



Vehicle-Mobility Systems Analysis Tech Team Roadmap

February 2020



This roadmap is a document of the U.S. DRIVE Partnership. U.S. DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy sustainability) is a voluntary, non-binding, and non-legal partnership among the U.S. Department of Energy; USCAR, representing FCA US LLC, Ford Motor Company, and General Motors; five energy companies – BP America, Chevron Corporation, Phillips 66 Company, ExxonMobil Corporation, and Shell Oil Products US; four utilities – American Electric Power, DTE Energy, Duke Energy Corporation, and Southern California Edison; and the Electric Power Research Institute (EPRI).

The Vehicle-Mobility Systems Analysis Tech Team (VMSATT) is one of 13 U.S. DRIVE technical teams whose mission is to accelerate the development of pre-competitive and innovative technologies tenable a full range of efficient and clean advanced light-duty vehicles, as well as related energy infrastructure.

For more information about U.S. DRIVE, please see the U.S. DRIVE Partnership Plan, at www.vehicles.energy.gov/about/partnerships/usdrive.html or www.uscar.org.

Key Terms and Acronyms

AI: Artificial intelligence

ATTM: All-Tech Team Meeting

CAV: Connected and Automated Vehicle

DOE: U.S. Department of Energy

EEMS: the Energy Efficiency Mobility Systems program at the U.S. Department of Energy's Vehicle Technologies Office

EERE: Energy Efficiency and Renewable Energy

EV: Electric Vehicle

LDV: Light-Duty Vehicle

M/HDV: Medium- and Heavy-Duty Vehicle

ML: Machine learning

ODD: Operational Design Domain

R&D: Research and development

V2I: Vehicle-to-Infrastructure connectivity, e.g., communication between a vehicle and a traffic intersection signal

V2V: Vehicle-to-Vehicle connectivity, e.g., communication between a vehicle and other vehicles on road nearby

V2X: Vehicle-to-“X” connectivity, where “X” is a variable that could represent many or multiple technologies

VHT: Vehicle Hours Traveled

VMSATT: the Vehicle Mobility Systems Analysis Tech Team of the U.S. DRIVE Partnership

VMT: Vehicle Miles Traveled

VTO: the Vehicle Technologies Office at the U.S. Department of Energy

VTS: Vehicle Technical Specification

Introduction

In support of the U.S. DRIVE Partnership, the Vehicle-Mobility Systems Analysis Tech Team (VMSATT) facilitates precompetitive technical information exchange among experts in the analysis, development, and testing of vehicle and mobility systems who interact as equal partners to 1) discuss relevant R&D needs, 2) support the development of Partnership goals and technology roadmaps, and 3) evaluate relevant R&D progress regarding advanced vehicle technologies in future potential mobility systems contexts. For the purposes of this Roadmap and for the VMSATT scope, “mobility system” is defined as all elements that define the flow of people and goods across a travel area (travelers in all modes, vehicles, infrastructure, and communication/connectivity). VMSATT consists of a community of peers from U.S. DRIVE Partner organizations and will focus on technology that creates national benefits while avoiding duplication of efforts across government and industry to ensure that publicly-funded research delivers high-value results. VMSATT will strive to overcome high-risk barriers to technology commercialization and prioritize timely research questions that individual Partner organizations would not be able to answer alone.

The vehicle and its environment are undergoing a transformation and from this potential paradigm shift stems new research questions. The Partnership recognizes this transformation, warranting the creation of this new technical team and views the perspective and focus of VMSATT as additive and complementary to existing Partnership activities. This new tech team will leverage the technical knowledge within Partner organizations, including the Department of Energy, Office of Energy Efficiency and Renewable Energy’s Vehicle Technologies Office’s Energy Efficient Mobility Systems (EEMS) Program, to evaluate technology deployment, prioritize projects, and provide models, tools, and other capabilities for integrated transportation and mobility systems analysis. In summary, VMSATT will identify, analyze, and accelerate the development of pre-competitive, innovative energy efficient mobility system technologies that affect the future of light-duty vehicles and associated infrastructure (communications, fueling, and built environment).

