models and simulations (M&S) for testing and validation**. The terminology implies the binary state (i.e., real vs. simulated) of two essential components to a simulation: i) the degree of human participation, as well as ii) the degree of equipment realism. In more recent times, the original LVC (matrix) definition has been expanded to include the fourth scenario, that being the situation where a *simulated human operates a real system*, which constitutes an Autonomous system (e.g., Johnson et al., 1998; Mclean et al., 2013). Refer to Figure 2. For the purposes of our work, we will continue to adopt the more recent LVCA convention.

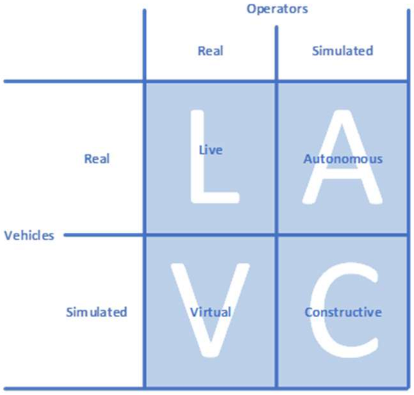


Figure 2 – LVCA taxonomy

Live: *Simulation involving real people operating real systems.* ***Virtual:*** *Simulation involving real people operating simulated systems.* ***Constructive:*** *Simulation involving simulated people operating simulated systems.* ***Autonomous****: Simulation involving simulated people operating real systems*.

Through direct application of the LVCA taxonomy – and successful application and integration of its four components - an improved understanding of the varied, interdisciplinary complex factors associated with AAM can be attained. An implementation of this nature is required to govern future modes of sustainable operation. For example, the evolution of AAM will demand advanced M&S to determine:

1) Handoff periods between manual and autonomous vehicle control;
2) Operational vehicle dynamics transitions (for takeoffs/landings);
3) Human responses to autonomous transport features.

Ultimately – observed behavioral patterns ascertained in conjunction with LVCA testing will clarify many technological, logistical, regulatory, environmental, and infrastructural challenges associated with real-world deployment. To our knowledge, no such testing and validation capacity currently exists within academia. Therefore, the proposed ACTT will serve as a vital point-of-entry for technical and human factors evaluations to guarantee the preliminary establishment and long-term sustainability of AAM.

In the following subsections, we present a detailed examination of current and planned Simulation developments towards the realization of AAM on a broader scale. Refer to Figure 3, which illustrates our notional strategic vision for achieving ACTT through the integrated application of M&S. Accordingly, we decompose this presentation into four primary ACTT's, each one dedicated to essential components of the LVCA taxonomy.

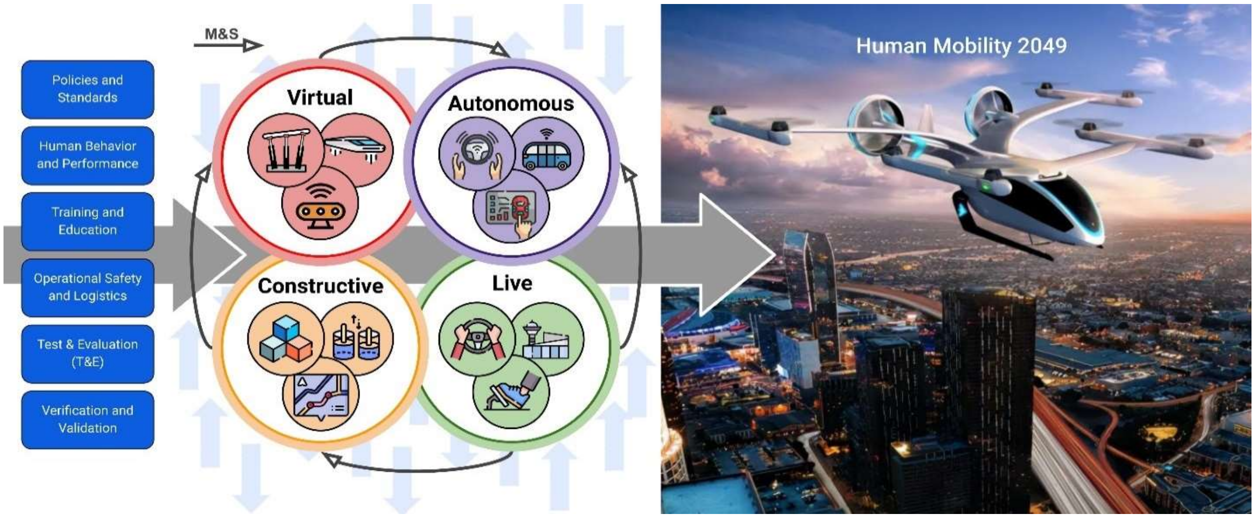
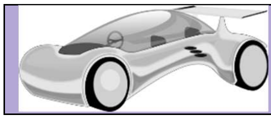


Figure 3 – Implementation of LVCA towards realization of ACTT



ACTT 1:

Autonomous system implementations for prioritizing safety and maximizing efficiency

In this subsection, we outline system developments pertinent to the ***Autonomous*** component of the LVCA taxonomy, towards prioritizing safety and maximizing efficiency. An autonomous system implies ***real systems being operated by simulated people***, a transformative concept that implies aspects of Artificial Intelligence (AI). This notion of sensors and complex algorithms employed to detect and respond to their surroundings (e.g., Computer Vision, LIDAR) with human-like intelligence (e.g., Ippolito, 2020; Joshi, 2019) is essential towards the sustainable realization of AAM on a broad scale. Technologists forecast that the rapidly emerging *AI in transportation* marketplace – valued at $1.4 billion in 2017 - will achieve $3.5 billion dollars by 2023 (Prescient & Strategic Intelligence, 2018), with use cases ranging from self-driving vehicles, traffic management, delay predictions, and personalized mobility and mobility-as-a-service. Standardized levels of system autonomy for ground vehicles range from Level 0 (*no autonomy*) to Level 5 (*fully autonomous system*) (SAE, 2021). Transportation technologists have long-struggled to reliably achieve high autonomy (i.e., Level 4 and Level 5) thresholds, and might still be decades away from being realized (Ramey, 2020). These lessons learned (e.g., related to software, sensor, and infrastructural limitations) are invaluable as we continue to innovate and forecast the future of AAM. We now briefly outline recent progress in three key areas related to Autonomous AAM systems.

Vehicle-to-Everything (V2X) AAM systems

V2X is defined as communication (*either WLAN or cellular*) between a vehicle and adjacent entities (e.g., infrastructure, network, other vehicles, pedestrians, and devices) that might involve cooperation or interaction (e.g., Saeed et al., 2021). As we translate current V2X technologies (see Figure 4) towards the AAM conceptualization for tomorrow, a large autonomous network of connected sensors will construct a data map of the urban environment and collect data (i.e., about other vehicles, cyclists, pedestrians, road conditions) to estimate journey times, minimize bottlenecks, and assess charging station availability. Such "Smart Cities" can make real-time adjustments to ease congestion and optimize throughput (Thales, 2022).

System autonomy and scalability

For sustenance of AAM technologies, it remains critical to achieve safe, efficient, and integrated (intermodal) airspace operations high fleet volume over small areas. To enable viable scalability of AAM fleets, it is essential to determine how to safely transition from on-board pilots (i.e., *human-in-the-loop* HITL autonomy) towards a situation characterized by off-board, multi-aircraft teleoperation, supervision and emergency takeover, functioning under the influence of contemporary wireless communication capabilities (e.g., 5G), referred to as *human-over-the-loop* HOvTL autonomy (e.g., Memar and Esfahani, 2018). In studying HOvTL (see Figure 5), eye-tracking and brain activity can be synchronized to estimate performance indicators (e.g., situational awareness, mental workload, distraction, reaction time) and their impact on operational safety.

