Game Engine Modeling & Simulation (M&S) implementations to evaluate Human Performance in Transportation Engineering

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ABSTRACT

Transportation (including modes for humans, goods, and services) remains a critical multidisciplinary challenge, and as multimodal transit continues to evolve, complex transportation systems are increasingly paramount to our everyday lives. To appropriately advise future Test & Evaluation (T&E) and validation of next-generation mobility mechanisms, advanced digital platforms for human performance analysis remain an essential requirement. Advanced Modeling & Simulation (M&S) – including the Live-Virtual-Constructive-Autonomous (LVCA) taxonomy - continues to transform all aspects of our current and future research, training, and educational communities. In recent times, high-fidelity digital graphics, computational visualizations, and novel gamification approaches, including game engine utilities (such as Unity 3D and Unreal Engine) have revolutionized development of context-specialized asset creation and authentic virtual environments to observe human behavior within next-generation mobility scenarios.

The ethos of the 2023 MODSIM World Theme: *Make it Happen* - is to evince innovative M&S and LVCA technologies to overcome diverse transportation challenges for widespread benefit. In this timely research paper, and for the primary welfare of the training & education community of practice, we offer a demonstration of two game engine implementations in-development that enable ongoing human performance assessments within diverse transportation applications. The first implements the Unity game engine for the creation of a ground transportation network to support the analysis of distraction potential, during manual operation, amidst navigational information sources that can be internal/external to both the vehicle and the driver. The second implements the Unreal game engine for the creation of a T&E network to forecast future modes of human transport during autonomous operation, particularly hybrid ground-flight vehicles and Advanced Air Mobility (AAM).

Keywords: Transportation Engineering, Modeling & Simulation (M&S), Live-Virtual-Constructive-Autonomous (LVCA), game engines, Unity 3D, Unreal Engine, human performance, human-machine interaction (HMI), cognitive distractions, advanced air mobility (AAM).

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INTRODUCTION

A sound transportation network is the foundation of any society, and promotes successful commerce by enabling safe, sustainable, and efficient mobility of humans, goods, and services. The vitality and well-being of a nation is reliant upon a well-organized transport system and supporting multimodal (e.g., pedestrians, bicycles, cars, trucks, buses, airplanes, trains, trams) infrastructure (e.g., Litman, 2021). Current and forecasted technological pathways towards improving human mobility emphasize vehicles that are partially controlled by human drivers (Hancock et al., 2019). Longer-term modalities focus on fully automated technologies, most notably connected and autonomous vehicles (CAV's) (Ondruš et al., 2020), unmanned aerial vehicles (UAV's), and rapidly emerging "hybrid" transport modes such as Advanced Air Mobility (AAM) (National Academies of Sciences, Engineering, and Medicine, 2020).

The criticality of these societal needs has dramatically increased during recent times. The COVID-19 pandemic has permanently altered the global supply chain, and by extension, the supporting landscape for future urban and regional planning and development (Sharifi & Khavarian-Garmsir, 2020). Therefore, identifying novel mechanisms for multimodal transportation is an ongoing matter of national priority, with downstream impacts upon sustainable transportation and logistics. To address these time-sensitive priorities, we urgently require high-fidelity supporting environments within which to investigate current and future mobility technologies, using proven modeling methods embedded within novel simulation implementations. This capability will enable improved assessment of human performance and the Human-Machine Interface (HMI) (Martinez et al., 2019), and will necessitate Live-Virtual-Constructive-Autonomous (LVCA)* (McLean et al., 2013) models and simulations (M&S) for T&E and validation.

In this paper, we offer a demonstration of in-development M&S tools (i.e., game engine technologies) intended for the evaluation of human performance in transportation engineering. Note that our primary focus lies with Virtual (V) implementations to support the LVCA taxonomy. In the next section, we explore additional background from the literature on using game-inspired approaches for environment design in transportation engineering science. This is followed by a discussion of human performance challenges associated with two specific transportation applications. We then offer development details from our simulator implementations, including: i) notable features of the game engine environments themselves, ii) embedded (gamification) models for rating human performance, and iii) notional discussion of downstream candidate scenarios and forecasted use cases. Finally, we conclude this paper with a discussion of ongoing and future work, particularly with relation to near-term applications within the training and education community of practice, which serves as the MODSIM 2023 focus track for this paper.

***LVCA:** **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.*

M&S BACKGROUND

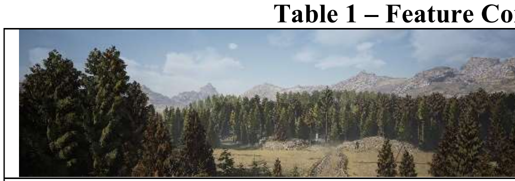
The discipline of Modeling & Simulation (M&S) (i.e., employing task-specific interactions by simulating "what if?" style scenarios in risk-free environments) (Frydenlund, 2021) remains an invaluable conceptual conduit between laboratory experimentation and real-world implementation. Over the last few decades, *e-learning* experiences (i.e., the process of learning by way of electronic or digital mediums; Peterson and Feisel, 2004) have proven to be an effective cross-disciplinary medium for high-fidelity M&S research, training, and education (e.g., Montecchiari et al., 2021). In such environments, trainees can interact with complex scenarios that incorporate physics-based modeling methodologies and accompanying high-fidelity simulation implementations (e.g., Hulme et al., 2021a) to promote both analysis and synthesis (Cunning, 2015) simultaneously in real-time.

