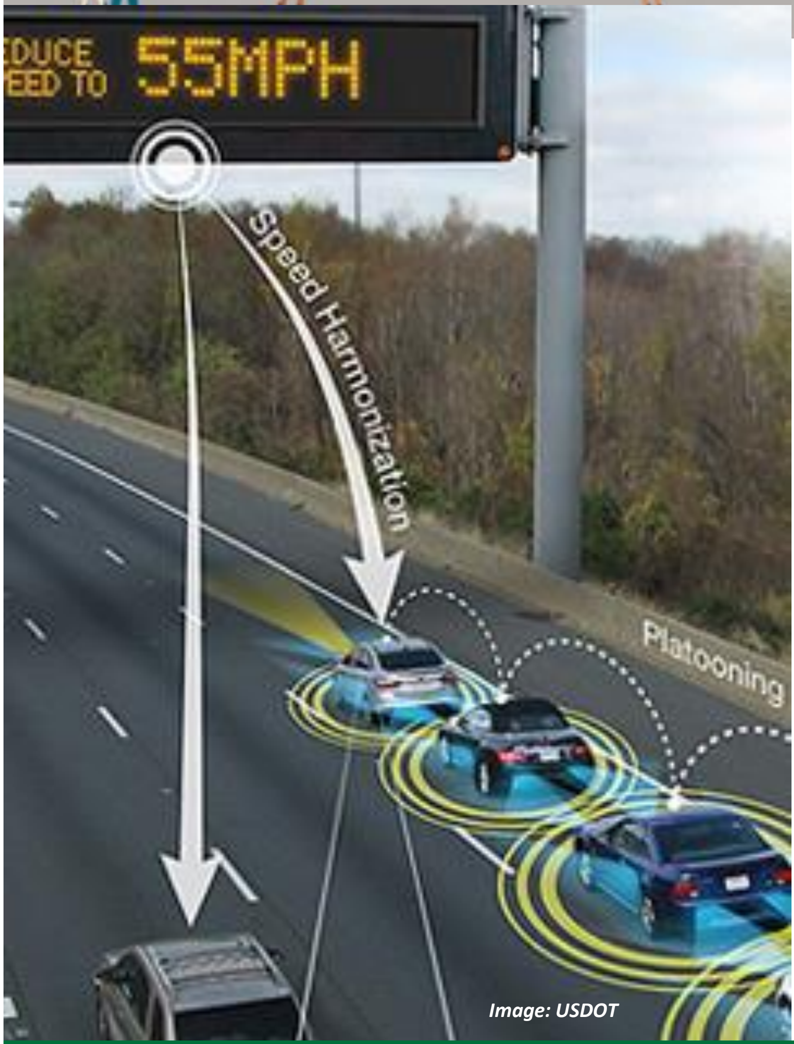
ITS INTEGRATION WITH CAV AND MAAS

FINAL REPORT



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ENTERPRISE TRANSPORTATION POOLED FUND STUDY TPF-5(359)

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16. Abstract The approach used for this project began with secondary research to identify what kind of outcomes are anticipated from CAV and MaaS. This was intended to provide some baseline information and context for each topic, independent of ITS and traffic operations. That information was then summarized and used in two workshops with ENTERPRISE members from the Minnesota Department of Transportation and Ministry of Transportation Ontario. Staff from traffic operations, ITS and planning participated in the workshops to share their thoughts of how CAV and MaaS may impact their work. Information from those workshops was then combined and used in a third workshop with the ENTERPRISE board members to further discuss potential impacts and agency actions in the near and long-term. This report presents research highlights on anticipated outcomes from CAV and MaaS; a summary of potential impacts on ITS/traffic operations; and suggested agency actions to stay engaged as CAV and MaaS continue to evolve.			
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Project Champion

Cory Johnson, Minnesota Department of Transportation, along with Dennis Tessarolo and Susan Boot, Ministry of Transportation Ontario, were the ENTERPRISE Project Champions for this effort. The Project Champions serve as the overall lead for the project.

ENTERPRISE Members

The ENTERPRISE Board consists of a representative from each of the following member entities of the program:

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Table of Contents

1. Introduction

Transportation is on the verge of dramatic change with the introduction of connected and automated vehicles (CAV) and mobility as a service (MaaS). As private industry identifies new market opportunities to deliver transportation automation and services, infrastructure owners and operators are working to understand what their roles and responsibilities will be in the future and during the ensuing transition period.

The ENTERPRISE pooled fund program is a leader in the research, development and application of ITS innovations to advance transportation system management and operations. ENTERPRISE initiated this project to begin exploring how CAV and MaaS may impact traffic operations, especially as it relates to ITS infrastructure.

The approach used for this project began with secondary research to identify what kind of outcomes are anticipated from CAV and MaaS. This was intended to provide baseline information and context for each topic, independent of ITS and traffic operations. That information was then summarized and used in two workshops with ENTERPRISE members from Minnesota Department of Transportation (MnDOT) and Ministry of Transportation Ontario (MTO). Staff from traffic operations, ITS and planning participated in the workshops to share their thoughts of how CAV and MaaS may impact their work. Information from those workshops was then combined and used in a third workshop with the ENTERPRISE board members to further discuss potential impacts and agency actions in the near and long-term. This report presents research highlights on anticipated outcomes from CAV and MaaS; a summary of potential impacts on ITS/traffic operations; and suggested agency actions to stay engaged as CAV and MaaS continue to evolve.

2. Working Definitions of CAV and MaaS

CAV and MaaS are continuously evolving topics and as such, it became clear that having working definitions of related terms would be important for this project. Many discussions around these topics also frequently include vehicle electrification. Although automation, connectivity, electrification and sharing may be interrelated and they are currently being discussed in public policy and appearing as consumer products and services, they were treated as separate topics for this project with specific emphasis on CAV and MaaS. This section highlights the working definitions and context that were used for CAV and MaaS throughout the project.

2.1. CAV Definitions and Context

CAV has been called many things over the years – automated highway systems, vehicle infrastructure integration, connected vehicles, automated vehicles, and cooperative automated transportation. As illustrated in Figure 1, USDOT envisions a future with connectivity and automation creating the opportunity for connected automated vehicles that leverage both capabilities to improve transportation safety and mobility.