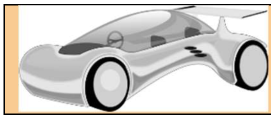
Figure 4 - V2X systems

Figure 5 – HOvTL autonomy

Figure 6 – AAM cybersecurity

AAM autonomy and cybersecurity

As with any autonomous transportation system that involves wireless networks, there is a growing concern over cybersecurity threats. Within modern-day ground autonomous vehicle systems, there are many potential system vulnerabilities and attack surfaces (see Figure 6), including the On-board diagnostics (OBD) port, the electronic control unit (ECU), dedicated short-range communications (DSRC), over-the-air connectivity (e.g., 5G), and WiFi systems. The ISO/SAE 21434 standard (Macher et al., 2020) specifies requirements for cyber risk management regarding engineering for concept, development, production, operation, maintenance, and decommissioning for road vehicle electronic systems (Teschler, 2020). This standard serves as a likely precursor for similar policies and standards that will be required to preserve safe and secure autonomous AAM systems.



ACTT 2:

Constructive Modeling for traffic coordination and cooperation

In this subsection, we outline modeling developments pertinent to the ***Constructive*** component of the LVCA taxonomy, towards cooperative AAM traffic models utilizing a 3D workspace. An autonomous system implies ***simulated systems being operated by simulated people***, which will be mandatory for crafting meaningful simulations of vehicle egress with communication and coordination between participating agents. Such capacity will enable an improved understanding of segregated versus integrated airspace implementations (Stewart, 2018) for flying autonomous vehicles. We now briefly outline recent progress in three key areas related to Constructive AAM systems.

Technology Translation – from Semi-automated Forces (SAF) to AAM Traffic networks

Constructive simulations are essential to improve readiness and situational awareness, and are often conducted at lower cost to enable analysis of diverse scenarios efficiently. Within the military domain, computer-generated, semi-automated forces (e.g., OneSAF, ModSAF, JSAF; Padilla, 2012) provide entity-level models (e.g., including aviation assets) and associated behaviors (e.g., friendly/adversarial). In an analogous manner, an immediate requirement for AAM is hybrid 3D traffic simulation for network communication and interoperation (see Figure 7). With this capacity, forecasted transport behaviors (i.e., including stochastic models for human error) can be simulated using digital assets (e.g., humans, vehicles, infrastructure) to analyze traffic scenarios in both the vertical and horizontal dimensions.

Traffic Flow Modeling (Micro, Meso, and Macroscopic)

Translation of ground traffic flow models (see Figure 8) into the flight domain (and into the third spatial dimension) constitutes a major challenge, as flying autonomous vehicles must navigate at different elevations, which adds considerable complexity (e.g., Khurana and Khurana, 2018). In the UAV regime, 3D flow models have been developed (Gharibi et al., 2019) to analyze the formation of flight traffic that eliminates the notion of traffic lanes, instead using *flow density* to model individual vehicle motions and interactive behaviors (e.g., passing; blocking). A standardized AAM traffic modeling capacity will expand upon existing flow models (e.g., Li et al., 2014, Zhang et al., 2014) and aviation software tools (e.g., ARC, 2022; Biesecker, 2021) that enable scenario-based micro- meso- and macroscopic simulations. Such a capability will enable simulation of: a) individual flying autonomous vehicles - and their interactions; b) realistic traffic patterns in terms of density, headway, and take-off and landing distance; and c) varying penetration rates and traffic conditions to maximize both network efficiency and human safety.

Figure 7 – AAM traffic

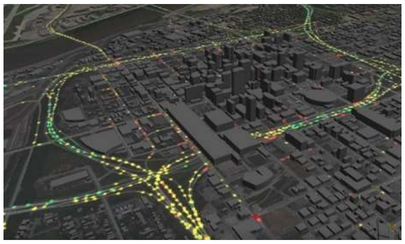


Figure 8 – Flow modeling

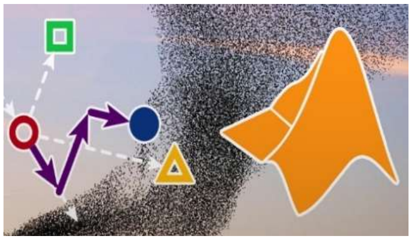
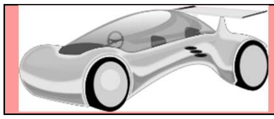


Figure 9 – Particle swarm

Nature-inspired computing

Development of a high-fidelity mechanism to model realistic traffic patterns while considering dynamic interactions between heterogeneous participants (i.e., ground, air, and hybrid-capable vehicles) is an extreme interdisciplinary challenge. Nature-inspired computing is an emerging discipline that emulates group behaviors of naturally occurring phenomena (e.g., bees, birds, insects) to solve complex engineering problems. Particle swarm (or swarm intelligence) is a branch of AI that is based on the behavioral analysis of cooperative systems (Teodorović, 2008) and is characterized by aspects of autonomy, distributed functioning, and self-organization. Recent transportation implementations have included modeling urban traffic (e.g., Krol and Mrozek, 2011); air traffic flow management (e.g., Torres, 2012) and flow prediction (e.g., Poole and Kotsialos, 2016; Shang et al., 2016); traffic flow guidance and optimization (e.g., Li et al., 2019); cooperation of autonomous ground vehicles (AV's) (e.g., Anand and Ajithkumar, 2019) and most recently, electric vertical takeoff and landing (eVTOL) drones (Clarke, 2020). Using UAV's, cooperative agents with decentralized decision-making serves as a viable solution for overcoming challenges related to scalability, fault tolerance, and communication (Odonkor et al., 2019). To successfully translate drone/robot technologies to full-scale, automated approaches are required for tactical level decision-making, including task allocation, path planning, formation control, target search, and group coverage (Behjat et al., 2021).



ACTT 3:

Virtual Simulation for assessment of human factors and human-machine interaction

In this subsection, we outline Simulation-based assessments pertinent to the ***Virtual*** component of the LVCA taxonomy, to better understand human factors, and the complex human-machine AAM interface as it continues to evolve. A virtual system implies ***simulated systems being operated by real people***, which is essential for authentic and safe examination of next-generation egress scenarios. Such a capacity will accommodate diverse AAM travel modes, including ground ("car") dynamics, flight ("plane") dynamics, as well as the takeoff/landing transitions between these regimes. A primary goal is to develop a Virtual AAM testing capacity that embodies an appropriate balance of operational simplicity (i.e., training new users to operate flying autonomous vehicles) vs. system fidelity (i.e., ensuring that the simulation encapsulates a sufficient degree of realism). We describe the ongoing development of a parameterizable Flying Car Simulator (FCS) that is – by design - not dedicated to a specific vehicle concept.