Recent efforts to enable an improved conceptual understanding using traditional *video game* techniques have been referred to as ***serious games*** (Iten and Petko, 2016). Formally defined, serious games are innovative, exploratory, inquiry-based methods for complex problem-solving, often employed for specialized skill acquisition. The related notion of *gamification* continues to gain recognition as a valuable resource for quantifying human factors and human performance in research, with profound downstream impacts on training and education. Gamification is defined as employing game mechanics in non-game situations to enhance motivation and positively influence behavior (Pirker and Gütl, 2015), and typically incorporates traditional elements of game playing, including rewards to motivate, point scoring (e.g., badges), and group participation (Balci et al., 2022). Refer to Figure 1.

Figure 1 – Serious Games to enhance training and education effectiveness *(adapted from: Gómez, 2017)*

These concepts have included the development and implementation of novel graphics tools and APIs (i.e., gaming engines) for virtual world visualizations to support next-generation training (Navarro et al., 2012). Unity 3D (Haas, 2014) is a widely available game development engine for the creation of 2D and 3D virtual environments for interactive simulations. Unity is currently the most popular game engine because of its user-friendliness, cross-platform nature, and its propensity for well-documented assets and supporting resources. Another example is Unreal Engine (Epic Games, 2022). Like Unity, Unreal Engine serves as a key component to game development as it combines numerous common game elements (e.g., sound, graphics, and artificial intelligence) directly into the framework of the game (Trainor-Fogleman, 2021). Refer to Table 1, which offers a high-level feature comparison of Unity and Unreal (Arora, 2021), both of which are featured prominently in this publication.

Table 1 – Feature Comparison of Unity 3D and Unreal Engine

	unity	UNREAL ENGINE
Developer:	Unity Technologies	Epic Games
Definition:	Source-available game engine	Cross-platform game engine
Native programming language:	C# (*intermediary/intuitive*)	C++ (*advanced/challenging*)
Native asset availability:	Exceptional (> 30,000)	Good (> 10,000)
Graphics quality:	High-quality | game grade	Advanced | photorealistic
Visual Scripting system (gameplay):	Bolt (*inspired by Blueprints*)	Blueprints (*powerful*)
Common Use Case:	2D/3D gaming simulation	Large, graphics-driven games

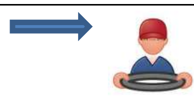
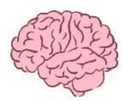
In the domain of *Transportation*, game-based frameworks are essential for human performance evaluation - now more than ever - as we continue to forecast and analyze next-generation sustainable modes of mobility. This notion remains critical both for ground and air vehicle types, as well as for the entire spectrum of control automation, ranging from purely manual (Level 0) to fully autonomous (Level 5) operability (Wang et al., 2021). For this paper, we offer development details for two transportation applications on supporting modeling methodologies for such purposes, and as driven by Unity/Unreal game engine implementations. The first is a ground vehicle application (*intended primarily for manual operation*) which can be implemented explicitly to analyze internal/external driver distraction potential. The second is a flight vehicle application (*intended primarily for autonomous operation*) which can be implemented to analyze the HMI for rapidly emerging hybrid mobility alternatives.

HUMAN PERFORMANCE CHALLENGES

Ground vehicle application: internal/external distraction analyses

Driving continues to be a multi-sensory technological and public health challenge that involves continuous coordination between visual (i.e., taking eyes off the road), mechanical (i.e., taking hands off the wheel), and cognitive (i.e., taking mind off driving) task demands (Ma et al., 2018; Gursten, 2019), and can be either internal or external to the driver (Sosa et al., 2014). Purely *internal* distractions (i.e., mindlessness, task-unrelated thought, mind wandering) is defined as "the decoupling of attention from the task at hand coincident with a shift in focus to internal thought processes" (Smallwood et al., 2003) can compromise the ability of the driver to incorporate information from the surrounding environment. Conversely, distractions that are external to the driver can manifest either internal or external to the vehicle. Regarding the former (*internal to the vehicle*), a primary example is device technology. As portable technologies materialize (e.g., smartphones for communication and navigation), and as autonomy safety features further evolve (e.g., backup cameras and lane-departure warnings), potential sources of external distraction will continue to manifest. Regarding the latter (*external to the vehicle*), a primary example are traffic road signs, which remain a critical aspect of driving-related safety. Clearly marked roads allow drivers to follow local regulations and navigate towards their destination accurately and efficiently. However, "information overflow" caused by new signage and their associated parameters (e.g., content, size, height, thickness, shininess, color, shape, font) (FHWA, 2012) continues to be a major concern, as the amount of visual information presented to drivers is ever-increasing. Table 2 illustrates contemporary examples of internal/external distraction sources during the driving task.

Table 2 – Internal/external Distractions in Driving

Distraction source: *Driver*  *Vehicle* 	**Internal** 	**External** 
Internal	Task-unrelated thought (e.g., "mind wandering")	Device technologies
External		Roadway signs for navigation

For these reasons - distraction continues to be a timely and critical area of analysis for driving simulators. To effectively observe and analyze such distractions within a driving simulator, a car-following paradigm is often adopted as a proven, trusted, and validated mechanism to analyze cognitive distraction. In such approaches, a "lead vehicle" (i.e., a digital asset whose placement is dictated to be ahead of the human driver in the simulator) is programmed to brake suddenly to enable measurement of driver alertness, engagement, and arousal (e.g., Sena et al, 2016). Refer to Figures 2-3 for illustrative examples of the lead vehicle approach embedded within a simulated driving context.

