AV2.1 SCENARIO DEVELOPMENT FINAL REPORT

AV2.1: Conduct a Planning Process to help the North Texas Region Prepare for Automated Vehicles and Related Technologies

February 2022

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EXECUTIVE SUMMARY

Local agencies need guidance on how to plan for uncertainties in the future of transportation. Decision makers want to understand **how** technologies could change travel behaviors and land use patterns, **when** these impacts are likely to occur, and **what** additional infrastructure, if any, agencies may need to support the future travel demands.

The North Central Texas Council of Governments (NCTCOG) is preparing for emerging transportation technologies through a three-phase Automated Vehicle 2.0 (AV2.0) program.

- **Planning (AV2.1)** – *Connecting North Texas Communities with Emerging Transportation Technologies* – Helping North Texas communities plan for the arrival of emerging transportation technologies, such as automated vehicles (AVs)
- **Partnerships (AV2.2)** – Funding to help North Texas communities build effective partnerships with the AV developers when they deploy AVs in the community
- **Investment (AV2.3)** – Making strategic investments as a region in AV service to explore use cases that are important to the region but not being adequately addressed by the private sector

This AV2.1 Planning Phase is **our opportunity to hear from the public and the local governments**. We want to understand transportation and mobility challenges facing North Central Texas so we can identify ways emerging transportation technologies can address those challenges. By proactively planning, North Central Texas communities can create unified plans to use technology to solve local and regional transportation needs.

This Scenario Development Report represents the first in a series of deliverables documenting the future transportation automation scenario planning completed as part of AV2.1.

The purpose of this Scenario Development Report is to document the process of determining transportation automation scenarios that are potential futures for the North Central Texas region. The study team developed seven potential scenarios in this task. The project scope will further develop three of these future scenarios for travel demand model evaluation.

Planning for Uncertainties

Long-range transportation plans forecast needs 20 to 30 years into the future. Transportation planners are trying to predict the future impacts of technologies that are new, under development, or still merely concepts today. Data on the real-world impacts of these new technologies are not always available today, so planners use modeling tools to understand the possible level of impacts these technologies could have—both beneficial and potentially harmful impacts. Modeling lets agencies measure now to plan for tomorrow.

Impacts of new technologies could include reducing or increasing the need for other services, such as shifting travel mode choice or changing population or employment land use patterns. Planners use modeling to quantify transportation system performance measures, such as travel delay, level of service, and congestion to understand economic and quality of life impacts.

Potential Future Technology Scenarios

The greatest uncertainty in planning is private sector market forces and what will emerge as the sustainable price point of automation and other emerging transportation technologies. Currently, planners do not have enough data to assign probabilities to potential future scenarios, so proactively identifying a diverse suite of potential future scenarios to assess potential needs provides a framework that agencies can use to start the planning process and adapt agilely as more information emerges from external market forces.

The AV2.1 Team developed seven potential future transportation automation scenarios for the North Central Texas region:

1. Connected-Automated Vehicle (CAV) Impact on Roadway Network Performance
2. CAV Intersection Systems
3. CAV Effect on Population and Employment Distributions
4. Automated Shuttles for Improved First- and Last-Mile Travel
5. CAV Technology Lane and Impact on Truck Routing
6. Long-Distance, High-Speed Mass Transit Services
7. Urban Air Mobility (UAM) Systems for People and Goods Movement

Scenarios Selected for Evaluation

After consultation with the Project Advisory Committee and the NCTCOG travel demand modeling group, the three transportation automation scenarios selected for further modeling evaluation under the AV2.1 project are:

1. **Connected-Automated Vehicle Impact on Roadway Network Performance.** This scenario assumes that vehicles that are both connected and automated will enhance network capacity and reduce the value of time for drivers.

2. **Connected Vehicle-Intersection Systems.** This scenario assumes that connected vehicle-to-infrastructure technology will improve intersection capacity and reduce intersection delays.

3. **Connected-Automated Vehicle Effect on Population and Employment Distributions.** This scenario assumes that connected-automated vehicles (CAVs) will cause travelers to make longer trips due to the decreases in their travel delay and the value of time for drivers. It will capture possible growth opportunity scenarios due to CAVs. Each city or county can use these scenarios to define what it considers desired or undesired growth patterns for their area and to develop policies to incentivize their desired growth pattern.

The study team will analyze these three scenarios to provide insight into other critical technology-specific and goal-specific scenarios that were not considered in this study. For example, while no freight-focused automation technology scenario is considered, the impact on freight mobility will be quantified. Similarly, the analysis will assess the effects of the technologies on safety and environmental quality due to the change in the mobility pattern.

Modeling Tool Selected for Evaluation

The AV2.1 Team coordinated with the NCTCOG Modeling Team to determine which simulation tool(s) will be used to model the three selected transportation automation scenarios. The NCTCOG Modeling Group selected a modeling platform developed by the University of Texas Austin in conjunction with NCTCOG staff (the UTAV-TAFT model) for the AV2.1 Team to use to evaluate future technology scenarios.

The project team conducted a preliminary review of the UTAV-TAFT model. The UTAV-TAFT model appears to take more emerging technologies into consideration than the NCTCOG's existing TAFT model and has the functionality to simulate the three AV2.1 technology scenarios. The NCTCOG's TAFT model does not include that functionality in any of the modeling stages. The UTAV-TAFT model also has a zero-occupancy module, which the NCTCOG TAFT model does not have.

Next Steps

The project team is currently evaluating the UTAV-TAFT model platform and coordinating with NCTCOG on baseline model parameters. The project team will continue to outline the modeling methodology for each scenario. Then the project team will evaluate the three selected scenarios and document the findings in a Scenario Evaluation Report.

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1. INTRODUCTION

The planning and development of automated transportation projects are associated with high levels of uncertainty due to the fast technological advancements and difficulty in predicting operational conditions under which these projects will be deployed. Thus, developing a scenario generation and evaluation framework is essential to capture the full range of expected benefits and detriments and to mitigate against the potential adverse effects of uncertainty on the decision-making and deployment processes. In addition, the framework will assist stakeholders in developing a range of different futures that illustrate the tradeoffs of technology adoption approaches and help clarify a preferred vision that sets the framework for identifying specific implementation strategies for automated transportation that support a broader mobility vision.

The main goals of this framework can be summarized as follows:

- Conceptualize the deployment of a wide variety of automated transportation applications,
- Provide insight into how applications can integrate into existing mobility plans and long-range transportation plans,
- Support project screening for the purpose of budgeting and proposal development, and
- Quantify the benefits and capture unintended consequences of the proposed automated transportation applications and technologies.

Scenario planning lets communities study future impacts of new technologies like transportation automation.

Our team worked closely with the different stakeholders to determine future technology scenarios to be developed and evaluated as part of the study. These scenarios are expected to reflect the mobility plans identified for the region as well as the strategic improvement plans developed for the region's multimodal transportation system.

Scenario Development Process

Figure 1 summarizes the steps of the process adopted by our team to identify scenarios that merit further investigation using adequate modeling platforms. The process involves assessment of existing conditions to identify key mobility challenges in the region, generating an initial set of operational scenarios representing a wide array of transportation automation technologies, obtaining the stakeholder input on these scenarios, and finally developing modeling platforms to carefully evaluate the three scenarios selected for further analysis.