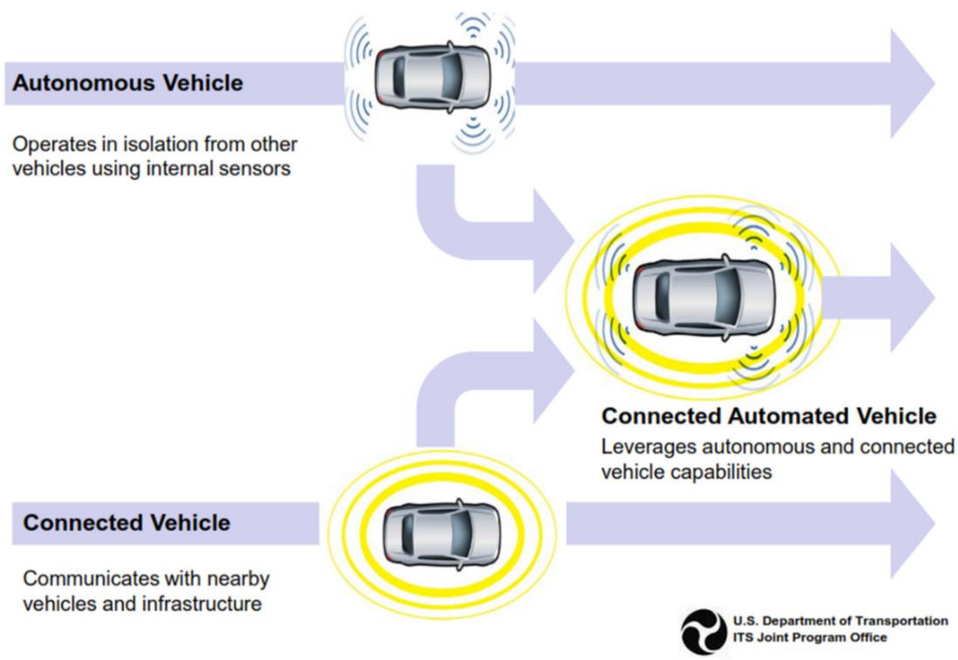

Figure 1 Connected Automated Vehicles

Connected vehicles are equipped with safe, interoperable networked wireless communication allowing connections to other vehicles, roadway infrastructure and personal communication devices. The acronym V2X is also often used in this context to indicate vehicle-to-everything communication. Such connectivity may be used for navigation, safety and entertainment. USDOT identified over three dozen connected vehicle applications grouped into the following seven categories according to their primary function.[1]

- V2I Safety
- V2V Safety
- Agency Data
- Environment
- Road Weather
- Mobility
- Smart Roadside

In 2015, USDOT sponsored three Connected Vehicle Pilot[2] projects to demonstrate several applications in real-world environments. The pilots in Wyoming, Florida and New York City are nearing the end of their pilot stage, after which a pilot site impact analysis and national-level evaluation will be conducted. Many of the connected vehicle applications in the V2V Safety category have also become commercially available in the past five years. Forward collision warning, blind spot monitoring and lane departure warning are commonly available across most makes and model vehicles. The proliferation of such features and consumer confusion over them prompted the National Safety Council, AAA, JD Power and Consumer Reports to issue in November 2019 common naming for several applications based on system functionality. In addition to establishing common naming, the effort is intended to ensure that drivers are aware that such systems are designed to assist, not replace an engaged driver.[3]

Automated vehicles represent a switch in responsibility for the task of driving from human to machine. They encompass a diver range of automated technologies from relatively simple driver assistance systems to fully automated vehicles. SAE International defines the levels of driving automation from Level 0 to Level 5 with Levels 0-2 considered driver support features and Levels 3-5 as automated driving features.[4] USDOT has published three guidance documents to facilitate the safe development, testing and deployment of automated vehicle technology.[5]

The department also awarded in September 2019, eight projects in seven states to test the safe integration of automated driving systems (ADS) on public roadways. The grants aim to gather significant safety data to inform rulemaking and foster collaboration among state and local government and private partners.[6]

The CAV-specific terms used throughout this project are included in Appendix A.

2.2. MaaS Definitions and Context

Similar to CAV, there is still a considerable amount of norming going on around terms. MaaS and MOD – mobility on demand – are often used interchangeably. It is also common to see MaaS used more in Europe and MOD more in the US. The following the definitions were established in an operational concept commissioned by USDOT in 2017.[7] These definitions and the corresponding illustrations are intended to distinguish between MOD and MaaS for the purpose of this project. A complete list of the MaaS-specific terms used through the project is included in Appendix B.

As illustrated in Figure 2, MOD is a concept where consumers can access mobility, goods and services on demand by dispatching or using shared mobility, courier services, unmanned aerial vehicles, and public transportation. Such services typically do not require a reservation in advance and may be requested by mobile application, or through a system of call centers and transportation providers.

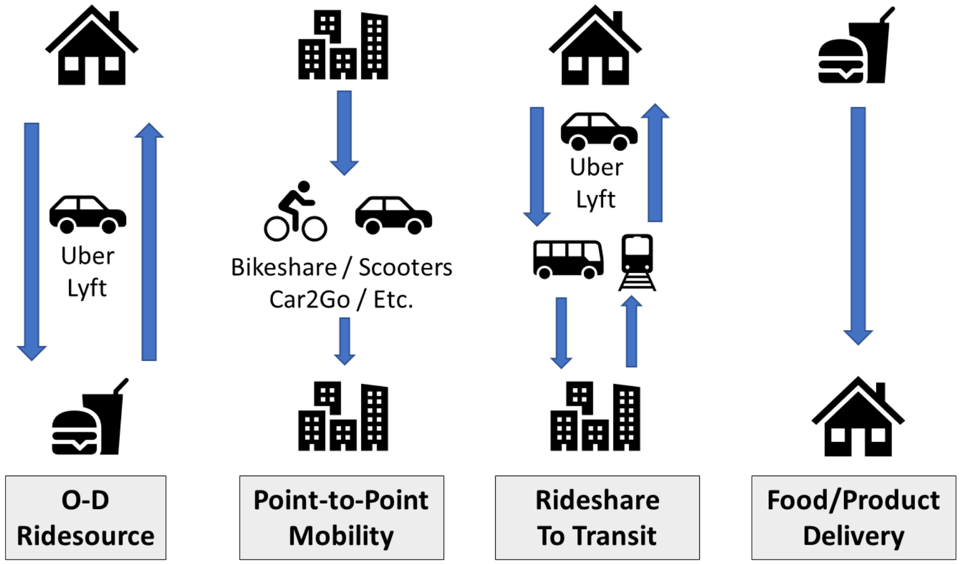

Figure 2 Mobility on Demand

In contrast, MaaS embodies the integration of various forms of MOD options into single platform of mobility service, accessible on demand, with real-time information about choices, and one point of fare payment. Figure 3 illustrates a scenario where a traveler is planning to attend an evening concert, would like to grab dinner before and return home after using MaaS. Such a request for service would show the sequence of service options, schedule and the related fee.