FCS: Software (environment) Modeling

Leveraging funding support from the EPIC MegaGrants program, we have begun the development of a simulation-based test facility, which we refer to as a "Virtual Campus" (see Figure 10) that will enable high-fidelity scenario testing for current and future flying autonomous vehicles. The campus, modeled using the Unreal Game Engine (alongside asset modeling assistance from Cesium, terrain.party, and PLW Modelworks) consists of an environment that includes ground assets (e.g., streets, signage, traffic control devices) for "car" mode, and communications control tower and a vertiport (see Figure 11) for "flight" mode (i.e., for hybrid vehicle takeoffs and landings). The longer-term goal is to develop a Buffalo-Niagara regional environment to support human factors examinations for new vehicle types (see Figure 12). Primary design features of this environment include both campuses of the University at Buffalo, as well as the Buffalo-Niagara International Airport, which will be essential for preliminary route examination.

Figure 10 – Virtual Campus

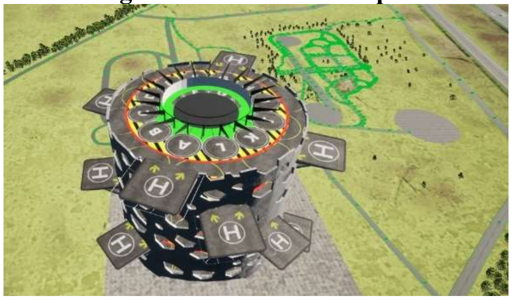


Figure 11 – Proposed vertiport

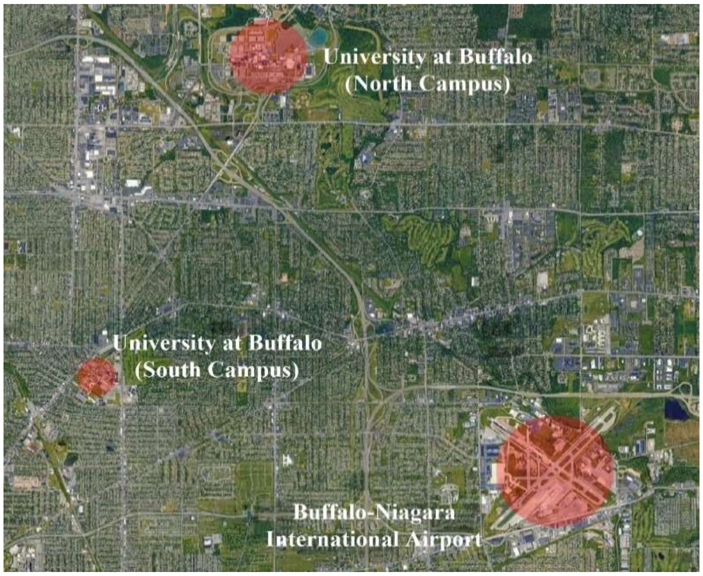


Figure 12 – Virtual Buffalo-Niagara region

FCS: Hybrid vehicle dynamics

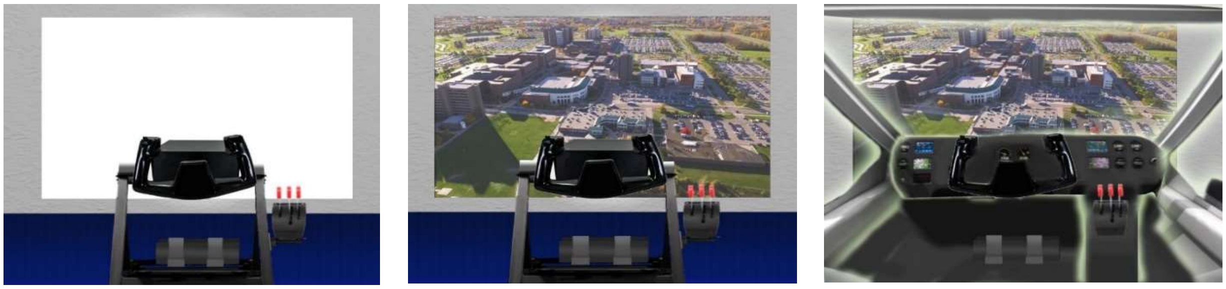
Within the FCS framework, physics-based models (i.e., non-linear coupled differential equations of motion) are being developed to encapsulate the dynamics for next-generation personalized mobility vehicles. *Ground mode* dynamics utilize simplified models (e.g., Milliken and Milliken, 1995) whose inputs are steering wheel angle and tire longitudinal force (i.e., throttle and brake), and whose outputs include vehicle velocities and accelerations. *Flight mode* dynamics of traditional aircraft (e.g., L'Afflitto, 2017) and quadcopters (e.g., Ruihang et al., 2019) likewise employ simplified models that serve as a critical balance of (static/dynamic) stability and control properties (i.e., aerodynamics), and serve as a response to atmospheric disturbances for prevailing flight conditions. In both operational modes - reduced-order linear models can be derived to analyze nominal drive/flight motions. Once the model outputs (vehicle states) are calculated, meta-analyses (e.g., scaling, limiting, and tilt coordination; Berger et al., 2007) can be performed to achieve effective motion cueing (e.g., longitudinal/lateral accelerations). The FCS is designed to be modular across AAM vehicle types, including: a) electric vertical take-off and landing (eVTOL) rotorcraft, b) eVTOL fixed-wing aircraft, and c) short take-off and landing (STOL) gyrocopter vehicle types. Refer to Figure 13 (a-c). The dynamics models for each vehicle type are designed in-house from first principals, based upon known, published, and assumed geometric parameters and technical specifications related to each vehicle.

(a) eVTOL (*rotorcraft*) **(b) eVTOL (*fixed wing*)** **(c) STOL gyrocopter**

Figure 13 – FCS modeled vehicle type classes

FCS: 3D Modeling and Mixed Reality interfaces

A critical aspect of our implementation is the capability to re-configure across AAM vehicle types. Components impacted by this requirement include: a) the vehicle itself (i.e., both the exterior chassis, and the interior cabin); b) an embedded, heads-up display (HUD) capability for spatial projection of navigation data, both during driving and flight (e.g., attitude, altitude, airspeed) modes; and c) 3D traffic markings (e.g., sky lanes; entry and exit points at different flight tiers) to assist with flight navigation; and ground/flight transitions. To enable a sense of presence and immersion (Wienrich et al., 2021), we have adopted Mixed Reality technologies. The "cabin" for each vehicle type is displayed in virtual space using Augmented Reality (AR) by leveraging detail-designed and optimized low-polygon 3D interior/exterior models of each of the three AAM vehicle types. Note that vehicle properties depicted within the pilot's AR space (i.e., using a HoloLens, or similar headset device) are simultaneously represented within the physics-based model parameters of the body geometry (e.g., aerodynamics properties, drag coefficients). Refer to Figure 14, which illustrates a progression of our Mixed-reality presentation: a) the physical space (e.g., display screen and controls); b) the embedded virtual space (e.g., the projected world scene graphics), and c) the overlaid augmented reality space (e.g., depicting the frame of the AAM vehicle, as well as control panels for navigation).

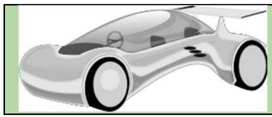


(a) Physical space **(b) Virtual space** **(c) Augmented space**

Figure 14 – FCS Cabin view: prototype of spatial interfaces (*Mixed Reality*)

FCS: Hardware manifestation and deployment

To adequately support simulator-based testing of novel and experimental vehicle types, a specialized hardware arrangement is necessary to enable high-fidelity virtual testing and evaluation. We are currently developing a custom simulation capability to human-machine interaction with diverse FCS vehicle types. Our display system comprises a large (120"), physical 4K-resolution front screen; expandable to three screens that will provide a full 150-degree forward (virtual) field-of-view. The flight chair is a truss framework upon which input controls (e.g., yoke, rudder, throttle) and flight gauges are physically mounted. The user controls initially consist of simplified capabilities to provide basic inputs for BOTH a ground vehicle and a flight vehicle (i.e., either eVTOL or STOL), depending on its real-time operational state. These control devices are situated on top of a motion control system that enables all 6 degrees-of-freedom (i.e., roll, pitch, yaw, heave, surge, sway) that are characteristic of common 3D ground/flight motions. The entire simulation is PC-based, and driven by state-of-the-art graphics capabilities.