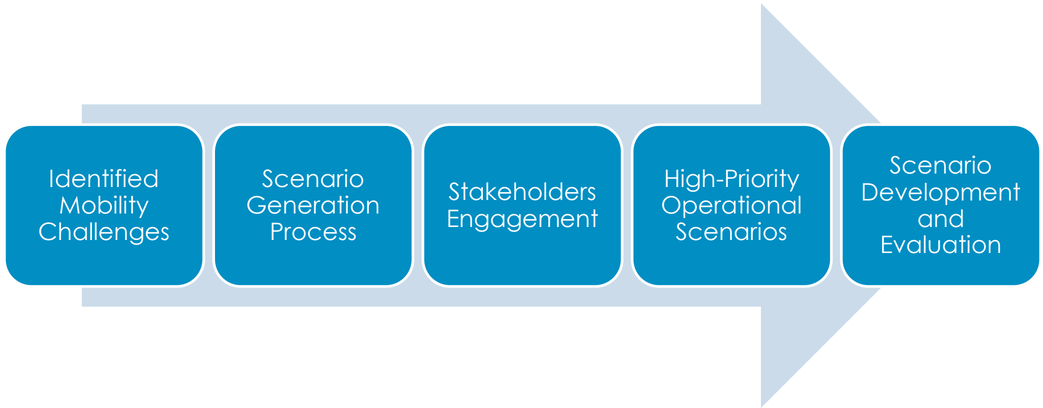


Figure 1. Prioritizing the Operational Scenarios for Development and Evaluation

What information does this report provide?

This document is the first of a series of reports that summarize the scenario generation framework and the evaluation results of the modeled scenarios. The report provides a summary of our efforts to generate an initial set of potential future technology scenarios and to engage the stakeholders to select three scenarios to further evaluate.

The document is organized as follows:

- Section 2 describes the main elements that define a transportation automation scenario.
- Section 3 summarizes the set of criteria that was used to generate this initial set of scenarios.
- Section 4 describes seven transportation automation scenarios covering different technologies. Each scenario is described in terms of the anticipated impact of the technology on the network performance, main variables to consider when modeling these scenarios, and key measures of performance for evaluation.
- Section 5 provides an overview of the main modeling approaches that can be used to model these scenarios.
- Section 6 provides a summary of the three scenarios that will be evaluated in this AV2.1 project and the planned next steps of this effort.

2. ELEMENTS OF TRANSPORTATION AUTOMATION SCENARIOS

For the purposes of this study, a transportation automation scenario is defined in terms of three key elements as follows:

The transportation automation technologies: Several emerging transportation technologies are expected to revolutionize the urban transportation systems. Examples of these technologies include automated vehicles (AVs), connected intersections, autonomous shuttles, high-speed mass transit services, and truck automation, to name a few. While a real-world operational scenario could involve a combination of some of these technologies, for the purpose of this planning effort, we define a scenario in terms of one dominant technology. This simplified approach will allow developing a better understanding of the impact of each technology on the transportation network without worrying about possible synergy/conflict with other technologies.

> We define a scenario in terms of one dominant technology to develop a better understanding of the impact of each technology on the transportation network.

Operating conditions: Several factors define the operating conditions of the transportation network, including demand level/pattern (e.g., peak vs. off-peak), congestion pattern (recurrent vs. non-recurrent due to incidents or work zones), and weather (e.g., fog, rain, hurricanes, natural disasters, and occasionally snow). The operation conditions could also cover extreme conditions, such as evacuation or the closure of a significant part of the network due to natural or man-made disasters. However, long-term planning applications are more concerned with studying the network performance considering the demand levels and patterns predicted for the target year. Other factors are usually considered in operation planning studies with short to medium planning horizons.

Spatial context: Evaluating automated transportation technologies could be conducted in a variety of spatial contexts, including a roadway facility (intersection, arterial or freeway), a corridor, a subarea, or the entire metroplex.

The idea of choosing a spatial context smaller than the entire metroplex is to be able to provide highly detailed modeling without worrying about model scalability issues. The assumption is that the impact of the examined technology could be adequately isolated and quantified for a part of the transportation network. This quantified impact can then be extrapolated for the entire metroplex.

For instance, a smart intersection technology could be evaluated for an arterial consisting of several intersections to estimate the reduction in delays and number of stops using a microscopic simulation platform. These estimated benefits could be assumed for all other similar arterials in the network and hence obtain a network-wide estimate of the technology benefits.

Several challenges usually arise with adopting this subarea analysis approach. First, defining the boundaries and the demand of the modeled subarea is usually a challenging task. Second, significant effort and data are usually required to calibrate a high-fidelity simulation model for the subarea. Third, the absence of adequate details on the technology, which reduces the value of any developed microscopic simulation platform. Fourth, extrapolating the benefits from a facility or a corridor to estimate the benefits for the entire metroplex is not a straightforward process. Finally, the subarea analysis could fail to capture the impact of policy conflict among different jurisdictions, if the selected subarea does not include these jurisdictions.

3. SCENARIO DEVELOPMENT AND SELECTION CRITERIA

Several criteria are considered for the process of scenario development and selection. These criteria can be summarized as follows:

Representing a Market-Rolling Technology. As mentioned above, we assume that each of the modeled scenarios will represent one transportation automation technology. Thus, scenarios are developed such that they represent widely known technologies with great potential for market rollout.

As large-scale deployments of most transportation automation technologies do not exist, several indicators are used to determine transportation automation technologies with high potential for large-scale real-world deployments. The first indicator is based on the results of global and national market studies conducted for these technologies.

Table 1 provides a summary of the anticipated market size for several transportation automation technologies. As shown in the table, large market sizes are anticipated for all listed technologies indicating their great potential for deployment in most urban areas. Although these market size numbers are for the entire country, these transformative technologies are expected to have a multi-billion-dollar impact on the region's economy and have a profound impact on the evolution of our transportation system.

Table 1. Estimated Market Growth for Different Transportation Automation Technologies

Technology	Market Size	**Source** (Access Date: October 4, 2021)
Autonomous and connected vehicles	$64.88 Billion by 2026	https://www.globenewswire.com/en/news-release/2021/08/06/2276438/0/en/At-22-7-CAGR-Global-Autonomous-Cars-Market-Share-Revenue-Expected-to-Reach-USD-64-88-Billion-by-2026-FnF-Research.html#:~:text=%5B225%2B%20Pages%20Research
Automated transit shuttles	$18 Billion by 2040	https://roboticsandautomationnews.com/2020/11/26/autonomous-shuttle-market-forecast-to-be-worth-18-billion/38517/
Connected vehicle-intersection systems	$180.9 Billion by 2025 (connected car market)	https://www.marketsandmarkets.com/Market-Reports/connected-car-market-102580117.html
Autonomous trucks	$4.3 billion by 2026	https://www.yahoo.com/now/global-autonomous-trucks-markets-report-134500766.html#:~:text=The%20global%20market%20for%20autonomous,the%20period%20of%202021%2D2026.
Long-distance high-speed mass transit services	5,287 units by 2025	https://www.marketsandmarkets.com/Market-Reports/bullet-train-high-speed-market-203819069.html#:~:text=The%20bullet%20train%2Fhigh%2
Urban air mobility for people transportation (air taxi)	$9.1 billion by 2030	https://www.prnewswire.com/news-releases/urban-air-mobility-market-worth-9-1-billion-by-2030--exclusive-report-by-marketsandmarkets-301232368.html#:~:text=In%2DLanguage%20News-
Drones for package delivery	$6.773 billion by 2026	https://www.globenewswire.com/en/news-release/2021/05/17/2230618/0/en/At-53-CAGR-Growth-Global-Drone-Package-Delivery-Market-Size-Share-Will-Reach-to-USD-6773-Million-by-2026-Facts-Factors.html

Input from the Project Advisory Committee. Seven scenarios representing different transportation automation technologies were presented to the Project Advisory Committee (PAC) during the project meeting on September 8, 2021. These technologies include autonomous vehicles, connected vehicle-intersection systems, autonomous shuttles, long-distance high-speed mass transit systems, autonomous and connected trucks, and urban air mobility systems for people and good transportation.

The PAC members were asked to provide other important scenarios/technologies that should be considered for modeling and to rank these scenarios/technologies based on their significance for the future of transportation automation in the Dallas-Fort Worth region.

The PAC members agreed that the provided list of scenarios is comprehensive and covers all key technologies. In addition, their ranking of these scenarios in terms of their significance matched the ranking provided by our team. This ranking is used to present the different scenarios considered for this study, as presented in Section 4.