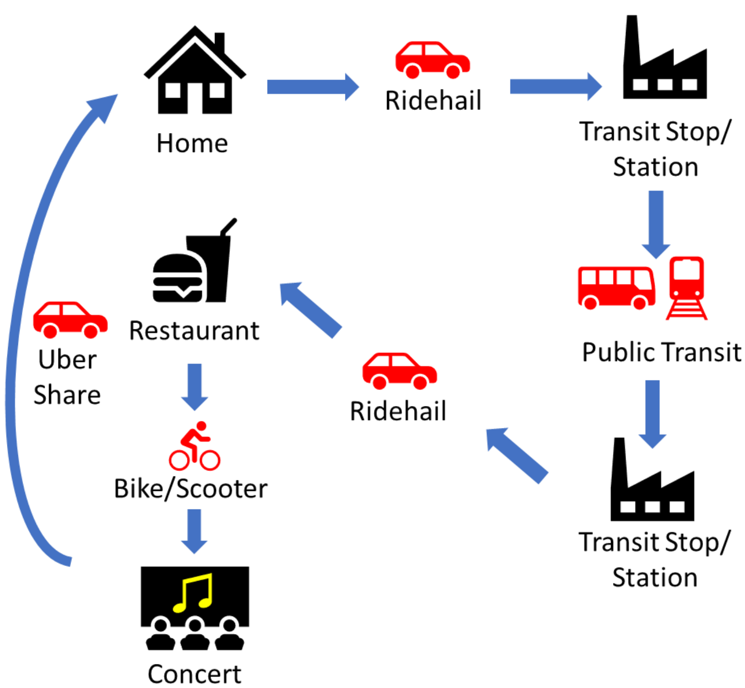

Figure 3 Mobility as a Service

Although this level of service integration may seem far off into the future, Google's map app already offers multiple travel options, including shared services such as bikes, scooters and ridehailing as illustrated in Figure 4.

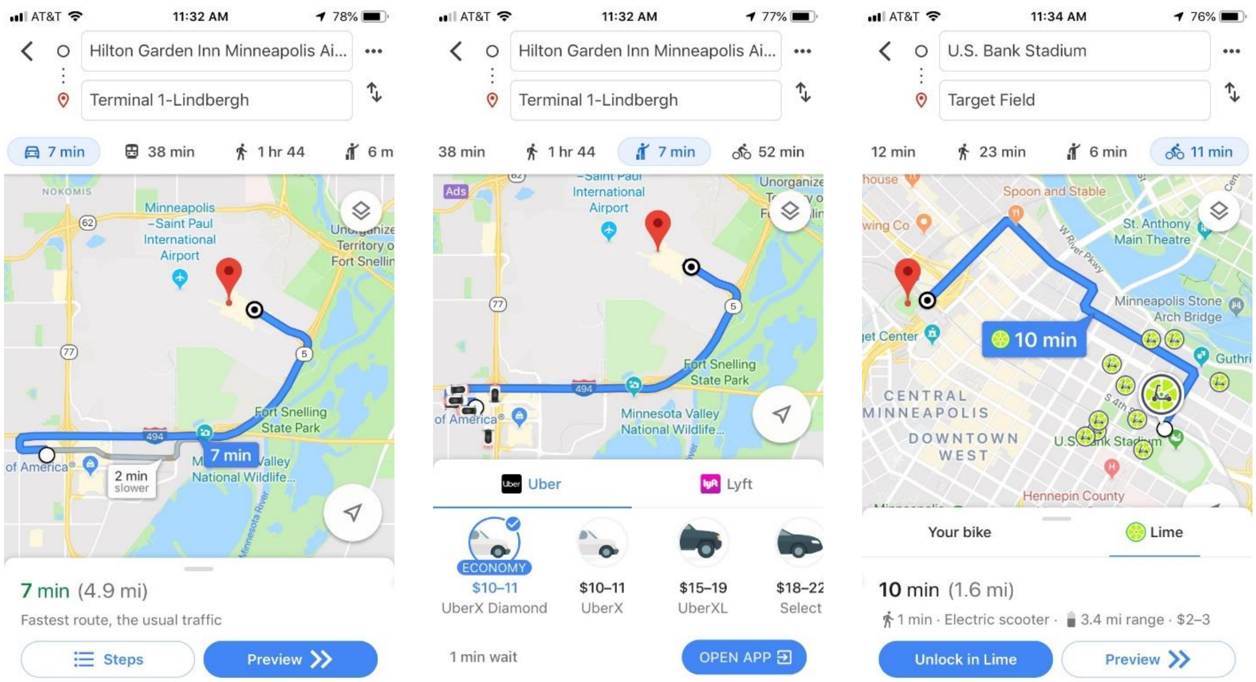

Figure 4 Google with MaaS-Like Options

As MaaS business models evolve, the public sector is also exploring its role in this space. TriMet in Portland, Oregon released in March 2019 a beta version of their next generation trip planner that integrates transit with other modes – driving, scooters, bikesharing, carsharing, park and rides, and ridehailing. Coincidentally, TriMet also worked with Google to develop the General Transit Feed Specification (GTFS) that is widely used in transportation applications offered by public and private sector organizations.

The potential for new mobility services to impact the traditional transit market prompted USDOT to sponsor in 2016 a series of 11 MOD Sandbox demonstration projects. The project teams were selected to innovate, explore partnerships, develop new business models, integrate transit and MOD solutions, and investigate new, enabling technical capabilities such as integrated payment systems, decision support, and incentives for traveler choices. Assessments are underway based on performance measures provided by the project partners, as well as an independent evaluation.[8]

3. Anticipated Outcomes of CAV and MaaS

In this section the anticipated outcomes of CAV and MaaS are presented. These outcomes were identified through secondary research on both topics with the intent to provide baseline information and context for each topic, independent of ITS and traffic operations.

3.1. CAV Outcomes

As with many new innovations, CAV has the potential for both positive and negative outcomes – those that help solve transportation challenges and those that create new problems. Ultimately, it is expected that CAV will yield more positive than negative outcomes in regard to congestion, mobility and safety.

Decrease or increase congestion?

On the surface, it appears that CAV has tremendous potential to solve many congestion challenges. Although a fundamental cause of congestion is traffic volume being at odds with roadway capacity, there are plenty of driver behaviors that also contribute to it. Drivers randomly tapping vehicles brakes, jockeying among lanes, and traveling at inconsistent speeds are some common behaviors that contribute to congestion. This could support the notion that removing or minimizing the driver role in CAV could decrease congestion.

CACC SHOWED AN INCREASE IN CAPACITY OF 59 PERCENT ON AVERAGE

A report from the National Cooperative Highway Research Program (NCHRP) that focused on updating regional transportation planning and modeling tools to address the impacts of CAV[9] notes that smoothing traffic flow can reduce queuing and congestion and facilitating vehicle platooning could shorten headway space and improve throughput. Researchers from Ford Motor Company, while testing adaptive cruise control (ACC) operation, discovered a byproduct of their work was a smoothing of traffic flow that could in fact reduce queuing and congestion. Cooperative adaptive cruise control (CACC) includes communication between vehicles and infrastructure allowing further speed adaptation based on surrounding conditions. USDOT conducted a meta-analysis of several ACC and CACC simulation studies[10] and found that CACC showed an increase in capacity of 59 percent on average. In contrast, although ACC studies did not always show capacity improvements, they do appear to smooth driving through less braking and reduced hard acceleration.