ACTT 4:

Live Prototyping for partial and full-scale T&E in a physical environment

Finally, in this subsection, we outline ongoing Test & Evaluation pertinent to the ***Live*** component of the LVCA taxonomy, to prototype AAM vehicles within a physical workspace. A live system implies ***real systems being operated by real people***, an essential component towards realization of partial-scale (e.g., UAV/drone) and full-scale (e.g., both piloted and unmanned) examination of next-generation mobility vehicles within organic real-world settings. For realization of a surmised future with AAM as a viable transport medium, the transition to Live prototyping is mandatory to demonstrate technological sustainability. We now briefly summarize ongoing developments.

Physical testing enclosure

One primary challenge associated with flight testing for unproven (experimental) vehicle types is the requirement for special approvals from the Federal Aviation Administration (FAA), so as not to disrupt, endanger, or hinder commercial aviation traffic. Recent advances in AAM have seen the emergence of large-scale testing enclosures that safely encapsulate the physical testing domain. Technologists recently demonstrated a crewed (non-autonomous) "flying car" test flight (e.g., Fingas, 2020), which was an essential first step towards an envisioned Flying Taxi service. Likewise, the Structure for Outdoor Autonomy Research (SOAR) (e.g., Nealon, 2020; see Figure 15) at the University at Buffalo is a netted, 24,000 ft^2, 86-foot high outdoor facility for UAV applications ranging from agriculture, disaster management (e.g., Worden et al., 2020), and small parcel delivery and logistics (e.g., Raj and Murray, 2020). The specialized features of SOAR also enable test, experimentation, and validation of drone fleets and partial-fidelity machine learning models (e.g., Iqbal et al., 2022) towards tomorrow's experimental AAM vehicles.

Partial-scale rural, urban, suburban landscapes

In the Live domain, physically-constrained testing, at partial-scale, must include the development of miniature "cityscapes" in rural, suburban, and urban settings to support AAM egress scenarios of varying fidelity. One recent example (Stager et al., 2018; Beaver et al., 2020) demonstrates a scaled "Smart City" that includes miniature roads, buildings, traffic infrastructure, and vegetation. Such implementations can be leveraged to examine V2X communications (i.e., between vehicles, infrastructure, and network), model and optimize traffic flow, and confront traffic challenges for ground/flight CAV's. Other implementations (e.g., MiniLand USA | Cong et al., 2021) have included alternative materials for re-creating ultra-miniature and highly-detailed dioramas (see Figure 16). Along parallel channels, additive manufacturing (e.g., 3D printing | Cameli, 2019) can be implemented for designing, pre-visualizing, and prototyping cost-effective, next-generation urban planning models and associated conceptualizations.

Figure 15 – SOAR

Figure 16 – AAM urban planning

Figure 17 – AAM infrastructure

Incorporation of AAM infrastructure

Lastly, within the Live testing domain, it is imperative to consider the incorporation of mechanisms that will enable a rigorous assessment and validation of forecasted impacts of AAM on our infrastructure. For example, this might include the model development and integration of vehicle storage facilities, centralized airports, and takeoff/landing zones (e.g., heliports, vertiports) at partial-scale, as they might appear in rural (e.g., surface terrain), suburban (e.g., re-purposed parking lots and ramps), and urban (e.g., elevated building-top) settings. Refer to Figure 17. Such capacities will enable examination of navigation concerns related to object layout, geometry, features, and placement that will influence near-term infrastructure design, but also, navigation capabilities for emerging AAM vehicles themselves. Critically, such capabilities will also permit the forecasting of associated related to the environment. These might include noise, network efficiency related to traffic volumes, modeling & simulation related to transportation system inter-modality, and green concerns (e.g., energy consumption, emissions).

ACTT – ONGOING STATUS AND TECHNOLOGY READINESS LEVELS (TRL)

Our Aeronautical Conceptualization for Tomorrow's Transportation (ACTT) proposes a substantial paradigm shift towards the future of human mobility (i.e., persons, goods, services). As a mechanism to evaluate ongoing status of our LVCA conceptualization, we rely upon the NASA-defined Technology Readiness Levels (TRL) - a standardized scale for estimating the maturity of technologies during planning, development, and acquisition (ISO 16290:2013; NASA 2012, 2022). The present metric uses a 9-point scale to determine technology readiness, ranging from 1 (*basic principles observed*); to 3 (*experimental proof of concept*); to 5 (*technology validated in relevant environment*); to 7 (*system prototype demonstration in operational environment*) to 9 (*proven and deployed technology*). Refer to Table 1, which provides a self-assessment of the integrated LVCA subcomponents described in this paper, color-coded, and listed in ascending order based on current (estimated) TRL.

Table 1 – Current Technology Readiness Levels (TRLs) for the proposed ACTT (2022)

LVCA asset development	Current status	Estimated TRL
Live: supporting AAM infrastructure	Ideas brainstormed to extend other aspects of Live testing framework	1
Live: scaled landscapes	Proposed concepts formulated to leverage existing supporting facilities	2
Constructive: technology translation	Parallels between SAF and intelligent 3D traffic assets identified with basic concepts formulated	2
Autonomous: cybersecurity	Applicable standards (ISO/SAE) recently surmised and developed for future technologies	2
Virtual: mixed-reality interfaces	CAD models obtained, with model optimization underway; proof-of-concept demonstrated	3
Virtual: vehicle dynamics	Diverse hybrid vehicle dynamics models tested (standalone); awaiting framework integration	4
Constructive: traffic flow modeling	2D framework has been previously conceived and lab-tested; transformation to 3D imminent	4
Autonomous: V2X	Automated ground vehicle applications currently tested/validated in closed environments	5
Autonomous: system scalability	Human-Over-the-Loop autonomy being tested and demonstrated for system supervision	5
Virtual: software infrastructure	Virtual testing campus conceived, constructed, and laboratory-tested	6
Virtual: hardware infrastructure	Multi-component hardware prototype demonstration in operational environment	7
Constructive: nature-inspired computing	Successful implementation of algorithms within diverse drone/optimization applications	8
Live: testing enclosure	Structure for Outdoor Autonomy Research (SOAR) specified, constructed, operative.	9

ACTT – SCENARIOS AND USE CASES

The proposed ACTT and accompanying LVCA framework outlined in this paper respond directly to a critical and emerging need for research regarding advanced prospects for human mobility. These ongoing efforts are timely, as cities and metropolitan regions recover from the COVID-19 pandemic (Acuto et al., 2020; Sharifi and Khavarian-Garmsir, 2020) and societies reconsider urban density with relation to public health (Carozzi et al., 2020), access and mobility considerations (Fatmi, 2020) growing traffic congestion (Roy et al., 2020), and the pursuit of sustainability goals. To mitigate these and other issues, alternative solutions and bold concepts are required to enhance access and mobility in our increasingly complex urban environments. Consequently, the proposed LVCA conceptualization rightfully serves to enable development and deployment of human-in-the-loop M&S scenarios and use cases which will aide societies to systematically address these compelling matters.