Discussions with the NCTCOG modeling team. Two meetings were scheduled with the NCTCOG modeling team to review potential future technology scenarios, learn which technology scenarios NCTCOG is planning to model for the region's long-range transportation planning (LRTP) effort, and discuss scenarios that can complement NCTCOG's modeling efforts. The NCTCOG team agreed that the developed list of scenarios would adequately cover their LRTP. Discussion is underway with the NCTCOG team to identify key scenarios that the project consulting team will model to complement NCTCOG's modeling effort.

Available Research. The purpose of this project is to help local agencies learn how to evaluate what is currently known about the effect of automation and other emerging technologies on the North Central Texas transportation system. The project team will use available research to determine model input parameters to estimate the future impacts of these technologies in the region.

Modeling Framework. **Figure 2** outlines the modeling framework process.

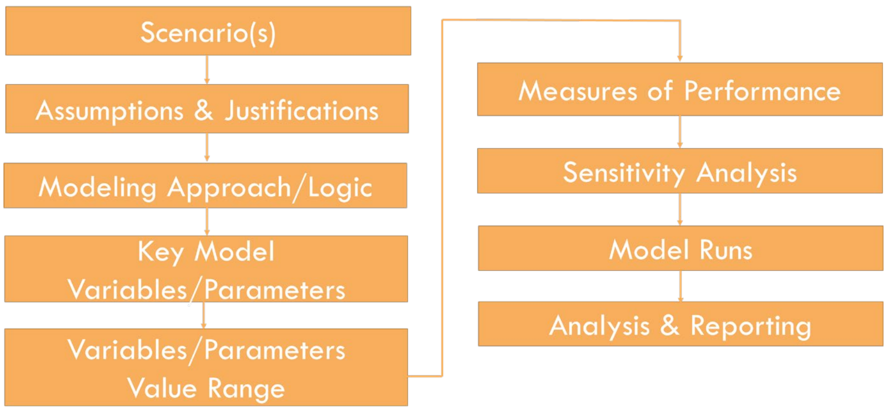


Figure 2. Modeling Framework

The modeling framework process begins with scenario development. Model assumptions are defined and justified for each scenario. Then the modeling approach or logic is defined, such as which modeling tool is best suited to simulate the scenario.

Key model parameters or variables are defined, as well as the value ranges to be simulated. The measures of performance are the key model outputs. Sensitivity analyses can be used to study impacts of a range of inputs, such as the increasing market penetration rate of CAVs.

When all scenarios, assumptions, parameters, and performance measures are defined, it is time to start evaluating model runs. The AV2.1 transportation modelers will analyze the model results and summarize the findings in the future Scenario Evaluation Report.

4. TRANSPORTATION AUTOMATION SCENARIOS

The AV2.1 project team conceptualized seven transportation automation scenarios for the North Central Texas region. The subsections below provide overviews of these scenarios, their expected impact on the performance of the regional network, key variables that need to be considered for their modeling, and main performance measures that can be used for their evaluation.

For this study, CV, AV, and CAV technologies are defined as:

Connected vehicles (CVs) can share data to infrastructure or traffic management centers (*vehicle-to-infrastructure, V2I*) about traffic, pavement, or weather conditions to inform maintenance and operations. CVs can communicate with other vehicles (*vehicle-to-vehicle, V2V*), for example, they can help a driver to "see" around blind spots, activate emergency braking sooner, detect vulnerable road users who can communicate with the CV. And CVs may be able to share travel and safety information to drivers through in-vehicle messaging (*CV warning applications*).

Automated vehicles (AVs) can perform driving tasks with limited to no input from a human driver. These can include purpose-built automated vehicles that have no steering wheel or pedals, or they can include vehicles with automated driving systems that can perform driving tasks for a driver in specific conditions. Potential personal mobility impacts of AV technology include increased roadway capacity, vehicle throughput, and travel time reliability; increased access to travel for people unable to drive; and reduced level of stress especially compared to driving in congested traffic. AVs may also impact land use by reduced parking requirements, especially in urban areas.

Connected-Automated Vehicles (CAVs) are vehicles that can both communicate with other vehicles and the roadway infrastructure and can perform driving tasks with limited to no input from a human driver. Research predicts connected automation is needed to safely enable closer following distances that will increase roadway capacity compared to human drivers.

Scenario 1: Connected-Automated Vehicle Impact on Roadway Network Performance

An Overview: Automated vehicles (AVs) are a significant innovation, which is expected to lead the next paradigm shift in the field of transportation.[1] The technology has considerable growth potential; the global autonomous vehicle market demand is estimated to grow from

[1] Narayanan, S., Chaniotakis, E., & Antoniou, C. (2020). Shared autonomous vehicle services: A comprehensive review. Transportation Research Part C: Emerging Technologies, 111, 255-293.

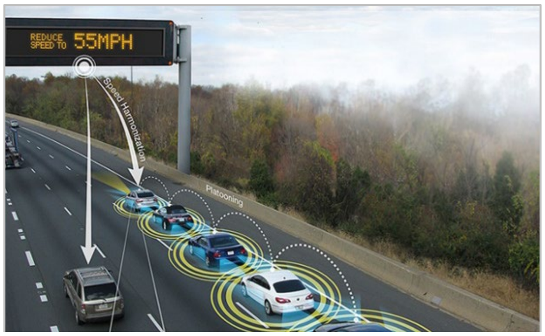


Figure 3. Cooperative driving of CAVs with reduced headways and harmonized speeds
(Source: USDOT)

approximately 6.7 thousand units in 2020 to about 4.3 million units in 2030.[2] With this fast growth and the ongoing race among major technology companies and car manufacturers to build the first operational vehicle, there is an urgency among planning agencies to carefully evaluate the benefits and issues associated with the introduction of AV technologies in their roadway networks. The evaluation of AVs at the regional level under different operational scenarios requires the development of adequate modeling platforms that can represent the anticipated changes in the transportation system at high fidelity.

Technology Impact: While effort is still underway to conceptualize AV operations in urban areas, there is agreement among transportation planners that AVs will have a significant impact on (1) the travelers' behavior and (2) the traffic flow efficiency.

For example, as technology becomes broadly available, AVs are expected to alter travelers' perception of long trips. As riders are not under the stress of driving and are probably involved in more productive activities, they will be more willing to spend more time in their vehicles to access farther destinations. Thus, one can expect a notable increase in the average vehicle miles traveled resulting from this behavior change.[3, 4, 5]

As technology advances, vehicles that are both connected and automated (CAVs) could allow vehicles to travel with shorter headways, enable platoons with harmonized speeds, and eliminate accidents due to drivers' errors. Thus, in the long-term, CAVs are expected to improve roadway capacity and eradicate non-recurrent congestion situations.[6, 7] However, in the near-term, most advanced driver assistance systems (like adaptive cruise control) and current automated driving systems are programmed to be more conservative using longer headways (2 or 3 seconds) compared to average human perception-reaction times (1.5 seconds).

Key Scenario Variables: The modeling of this scenario will involve the adjustment of several key variables related to the travelers' behavior and the roadway network capacity. The details of these variables are dependent on the modeling platform to be used. However, at this stage, we

[2] Autonomous Vehicle Market Size, Share & Trends Analysis Report by Application (Transportation, Defense), By Region (North & South America, Europe, APAC, MEA), And Segment Forecasts, 2021 – 2030. https://www.grandviewresearch.com/industry-analysis/autonomous-vehicles-market

[3] Ashkrof, P., Homem de Almeida Correia, G., Cats, O., & van Arem, B. (2019). Impact of automated vehicles on travel mode preference for different trip purposes and distances. *Transportation Research Record*, 2673(5), 607-616.

[4] Legêne, M. F., Auping, W. L., Correia, G. H. D. A., & van Arem, B. (2020). Spatial impact of automated driving in urban areas. *Journal of Simulation*, 14(4), 295-303.