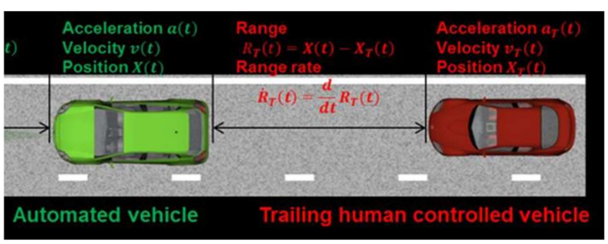


Figure 2 – lead vehicle (*methodology*)
(*Ref: Zhao et al., 2016*)

Figure 3 – lead vehicle (*implementation*)
(*Ref: Liu et al., 2017*)

Operation of modern-day ground vehicles remains predominantly a manual task, however, vehicles continue to emerge whose features are trending towards fully autonomous. To realize a long-term strategic vision for widespread vehicular autonomy, we first require guidelines for managing an extended period of transition during which both autonomous and non-autonomous vehicles will share the road (Klochikhin, 2019). This "co-existence" dilemma mandates simulation – and robust and parameterizable high-fidelity supporting environments that enable human performance evaluation within targeted driving scenarios. Ultimately, observations made within such environments could result in vast improvements with future vehicle designs, novel approaches to cooperation between autonomous vehicles (e.g., V2X, platooning; Dhawankar et al., 2021), and diverse downstream impacts on driver safety, training, and education (e.g., Hulme et al., 2021b).

Flight vehicle application: next-generation human mobility

As our surface infrastructure continues to devolve (e.g., traffic congestion, weather degradation, roadway disrepair), domain experts continue to forecast disruptive transport prospects that effectively utilize the third spatial dimension. Advanced Air Mobility (AAM) is defined as an air transportation system that moves people and cargo - using revolutionary and experimental new forms of aircraft (e.g., Johnson and Silva, 2021) - that effectively combine the ideal characteristics of both planes and cars. Prototype vehicles are designed to be more maneuverable and minimally susceptible to surface constraints (e.g., traffic jams, construction delays, adverse weather events) while traversing 3D airspace (Ahmed et al., 2020). To construct egress scenarios and examine HMI, M&S tools and frameworks – including game engine implementations - remain essential to i) conceptualize future aeronautical advancements to improve human mobility; ii) demonstrate baseline technological viability; and iii) achieve long-term sustainability.

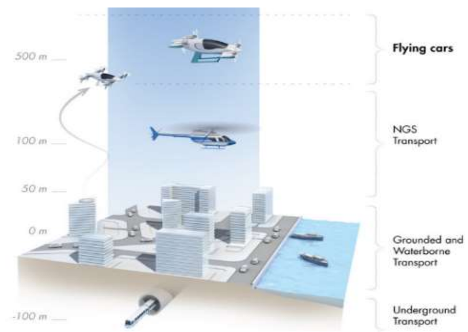


Figure 4 – AAM segregated flight elevations (*Ref: Pan & Alouini, 2021*)

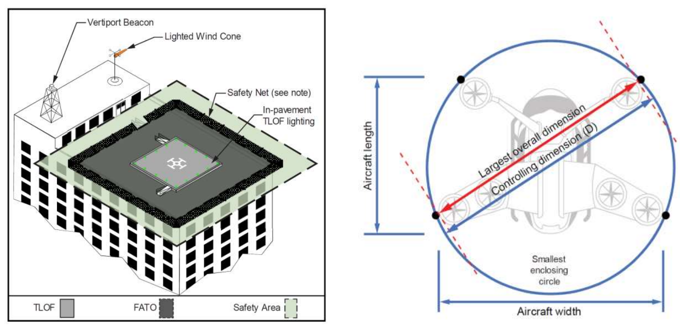


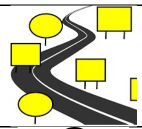
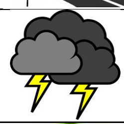
Figure 5 – AAM vertiport/vehicle geometric specifications (*Ref: FAA, 2022*)

Through direct application of the LVCA taxonomy, an improved understanding of the complex factors associated with AAM can be attained. *Constructive* simulations are essential to improve situational awareness and are often conducted to enable analysis of diverse mobility scenarios efficiently (e.g., Padilla, 2012). An immediate requirement for AAM is a 3D traffic simulation to demonstrate network communication and interoperation. With such capacity, forecasted transport behaviors can be simulated using digital assets (e.g., humans, vehicles, infrastructure) to analyze segregated airspace traffic scenarios in both the horizontal **and** vertical dimensions (e.g., refer to Figure 4 for a notional depiction or surmised flight elevations for a segregated AAM airspace) – a key surmised advantage of AAM.

Likewise, a *Virtual* testing framework is essential for authentic and safe examination of human performance and behaviors within next-generation mobility scenarios. Such a capacity will accommodate diverse AAM travel modes, including ground ("car") dynamics, flight ("plane") dynamics, as well as the transitions between these travel regimes and between manual Level 0 (*manual* | *piloted*) and Level 5 (*fully autonomous*) operation. These transitions will involve takeoff/landings zones (e.g., "vertiport" specifications for touchdown and liftoff area | TLOF and final approach and takeoff area | FATO; refer to Figure 5). The exact dimensional criteria of these facilities will be dependent upon the geometric specifications of diverse AAM aircraft types that are currently at varying stages of prototyping and development. These determinations demand validated empirical human performance data obtained from supporting high-fidelity T&E environments.