In addition to the anticipated outcomes of CAV operating with mixed traffic, studies have also explored the concept of dedicating lanes for select CAV use. Dedicating lanes for CAV use is a strategy that could both decrease and increase congestion. NCHRP used simulation to model CACC under various levels of market penetration and both priority and exclusive DL use.[11] At medium market penetration (25-40 percent) exclusive CAV dedicated lanes showed similar and higher average speeds compared to the baseline of exclusive dedicated lanes for high occupancy vehicles. In contrast, using dedicated lanes exclusively for CAVs fell apart when market penetration went over 50 percent, with average speeds falling and throughput decreasing.

Another NCHRP report on advancing CAV-related policy and planning strategies noted that informing vehicles of non-recurring congestion and delays will enable diversions and reduce crash-related delays.[12] Connectivity between vehicles and infrastructure could provide more ready information to drivers and allow them to divert when non-recurring congestion or delays are caused by crashes and other unplanned events. The report also acknowledged that higher levels of vehicle automation operating with higher levels of precision and control could allow redesigned facilities that would accommodate more traffic. In contrast, the report also noted that decreasing the cost of driving could also induce additional demand and demand is certain to increase when automation enables travel for those previously unable to do so.

Improve mobility options

Providing transportation options to meet the mobility needs of a growing and aging population is increasingly challenging for transportation agencies. Removing a human driver from vehicle operation, CAV has the potential to offer new mobility options for more people – especially elderly, teens under 16, and individuals with disabilities.[13] However, providing additional and new transportation options for those who may not have them today could also have the adverse effect of increasing travel demand and congestion. CAV, particularly when combined with MaaS, could be especially valuable for filling gaps in first and last mile public transportation service and providing specific service needs.[14]

Improve safety and introduce new risks

Over 90 percent of today's reported crashes cite human error as the primary cause. CAV features – with and without automation – have the potential to reduce human error and significantly improve safety by preventing crashes.[15] For example, safety warnings provided by connected V2V and V2I safety technology could enable drivers to take actions that could reduce the severity of collisions or avoid them. Automated vehicles, in particular, will avoid many of the common perception, decision and execution mistakes that humans make. Automated vehicle also won't tire or become impaired. In a study conducted by the USDOT-sponsored Technologies for Safe and Efficient Transportation, forward collision warning, blind spot monitoring and lane departure warning were evaluated for their potential to impact safety. The study concluded that all three could prevent or reduce the severity of as many as 1.3 million crashes a year, including 133,000 injury crashes and 10,000 fatal crashes.[16]

COULD PREVENT OR REDUCE THE SEVERITY OF AS MANY AS 1.3 MILLION CRASHES A YEAR

Similar to the potential for both positive and negative impacts on congestion, CAV may improve transportation safety while it also introduces new risks. The potential for flawed hardware or software could actually cause crashes and the dependence upon software and communication could also introduce cybersecurity risks that could also lead to crashes. These risks for malfunction could be especially challenging in vehicle with Level 3 automation that require human drivers to resume control of the vehicle. Drivers may be inattentive or unprepared to do so.[17]

3.2. MaaS Outcomes

Many of the most direct outcomes of MaaS will be visible on the local road network where mobility on demand services are already developing with ridehailing, scootersharing and bikesharing. Shifting congestion patterns, reducing parking demand, expanding transportation availability and shifting modal preferences are some of outcomes that will be evident on the local network. Some outcomes will be intertwined as a reflection of societal and cultural shifts in transportation use. Changing curbside use, for example, will be the result of changes in both personal transportation preferences and consumption choices that will demand use of curbside space. it is hoped that MaaS outcomes will extend to the broader transportation network and, as with CAV, be more positive than negative on modal choice, mobility, safety and vehicle miles traveled.

Increase transit ridership and carpooling

Increases in transit ridership and carpooling are anticipated as an outcome of MaaS, particularly as the longstanding challenges with the first and last mile of service can be addressed. Sponsored by the Conference of European Directors of Roads, the project Mobility as a Service for Linking Europe (MAASiFiE, assessed the impacts of MaaS-related services UbiGo in Gothenburg, Sweden and SMILE Vienna, Austria. Surveys conducted following the UbiGo deployment in 2013-2014 found that users reported 46 percent greater bus/tram use and 51 percent greater carsharing use.[18]

USERS REPORTED 46 PERCENT GREATER BUS/TRAM USE AND 51 PERCENT GREATER CARSHARING USE

A report from the Transit Cooperative Research Program (TCRP) notes that shared services tend to complement public transit and are associated with owning fewer cars and reducing transportation spending which enhance urban mobility overall.[19] The report also acknowledges that although some shared services may compete with transit it is only on select routes and at certain times of day. Ridehailing services, for example, experience the greatest levels of use on Friday and Saturday evenings between 7:00 p.m. and midnight,[20] times when transit runs infrequently or is unavailable.

Several of the MOD Sandbox projects are evaluating hypotheses around filling first mile/last mile service gaps and expanding service area to more clearly understand the impacts on transit service. For example, Dallas Area Rapid Transit (DART) has partnered with Uber and Lyft to allow transit riders to connect with the ridehailing services through DART's mobile ticketing application. Two key hypotheses from the DART evaluation plan focus on assessing the how these partnerships and changes in the ticketing application will impact transit ridership and carpools.[21] Similarly, the Los Angeles County Metropolitan Transportation Authority and the Puget Sound region are working with Via to deploy and assess the viability of public-private partnerships to deliver equitable access to the transit network.[22]

Streamlining payment options – one of the core elements of MaaS – is another element of the DART project which will implement a soft integration between its GoPass ticketing app and key shared services. During the project, they will integrate and test taxi, microtransit, on-demand, carpool, ridehail and bike sharing services. The GoPass app will allow users to request and pay for these services at one point with the goal of increasing transit ridership within the pilot region. In addition to integrating parking reservation and payment into an app, the Bay Area Rapid Transit (BART) project is focused on how to better match carpoolers and reserve space for them at transit stations where parking is limited. Partnering with the Metropolitan Transportation Commission and a local carpool matching service, called Scoop, the BART project expects to increase carpooling to their transit stations.