[5] Maleki, M., Chan, Y., & Arani, M. (2021). Impact of Autonomous Vehicle Technology on Long Distance Travel Behavior. *arXiv preprint* arXiv:2101.06097.

[6] Zhong, Z., Lee, E. E., Nejad, M., & Lee, J. (2020). Influence of CAV clustering strategies on mixed traffic flow characteristics: An analysis of vehicle trajectory data. *Transportation Research Part C: Emerging Technologies*, 115, 102611.

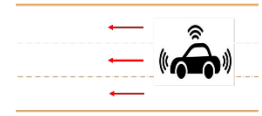
[7] Amoozadeh, M., Deng, H., Chuah, C. N., Zhang, H. M., & Ghosal, D. (2015). Platoon management with cooperative adaptive cruise control enabled by VANET. *Vehicular communications*, 2(2), 110-123.

try to present a model-free discussion of main variables/modules that can be adjusted to capture the impacts mentioned above.

With access to the UTAV-TAFT platform (a modeling platform developed for NCTCOG by the University of Texas Austin, which considers impacts of emerging technologies) we can assess the effect of increased roadway capacity on the traveled distances under constant trip length distribution assumptions. Potentially, drivers can travel longer distances in the same time under increased capacity assumptions.

Link Capacity

In addition, capturing the improvement in the network capacity can be achieved by adjusting the links' performance functions, which describe the travel time sensitivity to traffic volumes. As CAVs represent a larger fraction of overall traffic on a roadway link, travel time is expected to be less sensitive to the increase in that link's traffic volume.



Link Travel Speed

Performance Measures: Several performance measures are essential to evaluate the network performance under a CAV scenario. These measures include the *average vehicle miles traveled*, which quantifies the anticipated increase in the trip length due to reduced travel times as mentioned above and any induced trips facilitated by the emerging automated travel modes. *Average vehicle travel time* quantifies the conflicting effects resulting from the improvement in network capacity due to automation and the increase in the network congestion level due to the expected increase in miles traveled.

Scenario 2: CAV-Intersection Systems

An Overview: A CAV-intersection system aims at improving the performance of signalized intersections by reducing vehicle delays and stops. It establishes communication between the vehicles and the intersection's signal controller to enable real-time data sharing (vehicle-to-intersection communications).

The controller receives real-time data from the vehicles on their locations and speeds and uses this data to optimally adjust the amount of time the signal is green in various signal phases to optimize movement of CAVs through the intersection.

Figure 4. Connected Vehicle-Intersection Systems
(Source: USDOT)

Simultaneously, vehicles approaching the intersection receive information on the signal phasing and timing (SPaT) and recommendations to adjust their speeds to avoid unnecessary stops/delays at the intersection.

The system is also conceptualized to provide movement assistance to vehicles while navigating an intersection. For instance, a vehicle could receive a warning that it is not safe to enter an intersection when there is a high probability of colliding with other vehicles.

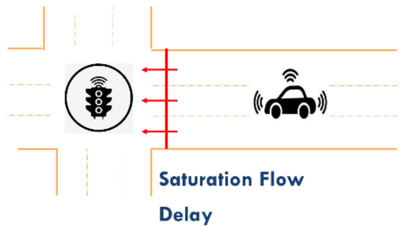
Technology Impact: The vehicle-intersection technology is expected to reduce delays and stops at intersections. A recent simulation-based study estimates the reduction in the average vehicle delay could range in the ideal conditions from 37.8% and 54.0% and that the number of stops could be reduced between 29.0% and 77.5%.[8] While these numbers provide benchmark for the these systems' achievable benefits, experts on the team suggest that agencies could achieve about 10% improvement in the performance of their signalized intersections in 5 to 10 years of deployment.

The technology will reduce the delays at the intersections and enable a better distribution of the traffic along the different roadway facilities in the network. For example, the anticipated reduction in the travel time along the arterials could attract a portion of the traffic to use these arterial facilities, shifting from adjacent freeways.

These estimated reductions will also translate into a significant reduction in fuel consumption—emissions reductions are estimated to range from 5% to 30%.[9]

As for the impact on traffic safety, the National Highway Traffic Safety Administration estimates that movement assistance systems in connected intersections would prevent between 413,000 and 592,000 crashes, save between 777 and 1,083 lives, and reduce 191,000 to 270,000 injuries in the U.S. every year.[10]

Key Scenario Variables: Studying the impact of the CAV-intersection technology at the regional level requires providing information on the number of connected intersections and their spatial distribution in the metroplex. Furthermore, the delay function at these intersections will need to be modified to capture the reduction in the delay, as mentioned above.



Performance Measures: One key performance measure that is required to evaluate this scenario is the *average vehicle travel time*. This measure could be estimated for the entire network or for subnetworks where the connected intersection technology is heavily deployed (e.g., one municipality might adopt the technology faster than others). The average vehicle travel time could also be estimated for the arterials and freeways to understand if the technology helps in alleviating the congestion along the freeway facilities.

Today, agencies across the country are using CV data to measure system performance. For the first time, CV data gives us safety data in near-real time (instead of waiting years for police-reported crash data). TTI and TxDOT are using Wejo CV data to study roadway safety and impacts of traffic queuing due to road construction.[11]

[8] Wu, W., Huang, L., & Du, R. (2020). Simultaneous optimization of vehicle arrival time and signal timings within a connected vehicle environment. Sensors, 20(1), 191.
[9] Kamalanathsharma, R. K., & Rakha, H. A. (2016). Leveraging connected vehicle technology and telematics to enhance vehicle fuel efficiency in the vicinity of signalized intersections. Journal of Intelligent Transportation Systems, 20(1), 33-44.
[10] https://www.its.dot.gov/cv_basics/cv_basics_type.htm
[11] Wejo (17 December 2021). "Deploying Proactive Data-Driven Solutions That Improve Road Safety & Accessibility – a Wejo Smart Mobility For Good™ Case Study". https://www.wejo.com/resources/tti-txdot-data-driven-solutions

Scenario 3: CAV Effect on Population / Employment Distribution

An Overview: The current practice in demographic forecasting generally relies on available historical data to establish a relationship between a zone's accessibility and amenities and the desire for future home or work locations to locate in those areas. In reality, the household's choice of home location is typically a complex function of factors, including but not limited to household income, accessibility, number of workers in the household, work location(s), and school district rating.

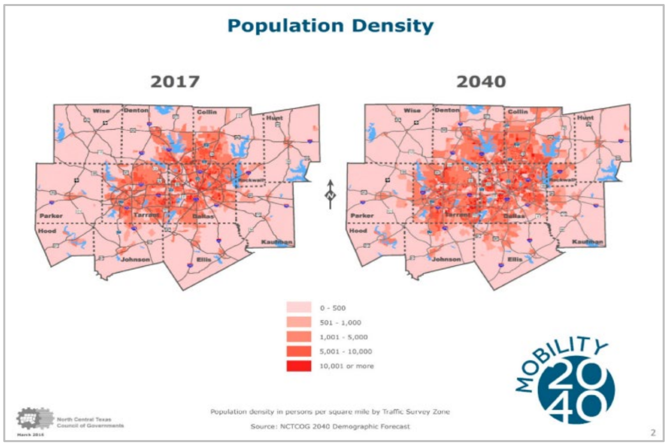


Figure 5. NCTCOG Mobility 2040 Population Density Projections (Source: NCTCOG)

The introduction of autonomous modes in the mix of transportation options can potentially change this paradigm and relax some of the constraints such as distance to work or entertainment/shopping venues from the home location choice selection process. This shift can result in a more uniform distribution of population and/or employment across the region.

Technology Impact: One of the important discussion topics among planners regarding introduction of CAVs into the traffic mix is their potential impact on travelers' perception of travel distance due to the increased travel comfort, reduction in driving stress and decreased vehicle operating cost. The added comfort can also potentially result in a more productive utilization of the in-vehicle time.