Critically, LVCA game engine frameworks will directly enable the development of M&S use case scenarios which will subsequently enable near-term decision-making for policymakers, design engineers, urban planners, and educators. For example, a primary challenge relates to ***commute scenarios***, to identify service scenario combinations for which AAM would be a superior alternative - considering both travel time and cost - to current ground-based transport options. Another key challenge is ***transport inclusivity***, for evaluating the potential of AAM towards providing greater access to mobility for the disadvantaged and to the remotely located population. Another ongoing challenge is related to ***supporting infrastructure*** to assess AAM vehicle prototypes to forecast network scalability. Other equally important candidates for scenario examination include ***extreme events*** (e.g., emergency vehicles/rescue scenarios, including those related to adverse weather events), ***green concerns*** (e.g., fuel consumption/emissions, as well as noise concerns), and ***life cycle*** (e.g., the pros and cons of electric vs. fuel power sources), all of which impart immediate downstream impacts related to ***training and education*** – which is the focus track for this paper. Table 3 provides a concise illustrated summary of these key challenges, for which the game engine environments outlined in the next section can be implemented for near-term T&E, analysis, and validation.

Table 3 – Forecasted AAM Use Cases Candidates for LVCA examination

	Use Cases	Formulation Description & Forecasted Outcomes
	Commute Scenarios	Simulate all commute scenarios, evaluate time/cost requirements ***What AAM commute scenarios are optimal (i.e., time vs. resources)?***
	Transport Inclusivity	Simulate 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 vehicles influence infrastructure/landscape requirements?***
	Extreme Events	Leverage emergency vehicles and rescue scenarios ***How optimize coordination between AAM ground/flight transport modalities?***
	Green Concerns	Optimize fuel sources/consumption, emissions, and component life cycle ***How will AAM propulsion modes guarantee environmental efficiency?***
	Training & Education	Ascertain near-term impacts on training, education, and workforce development ***How will the emergence of AAM influence future instructional content?***

GAME ENGINE MODELING & SIMULATION IN TRANSPORTATION ENGINEERING

Supporting Hardware

For ground vehicle applications, our simRING driving simulator (Figure 6) features a six-channel (*each 1920 x 1080p, resulting in a 11520x1080p 50Hz composite surround display image*) 360-degree display system that provides occupants with a fully immersive depiction of the Unity 3D driving world, complete with traffic, physical landmarks, traffic control elements and other roadway conditions. The PC-based system features input navigation controls, full-fidelity 6-degree-of-freedom (DOF) motion cueing, and a stereo sound system.

Figure 6 – simRING

Figure 7 – Flying Car Simulation (FCS)

For experimental hybrid ground/flight vehicle applications, we are currently developing a specialized Flying Car Simulation (FCS) (Figure 7) capability to enable HMI across diverse vehicle types. Our display system comprises a large (120"), physical 4K-resolution front screen. The flight chair is a modifiable truss framework upon which standard input controls (e.g., yoke, rudder, throttle) and flight gauges are physically mounted. The controls consist of simplified capabilities to provide basic inputs for either vertical- or short-takeoff and landing vehicle types (i.e., VTOL, or STOL). These control devices are situated on top of a compact and reduced fidelity 6-DOF motion system. The entire simulation is PC-based and driven by Unreal Engine graphics capabilities for flight scene rendering.

Ground vehicle application (Unity 3D)

To address ongoing challenges related to ground vehicle navigation and distractions (internal/external), the Unity game engine has been implemented to create a 3D environment terrain of a 10-square mile testing region. Within Unity, each environment asset was created using a *Terrain* tool to design the landscape and vegetation. The companion EasyRoads 3D asset tool (UnityTerrainTool, 2022) was implemented for creating multiple lanes of roadway with custom lane markings, center barriers, and other roadside elements that are typical of highway-style driving. Realistic traffic behaviors were provided by Unity's Simple Traffic System (STS) asset (Unity Technologies, 2022) that implements waypoint-based segments (see Figures 8-9) that can be interconnected to manage the configuration of routes and lanes. Traffic logic is managed by an Artificially Intelligent (AI) controller to which participating vehicles can register. Each of the traffic vehicles is guided by a separate instance of a car controller, which assigns the appropriate speed and direction for the car to follow the pre-defined waypoints and has the capability to sense adjacent traffic vehicles using ray casting.

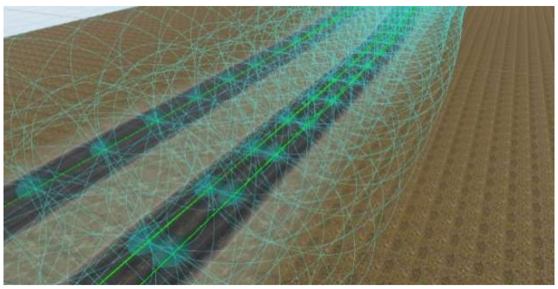


Figure 8 - STS traffic waypoints

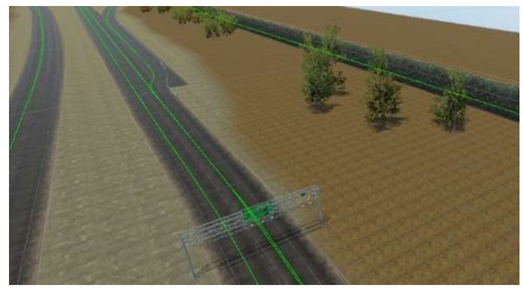


Figure 9 - STS roads, lanes, exits

To provide authentic dynamic behavior within Unity 3D, the Realistic Car Controller (RCC) physics engine asset (Bonecracker Games, 2018) customizes individual vehicle behavior (e.g., tire behavior, steering sensitivity, suspension parameters, vehicle stability) with C# scripting. Vehicle inputs are processed by a separate script that can receive signals from a Human Interface Device (e.g., the onboard steering wheel and pedals). Mappings for integration with the 6-DOF motion platform are subsequently determined; vehicle state outputs (e.g., position, speed, acceleration) are converted into DOF's (i.e., roll/pitch/heave/surge/yaw/sway | Figure 10) that define platform motion cues. This pipeline involves scaling, limiting, and tilt coordination/washout filtering (e.g., Riera et al., 2022). Table 4 summarizes the primary mappings that were used for our implementation.