VMSATT inherits a legacy of vehicle-level models, tools, and analysis from the former Vehicle Systems Analysis Tech Team (VSATT), which VMSATT subsumed. The new tech team will continue to build on the activities formerly encapsulated in VSATT, including vehicle modeling and simulation of advanced powertrain architectures, evaluation of technologies in terms of cost and performance, and experimentation on relevant hardware. VMSATT augments the previous vehicle systems-level focus by zooming out to a broader mobility system context and will tailor its efforts to topics accordingly. For example, VMSATT will model advanced technology operation, performance, and associated energy benefits (vs. baselines or other technologies) in a mobility system context; ground-truthing and validating mobility system models that simulate personal transportation choices and vehicle-relevant off-vehicle technologies, such as vehicle-to-infrastructure communications, to assess their associated energy impacts. VMSATT will coordinate with non-light-duty vehicle (LDV) mobility-system-relevant efforts, where and when appropriate (e.g., 21st Century Truck Partnership).

This Roadmap identifies 19 VMSATT outcomes. While each outcome falls within the scope of the tech team, 10 outcomes have been chosen as “targeted outcomes” and the remaining 9 outcomes are categorized as “ongoing outcomes”. The targeted outcomes will be the focus for VMSATT and have been assigned deliverable timelines. The remaining ongoing outcomes will be assessed periodically by the tech team and updated or completed as-appropriate.

Mobility Systems Modeling



Figure 1. VMSATT connects advanced vehicle component technologies to mobility systems context for evaluation and validation of energy-relevant insights.

The target audiences for VMSATT work includes decision makers within the Partnership, external stakeholders in the technical community, and policymakers. VMSATT will document its findings in the public domain, for example in National Laboratory reports and/or peer reviewed scientific papers.

Mission

Identify, analyze, and accelerate the development of pre-competitive, innovative energy-efficient mobility system technologies that affect the future of light-duty vehicles and associated infrastructure (communications, fueling, and built environment).

Scope

The U.S. DRIVE Partnership is broadly focused on advanced automotive, and related energy infrastructure, technology research and development specifically focused on technologies for cars and light trucks. **VMSATT will focus on advanced automotive and related energy infrastructure technology research and development in broader energy efficient mobility system contexts as relevant for, but not explicitly constrained to, technologies for cars and light trucks.** VMSATT will coordinate research that considers such metrics as energy, efficiency (including mobility system passenger efficiency through such measures as load factor), emissions, productivity, affordability/cost, time, aggregate measures of travel distance (e.g., miles) and duration (e.g., hours), accessibility, and resiliency.

Goals: Objectives and Key Focus Areas

As a new tech team, this inaugural roadmap affords VMSATT the opportunity to structure a systematic and intentional exploration of and contribution to vehicle mobility systems analysis.

VMSATT organizes its objectives into four key focus areas:

1. **Future mobility systems visioning** and process standardization
2. **Evaluation and augmentation of capabilities** for mobility systems research
3. Mobility system **technology characterization**
4. **Applied mobility systems R&D** to support tech teams, partners, and stakeholders

As is depicted in Figure 2, the tech team will first survey existing capabilities to identify knowledge gaps and utilize expert expectations to define possible new modeling priorities given potential future changes to the mobility system (key focus area 1: Future potential mobility systems visions). Once the gaps and perceived needs are identified, the team will then work to enhance or develop modeling tools (key focus area 2: new modeling capabilities) and new technologies and collect real-world data for validation (key focus area 3: technology development and characterization). Finally, armed with a toolbox of validated models, the team will analyze both mobility system technologies relevant to the tech team, and other technologies supported by other U.S. DRIVE tech teams in a mobility systems context (key focus area 4: applied research to support partners and stakeholders).

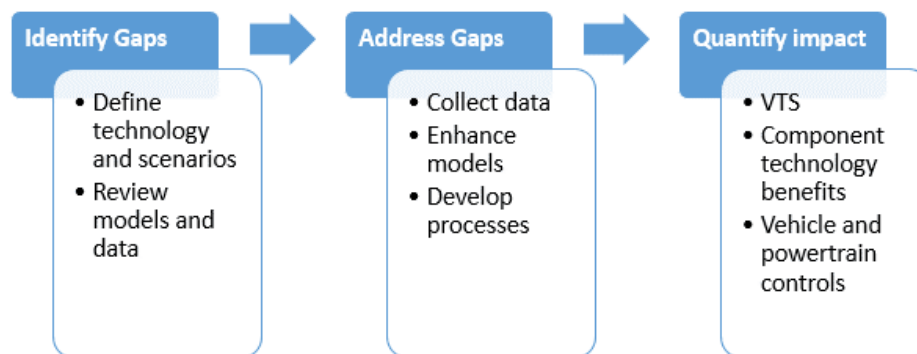


Figure 2. Generalized representation of VMSATT’s approach to identifying, addressing, and executing mobility systems analysis and R&D.