These factors can potentially change one's home location choice criteria and result in households deciding to live farther away from the center of activities where housing prices are more affordable and hence resulting in increased urban sprawl and an increase in total vehicles miles of travel. Some research indicates that under currently established typical land-use policies there can be a 10-30% increase in urban sprawl due to introduction of CAV technology.[12]

The implementation of both CAVs and automated public transit can potentially result in less suburbanization compared to a CAV-only scenario.[13] Thus, cities will need to modify their land-use and road use policies and invest in automated public transit to reduce the urban sprawl.

COVID Pandemic Impact: The COVID-19 pandemic has demonstrated how much people's travel patterns are changing downtown areas.[14] In addition to these impacts of automated vehicles, agencies also need to continue to monitor adoption and travel trends related to teleworking and e-commerce to understand the combined or overall impacts.

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[12] Victoria Transport Policy Institute, "Autonomous Vehicle Implementation Predictions", https://www.vtpi.org/avip.pdf accessed on 09/28/2021

[13] Gelauff, G., Ossokina, I., & Teulings, C. (2017). Spatial effects of automated driving: Dispersion, concentration or both. The Hague: KIM – Netherlands Institute for Transport Policy Analysis.

[14] The Wall Street Journal (10 December 2021), "That Big Office Building? It's an E-Commerce Warehouse Now." https://www.wsj.com/articles/covid-is-making-many-offices-obsolete-heres-what-happens-to-old-offices-11639079017

Key Scenario Variables: We propose to evaluate the effect of change in home location choice after a manual adjustment of the demographic data. A proxy for the manual modeling of increased population sprawl is to either assume uniform growth across the region to smooth out the attractiveness of the currently populated and more desirable areas or to define a set of growth scenarios for each county. We can also apply the same concept at a Transportation Analysis Zone (TAZ) level. The same adjustments can be applied on the employment forecasts but there is a higher likelihood that employment locations will still be attracted to city centers and major arterials following the historical trends. This operation can be applied on the currently approved set of demographic forecasts.

The new set of demographic forecasts will then need to be run through the trip generation, trip distribution, and mode choice stages to produce the updated trip tables which will then be the input to the traffic assignment stage. Although this method can evaluate the effect of change in demographic growth patterns, it will still follow the original regional model's trip length distribution. This operation can also be performed at a more fundamental level where the demographic forecasts are manually adjusted but applied in a modified trip distribution stage where the trip lengths are adjusted by trip purpose. Other modifications mentioned in Section 5 can be included to better reflect the adoption of CAVs.

Performance Measures: There are certain measures of effectiveness that can be extracted from a regional travel demand model runs for scenario comparisons. These measures include the *vehicles-miles-of-travel* (VMT), *vehicle-hours-of-travel* (VHT), *average network speeds*, the *total network delay*, and *volume to capacity ratios* by roadway functional classification.

Scenario 4: Automated Shuttles for Improved First- and Last-Mile Travel

Figure 6. Automated Shuttle Concept (Source: USDOT)

An Overview: Low-speed automated shuttle technology is currently the most widely deployed automated transportation technology. A 2020 study reports that automated shuttles have been piloted in at least 19 locations in the United States.[15] These shuttles typically operate in a high automation mode, which adopts an automated driving system that involves the driver's assistance in some situations. They are conceptualized to provide first/last mile travel as they connect major attractions (e.g., university campuses, commercial districts, downtown districts) in the metroplex with the regional public transportation system. It is worth mentioning that dozens of these automated shuttle systems have been deployed in many cities in the U.S. for demonstration purposes. A summary of these systems is given in **Table 2**. As shown in the table, these systems use limited number of low-occupancy

[15] Haque, A. M., & Brakewood, C. (2020). A synthesis and comparison of American automated shuttle pilot projects. Case Studies on Transport Policy, 8(3), 928-937.

vehicles serving short routes and operating at low speed. Studies are underway to collect lessons learned from these initial deployments to improve system design for deploying the service at larger scale.[16, 17]

Table 2. Automated Shuttle Deployment Case Studies

National Case Study Characteristics

Measure	Ann Arbor, MI	Columbus, OH	Park City, Farmington, UT	Las Vegas, NV	Arlington, TX (Milo)	Arlington, TX (Drive.ai)	Gainesville, FL	Orlando, FL (UCF Shuttle)	Hillsborough County, FL (USF Shuttle)
Shuttle Manufacturer	NAVYA	May Mobility	EasyMile	NAVYA	EasyMile	Drive.ai	EasyMile	Coast Autonomous	Coast Autonomous
Shuttle Type	AUTONOM Shuttle	Polaris GEM e5	EZ10	AUTONOM Shuttle	EZ10	Nissan NV200	EZ10	P-1	P-1
Procurement Type	Purchased	Paid for Service	Leased	Paid for Service	Leased	Paid for Services	Leased	Purchased	Leased
Funding Source	M-City and University of Michigan	Smart Columbus, Drives Ohio, May Mobililty, OSU	Utah DOT and Utah Transit Authority	AAA NCNU and USDOT	City of Arlington and USDOT	City of Arlington and Federal Gov	FDOT	FDOT	FDOT and USF
Cost*	$800,000 per year	$250,000 per Shuttle	$10,000 per month	$250,000 per Shuttle	$250,000 per Shuttle	$343,000 for the Service	$2.5 m/3 years	-	$8,000 per month/shuttle + $85 per hour of operations
Period of Operation	Ongoing	Ongoing	May 2018, Jun-July 2019	Nov 2017 - Oct 2018	Aug 2017 - Aug 2018	Oct 2018-May 2019	Ongoing	Planned 2019	Demonstration in 2019, No further plans
Number of Shuttles	2	3	1	1	2	3 to 7	3	2	2
Route Length (mi)	1.2 miles	1.4 miles	0.47 miles, 1.1 miles	0.6 miles	≤ 0.8 miles	≤ 1.3 miles	3 miles	0.36 miles, 0.42 miles	TBD
Headway (mi)	5	5	-	-	-	-	10(peak) 20 (off-peak)	TBD	TBD
Operating Hours	Weekdays 9 AM-3 PM	6 AM-10 PM	12 PM-6 PM	10 AM-6 PM	During Events	Thurs-Sun 11 AM-6 PM	8 AM-6 PM	Mon-Fri 9AM-10 PM, Sat 10 AM-4 PM	Weekdays 8 AM-6 PM, 8 PM-2 AM
Capacity per Vehicle	15 people	5 people	12 people	15 people	12 people	3 people	15 people	12 people	12 people
Operation Speed (mph)	12	15	15	15	15	Won't exceed 35	15	12	20
Local Context	College Campus	Urban	Resort, Shopping Center	Urban	Urban	Urban	Urban	College Campus	College Campus

*Cost shown is not necessarily the total cost for the above deployments.

[16] Low-Speed Autonomous Shuttles - Lessons Learned from Real-World Implementation. ISSN: 0148-7191, e-ISSN: 2688-3627. DOI: https://doi.org/10.4271/2021-01-1010. Published April 15, 2021 by SAE International in United States

[17] Smart Columbus Demonstration Program: *Smart Columbus AV Shuttle Deployment Lessons Learned*. Final Report, March 2019. https://d3hzplpmmz6qe4.cloudfront.net/2019-07/Smart%20Columbus%20Autonomous%20Vehicle%20Lessons%20Learned_0.pdf

Technology Impact: Automated shuttles are anticipated to provide convenient first/last mile travel, which generally enhances the attractiveness of public transportation services in the region. The strategic provision of autonomous shuttle services in the metroplex is expected to increase public transportation ridership and reduce dependence on private cars. The service could induce more trips as accessibility will be generally improved, especially for travelers with limited access to private cars. Finally, due to their reduced speed, autonomous shuttle services could also cause some congestion along their routes.