Table 4 – Vehicle Dynamics-DOF mappings for motion simulator implementation

DOF	Roll	Pitch	Yaw	Heave	Surge	Sway
State variable	Lateral acceleration (*tilt*)	Longitudinal acceleration (*tilt*)	Heading (rate-of-change)	Vehicle idle, collision events	Forward velocity	Lateral velocity

The simulator digital acquisition system collects various data describing the position, velocity, and orientation of the human-driven vehicle. In addition, the simulator saves information about the position of the lead vehicle and geometric information regarding other significant objects (e.g., coordinate positions of traffic signs and entry/exit ramps). The accompanying data module writes all collected variables to a comma separated value (.csv) file for post-processing. The resulting Unity test and evaluation environment is shown in Figure 11.

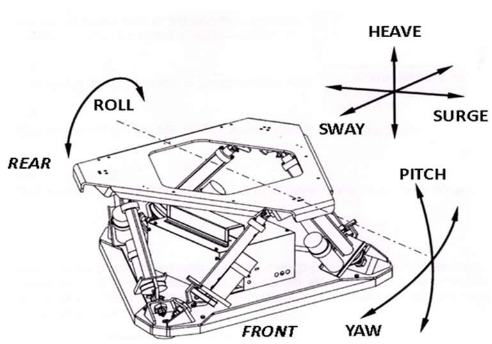


Figure 10 - motion DOF's in vehicle simulation

Figure 11 – Unity 3D test environment

As a companion to the Unity implementation, we developed a simple holistic rating system to assess navigational success against distraction potential. This "Gamification" methodology has been implemented to observe, measure, and quantify driver performance amidst specific assigned driving tasks. These metrics accompany the described game engine simulator implementation and enable quantification of driver performance across observed driving safety categories. The **Safety Rating (SR) model** scores participants on an intuitive 0-100 scale per the user-parameterizable (and scenario-specific) weightings (***W***) demonstrated in Equation 1, with supplemental details provided in Table 5.

$$SR\ (0\text{-}100) = W_{TS}*TS + W_{TD}*TD + W_{LD}*LD + W_{BE}*BE + W_{BA}*BA + W_{BD}*BD \qquad \{1\}$$

Table 5 – Score components for driver Safety Rating (SR) model

Symbol	Score component	Rationale for score subcomponent	Weight
TS	Travel speed (mph)	Travel near average speeds (to match roadway conditions)	30%
TD	Speed deviation (mph)	Maintain close to constant travel speed (minimal fluctuations)	20%
LD	Lateral deviation (feet)	Maintain lane-centric driving behaviors (minimal weaving)	20%
BE	Braking events (#)	Amount of braking required should match (average) conditions	5%
BA	Braking severity (%)	Moderate (gradual) braking is safer than harsh braking	15%
BD	Braking consistency (%)	Ideal braking applied uniformly across all slow-down events	10%
	TOTAL		**100%**

Flight vehicle application (Unreal Engine)

To address ongoing challenges related to a rapidly emerging hybrid ground/flight mobility paradigm (i.e., AAM), the Unreal game engine has been implemented to create a 3D virtual environment to enable next-generation egress scenarios. Within Unreal engine, the Blueprint-based visual scripting system was incorporated, and employs a node-based interface to create gameplay elements and object-oriented class/object definitions for environment creation. This interface makes it easier to generate environment events, functions, and variables in a manner that does not require advanced programming expertise. As an example, Figure 12 illustrates the general design approach employed for our virtual world development, which employs Blueprints for all environment entities, including textures, landscape elements, and traffic/navigation control devices.

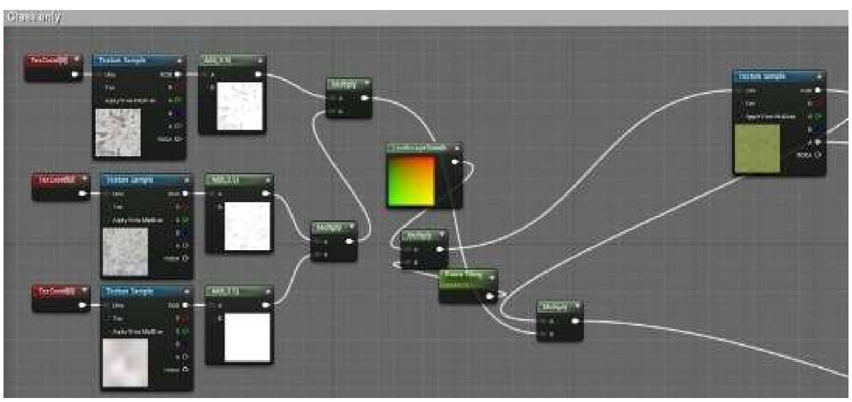


Figure 12 – Unreal Engine implementation: Blueprints

Figure 13 – AAM test facility

Using Unreal Engine (i.e., and the Blueprints-based design approach, alongside asset modeling assistance from Cesium, terrain.party, and PLW Modelworks), we have begun to develop a comprehensive simulation-based virtual AAM test facility. Refer to Figure 13 for an overhead view of the hybrid mobility environment that includes assets for both ground and flight modalities. The primary features of the ground-based infrastructure include residential interchanges (e.g., signalized intersections, 2- and 4-lane highways, roundabouts | see Figure 14) for examination of both manual/autonomous mode ground vehicles. Likewise, the modeled assets (e.g., streets, signage, traffic control devices) for "ground" mode also include Proving Grounds segments (see Figure 15), to enable manufacturers to improve the development process for new/experimental vehicle types. Furthermore, although our design is not a true "digital twin", the described testing capacity suitably enables the evaluation of systems and vehicles in a representative virtual environment both before and after physical prototypes are available for real-world validation.