A primary challenge relates to **Commute Scenarios**. In terms of mode usage, examples of commute scenarios include: i) point-to-point AAM service between pre-defined origin-destination pairs; and ii) door-to-door service by integrating ground transportation and AAM service (e.g., *trip origin > ridesharing service /public transit > AAM vertiport X > AAM vertiport Y > ridesharing service /public transit > trip destination* – and any other possible combinations). In terms of trip distance, examples of commute scenarios (e.g., Postorino and Sarné, 2020; Ahmed et al., 2020) include intra-city trips (*short distance: 20 miles or less*), and inter-city trips (i.e., considering the forecasted range of AAM aircraft, can be classified as *medium distance: 20-50 miles*, and *long distance: 50-150 miles*). It remains essential to implement integrated LVCA (ACTT 1-4) to identify the service scenario combinations for which AAM would be a superior alternative - considering travel time and cost - to current ground-based options. The second challenge is **Transport Inclusivity**. The existing transportation network is heavily reliant on expensive personal automobile-based trips (Canby, 2003; Zhao and Gustafson, 2013), often leaving low-income working families at a disadvantage, in terms of spending the majority of household income solely on transportation. In extreme cases, such families remain without access to any form of transportation due to no car ownership, or complete lack of access to public transportation. This problem is further exacerbated for the elderly, and for the disabled population (Rosenbloom, 2007). Moreover, a substantial portion of the population residing in remote rural locations rely solely on automobiles for essential travel over deficient roads and bridges (Bonifas, 2020). In this context, evaluating the potential of AAM in providing greater access to mobility for the disadvantaged and the remotely located population is essential. A critical aspect of this evaluation is to estimate the achievable societal and economic benefits, which can be achieved by the proposed ACTT 2 and 3. The third challenge is related to **Supporting Infrastructure**. STOL and eVTOL are the two major AAM vessel types, where the former would require short length runways to take-off and land, and the latter would require Vertiports. This is important, because the type of facility is going to have significant impact on land requirement, initial investment, and passenger handling capacity. ACTT 1 and 4 can be leveraged to assess the pros and cons of STOL (i.e., in combination with short runways) and eVTOL (i.e., in combination with Vertiports) vessel types to forecast AAM network scalability. Table 2 provides a general overview of these three M&S use case scenarios for AAM, including a basic description of the forecasted use case, and an associated problem formulation.

Table 2 – ACTT Use Cases

ACTT Use Cases	Formulation Description & *Forecasted Outcomes*
Commute Scenarios	Simulate all possible AAM commute scenarios, evaluate the time and cost requirements ***What AAM commute scenarios are optimal?***
Transport Inclusivity	Simulate AAM deployment scenarios to offer mobility access to the disadvantaged ***What are the social and economic benefits for rural/urban AAM access?***
Supporting Infrastructure	Assess infrastructure requirements considering different AAM vessel types ***How will AAM vehicle types influence infrastructure requirements and landscapes?***

Certainly, diverse opportunities exist to deploy the proposed ACTT towards other use cases and scenarios, including matters related to ***extreme events*** (e.g., emergency vehicles/rescue scenarios), ***green concerns*** (e.g., fuel consumption/emissions), and ***life cycle*** (e.g., electric vs. fuel power sources).

SUMMARY AND PRIMARY CONCLUSIONS

Human Mobility is an urgent, cross-disciplinary, bipartisan concern. The “Transportation Network of Tomorrow” has long been a topic of discussion and debate, with the potential for forward-thinking possibilities, including connected and autonomous vehicles (CAV's), and unmanned aerial vehicles (UAV’s). Longer-term, at the intersection of these technologies, domain experts are already investigating disruptive, bleeding edge prospects for human mobility, including so-called “Flying Cars” – formally referred to as Advanced Air Mobility (AAM) - defined as the safe development of an air transportation system that moves people and cargo between locations often underserved by aviation – using revolutionary new forms of aircraft.

With relation to these technological needs, the 2022 I/ITSEC edict to ACTT! (Accelerate Change by Transforming Training!) is timely -- to enable humankind to revolutionize innovations that will overcome the varied Mobility challenges we face in the near future. This paper has presented an overview of ongoing Simulation developments towards realization of AAM on a broader scale. Our ongoing strategic vision to address this matter is to, ourselves, ***ACTT - Aeronautical Conceptualization for Tomorrow's Transportation*** - through the rigorous application of advanced M&S. In particular, we have emphasized current innovations related to the Live-Virtual-Constructive-Autonomous (LVCA) taxonomy, including: **Live** Prototyping for partial and full-scale T&E in a physical environment; **Virtual** Simulation for assessment of human factors and human-machine interaction; **Constructive** Modeling for traffic coordination and cooperation; and **Autonomous** system implementations for prioritizing safety and maximizing efficiency. Recent, ongoing, and future developments were discussed within each of the four sectors of the taxonomy, with Technology Readiness Levels (TRL’s) summarized and estimated. Appropriately, our conceptualization concluded with an overview of Use Cases, which included details on how ACTT can be implemented for AAM human-in-the-loop evaluation and assessment. For each surmised travel scenario, notional problem formulations were presented to inform downstream simulation analyses.

FUTURE WORK

As we plan ahead, the authoring team continues to develop an integrated high-fidelity M&S framework – including coordination from all components of the LVCA taxonomy - to conceptualize the emerging operational feasibility of AAM. These capabilities will allow subject matter experts to prototype, model, analyze, and validate egress scenarios for tomorrow's transportation within diverse operational settings. The outcomes of such M&S frameworks will have a profound influence on activities related to all six subcommittees at I/ITSEC. Refer to Figure 18.

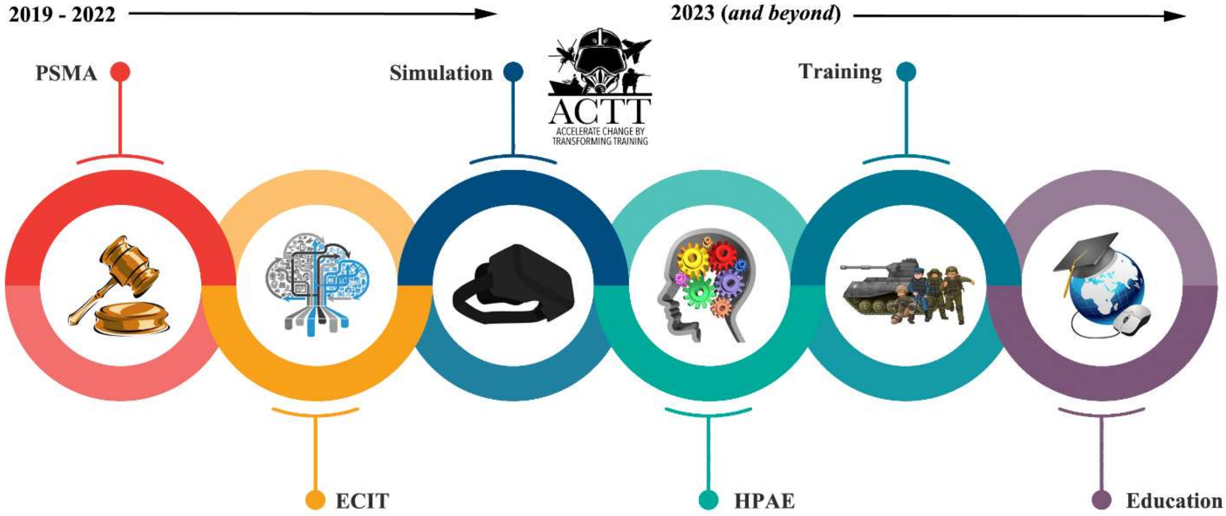


Figure 18 – Inter-relation between ACTT and the I/ITSEC subcommittees

Previously, the proposing Team conducted an extensive literature review (Hulme et al., 2019) to explore AAM **policies, regulations, and legal governance**, which are preliminary requirements for technological sustainability. More recently, we performed an expanded **emerging concepts** overview of the current state-of-the-art (Hulme et al., 2021) which explored the technologically disruptive evolution of AAM and the key challenges associated with wide-scale adoption. These efforts culminated with this work, whereby we have proposed to ACTT through the rigorous and integrated application of advanced **modeling & simulation**, with critical emphasis upon the LVCA taxonomy.