In the remaining sections, each of the key focus areas is described and specific associated strategies, activities, and tasks are identified for each.

1. Future potential mobility systems vision(s) for LDV technologies/usage

Recent and ongoing developments in vehicle electrification, connectivity and automation technologies, and the sharing economy have introduced new, and potentially important uncertainties into how personal transportation will evolve over time. VMSATT brings together expertise across automotive, energy, utility, and government sectors to forge a combined perspective of how different potential mobility futures could affect or be affected by the light-duty vehicle technologies supported by the Partnership.

Keywords

Future scenario visioning, vehicle usage (e.g. route)

Strategies, Activities, and Tasks

The highest-level, most conceptual VMSATT activities involve thinking through potential critical changes to how light-duty vehicles operate as part of the mobility system, unifying relevant changes into a set of future mobility narratives, and translating those future narratives into the input assumptions and constraints that shape modeling and simulation activities.

- Future scenario visioning:** Uncertainty about the future of mobility complicates forward-looking technology evaluation and R&D prioritization. Accordingly, VMSATT will collectively brainstorm a set of relevant, representative future mobility scenarios to provide context for potential impacts of, and inform prioritization of, technology R&D. Critical questions to start to answer in VMSATT's future visions include: What does the future of mobility look like? What are the ranges of possible scenarios for how people and goods will move in the future? How will these impact future R&D portfolios? What would be the vehicle fleet composition? What impact will these changes have on energy consumption? Shaping and defining the future scenarios will enable VMSATT to prioritize research questions to explore.

Targeted Outcome: VMSATT will brainstorm, discuss, down select, and describe in an appendix to this Roadmap a reasonable set of possible future mobility scenarios as a reference for considering U.S. DRIVE Partnership-relevant technology impacts and research priorities.

- Translating future mobility narratives to modeling workflow:** As models are simplified representations of reality, future mobility scenarios can inform modeling activities as reduced-form versions of those possible futures. VMSATT will step back from the models themselves to consider how underlying relationships—such as land constraints and implications for where people live, work, and travel—and specific variable assumptions—such as modal travel preferences—are translated from conceptual narrative to model implementation. Input from external experts with complementary perspectives (e.g. land use, city planning) will be solicited, as appropriate.

Targeted Outcome: VMSATT will crosswalk future mobility scenarios to mesoscopic transportation system modeling capabilities at DOE's national laboratories.

- Reconsidering operational scenarios, Vehicle Technical Specifications (VTS) and Operational Design Domain (ODD):** VTS and ODD have in common the idea of describing a set of underlying requirements for vehicle performance. They differ in that VTS focuses on vehicle response to

driver inputs (e.g., acceleration capability at different speeds or topographies); whereas, ODD is the set of “operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics” (definition from Society of Automotive Engineers SAE J3016). VMSATT inherits previous discussion and descriptions of VTS from its predecessor, VSATT, but ODD is newly relevant given the expanded scope of the tech team. VMSATT will consider how advances in connectivity and automation could alter both VTS and ODD, whether individually or in concert. For example, vehicle-to-vehicle communication for drive cycle smoothing could relax VTS (i.e., lower accelerations, decelerations), which, in turn could result in different component requirements and costs.

Targeted Outcomes:

- 1) VMSATT will discuss and maintain a “standard” (or set of standard, as appropriate) VTS and ODD descriptions, including revisiting previous VSATT-developed VTS and new ODD discussions.
- 2) VMSATT will agree on several illustrative variants of a reasonable CAV drive cycles or impacts to typical (non-CAV) driving profiles.

2. New capabilities for mobility systems research

Modeling capabilities are critical tools for a tech team focused on future technology systems. Many of the technologies relevant for exploration are either nascent or not yet in existence; as such the team will have to rely on models. Modeling can provide capabilities to explore not only new and emerging mobility technologies and but also their interaction with other parts of the mobility system, when such interactions could be difficult to instrument and measure in reality. New modeling capabilities for mobility system research will consider mobility technologies (including vehicle hardware, but also novel sensing, communications, and control) to provide a systems point of view to maximize desirable outcomes such as throughput, efficiency and accessibility and/or minimize undesirable outcomes such as delay, energy consumption and emissions. Relevant scales for consideration will range from vehicle- (single or few vehicles) to micro- (groups of vehicles or mobility corridors) to meso- (entire urban areas).