Increase mobility

In addition to supplementing services like transit and carpooling, MaaS is expected to increase mobility overall by providing additional transportation options. A TCRP study examining the interplay among public transit, shared mobility and personal automobile use, found that ridehailing service is predominantly being used for occasional, recreational purposes and is typically concentrated in urban cores. Outside urban centers, airport service is another common use for ridehailing service. The occasional use of ridehailing suggests that is one of many transportation options but not a primary option for most users as transit and driving tend to be.[23]

The same study explored how ridehailing service could be used in conjunction with transit in small, medium and large urban areas to improve mobility. In large urban areas, these services may complement one another with plans for curbside use to minimize conflicts and for operation during low or off-hour transit availability. Ridehailing service in small urban areas has the potential to provide alternatives on otherwise unproductive routes and provide service across greater geographic area and operating time. Notably, the study also found that the use of ridehailing service occurred across all income levels which suggests a degree of equity that further supports the notion of increased mobility.

Improve safety

Improvements to safety could come from simple shifts in MaaS use during late-night, weekend trips when people might otherwise risk driving under the influence. The high use of ridehailing service for recreational use on weekends, often between the hours of 10:00 pm and 4:00 am, suggests this may already be happening.[24] Because these are times when people tend to be drinking, ridehailing offers a door-to-door alternative and one that may be used when transit service is often less available or altogether unavailable. This could provide further incentive to avoid driving under the influence and could in turn lower the instances of crashes involving alcohol.

Decrease and increase VMT?

Mixed outcomes anticipated for MaaS and vehicle miles traveled (VMT). An impact assessment for the European MAASiFiE project reported 44% less private car use in the UbiGo MaaS pilot in Gothenburg, Sweden. [25] Similarly, a Shared Mobility Survey conducted by TCRP found ridehailing use is associated with lower vehicle ownership and single-occupant vehicle trips.[26] Less private care use, ownership and single-occupant vehicle trips prompted by the availability of MaaS, all support the theory that such service could decrease VMT.

44 PERCENT LESS PRIVATE CARE USE REPORTED IN THE UBIGO MAAS PILOT IN GOTHENBURG, SWEDEN

In contrast, elements of MaaS like ridehailing for personal transportation and goods delivery through courier network services could also increase VMT, leading to greater congestion and travel time overall. In 2018, the San Francisco County Transportation Authority conducted a study of ridehailing service. The study found that it accounted for 50 percent of the rise in congestion in San Francisco between 2010 and 2016, as indicated by three congestion measures: vehicle hours of delay, vehicle miles travelled, and average speeds.[27]

RIDEHAILING ACCOUNTED FOR 50 PERCENT OF THE RISE IN CONGESTION IN SAN FRANCISCO BETWEEN 2010 AND 2016

Uber and Lyft also released a report in August 2019 to address their contribution to VMT. Their study reviewed regional and core county VMT in six US area using service data from September 2018. The study found that ridehailing contributed to increased VMT in all six areas, with regional impacts ranging from 1.1-2.7 percent and core impacts ranging from 1.9-12.8 percent as illustrated in Figure 5.[28]

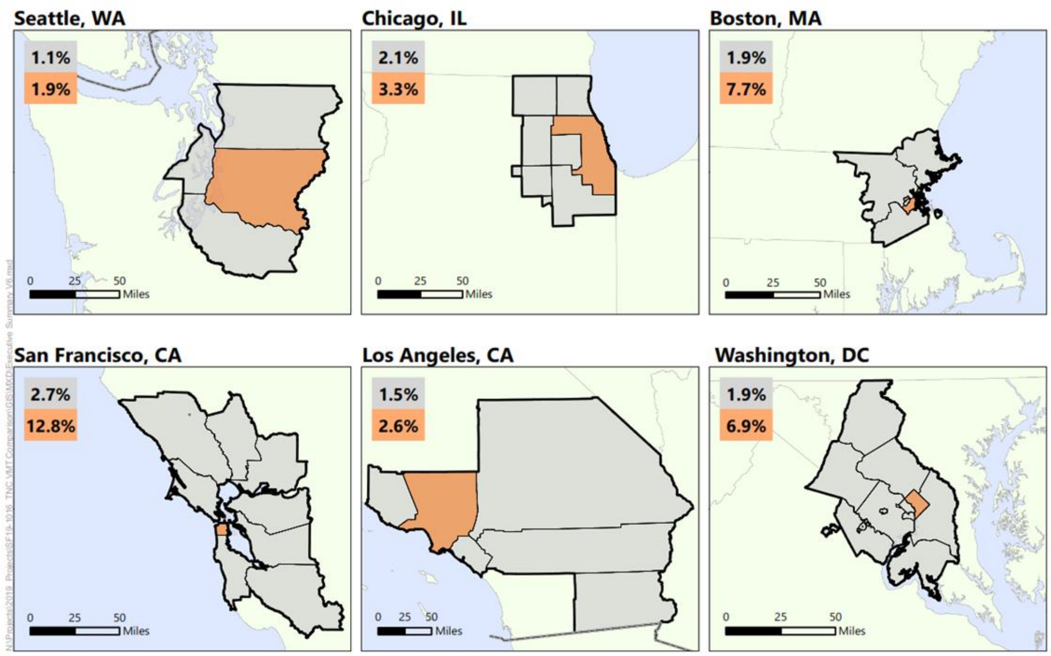

Figure 5 Uber and Lyft Contribution to VMT

As evidenced in the highlighted research, there is potential for MaaS and CAV to produce both positive and negative outcomes. Both are likely to shift public and private roles and travel behaviors in transportation.

4. Potential Impacts on ITS and Traffic Operations

ITS and Traffic Operations Systems | Infrastructure | Processes | Staffing | Relationships			
Traveler information	Traffic management	Incident / event management	Work zone management

The outcomes anticipated from CAV and MaaS were highlighted in the previous section to create awareness of what the likely outcomes are and how they might impact society, the economy, environment and transportation. Those outcomes were presented in two project workshops to establish a common context for discussing the potential impacts on ITS and traffic operations. This section presents a summary of the impacts on ITS and traffic operations that were identified during the workshops.

ITS and traffic operations includes the systems, infrastructure, processes, staffing and relationships associated with traveler information, traffic management, incident/event management and work zone management. The workshops focused on ITS and traffic operations impacts, to the exclusion of impacts on other operational functions such as enforcement, vehicle licensing/registration, commercial vehicles, etc. Impacts were categorized as activities, opportunities or challenges in both the near- and long-term. Several of more likely impacts for CAV and MaaS are also further described.

4.1. CAV Impacts on ITS/Traffic Operations

One of the more likely near-term opportunities identified for CAV is the potential for low-level automation features to positively impact safety. The opportunity to reduce or prevent crashes with forward collision warning, blind spot monitoring and lane departure warning is significant. In a study for NHTSA, it was estimated that these three applications could reduce and severity of or prevent as many as 1.3 million crashes annually.[29] Preventing crashes not only improve safety, it improves traffic operations – especially in urban areas where crashes lead to increased congestion and unreliable travel times.