Looking ahead, we are leveraging the integrated capabilities discussed in this work towards the analysis of mobility-based travel scenarios and use cases of tomorrow. This will enable the critical evaluation of **human performance** within this brand new travel medium. This year's Conference theme emphasizes the need to *Accelerate Change by Transforming Training (ACTT)*! The ongoing development of AAM will enable next-generation **training** methods within related technological domains, including: a) pilot training and certification, b) vehicle repair and maintenance, and c) connected/autonomous vehicles, including advanced robotics, sensor fusion, machine learning and artificial intelligence (AI). Lastly, the rapid emergence of tomorrow's transportation will have profound downstream impacts on **education**, including National Aeronautics and Space Administration (NASA, 2020) advised common core state standards for science technology, engineering, and mathematics (STEM).

ACKNOWLEDGEMENTS

Foremost, the authors extend their extreme thanks for ongoing fiscal support from the University at Buffalo Stephen Still Institute for Sustainable Transportation and Logistics (SSISTL), including direct support towards constructing prototype Simulation assets described in this paper. The authors continue to extend their gratitude to Moog, Inc. (East Aurora, NY), for generously donating motion control hardware to the School of Engineering and Applied Sciences (SEAS) at the University at Buffalo, and for their ongoing technical and fiscal support. Lastly, we would like to acknowledge the partial support offered by the MegaGrants program sponsored by Epic Games, which provided student funding towards Unreal Game Engine environment development for this work.

REFERENCES

- Acuto, M., Larcom, S., Keil, R., Ghojeh, M., Lindsay, T., Camponeschi, C., and Parnell, S., (2020), Seeing COVID-19 through an urban lens. *Nat Sustain* 3, 977–978 (2020). https://doi.org/10.1038/s41893-020-00620-3
- Ahmed, S.S., Hulme, K.F., Fountas, G., Eker, U., Benedyk, I.V., Still, S.E., and Anastasopoulos, P., (2020), The Flying Car – Challenges and Strategies towards Future Adoption, *Frontiers of the Built Environment*, vol. 6, https://doi.org/10.3389/fbuil.2020.00106
- Airport Research Center (ARC), 2022. CAST, https://arc.de/cast-simulation-software/cast-aircraft-simulation/
- Anand, Y., and Ajithkumar, R., (2019). Autonomous Car with Swarm Intelligence, Conference on Intelligent Computing, Instrumentation, and Control Technologies, https://doi.org/10.1109/ICICICT46008.2019.8993301
- Beaver, L.E., Chalaki, B., Mahbub, A M., I., Zhao, L., Zayas, R., Malikopoulos, A.A., (2020), Demonstration of a Time-Efficient Mobility System Using a Scaled Smart City, *Vehicle System Dynamics*, 58, 5, 787-804, https://doi.org/10.1080/00423114.2020.1730412
- Behjat, A., Manjunatha, H., Kumar, P.K., Jani, A., Collins, L., Ghassemi, P., Distefano, J., Doermann, D., Dantu, K., Esfahani, E. and Chowdhury, S., (2021). Learning Robot Swarm Tactics over Complex Adversarial Environments, IEEE Multi-Robot and Multi-Agent Systems (MRS), https://doi.org/10.48550/arXiv.2109.05663
- Berger, D., Schulte-Pelkum, J., and Bülthoff, H. (2007). Simulating Believable Forward Accelerations on a Stewart Motion Platform. *ACM Transactions on Applied Perception*, https://doi.org/10.1145/1658349.1658354
- Biesecker, C., (2021). Raytheon Technologies To Acquire Flight Tracking Company FlightAware, Aviation Today, (*online article*), https://www.aviationtoday.com/2021/08/30/raytheon-technologies-acquire-flight-tracking-company-flightaware/
- Bonifas, C. (2020). Rural Connections: Challenges and Opportunities in America's Heartland (*web link*), https://tripnet.org/wp-content/uploads/2020/05/TRIP_Rural_Roads_Report_2020.pdf
- Cameli, S.A. (2019). 3D Printing of Cities: Is Urban Planning Ready?, *Planning Theory & Practice*, 20:5, 776-784, https://doi.org/10.1080/14649357.2019.1660075
- Canby, A. (2003). Affordable housing and transportation: Creating new linkages benefiting low-income families. *Housing Facts & Findings*, *5*(2), 1-8.
- Clarke, D., (2020). Swarm Intelligence of eVTOL Drones, AeroCar (*online journal publication*), https://aerocarjournal.com/swarm-intelligence-of-evtol-drones/
- Cong, Y., Liu, C., and Qian, J. (2021), Research on Lego Multi-channel Development: Success and Improvement, 3rd International Conference on Economic Management and Cultural Industry (ICEMCI), https://doi.org/10.2991/assehr.k.211209.345
- Carozzi, F., Provenzano, S., and Roth, S., (2020). Urban Density and COVID-19, IZA Discussion Papers 13440, Institute of Labor Economics (IZA).
- Department of Defense, 2011. M&S Glossary, DoD 5000.59-M, 1998 (*revision: October 1 2011*).
- Fatmi, M.R., (2020). COVID-19 Impact on Urban Mobility, *Journal of Urban Management*, Volume 9, Issue 3, https://doi.org/10.1016/j.jum.2020.08.002
- Federal Highway Administration. (2017). 2017 National Household Travel Survey, U.S. Department of Transportation, Washington, DC. Available online: https://nhts.ornl.gov.
- Fingas, J., (2020). Watch a Toyota-backed flying car's first public, piloted test flight, engadget (*online news article*), https://www.engadget.com/skydrive-flying-car-test-flight-195528927.html
- Gharibi, M., Boutaba, R., Waslander, S.L. (2019). 3D traffic flow model for UAVs, https://doi.org/10.48550/arXiv.1909.04838
- Gillespie, R., (2021). With NASA partnership, Orlando begins planning for air taxis, flying cars, Orlando Sentinel, (*web link*), https://www.orlandosentinel.com/news/orange-county/os-ne-orange-orlando-flying-cars-20211007-nxtumsnphjeejc42gxgemgxoki-story.html
- Hansen, I.A., (2020). Hyperloop transport technology assessment and system analysis, Transportation Planning and Technology, 43:8, 803-820, https://doi.org/10.1080/03081060.2020.1828935
- Hulme, K.F., Anastasopoulos, P., Still, S.E., Fountas, G., Pantangi, S.S., Eker, U., and Ahmed, S.S., (2019). The Flying Car - Emergent Modeling & Simulation (M&S) Policies and Standards concerns, The Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), Orlando.
- Hulme, K.F., Anastasopoulos, P., Still, S.E., Benedyk, I., Ahmed, S., Lim, R., and Fountas, G., (2021). Advanced Air Mobility (AAM) - Innovating Modeling & Simulation (M&S) to Revolutionize the Future of Transportation, The Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), Orlando.
- Impoff.com, (2020). Importance of Transportation in Different Aspects of Life, (*web link*), https://impoff.com/importance-of-transportation