Keywords

Agent-based modeling, network optimization, active traffic management, active traffic signal control, multi-scale modeling (vehicle-/micro-/meso-), mixed traffic modeling, vehicle technical specifications (VTS), operational design domain (ODD)

Strategies, Activities, and Tasks

This inaugural roadmap affords VMSATT the opportunity to structure a systematic approach to explore existing mobility systems models to identify relevant capabilities to incorporate and apply into the tech team’s activities while also identifying gaps that need filling. Accordingly, VMSATT will conduct a gap analysis, explore existing control algorithms, models and tools, and conduct initial model application for priority topics such as vehicle and highway automation and EV charging in a future mobility system.

- **Capabilities gap analysis:** Review tools, control algorithms, testing capabilities, and data related to advanced mobility and identify gaps. Multiple vehicles need to be considered along with their environment to estimate the impact of many new technologies (e.g., ACC, eco-signal...). Current capabilities and processes (i.e. traditional systems engineering “V Diagram”) need to be extended to characterize individual vehicles within an environment.

Targeted Outcomes:

- 1) VMSATT will develop a matrix identifying priority modeling needs and identify relevant Partner capabilities and/or gaps/opportunities.
- 2) VMSATT will revisit and expand the traditional systems engineering “V Diagram” to consider vehicle operational environment.

- **Explore and enhance current models/tools:** Existing models and tools have been developed to focus on individual vehicles over pre-defined driving cycles. The technologies considered in VMSATT require a new focus to be placed on specific models (e.g., human driver) and capabilities (e.g., multi-vehicle system simulation within an environment). Over time, VMSATT will be briefed on relevant EEMS-supported models (such as BEAM, POLARIS, RoadRunner, and UrbanSIM), both as a means for technical information exchange within the Partnership and as a specific mechanism for Partner feedback and suggestions for model application.

Ongoing Outcome: VMSATT will, on a recurring basis, be briefed on, offer feedback for potential improvements to, and suggest research applications for DOE-supported mobility systems-relevant models and associated findings.

- **Artificial intelligence and machine learning for CAV development:** Neural networks and reinforcement learning for sensing, control, and communication play in critical role in CAV operation and deployment. VMSATT will monitor R&D on new algorithms, sensors (e.g. machine vision), and tools to understand their potential applications and technical readiness. The team will cultivate awareness of what industry has already done—what worked? What remains to be tried? Where possible, real-world data (versus current simulated data) will be sought out for validation.

Ongoing Outcome: VMSATT will review existing use of AI/ML related to mobility and develop/implement them in the previously developed workflow.

3. Mobility system technology characterization

Quantifying the impact of new mobility trends requires not only a deep understanding of the new technologies but also how these will influence vehicle usage, energy consumption and cost. As an example, automation might lead to increased travel (i.e., VMT), resulting in different economic benefits and higher fleet turnover. Ride-hailing mode might require fast charging, and impact battery design and cost. Connectivity might smooth traffic and reduce the number of stops, thus influencing the benefits of electrified powertrains compared to conventional vehicles.

Keywords

Data collection, technology impact cost, performance

Strategies, Activities, and Tasks

VMSATT will focus on characterizing technologies by collecting data at the component (e.g., sensors...) and vehicle levels (e.g., speed, distance between vehicles...) to characterize the state of the art as well as develop and validate models. Those models will then be used to quantify the impact of new mobility technologies at the vehicle, multi-vehicle and metropolitan area levels. Specific early priorities will include AI/ML for CAV development, advanced vehicle control, and cybersecurity.

- Data collection:** Regular and systematic data collection on relevant vehicle and vehicle-environment (e.g., V2I) technologies is fundamental to understanding the technology state of the art and to identify challenges and opportunities. Understanding sensors capabilities (e.g., how far an object can be detected), communication delay, and power requirements are critical to understand current state-of-the-art capabilities and limitations. Understanding how people currently drive is necessary to develop a baseline to estimate benefits of new technologies. Additional data collected at the component and the vehicle level on dynamometers, test tracks and on-road are necessary.