Figure 14 – Residential interchanges

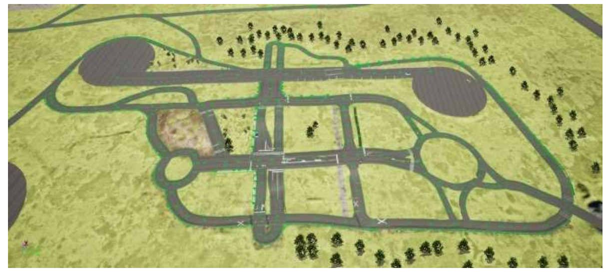


Figure 15 – Proving ground testing area

Through our game-based Unreal Engine implementation, we have enabled a specialized capacity within which an improved understanding of interdisciplinary factors associated with forecasted AAM vehicles/infrastructure can be achieved. For example, the evolution of AAM demands high-fidelity models to determine a) handoff periods between manual and autonomous vehicle control; b) operational vehicle dynamics transitions (refer to Figure 16); and critically, c) human responses to emergent autonomous transport features. Within our AAM test facility, we have incorporated features to address these requirements, including a communications control tower for air traffic control, and a prototype vertiport (see Figure 17) to enable vehicle takeoffs and landings.

Figure 16 – Ground-to-flight Transition zone

Figure 17 – Virtual vertiport

Within our T&E Unreal Engine environment, *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) employ simplified models that balance (static/dynamic) stability and control properties (i.e., aerodynamics), and serve as a response to atmospheric disturbances for prevailing flight conditions. Flight dynamics models are therefore being designed to be modular across existing and forecasted AAM vehicle types, including electric vertical take-off and landing (eVTOL) rotorcraft and fixed-wing aircraft, as well as true "flying cars", such as short take-off and landing (STOL) gyrocopter vehicle types. Reduced-order linear models are being derived to analyze nominal drive/flight motions, and once the model outputs (i.e., the vehicle states) are calculated, meta-analyses will be performed to achieve effective motion cueing, as described previously.

ONGOING AND FUTURE WORK

This paper has described the ongoing development of advanced M&S (game engine) technologies to enable the evaluation of human performance in two applications within contemporary transportation engineering. Note that our primary focus has been Virtual (V) implementations to support the LVCA taxonomy. Now that the supporting environments have been constructed, subsequent phases of this effort will transition towards human performance analysis and engineering and mobility feasibility studies enabled by the described game engine M&S resources.

The Unity 3D implementation forecasts the emerging need to analyze the HMI to identify an appropriate balance between navigational success and distraction potential during a predominantly manual driving task. This capability is especially timely as modern-day vehicles become more complex to operate, with navigational safety features that produce additional opportunities for cognitive distraction. Virtual environment features (and the Safety Rating model) described in this paper have been explicitly designed to observe and analyze cognitive driving task demands that can manifest either internal or external to both the driver and vehicle. Figure 18 notionally illustrates an implementation example for the Unity game environment to monitor human driving across multiple measures and data sources (e.g., quantitative, qualitative, self-report, survey and physiological) to comprise a truly holistic performance assessment.

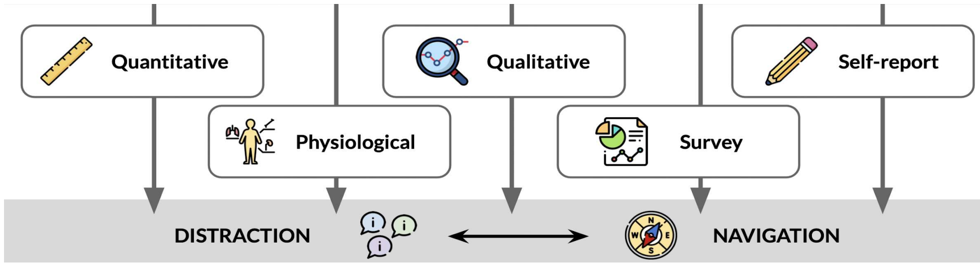


Figure 18 – Fusion of multiple data measures to analyze distraction/navigation in driving tasks

The Unreal Engine implementation provides a novel capability to examine current and forecasted challenges associated with next-generation mobility. Herein, we described the development of a hybrid mobility environment that includes assets for both ground and flight modalities and enables the evaluation of systems and vehicles once physical prototypes are available for real-world validation. A longer-term goal is to fully develop an expanded virtual Buffalo-Niagara environment (see Figure 19) for region-specific scenario evaluations. Primary design features of this environment include multiple campuses of the University at Buffalo, as well as the Buffalo-Niagara International Airport (BUF), which will be essential for preliminary regional route examination and egress scenario forecasting.

A critical aspect of our ongoing implementation is the capability to re-configure across AAM vehicle types. Mixed Reality (MR) technologies (e.g., Chaudhari, 2021) - combining real world and digital elements allow us to display the cabin for each vehicle type in virtual space using Augmented Reality (AR) by leveraging detail-designed and optimized low-polygon 3D interior/exterior models of each AAM vehicle type. 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). Figure 20 illustrates aspects of our (in-development) MR presentation, including physical, virtual, and augmented spaces.