- Ippolito, P.P., (2020). Future of Cyber Security for Connected and Autonomous Vehicles, https://towardsdatascience.com/future-of-cyber-security-for-connected-and-autonomous-vehicles-4c553def6d50
- Iqbal, R., Behjat, A., Adlakha, R., Callanan, J., Nouh, M., and Chowdhury, S., (2022). Efficient Training of Transfer Mapping in Physics-Infused Machine Learning Models of UAV Acoustic Field, AIAA SCITECH Forum, AIAA 2022-0384, San Diego, CA, https://doi.org/10.2514/6.2022-0384
- ISO.org, (2013). Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment, (*online link*), https://www.iso.org/obp/ui/#iso:std:iso:16290:ed-1:v1:en
- Jeelani, I. & Gheisari, M. (2021). Safety Challenges of UAV Integration in Construction: Conceptual Analysis and Future Research Roadmap. *Safety Science*. 144. 1-16. https://doi.org/10.1016/j.ssci.2021.105473
- Johnson, M.V.R., McKeon, M.F., & Szanto, T.R., (1998). Simulation Based Acquisition: A New Approach, Defense Systems Management College (DSMC), (*web link*), https://apps.dtic.mil/sti/pdfs/ADA359264.pdf
- Johnson, W. & Silva, C. (2021). NASA concept vehicles and the engineering of advanced air mobility aircraft. *The Aeronautical Journal*. 1-33. https://doi.org/10.1017/aer.2021.92
- Jongen, R. (2018). Transportation in 2049: Even More Awesome then in Blade Runner, RevelX, (*web link*), https://www.revelx.co/blog/future-of-transportation/
- Joshi, N., (2019). How AI can Transform the Transportation Industry, Forbes (*web link*), https://www.forbes.com/sites/cognitiveworld/2019/07/26/how-ai-can-transform-the-transportation-industry/
- Khurana, M., and Khurana, R., (2018). "Virtual Highway: A special case of flying cars", *International Journal of Advanced Research in Science and Engineering (IJARSE)*, Vol. 7, No. 3, January.
- Krol, D. & Mrozek, M. (2011). Swarm-Based Multi-agent Simulation: A Case Study of Urban Traffic Flow in the City of Wroclaw. 6923. 191-200. https://doi.org/10.1007/978-3-642-23938-0_20
- L'Afflitto, A. (2017). A Mathematical Perspective on Flight Dynamics & Control, https://doi.org/10.1007/978-3-319-47467-0
- Li, T., Antonio, T., Gunnam, A.K., & Campos, N.V., (2014). A microscopic simulation model for the air traffic in the organized track system of the North Atlantic airspace, Integrated Communications, Navigation and Surveillance Conference (ICNS) Conference, https://doi.org/10.1109/ICNSurv.2014.6820051
- Li, Q., Shangguan, W., Cai, B., Chai, L., (2019). Traffic Flow Guidance & Optimization of Connected Vehicles Based on Swarm Intelligence, Chinese Control Conference, https://doi.org/10.23919/ChiCC.2019.8866595
- Macher, G., Schmittner, C., Veledar, O., & Brenner, E. (2020). ISO/SAE DIS 21434 Automotive Cybersecurity Standard - In a Nutshell. https://doi.org/10.1007/978-3-030-55583-2_9
- McLean, T., Hoke, J., Vogl, T., & Schnell, T. (2013). LVCA: An Integrated Architecture of Live, Virtual, Constructive and Automated Elements for UAS Experimentation and Training, Association for Unmanned Vehicle Systems International (AUVSI) Conference, Washington DC.
- Memar, A.H. and Esfahani, E.T., (2018). Physiological measures for human performance analysis in human-robot teamwork: Case of tele-exploration, *IEEE Access*, vol. 6, https://doi.org/10.1109/ACCESS.2018.2790838
- Milliken, W. F. and Milliken, D. L., (1995). Race Car Vehicle Dynamics, SAE, 1995.
- National Aeronautics and Space Administration (NASA), (2012). Technology Readiness Level, (*online link*), https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level
- National Aeronautics and Space Administration (NASA), (2020). Advanced Air Mobility: What is AAM? (*White Paper*), https://www.nasa.gov/sites/default/files/atoms/files/what-is-aam-educator-guide_0.pdf
- National Aeronautics and Space Administration (NASA), (2022). Technology Readiness Levels (TRLs), (*online link*), https://esto.nasa.gov/trl/
- National Association of Counties (NACo), 2022. NACo Legislative Analysis: Build Back Better Act (*web link*), https://www.naco.org/resources/featured/buildbackbetter
- Nealon, C., (2020). UB builds massive outdoor drone testing facility, UB Now (*online article*), https://www.buffalo.edu/ubnow/stories/2020/11/drone-research.html
- Odonkor, P., Ball, Z., and Chowdhury, S., (2019). Distributed operation of collaborating unmanned aerial vehicles for time-sensitive oil spill mapping, *Swarm and Evolutionary Computation*, Volume 46, Pages 52-68, https://doi.org/10.1016/j.swevo.2019.01.005
- Padilla, J.J., (2012). Annex 2. Military Simulation Systems, in *Engineering Principles of Combat Modeling and Distributed Simulation*, First Edition, edited by Andreas Tolk, John Wiley & Sons, Inc.
- Pan, G., Alouini, M. (2021). Flying Car Transportation System: Advances, Techniques, and Challenges. *IEEE Access*, https://doi.org/10.1109/ACCESS.2021.3056798
- Poole, A., and Kotsialos, A., (2016). Swarm intelligence algorithms for macroscopic traffic flow model validation with automatic assignment of fundamental diagrams, *Applied Soft Computing*, Volume 38, Pages 134-150, https://doi.org/10.1016/j.asoc.2015.09.011