Key Scenario Variables: The modeling of this scenario requires modifying the transit network to represent the routes of new autonomous shuttle services. These routes are described in terms of the sequence of the roadway links, the stop locations, and the operation schedule (e.g., service headway). The effort could also require developing new mode choice models to capture travelers' choice behavior with respect to autonomous shuttle services. One challenge associated with modeling this scenario is the absence of real-world ridership data that can be used for model calibration/validation.

Performance Measures: The change in the transit ridership for the different transit routes and the overall impact on mobility equity are primary measures of performance for this scenario. In addition, the *average trip travel time* for transit and non-transit users are useful performance measures for this scenario to quantify the possible benefits resulting from the possible reduction in private car use resulting from providing better access to transit services.

Scenario 5: CAV Technology Lane and Impact on Truck Routing

Figure 7. AV Technology Lane Cooperative Driving (Source: FMCSA)

An Overview: The underlying technologies that aim to make autonomous trucks a reality continues to advance rapidly. This trend could be accelerated due to demand created by a current shortage of truck drivers. Still a more controlled environment like a lane reserved for CAVs may allow for adoption faster as current high-definition (HD) mapping solutions are good at establishing the location of an object to centimeter-level precision; however, it's much more challenging for the technology to understand the context of traffic signs and the rule(s) they communicate.[18] These challenges may be reduced and simplified in the near term through the use of lanes reserved for CAVs, a technology lane. Benefits of dedicating lanes to CAV use, or even exclusive to CAV trucks, include enhanced safety, increases in mobility, and reduced impacts on the environmental.

The availability of technology lanes and the amount of market penetration or utilization of CAV trucks are interdependent in this scenario. Given the theoretical nature of this scenario and scope limitations, 25% could be assumed to be a feasible market penetration rate of CAV trucks. Market

[18] Inrix, Building the Foundation for Successful Deployment of Highly Automated Vehicles on Public Roads - INRIX, accessed 10/1/20021

penetration is defined as the percentage of trucks equipped and operated as CAVs that are therefore permitted access to the technology lanes.

Several CAV features for commercial travel could address infrastructure capacity constraint issues that are either currently being faced or that will result from the forecasted freight growth in the coming decades. Truck platooning reduces the headway between trucks, frees up space on the roadway for other vehicles, and removes freight to specific lanes.[19]

Under this scenario, a network of technology lanes will be identified statewide. Groups of platooning vehicles speed could be controlled by one onboard driver/operator, no onboard "drivers", or an offsite operator. This scenario does not aim to define the specific technologies used to automate navigation and operation of trucks in the proposed technology lanes, instead it describes the impacts of their use. Likely a combination of technologies will be used to coordinate the maneuvers of vehicles, allow them to be operated closer together (platooning), and to harmonize their speeds. The resulting speeds will be more stable and could increase safety and the average travel speed.

TxDOT's Texas Technology Task force states that, "Short-term recommendation for Texas include the need to closely follow and learn from the Texas Connected Freight Corridors project. Once CV applications have been proven in highway and freight environments, they can be expanded. Texas agencies should also continue to monitor developments and technology advancements between dedicated short-range communications (DSRC) and cellular communication technologies as they are rapidly changing. Several local agencies (City of Austin, City of Frisco, etc.) are deploying limited CV applications. Texas should learn from and document best practices from these trials. Texas agencies should also keep Informed on security and data needs."

In late 2021 autonomous truck tech startup Embark Trucks announced a research partnership with Texas A&M and a focus on use of its trucks in general purpose lanes between Houston and cities 300 to 600 miles from there. Embark expects to begin hauling freight between San Antonio and Houston as early as 2022.[20] This trend away from reliance on expensive truck lanes is growing in the industry. Kodiak, another company developing self-driving trucks has noted they are not focused on truck platooning or operating exclusively in dedicated lanes, but instead are focused on building technology designed to operate on existing highway infrastructure.[21]

Technology Impact: The introduction of CAV Technology Lane for use by CAV Trucks impacts the routing of trucks in the DFW region. The limits on routes and access and egress points make dedicate lanes challenging for logistics. Technology Lane use will also impact the routing of long-distance truck traffic to and through the region. In this scenario CAV trucks are restricted to technology lanes and would adapt their routing to make use of these enhanced facilities. In addition, CAV systems will enable vehicles to travel with shorter headways, enable platoons with harmonized speeds, and reduce some crashes due to driver errors. Thus, CAVs are expected to improve roadway capacity and reduce non-recurring congestion situations.[22]

Key Scenario Variables: The modeling of this scenario would involve the adjustment of several key variables related to the travelers' behavior and the roadway network capacity. Rules for existing

[19] TTI, Transportation Planning Implications of Automated/Connected Vehicles on Texas Highways, Report 0-6848-1, 2017
[20] Embark expands in Texas, intros new autonomous truck lane | Commercial Carrier Journal (ccjdigital.com)
[21] Correspondence with Daniel Goff, Head of Policy at Kodiak, January 18, 2022
[22] Center for Transportation Research, Texas Technology Task Force. 2020 Tech Utilization Plan. 2020

HOV lanes could be revised to allow trucks. The lanes could also be extended and connected to allow for a network of technology lanes and navigation to/from points within and beyond the DFW region. The operating speed and roadway capacity for this new or enhanced functional classification of roadway, technology lanes, would be defined based on current research. Speed and capacity are impacted by access points, the length of the facility, number of lanes included in the facility, and the types of traffic allowed among other factors. Modeling technology lanes and their impact on the region will rely upon a combination of models (DFX or TAFT or UTAV-TAFT, statewide, and microscopic simulation) to understand both demand and routing.

Performance Measures: Several performance measures are essential to understand the impacts of this scenario. *Change in Average Regional Travel Time* can show the regional impact on mobility. Any change to the regional average can be significant as the size of the region and number of roadways make moving the needle difficult. *Change in Travel Speeds of General-Purpose Lanes*[23] would be accessed for roadways that include technology lanes in their cross section. This measure indicates whether the general-purpose lanes had higher speeds or lower speeds compared to the base case.

Scenario 6: Long-Distance, High-Speed Mass Transit Services

An Overview: Many of the long distance (e.g., intra-city) transit services are currently subsidized such that they can be a viable alternative for all income groups, the travelers that cannot drive due to various reasons, and other captive (i.e., transit-dependent) riders. The introduction of autonomous transit services can potentially reduce the need for these subsidies and might even reduce the need for intra-city transit services by providing a competitive transportation option to all riders—captive or choice.

Figure 8. High Speed Mass Transit Options considered by NCTCOG's High-Speed North Texas Program (Source: NCTCOG)

Currently, transit automation systems in development are still in pilot phase and most of the products are prototypes.[24] The first full-size automated bus in the US is planned in Connecticut on CTfastrak, a dedicated 9-mile route from New Britain to Hartford. The electric bus will include automated features like steering and docking, but it still needs a human operator behind the wheel.[25]

[23] National Academies of Sciences, Engineering, and Medicine. 2018. Dedicating Lanes for Priority or Exclusive Use by Connected and Automated Vehicles. Washington, DC: The National Academies Press. https://doi.org/10.17226/25366
[24] Federal Transit Agency. 2020. Transit Bus Automation Market Assessment (Report 0144). Washington DC. https://www.transit.dot.gov/sites/fta.dot.gov/files/2020-07/FTA_Report_No._0144_Update.pdf. Accessed 10/05/2021
[25] https://www.masstransitmag.com/alt-mobility/autonomous-vehicles/article/21143509/ctdot-scheduled-to-deploy-first-fullsize-automated-transit-bus-in-north-america

Some other pilot projects such as CityMobil and CityMobil2 have already tested the concept of providing driverless low-speed intra-city transit services to supplement mass transit.[26] The new technology can potentially increase the demand for high-speed inter-city transportation by eliminating the high cost of labor, which can then provide an opportunity for more frequent service.