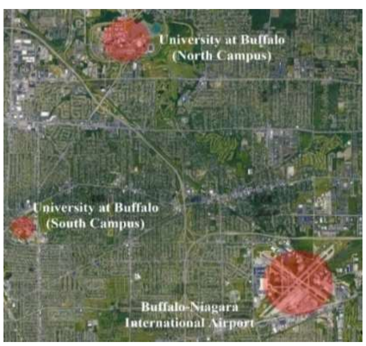


Figure 19 – Virtual Buffalo-Niagara

Figure 20 – AAM Mixed reality interfaces

Finally, the rapid emergence of "the transportation network of tomorrow" will have profound impacts on education and science technology, engineering, and mathematics (STEM). Reminding the reader that the training and education community of practice serves as the MODSIM 2023 focus track for this paper, both game engine implementations described in this work will directly influence future practices in transportation education (e.g., Garanin, 2020), including driver/pilot training and certification, repair, and maintenance for emerging and experimental vehicle types, and supporting technologies (e.g., robotics, sensor fusion, machine learning, AI, and cybersecurity).

ACKNOWLEDGEMENTS

The authors extend extreme thanks to 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, the authors acknowledge partial support offered by two sources: NSF MRI (*award #1626374*) for providing staff support for Unity 3D environment development, and the Epic Games Mega Grants program which provided student funding towards Unreal Game Engine environment development.

REFERENCES

- 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
- Arora, S.K., (2021). Unity vs Unreal Engine: Which Game Engine Should You Choose? hackr.io (online article), https://hackr.io/blog/unity-vs-unreal-engine, published: November 18, 2021.
- Balci, S., Secaur, J.M. & Morris, B.J. (2022). Comparing the effectiveness of badges and leaderboards on academic performance and motivation of students in fully versus partially gamified online physics classes. *Educ Inf Technol* 27, 8669–8704. https://doi.org/10.1007/s10639-022-10983-z
- Bonecracker Games, (2018). Realistic Car Controller v 3.52, (*online product site*), https://www.bonecrackergames.com/realistic-car-controller/, Copyright 2018.
- Chaudhari, K. (2021). Mixed Reality in Transportation Industry, (*unpublished article*), https://www.researchgate.net/publication/357327231
- Cunning, D. (2015). Analysis versus Synthesis. In L. Nolan (Ed.), The Cambridge Descartes Lexicon (pp. 7-12). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511894695.007
- Dhawankar, P., Agrawal, P., Abderezzak, B., Kaiwartya, O., Busawon, K., & Raboacă, M. (2021). Design and Numerical Implementation of V2X Control Architecture for Autonomous Driving Vehicles. Mathematics. 9. 1696. https://doi.org/10.3390/math9141696
- Epic Games. (2022). Unreal Engine. Retrieved from https://www.unrealengine.com
- Federal Aviation Administration (FAA), (2022). Engineering Brief No. 105: Vertiport Design, September 2022, available from https://www.faa.gov/sites/faa.gov/files/2022-09/eb-105-vertiports.pdf
- Federal Highway Administration (FHWA), (2012). Manual on uniform traffic control devices for streets and highways (MUTCD), 2009 Edition with Revision Numbers 1 and 2 incorporated, U.S. Dept. of Transportation, available from: https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm
- Frydenlund, E. (2021). Modeling and Simulation as a Bridge to Advance Practical and Theoretical Insights About Forced Migration Studies. *Journal on Migration and Human Security*, 9(3), 165–181. https://doi.org/10.1177/23315024211035771
- Garanin, M. (2020). Trends in the development of transportation education. Transport Technician: Education and Practice. 1. 157-164. https://doi.org/10.46684/2687-1033.2020.3.157-164
- Gómez, B., (2017). Differences between e-Learning, Gamification and Serious Games, *on serious games*, http://www.onseriousgames.com/differences-between-e-learning-gamification-and-serious-games/
- Gursten, S.M., (2019). 3 types of distracted driving: visual, cognitive and manual, Michigan Auto Law, https://www.michiganautolaw.com/blog/2019/04/25/types-of-distracted-driving-visual-cognitive-manual/.
- Haas, J. K. (2014). A history of the unity game engine.
- Hancock, P., Nourbakhsh, I., & Stewart, J. (2019). On the future of transportation in an era of automated and autonomous vehicles. *Proceedings of the National Academy of Sciences of the United States of America*. 116. 7684-7691. https://doi.org/10.1073/pnas.1805770115
- Hulme, K.F.; Schiferle, M.; Lim, R.S.A.; Estes, A.; Schmid, M. (2021a). Incorporation of Modeling, Simulation, and Game-Based Learning in Engineering Dynamics Education towards Improving Vehicle Design and Driver Safety. *Safety* 2021, 7, 30. https://doi.org/10.3390/safety7020030
- Hulme, K.F.; Lim, R.S.A.; Bauer, M.; Hatten, N.; Destro, H.; Switzer, B.; Dequesnay, J.-A.; Cashmore, R.; Duncan, I., Jr.; Abraham, A.; Deutsch, J.; Bald, N.; Fabiano, G.A.; Lewis, K.E., (2021b). Blueprint for a Simulation Framework to Increase Driver Training Safety in North America: Case Study. Safety 2021, 7, 24. https://doi.org/10.3390/safety7020024
- Iten, N. & Petko, D. (2016), Learning with serious games. *Br J Educ Technol*, 47: 151-163. https://doi.org/10.1111/bjet.12226
- 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
- Klochikhin, E., (2019). Sharing the road: an often overlooked problem of lengthy co-existence between autonomous and driven cars, medium.com (online article), https://medium.com/@eklochikhin/sharing-the-road-an-often-overlooked-problem-of-lengthy-co-existence-between-autonomous-and-d35465e6d831.
- L'Afflitto, A. (2017). A Mathematical Perspective on Flight Dynamics & Control, https://doi.org/10.1007/978-3-319-47467-0
- Litman, T. (2021). Introduction to Multi-Modal Transportation Planning: Principles and Practices. Victoria Transport Policy Institute, https://www.vtpi.org/multimodal_planning.pdf