Ongoing Outcome: Leveraging DOE and/or other external cost models and estimates, VMSATT will inventory current costs/performance and develop and assign some measure of future potential improvement for at least one technology “family” (e.g., on-board sensing and computing).

- Multi-scale modeling of vehicle and highway automation:** Depending on design, technology, or mode under consideration, one or more scales of traffic modeling may be utilized. Micro-level results can inform meso- and macroscopic level modeling. In an effort to understand the opportunities from system coordination, VMSATT will consider three aspects (1) highway traffic detection and active management automation; (2) vehicle automation with V2V connectivity; (3) the integration of the two with V2I. Potential mobility and energy metrics in these network analyses include vehicle hours travelled (VHT), vehicle miles travelled (VMT), total delay, average energy consumption per mile, and mobility energy productivity (MEP).

Targeted Outcome: VMSATT will apply relevant models to explore and quantify the benefits of Active Traffic Management with and without connected and automated vehicle technologies.

- **Technology threat assessment:** VMSATT should be aware of potential cybersecurity and other vulnerabilities of the evolving mobility system, especially including newly and increasingly relevant V2X considerations. Recognizing that the most state-of-the-art cybersecurity expertise resides external to the tech team, VMSATT will engage relevant specialists to stay abreast of issues potentially affecting mobility system cybersecurity (at present and/or in the future). Through systematic scenario examination, the team can consider the impact of system failures and potential failsafes for these attacks. This effort will highlight the value of having a robust system and validate the investment in developing standards and methods to ensure resiliency of that future vehicle and transportation systems.

Ongoing Outcome: VMSATT will coordinate with outside experts to develop an inventory of potential mobility system threats and conduct a Failure Modes and Effects Analysis (FMEA) to prioritize vulnerabilities for study and prevention.

4. Applied R&D to support partners and stakeholders

The intent of US Drive partnership is to stimulate precompetitive research, which can benefit partners and advance understanding more broadly. The knowledge generated from the VMSATT should inform decision-making and subsequent research projects in support of the partners' and their stakeholders' organizational goals.

Keywords

Component technology benefits, target-setting, tech team collaboration

Strategies, Activities, and Tasks

VMSATT leverages the team's capabilities to provide analytical support to partners and other key stakeholders. This support involves targeted assessment of the opportunities and risks associated with vehicle and mobility systems technology development and deployment.

- Quantify the impacts of Partnership-supported technologies in future mobility scenarios:** Past work in the U.S. DRIVE Partnership has considered the cost, energy savings, and emissions reductions impacts of technology research supported by Partnership tech teams, such as advanced combustion, lightweight materials, advanced energy storage, and fuel cell and hydrogen storage technologies. The benefits these same technologies offer in alternative potential futures (e.g., as a function of connectivity/automation and the shared economy) has not yet been evaluated and is appropriate and important for VMSATT to explore. Consistent with the activities described previously in the "Future potential mobility systems visions" section, VMSATT will use a consistent set of parameters (e.g., a world with partially automated vehicles, small penetration of vehicle electrification, small value of travel time change and small population increase) to re-evaluate Partnership-relevant technologies.

Targeted Outcomes: VMSATT will develop and demonstrate a framework for estimating the energy consumption reduction, cost, and emissions reduction benefits of vehicle technologies under research and development by other Partnership tech teams across future mobility scenarios.

- Identify synergies and offer feedback for on-going research:** In quantifying the impacts of Partnership-supported technologies, VMSATT will gain an understanding of the interplay between component-level technology improvements within the transportation system. VMSATT will identify opportunities for coordination across technologies for broader system-level benefits. This could include, for example, utilizing knowledge of how new modes, such as ride-hailing or AVs, are likely to be utilized to provide insights on charging behavior that can be used to inform requirements for other technologies such as fast and extreme fast charging. The expectation is that VMSATT will stay current on research happening both internally and externally to US DRIVE that is relevant to the mobility space, and to continually ensure that new findings and knowledge are reflected in ongoing research activities.

Ongoing Outcomes:

- Identify potential synergies between component and new mobility technologies across future mobility scenarios.