A generally accepted criterion for defining high-speed transit is systems with travel speeds higher than 120-160 mph.[27] An example of this technology has been recently constructed in China ahead of the 2022 winter Olympics.[28] California started construction of high-speed rail between Los Angeles and San Francisco.[29]

There are discussions underway for constructing high-speed rail between Dallas and Fort Worth and linking it to the proposed high-speed rail between Dallas and Houston.[30]

Technology Impact: The introduction of autonomous modes in the traffic mix can potentially introduce an option which is cheaper than the human-operated taxis and ride-hailing services and hence reduce the need for subsidized mass transit for the lower income groups. However, this most likely applies to intra-city transit patterns and not the longer distance mass-transit services.

The introduction of autonomous technology in long-distance mass transit can significantly reduce the cost of labor and hence allow the transit agencies to provide more frequent services. Some research indicates that the transit fares could get as low as $0.2 to $0.4 per passenger-mile.[31] In this scenario, the effect of lower cost and higher frequency long-distance transit services will be evaluated.

Although fully automated buses are yet to come, cities could plan for infrastructures that gear towards automated public transit. First, transit stations which integrate automated buses and first- and last-mile shared autonomous vehicles (SAVs) would increase accessibility for low-income neighborhoods and suburban communities. Second, installing cameras and LiDAR sensors on regular buses could get cities a head-start in the implementation of automated public transit, as images and videos captured during operation could be utilized for self-driving machine learning. Last, building a well-covered 5G network for key corridors would pave the way for CAVs and connected bus platoon's implementation.

Key Scenario Variables: Scenario planning is necessary before modifying regional models, as states, MPOs and the public are still in the stage of understanding automated public transit and its impact economically and socially. There is no consensus on how the implementation of automated transit systems will proceed regarding level of automation, accessibility, capacity, service model and so on.

High level of automation reduces the operating cost but might face distrust from the public over safety and privacy concerns. Low level of automation is easier to implement but needs human operation or interventions, which increases its operating costs.

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[26] https://cordis.europa.eu/project/id/314190/reporting
[27] https://en.wikipedia.org/wiki/High-speed_rail_in_the_United_States
[28] https://www.cnn.com/travel/article/driverless-bullet-train-china/index.html
[29] https://hsrail.org/california-building-high-speed-rail
[30] Texas High Speed Rail Alliance. hsrail.org
[31] Victoria Transport Policy Institute, "Autonomous Vehicle Implementation Predictions", https://www.vtpi.org/avip.pdf accessed on 09/28/2021

Many would debate over whether this technology should prioritize inter-city transit lines (Dallas-Fort Worth) or commuter routes (CBD-Suburb). Other factors such as operating speed and how the automated lane interacts with other road users have not had definite answers among stakeholders. A series of favorable scenarios from the key stakeholders via scenario planning would provide directions for the following modeling process.

The favorable scenarios can be implemented in the regional travel demand model by reduced cost and increased frequency to mimic certain transit modes. These scenarios need to be applied starting from the mode choice stage to create the updated trip tables for traffic and transit assignments. A similar concept can be applied in the SAM where inter-city transit services are modeled as well.

Performance Measures: There are certain measures of effectiveness that can be extracted from regional travel demand model runs for scenario comparisons. These measures include the *vehicles-miles-of-travel* (VMT), *vehicle-hours-of-travel* (VHT), *average network speeds*, the *total network delay*, *volume to capacity ratios* by roadway functional classification, and the *transit ridership*.

Scenario 7: UAM Systems for People and Goods Transportation

Figure 9. Wing Commercial Drone Delivery Service to test in Frisco (Source: friscotexas.gov)

An Overview: Urban Air Mobility (UAM) systems leverage manned and unmanned aerial vehicles to transport people (e.g., air taxis) and goods (e.g., drone delivery) in congested urban areas. A typical UAM system is envisioned to consist of a network of aerial corridors connecting a set of vertiports and landing stations for light drones. These vertiports and stations are strategically distributed in the metroplex to ensure that they efficiently serve the demand.

Recent technological developments, the increasing UAM applications, and the significant investments in emerging economies would continue to drive the urban air mobility market. For example, the urban air mobility market is estimated to grow from $2.6 billion in 2020 to $9.1 billion by 2030, at an annual growth rate of 13.5% from 2020 to 2030.[32]

Technology Impact: UAM systems will provide fast travel options to passengers and fast delivery services to customers. Thus, UAM systems would shift some trips from the surface network to the air network, which could result in a reduction in the surface network's congestion level. Of course, a successful deployment of this technology would require coordination with many stakeholders

[32] Markets and Markets (2021), Urban Air Mobility Market by Component (Infrastructure, Platform), Platform Operation (Piloted, Autonomous), Range (Intercity, Intracity), Platform Architecture, Unmanned Platform Systems, End User and Region - Global Forecast to 2030

including aviation authorities, airports, shippers, and service providers. Nonetheless, careful attention should be given to the possible adverse impact of the technology on the environment, especially due to the high noise of their vehicles.

Key Scenario Variables: On the passengers' side, modeling this scenario will require developing an optimized hub location choice model and a new travel mode choice model that incorporates air mobility services. The services will need to be defined in terms of routes, schedule, cost, and in-vehicle and out-of-vehicle travel times.

For the delivery services, an effort will be required to properly split the freight demand between the surface and the aerial networks, which requires information on the type of products that can be served by air transportation, their origin-destination pairs, and the cost of air transportation, to name a few.

Performance Measures: The *average trip travel time* and *average vehicle travel time* are key measures of performance to quantify how the UAM system could create efficient travel options for travelers and reduce surface network congestion. In addition, the *average truck travel time* and indicators of the *total freight transportation cost* will be useful in assessing the benefits of the UAM system for freight transportation in urban areas.

5. MODELING APPROACHES

A considerable research effort is underway to develop adequate models that capture the effect of transportation automation technologies on transportation network performance. This effort is devoted to developing behavioral models that represent the anticipated change in traveler's behavior in terms of residential and work location choice, vehicle ownership versus participating in a shared economy environment, and mobility service choice. The research effort also extends examining the impact of these technologies on the capacities of interrupted and uninterrupted roadways.

As this effort is still in its infancy, there is no agreement in the transportation network modeling community on the most appropriate modeling approach that can be used to evaluate the emerging technologies on the network performance.

While many factors could contribute to the selection of the modeling platform, our team examined the feasibility of the different existing modeling approaches in modeling the potential future technology scenarios. **Figure 10** provides main modeling approaches that could be used to model the scenarios. An overview of these approaches is as follows.