NEAR-TERM

CAV ACTIVITIES	• Attempt to understand quantifiable costs and benefits of CAV to make infrastructure deployment decisions >> INFRASTRUCTURE, SYSTEMS • Researching available automation features (e.g. adaptive cruise control) to assess impacts on travel time and speed >> PROCESS • Identify traffic operations problems that CAV could potentially solve >> PROCESS • Explore options – both technical and policy – to receive data directly from CAV service providers >> PROCESS, SYSTEMS, RELATIONSHIPS
CAV CHALLENGES	• Unclear what features are available, how many vehicles have features, and how much penetration is needed to be of value to operations >> PROCESS • Ensure policies do not overly restrict research and development happening with CAV >> PROCESS, RELATIONSHIPS • Understanding implications to staffing levels and expertise as CAV expands >> STAFFING • Physical infrastructure changes to support partial automation in vehicles on the road today >> INFRASTRUCTURE
CAV OPPORTUNITIES	• Study safety impacts of partial automation features available in vehicles today >> PROCESS • Education to support both public and staff understanding of partial automation available in vehicles today >> STAFFING, RELATIONSHIPS • Low-level automation features like lane-keeping assist, automatic emergency braking, and blind spot warnings could prevent/minimize severity of thousands of crashes >> PROCESS • Continue studies to identify and quantify operational impacts of V2I connectivity >> PROCESS

In the long-term, one of the more likely and concerning challenges identified is the additional costs for redesign, higher levels of maintenance and additional infrastructure and systems to support CAV. Although agencies are encouraged to maintain pavement markings and signing to certain standards for human drivers, there are often budgetary challenges balancing those demands with other infrastructure maintenance needs. Although human drivers would benefit from higher standards of maintenance than may be required for CAV, it does not resolve the budgetary challenges agencies will face with meeting those standards.

Using scenario planning is one way that agencies can begin to establish possible future needs and have dialogue with stakeholders and policymakers about the financial trade-offs that may be necessary. MnDOT used scenario planning to inform their strategic investment in CAV, which also included assumptions about electrification and shared mobility services. The process established four potential scenarios for Minnesota in the year 2040. The scenarios ranged from describing a future with incremental change from today's technology to a future with a fleet of fully automated vehicles operating as part of a robust multimodal system. Workshops were then held throughout the state with key transportation stakeholders to identify which scenario is most likely to happen and which scenario would they most want to happen. Although there was some variability between urban and rural Minnesota was which scenarios is mostly likely to happen, there was nearly unanimous agreement on the scenario stakeholders most want to happen. That scenario is one of integrated mobility that leverages technology to make transportation more affordable and efficient with benefits for all users.[30]

LONG-TERM

CAV ACTIVITIES	• Determine what policies may be needed to support the use of CAV to solve traffic operations problems >> PROCESS • Using scenario/horizon planning to understand how network may need to adapt >> INFRASTRUCTURE, SYSTEMS, PROCESS, RELATIONSHIPS
CAV CHALLENGES	• Staffing and workforce impacts of V2I deployments >> STAFFING • Using approaches like exclusive dedicated lanes could create equity issues >> PROCESS, RELATIONSHIPS • Additional costs for redesign, higher levels of maintenance, or additional infrastructure and systems to support CAV >> PROCESS, INFRASTRUCTURE, SYSTEMS • Unclear if future costs will be capital (e.g. infrastructure oriented) or operational (e.g. software as a service) oriented >> PROCESS • Rural applications are unclear and should be understood to find optimal use of CAV in both rural and urban settings >> PROCESS • Potential for automation alerts/messages increasing driver distraction >> PROCESS
CAV OPPORTUNITIES	• Additional real-time data could allow for signal timing adjustments and arterial performance improvements >> PROCESS • Improved work zone management – especially detecting queues >> PROCESS • Improved mobility options for more travelers >> PROCESS, RELATIONSHIPS • New source of data for traveler information and traffic management >> PROCESS, SYSTEMS • Collecting and integrating more data, especially from passenger vehicles, could minimize agency dependence upon third party data vendors >> PROCESS, SYSTEMS • Potential for reduced VMT or improved capacity could reduce need for roadway expansion which could further offset new costs >> PROCESS, INFRASTRUCTURE

4.2. MaaS Impacts on ITS/Traffic Operations

Shared mobility services, like ridehailing and bikesharing, are commonly being used during sports and other events at large venues. Studying how those services are being used today is an activity that agencies can undertake to better understand operational impacts near-term and in the future. This will also support greater familiarity with service providers and the opportunity to include them in plans for event management. Through those relationships, agencies can also become more familiar with new and additional data that may be available from service providers to support event management.

NEAR-TERM

MaaS ACTIVITIES	• Establishing joint/single payment mechanisms across mobility services (e.g. Metro Transit, HourCar) >> SYSTEMS • Managing impacts from mobility services on as-needed basis around events >> PROCESS • Hiring a shared mobility position to bring agency focus to the subject and corresponding activities >> STAFFING • Studying mobility services around events today to better understand potential future operational impacts >> PROCESS
MaaS CHALLENGES	• Ride-hailing resulting in more congestion at large events >> RELATIONSHIPS • Current performance measures do not reflect mobility goals for overall network >> PROCESS • May be limited ability to make significant traffic management changes in real-time >> PROCESS
MaaS OPPORTUNITIES	• Data sharing agreements through negotiations with mobility service providers (sometimes via local agencies) >> RELATIONSHIPS • Review data to assess and predict potential impacts of mobility services as they evolve >> RELATIONSHIPS

The long-term opportunity for combined payment systems with MaaS could facilitate offering broader incentives to shift travel among modes. The example from Google that was shared in Figure 4, illustrates how travelers can already compare travel times across modes when making transportation decisions. This example could eventually lead to more direct comparisons of cost that would further inform travelers' decisions. Combined payment systems also imply a higher level of collaboration among public and private transportation providers which could lead to greater exchanges of data and potentially new traffic operation strategies that improve transportation efficiency. For example, data showing when ridehailing services are going to peak in an area may allow transportation agencies to consider route diversions or price adjustments in managed lanes and parking facilities.