- Postorino, M. N., and Sarné, G. M. L. (2020). Reinventing mobility paradigms: Flying car scenarios and challenges for urban mobility. *Sustainability (Switzerland), 12*(9). https://doi.org/10.3390/SU12093581
- Prescient & Strategic Intelligence, (2018). AI in Transportation Market to Generate Revenue Worth $3.5 Billion by 2023, (*web link*), https://www.psmarketresearch.com/press-release/ai-in-transportation-market
- Raj, R. and Murray, C., (2020). The multiple flying sidekicks traveling salesman problem with variable drone speeds, *Transportation Research C:Emerging Technologies*, Vol. 120, https://doi.org/10.1016/j.trc.2020.102813
- Ramey, J., (2020). Here's Why our Self-Driving Future has been Delayed Indefinitely, Autoweek (*web link*), https://www.autoweek.com/news/technology/a32782600/why-level-5-autonomous-driving-has-not-happened/
- Rosenbloom, S. (2007). Transportation patterns and problems of people with disabilities. *The future of disability in America*, 519-560. https://www.ncbi.nlm.nih.gov/sites/books/NBK11420/
- Roy, S., Cooper, D., Mucci, A., Sana, B., Chen, M., Castiglione, J., Erhardt, G.D., (2020). Why is traffic congestion getting worse? A decomposition of the contributors to growing congestion in San Francisco-Determining the Role of TNCs, *Case Studies on Transport Policy*, https://doi.org/10.1016/j.cstp.2020.09.008
- Ruihang, J., Ma, J. and Ge, S. (2019). Modeling and Control of a Tilting Quadcopter. *IEEE Transactions on Aerospace and Electronic Systems*. https://doi.org/10.1109/TAES.2019.2955525
- Saeed, N., Al-Naffouri, T., & Alouini, M. (2021). Wireless Communication for Flying Cars. *Frontiers in Communications and Networks*. 2. 689881. https://doi.org/10.3389/frcmn.2021.689881
- Sarkar, P.K., and Jain, U., (2017). Benchmarking of personal rapid transit system (dynamic model), *Transportation Research Procedia*, 25 (2017), pp. 4207-4218, https://doi.org/10.1016/j.trpro.2017.05.370
- Shang, Q., Lin, C., Yang, Z., Bing, Q., & Zhou, X. (2016). Short-term traffic flow prediction model using particle swarm optimization-based combined kernel function-least squares support vector machine combined with chaos theory. *Advances in Mechanical Engineering*. 8. https://doi.org/10.1177/1687814016664654
- Sharifi A, Khavarian-Garmsir AR, (2020). The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. *Sci Total Environ*. https://doi.org/10.1016/j.scitotenv.2020.142391
- Singh, S., & Saini, B.S. (2021). Autonomous cars: Recent developments, challenges, and possible solutions, *Materials Science and Engineering*. 1022. 012028. https://doi.org/10.1088/1757-899X/1022/1/012028
- Society of Automotive Engineers (SAE), (2021). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, J3016_202104, https://doi.org/10.4271/j3016_201609
- Stager, A., Bhan, L., Malikopoulos, A.A., L. Zhao, (2018), A Scaled Smart City for Experimental Validation of Connected and Automated Vehicles, 15th IFAC Symposium on Control in Transportation Systems, 120–135.
- Stewart, J., (2018). Uber's Flying Car Plan Meets the Regulator it Can't Ignore, Wired, (*web link*), https://www.wired.com/story/uber-flying-cars-faa-regulation/
- Strauss, M., (2021). A Fleet of Air Taxis is Coming to Central Florida by 2025, Smithsonian Magazine, (*web link*), https://www.smithsonianmag.com/air-space-magazine/orlando-takes-high-road-180976721/
- Teodorović, D., (2008). Swarm intelligence systems for transportation engineering: Principles and applications, *Transportation Research Part C: Emerging Technologies*, https://doi.org/10.1016/j.trc.2008.03.002
- Teschler, L., (2020). Safety and cyber security for the connected car, Microcontroller Tips (*web link*), https://www.microcontrollertips.com/safety-and-cyber-security-for-the-connected-car-faq/
- Thales (2022). How connected cars will integrate with the smart city, Thales Group, (*web link*), https://www.thalesgroup.com/en/markets/digital-identity-and-security/iot/inspired/connected-cars/smart-cities
- Torres, S. (2012). Swarm Theory Applied to Air Traffic Flow Management. *Procedia Computer Science*. 12. 463–470. https://doi.org/10.1016/j.procs.2012.09.105
- Visnic, B., (2020). 2020 Hype Cycle for Connected and Smart Mobility, SAE International (*web link*), https://www.sae.org/news/2020/09/2020-hype-cycle-for-connected-vehicles-and-smart-mobility
- Wienrich, C., Komma, P., Vogt, S., and Latoschik, M. (2021). Spatial Presence in Mixed Realities–Considerations About the Concept, Measures, Design, and Experiments. *Frontiers in Virtual Reality*. 2. 694315. https://doi.org/10.3389/frvir.2021.694315
- WH.gov, (2022). Build Back Better Framework, (*web link*), https://www.whitehouse.gov/build-back-better/.
- Worden, M., Murray, C., Karwan, M., Ortiz-Peña, H.J, and Nagi, R., (2020). Sensor tasking for unmanned aerial vehicles in disaster management missions with limited communications bandwidth, *Computers & Industrial Engineering*, Volume 149, https://doi.org/10.1016/j.cie.2020.106754
- Zhang, H., Xu, Y., Yang, L., & Liu, H., (2014). Macroscopic Model and Simulation Analysis of Air Traffic Flow in Airport Terminal Area, *Discrete Dynamics in Nature and Society*, https://doi.org/10.1155/2014/741654
- Zhao, F., & Gustafson, T. (2013). Transportation needs of disadvantaged populations: where, when, and how? FTA Report No. 0030, https://doi.org/10.21949/1503567

REFERENCES (*image sources*)

Figure 1:
https://www.clipartmax.com/middle/m2i8b1Z5b1Z5N4A0_futuristic-car-clipart-flying-car-clip-art/
https://www.core77.com/posts/102614/Heres-Video-of-a-Flying-Car-Actually-Flying
https://www.ansys.com/applications/autonomous-software-development
https://www.autocar.co.uk/car-news/features/pal-v-liberty-exploring-flying-car
https://flightaware.com/

Figure 2:

- Privately-shared image

Figure 3:
https://seekingalpha.com/article/4524106-joby-aviation-stock-uber-flying-taxis-by-2024

Figure 4:
https://www.thalesgroup.com/en/markets/digital-identity-and-security/iot/inspired/smart-cities

Figure 5:
https://dronewars.net/2021/10/26/on-the-horizon-drone-spies-coming-to-uk-skies/

Figure 6:
https://www.micron.com/about/blog/2019/april/evolution-of-in-vehicle-infotainment-systems-part-four

Figure 7:
https://www.urbanairmobilitynews.com/air-taxis/tnmt-aam-investment-dashboard-for-evtol-industry-movers-and-shakers/

Figure 8:
https://www.inrosoftware.com/en/products/dynameq/

Figure 9:
https://www.mathworks.com/matlabcentral/fileexchange/69145-quantum-behaved-particle-swarm-optimization

Figure 10:

- Screen capture from in-house software development

Figure 11:

- Screen capture from in-house software development

Figure 12:
www.googlemaps.com (*screen capture / labelled*)

Figure 13:
https://www.suasnews.com/2021/09/moog-inc-announces-participation-in-afwerxs-agility-prime-initiative/
https://www.autocar.co.uk/car-news/new-cars/new-terrafugia-tf-x-flying-car-revealed
https://twitter.com/cnbc/status/990636840259596289

Figure 14:

- Illustration from in-house hardware development

Figure 15:
https://www.gorillanetting.com/services/commercial-netting/netted-drone-enclosures/

Figure 16:
https://www.visitcalifornia.com/in/node/36546

Figure 17:
https://depositphotos.com/281126724/stock-photo-vtol-passenger-aircraft-closing-airport.html

Figure 18:
https://www.pngkey.com/detail/u2q8u2i1e6t4t4a9_innovation-free-png-image-internet-of-everything-icon/
https://www.shutterstock.com/image-illustration/airplane-flying-around-globe-wearing-graduation-68492701
https://www.pikpng.com/transpng/hTTmii/
https://www.pinterest.com/pin/595178906981535418/
https://www.pngkit.com/view/u2w7q8o0i1y3t4i1_virtual-reality-clipart-transparent-ar-and-vr-logo/
https://www.vectorstock.com/royalty-free-vector/soldiers-and-fighting-tank-vector-10113208
www.iitsec.org