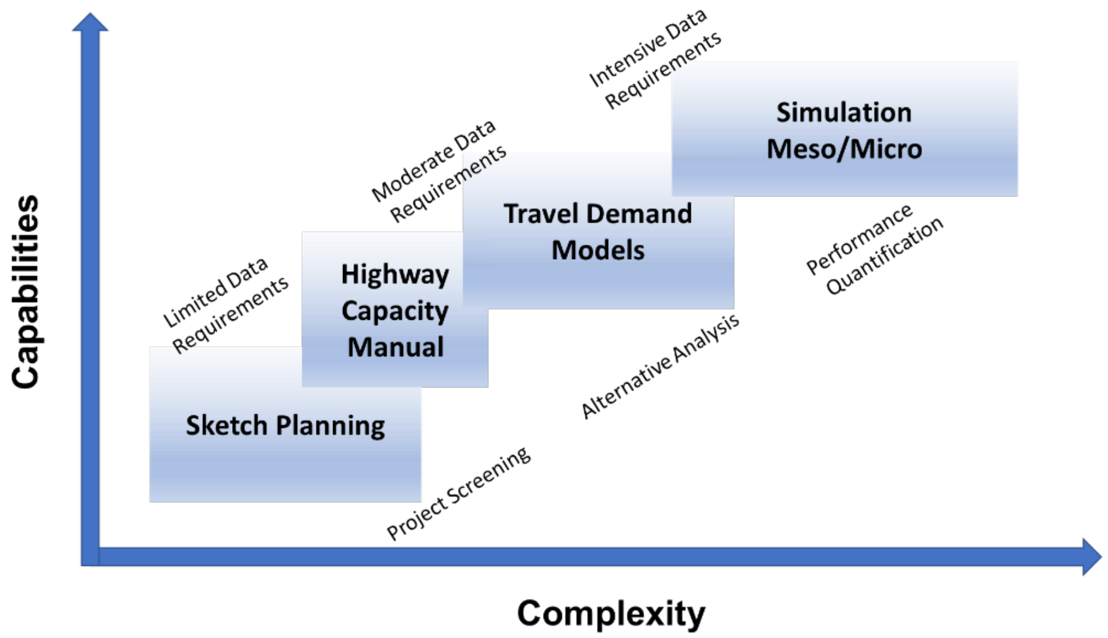

Figure 10. Scenario Evaluation Modeling Approaches

Sketch-Planning Tools are used to evaluate common transportation improvement projects that do not require detailed analysis. The tools are used primarily for project screening for the purpose of preliminary budgets and proposals. Developing these tools for an operation scenario depends on aggregated data and outcomes collected from past projects. While they are simple to perform and require a relatively low investment of money, time, and resources, their results are imprecise approximations and lack analytical robustness.

The Highway Capacity Manual (HCM) methods are used to estimate the performance and/or the Level of Service (LOS) of a single location or facility. The methods are in the form of analytical, closed-form, deterministic procedures that are used to estimate various performance outcomes (e.g., capacity, density, speed, delay, and queues) based on the prevailing operational conditions measured/estimated at a macroscopic-level. These procedures are based on empirical data collected from small-scale field experiments. While the methods can provide reasonable results with few inputs, they are not suited for capturing network effects or system-wide performance.

Travel Demand Models are static models which have limited capabilities with respect to estimating changes in operational characteristics (such as speed, delay, and queuing) resulting from the implementation of operational strategies. Designed to predict travel demand patterns under capacity improvement scenarios, these models were not designed to evaluate impacts of emerging transportation technologies, such as automated vehicles. However, travel demand models can be used in conjunction with other tools and methods to support automated transportation analysis.

Microscopic Simulation Models can provide detailed representations of the traffic and road networks. They represent individual vehicles and traffic control strategies (such as ramp metering or traffic signal preemption) at high resolution. Hence, these tools demonstrate substantial promise for modeling automated transportation applications and strategies. Nonetheless, they require large amounts of data for their calibration and validation. Their ability to model large networks is limited, considering their significant computational requirements.

Mesoscopic Simulation Models combine some properties of both microscopic and macroscopic simulation models. As they use macroscopic speed/volume relationships, they have less fidelity than microscopic simulation tools with respect to modeling lane changing and weaving maneuvers. However, superior to travel demand models, they can capture the effects of queue lengths and the temporal distribution of congestion. Moreover, mesoscopic models can evaluate dynamic traveler diversions on large-scale networks. Thus, these tools are useful in the modeling of regional automated transportation applications and strategies. As aerial technologies evolve, agencies will need to coordinate with airports on master plans to ensure there is a shared vision on approach paths that must be protected as well as air corridors for UASs.

Modeling Tool Selection

The AV2.1 Team coordinated with the NCTCOG Modeling Team to determine which simulation tool(s) will be used to model the three selected transportation automation scenarios. The NCTCOG Modeling Group selected a new modeling platform developed by the University of Texas Austin in conjunction with the NCTCOG Modeling Team (the UTAV-TAFT model) for the AV2.1 Team to use to evaluate future technology scenarios.

The project team conducted a preliminary review of the UTAV-TAFT model. The UTAV-TAFT model appears to take more emerging technologies into consideration than the NCTCOG's existing TAFT model and has the functionality to simulate the three selected AV2.1 technology scenarios. The NCTCOG's TAFT model does not include that functionality in any of the modeling stages. The UTAV-TAFT model also has a zero-occupancy module, which the NCTCOG TAFT model does not have.

6. SCENARIO SELECTION AND NEXT STEPS

New technologies like automation are changing travel behavior, travel patterns, and land use. To understand the potential impacts of future transportation technologies, the project team developed seven operational scenarios that reflect the region's Mobility 2045 goals: mobility, quality of life, system sustainability, and implementation.

These operational scenarios consider a regional approach to implementation and to impacts of automation. The scenarios consider passenger mobility, as well as freight and goods movement. The scenarios also consider the impacts of existing pilots that could be scaled up to the regional level, such as fully automated vehicles, partially automated vehicles, and urban air mobility.

TRANSPORTATION AUTOMATION SCENARIOS SELECTED FOR EVALUATION:

- Automated Vehicle Impact on the Performance of Roadway Network
- Connected Vehicle-Intersection Systems
- CAV Effect on Population / Employment Distribution

Future Technology Scenarios Selected for Evaluation

Of course, all these reviewed scenarios are important for the planning of automated transportation in the region. However, the project budget allowed for three scenarios to be further developed and modeled. The project team reviewed the operational scenarios with stakeholders on the AV2.1 Project Advisory Committee and the NCTCOG travel demand modeling group. The team asked the stakeholders to rank and select scenarios that their analysis will be of high benefits for transportation automation planning in the region.

The three future technology scenarios selected for the AV2.1 project modeling are:

- Scenario 1: Automated Vehicle Impact on Roadway Network Performance
- Scenario 2: Connected Vehicle-Intersection Systems
- Scenario 3: AV Effect on Population and Employment Distributions

Baseline Scenario. The project Baseline scenario will be the 2045 scenario with almost zero percent automated vehicle market penetration with warm-start provided by NCTCOG in the UTAV-TAFT platform.

Evaluation Scenario 1: Connected-Automated Vehicle (CAV) Impact on the Performance of Roadway Network. CAV technology has considerable growth potential. Thus, there is an urgency among planning agencies to carefully evaluate the benefits and issues associated with the introduction of CAV technologies in their roadway networks. The evaluation of CAVs at the regional level under different operational scenarios requires the development of adequate modeling platforms that can represent the anticipated changes in the transportation system at high fidelity.

Evaluation Scenario 2: CAV Intersection Systems. A connected vehicle-intersection system aims at improving the performance of signalized intersections by increasing the vehicle throughput and reducing vehicle delays and stops. With the increase in the CAV penetration rate, municipalities will gradually upgrade the intersections' control technology to take advantage of the benefits of the connected vehicle-intersection systems. Modeling this scenario will enable the municipalities to quantify the benefits of this technology and justify an investment plan for its deployment.

Evaluation Scenario 3: CAV Effect on Population/Employment Distribution. The household's choice of home location is a complex function of household income, accessibility, number of workers in the household, work location(s), and school district rating. The introduction of autonomous modes in the mix of transportation options can potentially change this paradigm and relax some of the constraints, such as distance to work or entertainment / shopping venues from the home location choice selection process. This shift can result in a more uniform distribution of population and/or employment across the region. This scenario will provide a better understanding on the effect of CAVs on population and employment distribution in the DFW region to capture possible growth opportunity scenarios. Each city or county can use these scenarios to define what it considers desired or undesired growth patterns for their area and to develop policies to incentivize their desired growth pattern.

Next Steps

The project team is currently testing and troubleshooting the UTAV-TAFT model platform and coordinating with NCTCOG on baseline model parameters. The project team will continue to outline the modeling methodology for each scenario.

Then the project team will evaluate the three selected future technology scenarios and document the findings in a Scenario Evaluation Report. The Scenario Evaluation Report will provide guidance on how NCTCOG or local agencies can use the selected modeling tools for future scenario planning or sketch-level evaluation of regional technology impacts. Guidance will also include a list of criteria that NCTCOG and local entities can monitor to track trends and impacts of new deployments of automated transportation over time. These tools will allow NCTCOG and local agencies to plug in a variety of inputs to generate a range of scenarios and potential impacts.