LONG-TERM

MaaS ACTIVITIES	• Integrate traveler information data with MaaS systems to provide real-time impacts – especially for road weather and road work >> SYSTEMS, RELATIONSHIPS • Researching how simulation and predictive algorithms could be used to assess traffic operations strategies that could mitigate potential impacts >> PROCESS • Using scenario/horizon planning to understand how network may need to adapt >> PROCESS
MaaS CHALLENGES	• Most of the control and immediate impacts are on the local network >> RELATIONSHIPS • Ongoing operational costs associated with any new or additional infrastructure could be a potential barrier if such costs are not planned for >> SYSTEMS, INFRASTRUCTURE • Combined payment systems could impact transportation financing by changing what and how fees, taxes, etc. are charged and collected (also Opportunity) >> SYSTEMS, PROCESS • Potentially less fuel tax collected from fewer, shared and electric vehicles could create a need for other forms of user tax >> PROCESS
MaaS OPPORTUNITIES	• Data about upcoming trips/travel patterns could benefit operations (e.g. ramp metering, travel times, signal timing) >> PROCESS • Possible new role for traveler information and 511 brand >> RELATIONSHIPS, PROCESS • Permitting process could be a possible option for influencing MaaS/MOD >> PROCESS, RELATIONSHIPS • Combined payment systems may facilitate broader incentives to shift travel among modes >> PROCESS, SYSTEMS, RELATIONSHIPS • Combined payment systems may lead to new traffic operation strategies and relationships >> PROCESS, SYSTEMS, RELATIONSHIPS • Combined payment systems could impact transportation financing by changing what and how fees, taxes, etc. are charged and collected (also Challenge) >> PROCESS, SYSTEMS

These near- and long-term impacts were presented in a third and final workshop with the ENTERPRISE members and guest presenters provided additional information about activities underway to identify and manage the impacts of CAV and MaaS on ITS and traffic operations. Planning staff from the Minnesota Department of Transportation (MnDOT) presented their use of scenario planning to engage transportation stakeholders around a series of likely future scenarios and gather feedback on preferences for CAV and MaaS. Metro Transit, public transportation provider for the Twin Cities metropolitan areas, highlighted their technology innovations supporting CAV and MaaS – including predicted bus/train arrival times, bus/train signal priority, park and ride availability, flexible card and mobile app ticketing and more. Move Minneapolis, the downtown transportation management organization, shared their work with MnDOT, Metro Transit and several other regional organizations to implement a Twin Cities Shared Mobility Action Plan[31] that aims to reduce single-occupant vehicles in the region by 50,000 within ten years.

5. Conclusion

At the conclusion of the final project workshop, ENTERPRISE members discussed potential actions their agencies could take to stay engaged, continue learning and plan for the changes that CAV and MaaS will have on ITS and traffic operations. Changes in public and private sector roles in transportation make it challenging to understand who should assume a leadership role in these activities. This is evident in the stronger role that the private sector will play in services offered for MaaS, as well as the features and capabilities that vehicle manufacturers will offer for CAV.

ENTERPRISE members also agreed that CAV and MaaS are unlike traditional DOT activities. Both involve new stakeholders, new business models for both capital and operating costs, new challenges with security and data ownership, new approaches to funding and operating and new approaches for planning and forecasting transportation needs. More specifically, CAV represents a significant change in the interaction between vehicles and transportation infrastructure. MaaS represents a change in the policies that drive travel patterns and the collaboration necessary to support it. In the midst of these realizations, DOTs are still working to change their traditionally focused capital role in planning, designing, building and maintaining infrastructure. The introduction of CAV and MaaS raises many questions about what infrastructure will be needed in the future, and who will deploy, own and operate it. Studying the impacts is relatively easy but understanding and implementing changes to address potential impacts is more difficult.

One action there was strong agreement on is the need to begin, or in some cases continue, the conversation about CAV and MaaS among transportation stakeholders, particularly those involved in ITS and traffic operations. In addition to the previously noted stakeholder engagement that MnDOT used in its scenario planning, many states have established public/private advisory groups on the topic of CAV and/or MaaS to discuss broader transportation, societal, economic and environmental impacts. Some of these groups have smaller working groups dedicated to traffic operations and related topics. For example, the Iowa Department of Transportation leads the Iowa Advisory Council on Automated Transportation which provides guidance, recommendations and strategic oversight of automated transportation activities in the state. The Council has four subcommittees that serve as in-depth resources on topics related to automated transportation, and one of those subcommittees is focused on infrastructure readiness. This subcommittee addresses physical, digital, energy, security, institutional, workforce and support topics on infrastructure.

In addition to state and local level actions to stay engaged, agencies can also monitor or become involved in a number of national activities such as those noted here.

- **Cooperative Automated Transportation (CAT) Coalition** is sponsored by USDOT and managed by AASHTO, ITE and ITS America. It serves as a collaborative focal point for federal, state and local government officials, academia, industry and their related associations to address critical program and technical issues associated with the nationwide deployment of connected and automated vehicles on streets and highways.
- **AASHTO Committee on Transportation System Operation (CTSO)** has a subcommittee on technology with working groups focused on both CAV and ITS, addressing topics such as deployment support, education and outreach, data, standard and guidelines.

- **ITS America MOD Alliance** promotes an innovative, customer-focused approach to transportation that leverages technology, mobility services, real-time data, transit and intelligent transportation systems to provide improved mobility options for all.
- **TRB Standing Committee on Vehicle-Highway Automation (AHB30)** is concerned with the development, application, and operation of driver assistance and automated control to the vehicle and highway system.

Finally, the information gathered on the anticipated outcomes of CAV and MaaS can be traced to the resources listed in the references section of this report, many of which are art of larger efforts to explore CAV and MaaS. For example, NCHRP Project 20-102 is an ongoing effort to research the impacts of CAV on state and local transportation agencies. Task (15) Impacts of Connected and Automated Vehicles on the Highway Infrastructure is scheduled to complete a final report in early 2020 that will contain guidance for agencies in evaluating and adapting standards and practices for roadway and ITS designs to address CAV technologies.

Historic transformative changes in transportation happened relatively fast. For example, the transition from horse and buggy to the automobile happened in roughly 10 years. In contrast, the introduction of CAV happened over 20 years ago and MaaS has also been recognized for several years, yet transformative change is not imminent. Some potential reasons for the longer transitions could be today’s more litigious and security sensitive society, uncertainties in supporting infrastructure like communications, and a lack of clarity in product and service releases.

The impacts of CAV and MaaS on ITS and traffic operations are not entirely clear at this time. However, this project provided ENTERPRISE members with background information on the anticipated outcomes of CAV and MaaS and facilitated discussions about the potential impacts both may have on ITS and traffic operations. Those impacts are presented in this report as a starting point for agencies to continue their education and engagement on the subjects of CAV and MaaS so they might prepare for future changes to ITS and traffic operations.

Appendix A: CAV Terms Used in Project

Connected and Automated Vehicles

Terminology and definition are still evolving around Connected and Automated Vehicles (CAV). The following terms and definitions will be used for the purpose of this ENTERPRISE project and were excerpted from SAE International *J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles* revised June 2018.

Connected vehicles are equipped with safe, interoperable networked wireless communications allowing connections to other vehicles, roadway infrastructure, and personal communication devices. The acronym V2X is sometimes used to designate vehicle-to-everything (including pedestrian and bicyclist) communication. Such connectivity may be used for navigation, safety and entertainment.