- **Mobility scenario modeling and tools for component technology target-setting:** Future mobility scenarios may suggest if/how the new usage changes requirements for technology components: Estimate the impact of advanced component technologies (e.g., current engine vs ACEC targets) across different usage (e.g., personally owned, ride-hailing, fully automated ride-hailing...) for multiple powertrains. Provide feedback to each tech team and based on the different operating conditions, they each can decide to adopt same/different targets for different usage/technologies.

Ongoing Outcome: VMSATT will develop and demonstrate a framework for identifying breakeven values within ranges of potential future Partnership tech team technology outcomes (cost and performance) across future mobility scenarios.

- **Outreach and Coordination:** VMSATT will act as a forum for sharing of insights and dissemination to other key stakeholders. Coordination efforts will include interaction with other Tech Teams at the biannual All-Tech Team Meeting (ATTM) and through scheduling other opportune events/meetings to help connect VMSATT findings and outcomes with other teams and their activities. Following completion of each targeted analysis, VMSATT will collect/identify remaining gaps and unexplored questions and apply these to inform future desired research directions.

Ongoing Outcomes:

- 1.) VMSATT will coordinate with other tech teams on an annual basis for potential mobility systems research questions and knowledge gaps as timely opportunities to leverage VMSATT modeling and technology characterization capabilities for cross-Partnership support.
- 2.) VMSATT will engage with external stakeholders for mutual benefit—sharing publicly-releasable outcomes of VMSATT research, and gathering input on stakeholder constraints, desires and ability to support various future mobility solutions.

- **Develop, deploy, and validate advanced vehicle and system control:** Connectivity and automation provide additional information that opens new opportunities for control at the vehicle as well as the system levels. Vehicle and powertrain optimization combined with system level control (e.g., traffic signal timing) have the potential to significantly impact energy and traffic flow. Knowledge about the environment and the route opens new avenues for control development both at the component and the vehicle level. Connectivity and automation enable the simultaneous optimization of vehicle speed and powertrain control. Using the collected data, VMSATT will estimate the potential energy impact of advanced controls under multiple scenarios both using system simulation and hardware testing.

Targeted Outcomes:

- 1.) VMSATT will explore and benchmark control algorithms enabled by connectivity and automation.
- 2.) VMSATT will quantify and validate with real-world data the energy savings benefits of optimized advanced vehicle control.

VMSATT Activity Plan

The prior four sections summarize the four key focus areas and several associated outcomes for each area. Many of these outcomes can be characterized as discrete activities (referred to “targeted outcomes”) while other outcomes may be achieved in the pursuit of multiple activities (referred to as “ongoing outcomes”). To highlight priorities and to be aware of research dependences, an activity plan was established to provide guidance to the tech team particularly in the initial years.

	Year 1	Year 2	Year 3+
System Modeling Workflow			
Develop framework for energy, emissions, and cost benefits of vehicle technologies under research and development			
Revisit and expand the traditional systems engineering “V Diagram”			
Mobility System			
Define future mobility scenarios		●	●
Crosswalk future mobility scenarios to mesoscopic transportation system modeling capabilities at DOE’s national laboratories.			
Update matrix identifying priority modeling needs and identify relevant Partner capabilities and/or gaps/opportunities.	●	●	●
Vehicle System			
Discuss and maintain a “standard” VTS and ODD descriptions			
Quantify with real-world data the energy savings benefits of optimized advanced vehicle control			
Agree on several illustrative variants of a reasonable CAV drive cycles or impacts to typical (non-CAV) driving profiles.			
Explore and benchmark control algorithms enabled by connectivity and automation	●	●	●
Infrastructure			
Explore and quantify the benefits of Active Traffic Management with and without connected and automated vehicle technologies.			

This action plan represents many of the most actionable outcomes with an approximate timeline for their duration. This is not to suggest the other outcomes are of lesser importance, but rather that they are more likely to occur as part of carrying out the activity plan.

Of course, it is important to note that the pursued outcomes listed in the table may be altered based on the evolving state of knowledge and research priorities of the collective VMSATT membership. New activities may emerge and/or other activities may be delayed or deemphasized over time in order to pursue the most timely research. The need for adaptation is especially true given the nature of the topic.

Acknowledgements

VMSATT Organizational Members

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FCA US LLC
Ford Motor Company
General Motors
Argonne National Laboratory
Idaho National Laboratory
National Renewable Energy Laboratory
Oak Ridge National Laboratory

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Team Member Roles

Team members follow roles as defined in the [U.S. DRIVE Partnership Plan](#).