- Liu, X., Dmowski, R., Gupta, A., Tang, L., Qiao, C., Sadek, A., He, Q., Wu, C., Hulme, K.F., Ziarek, L., and Koutsonikolas, D., (2017). "Development of iCAVE2: Instrument for Connected and Autonomous Vehicle Evaluation and Experimentation", Graduate Research Conference, CSE 50th Anniversary Celebration, University at Buffalo, Buffalo, NY, September 2017.
- Ma, Y., Hu, B., Chan, C.-Y., Qi, S., and Fan, L., (2018), Distractions intervention strategies for in-vehicle secondary tasks: An on-road test assessment of driving task demand based on real-time traffic environment, *Transportation Research Part D: Transport and Environment*, Vol. 63, pp. 747-754, https://doi.org/10.1016/j.trd.2018.07.005
- Martinez, M., Ariza, G., Rico-Bautista, D., & Riaño, E. (2019). Human computer interaction in transport, a systematic literature review. *Journal of Physics: Conference Series*. 1409. 012002. https://doi.org/10.1088/1742-6596/1409/1/012002
- 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. *Proceedings of the Association for Unmanned Vehicle Systems International (AUVSI) Conference*, Washington DC.
- Milliken, W. F. and Milliken, D. L., (1995). Race Car Vehicle Dynamics, SAE, 1995.
- Montecchiari, G., Bulian, G., & Gallina, P, (2021). Ship Evacuation Simulation Using a Game Engine: Modelling, Testing and Validation. *International Shipbuilding Progress*, vol. 68, no. 3-4, pp. 129-189. https://doi.org/10.3233/ISP-210017
- National Academies of Sciences, Engineering, and Medicine (2020). Advancing Aerial Mobility: A National Blueprint. Washington, DC: The National Academies Press. https://doi.org/10.17226/25646
- Navarro, A., Pradilla, J.V., & Rios, O. (2012). Open Source 3D Game Engines for Serious Games Modeling. In: Modeling and Simulation in Engineering | Catalin Alexandru (Ed.) IntechOpen. https://doi.org/10.5772/29744
- Ondruš, J., Kolla, E., Vertal, P. & Šarić, Ž. (2020). How Do Autonomous Cars Work? *Transportation Research Procedia*. 44. 226-233. https://doi.org/10.1016/j.trpro.2020.02.049
- Padilla, J.J., (2012). Annex two. 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-S. (2021). Flying Car Transportation System: Advances, Techniques, and Challenges. IEEE Access. PP. 1-1. https://doi.org/10.1109/ACCESS.2021.3056798
- Peterson, G. & Feisel, L. (2004). e-Learning: The Challenge for Engineering Education. *Proceedings of the 2002 eTEE Conference 11-16 August 2002 Davos, Switzerland*.
- Pirker, J., & Gütl, C. (2015). Educational Gamified Science Simulations. In: Reiners, T., Wood, L. (eds) Gamification in Education and Business. Springer, Cham. https://doi.org/10.1007/978-3-319-10208-5_13
- Riera, J.V.; Casas, S.; Alonso, F.; Fernández, M. A Case Study on Vestibular Sensations in Driving Simulators. *Sensors* 2022, 22, 5837, https://doi.org/10.3390/s22155837
- 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
- Sena, P., d'Amore, M., Brandimonte, M.A., Squitieri, R., and Fiorentino, A., (2016), Experimental Framework for Simulators to Study Driver Cognitive Distraction: Brake Reaction Time in Different Levels of Arousal, Transportation *Research Procedia*, Vol. 14, pp. 4410-4419, https://doi.org/10.1016/j.trpro.2016.05.363
- Sharifi, A. & Khavarian-Garmsir, AR. (2020). The COVID-19 pandemic: Impacts on cities and major lessons for urban planning, design, and management. *Science of The Total Environment*. 749. 142391. https://doi.org/10.1016/j.scitotenv.2020.142391
- Smallwood, J., Obonsawin, M.C., and Heim, D., (2003). Task Unrelated Thought: The Role of Distributed Processing, *Consciousness and Cognition* 12 (2): 169–189. https://doi.org/10.1016/s1053-8100(02)00003-x
- Sosa, A., Sweetman, R.J., Simon, G., Rupp, M., Michaelis, J., & McConnell, D., (2014). Driving distracted: Analysis of external and internal driving distractions, Human Factors & Applied Psychology Student Conference, Embry-Riddle University, Daytona, FL.
- Trainor-Fogleman, E. (2021). Unity vs Unreal Engine: Game engine comparison guide for 2021. evercast (online article), https://www.evercast.us/blog/unity-vs-unreal-engine, published: September 30, 2021.
- Unity Technologies, (2022). Simple Traffic System (STS), (*online product site*), https://forum.unity.com/threads/simple-traffic-system.794268/, Copyright 2022.
- UnityTerrainTool, (2022). EasyRoads 3D – Tools for the Unity Engine, https://www.easyroads3d.com/.
- Wang, J., Huang, H., Li, K. & Li, J., (2021). Towards the Unified Principles for Level 5 Autonomous Vehicles, *Engineering*, Volume 7, Issue 9, Pages 1313-1325, ISSN 2095-8099, https://doi.org/10.1016/j.eng.2020.10.018
- Zhao, D., Peng, H., Bao, S., Nobukawa, K., LeBlanc, D. & Pan, C. (2016). Accelerated evaluation of automated vehicles using extracted naturalistic driving data, https://doi.org/10.1201/b21185-33