Automated vehicles represent a switch in responsibility for the task of driving from human to machine. They encompass a diverse range of automated technologies, from relatively simple driver assistance systems to fully automated vehicles. SAE International defines the levels of driving automation as shown in the figure below.

SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

For a more complete description, please download a free copy of SAE J3016: https://www.sae.org/standards/content/J3016_201806/

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Advanced Driver Assistance Systems (ADAS) – ADAS are becoming increasingly common and in some cases assist the driver but do not perform the driving function. These vehicle technologies are found in levels 0, 1, and 2 of driving automation. ADAS are designed to help drivers with certain driving tasks such as lane keeping, parking, braking, avoiding crashes, reducing blind spots, and maintaining a safe space cushion.

Automated Driving System (ADS) – The hardware and software that are collectively capable of performing the entire DDT on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a level 3, 4, or 5 driving automation system.

Driverless Operation (of an ADS-equipped vehicle) – Operation of an ADS-equipped vehicle in which either no on-board user is present, or in which on-board users are not drivers or fallback-ready users.

Dynamic Driving Task (DDT) – All of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints, and including without limitation: lateral vehicle motion control via steering (operational); longitudinal vehicle motion control via acceleration and deceleration (operational); monitoring the driving environment via object and event detection, recognition, classification, and response preparation (operational and tactical); object and event response execution (operational and tactical); maneuver planning (tactical); and enhancing conspicuity via lighting, signaling and gesturing, etc. (tactical).

Minimal Risk Condition – A condition to which a user or an ADS may bring a vehicle after performing the DDT fallback in order to reduce the risk of a crash when a given trip cannot or should not be completed.

Operate (a motor vehicle) – Collectively, the activities performed by a (human) driver (with or without support from one or more level 1 or 2 driving automation features) or by an ADS (level 3-5) to perform the entire DDT for a given vehicle during a trip.

Operational Design Domain (ODD) – 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

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Appendix B: MaaS Terms Used in Project

Mobility as a Service

Terminology and definition are still evolving around Mobility as a Service (MaaS). The following terms and definitions will be used for the purpose of this ENTERPRISE project and were excerpted from SAE International *J3163 Taxonomy and Definitions for Terms Related to Shared Mobility and Enabling Technologies* revised September 2018, and FHWA *Mobility on Demand Operation Concept Report* dated September 2017.

Mobility as a Service (MaaS) emphasizes mobility aggregation, smartphone and app-based subscription access, and multimodal integration (infrastructure, information, and fare integration). MaaS tends to emphasize the integration and convergence of passenger mobility services, mobile devices, real-time information, and payment mechanisms.

Mobility on Demand (MOD) is an innovative transportation concept where consumers can access mobility, goods, and services on demand by dispatching or using shared mobility, courier services, unmanned aerial vehicles (UAVs), and public transportation solutions.

Shared Mobility – The shared use of a vehicle, motorcycle, scooter, bicycle, or other travel mode; it provides users with short-term access to a travel mode on an as-needed basis.

Mobility Applications – Mobility applications include an array of services that assist users in planning or understanding their transportation choices and may increase their access to alternative travel modes. There are eight subcategories of mobility apps, including:

- **Business-to-Consumer (B2C) Sharing Apps** – Sell access to shared transportation vehicles, equipment, and services from a business to an individual consumer, including one-way and roundtrip sharing.
- **Mobility Tracker Apps** – Track a traveler's speed, direction, and elapsed travel time. These apps often include both wayfinding (guided directions) and fitness functions that are colored by metrics, such as caloric consumption while walking.
- **Peer-to-Peer (P2P) Sharing Apps** – Enable private owners of transportation vehicles or equipment (e.g., vehicles, bicycles, scooters, etc.) to share with other users generally for a fee.
- **Real-Time Information Apps** – Provide users with up-to-date travel information across multiple modes, including current traffic data, public transit wait times, carsharing, bikesharing, and parking availability.
- **Ridesourcing Apps** – Provide a platform for sourcing rides. This category is expansive in its definition and includes "ridesplitting" or "pooling" services, in which fares and rides are split among multiple strangers who are traveling in the same direction.
- **Trip Aggregator Apps –** Route users by considering multiple travel modes and providing users with optimal travel times, connection information, distance, and trip cost.

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Travel Modes – Shared mobility includes various travel modes to meet the diverse needs of users. Examples of shared travel modes that are a part of the shared mobility ecosystem include:

- **Bikesharing** – Provides users with on-demand access to bicycles at a variety of pick-up and drop-off locations for one-way (point-to-point) or roundtrip travel. Bikesharing fleets are commonly deployed in a network within a metropolitan region, city, neighborhood, employment center, and/or university campus.
- **Carsharing** – Offers members access to vehicles by joining an organization that provides and maintains a fleet of cars and/or light trucks. These vehicles may be located within neighborhoods, public transit stations, employment centers, universities, etc. The carsharing organization typically provides insurance, gasoline, parking, and maintenance. Members who join a carsharing organization typically pay a fee each time they use a vehicle.
- **Microtransit** – A privately or publicly operated, technology-enabled transit service that typically uses multipassenger/pooled shuttles or vans to provide on-demand or fixed-schedule services with either dynamic or fixed routing.
- **Ridesharing (also known as carpooling and vanpooling)** – The formal or informal sharing of rides between drivers and passengers with similar origin-destination pairings. Ridesharing includes vanpooling, which consists of 7 to 15 passengers who share the cost of a van and operating expenses, and may share driving responsibility.
- **Ridesourcing (Ridehailing)** – Services are prearranged and on-demand transportation services for compensation in which drivers and passengers connect via digital applications. Digital applications are typically used for booking, electronic payment, and ratings.
- **Scooter Sharing** – Allows individuals access to scooters by joining an organization that maintains a fleet of scooters at various locations. Scooter sharing models can include a variety of motorized and non-motorized scooter types. The scooter service provider typically provides gasoline or charge (in the case of motorized scooters), maintenance, and may include parking as part of the service. Users typically pay a fee each time they use a scooter. Trips can be roundtrip or one way.
- **Shuttles** – Shared vehicles (typically vans or buses) that connect passengers from a common origin or destination to public transit, retail, hospitality, or employment centers. Shuttles are typically operated by professional drivers, and many provide complimentary services to the passengers.
- **Taxis** – Provide prearranged and on-demand transportation services for compensation through a negotiated price, zone pricing, or taximeter (either traditional or GPS-based). Passengers can schedule trips in advance (booked through a phone dispatch, website, or smartphone app), street hail (by raising a hand on the street, standing at a taxi stand, or specified loading zone), or e-Hail (by dispatching a driver on-demand using a smartphone app).

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