IOWA DOT
I-380 Planning Study

INTERSTATE 380
PLANNING STUDY (PEL)

Automated Corridor

Office of Location and Environment | July 2018

Table of Contents

Figures

Tables

Executive Summary

The Iowa Department of Transportation (Iowa DOT) is conducting a planning study of the Interstate 380 (I-380) corridor between the Iowa City and Cedar Rapids metropolitan areas to best address safety and mobility needs of all freight and passenger travelers. This study is being conducted using the federally adopted Planning and Environmental Linkage (PEL) Study process. It will allow near-term improvements to be planned, designed, and as funding is available, constructed in accordance with the long-term plan. As part of the Planning Study, an Automated Corridor study was conducted. The goals of the I-380 Automated Corridor Study include:

- Leverage existing AV knowledge
- Help understand AVs and other transformative shifts in transportation
- Prepare for AV impacts on safety, mobility and reliability in Iowa
- Consider the impact of AVs on the future I-380 design criteria

The guiding principles for the Planning Study include balancing mobility and access, designing for the future needs, and right-sizing the corridor. These principles are the key reasons for the I-380 Automated Corridor Study. Iowa envisions a future where advanced technologies make travelers safer and the transportation system more efficient and reliable. Automated vehicles (AVs) are the primary technology to deliver these benefits.

As part of their vision, Iowa DOT will build a smart corridor with communication and sensing technology to enable AVs to deliver increased safety and mobility benefits to travelers. AVs are vehicles enabled with technology that allow vehicles to control parts of the driving task, under a range of circumstances. This study employs the Society of Automotive Engineers (SAE) definitions of the scale of vehicle automation to plan for future vehicles on the interstate ranging from levels three to five. Benefits include:

- Reducing the number of crashes related to human factors and weather
- Making significant improvements to highway capacity without the need for additional construction
- Reducing aggressive driving
- Improving travel efficiency and reliability
- Improving mobility to disabled and senior citizens
- Improving fuel efficiency through vehicle drafting

A needs analysis was conducted to account for AVs in the future I-380 design. The study approach acknowledged the uncertainty involved with technology advancements and market adoption and systematically accounted for that uncertainty to drive a robust set of conclusions and recommendations. This study considered multiple future scenarios. Three primary factors were considered as part of the needs analysis; quality of peak traffic service, traffic safety and travel time reliability.

The study approach used a three-step method of scenario planning, scenario analysis and future-proofing. Scenario planning considered the range of possible futures and how likely trends may affect future transportation operations. From the scenario planning stage, four scenarios were advanced to scenario analysis: Early AV Adoption, Rise of the AVs, Limited AV Adoption, and AV Domination.

The analysis of each scenario informed the project team of the range of future design needs. Future-Proofing provided flexibility in the proposed design features, resulting in enhanced adaptability to future trends including AVs.

Conclusions were reached about how I-380 might operate in the future at certain levels of AV adoption. Each of these findings will help Iowa DOT shape future agency policy and practices on how to deal with emerging AV technologies. Key to the study is several recommendations regarding I-380 design and an additional study that should be completed to prepare Iowa DOT for AVs.

Key findings were identified for each topic area and provide Iowa DOT data that can be shared with others within the agency to lead to organizational awareness and impact policies related to AVs. Key findings for each topic area include:

SCENARIO PLANNING

- AVs will serve as the primary vehicle type in the future. Design projects need to consider how current design practices might change to accommodate future trends including AVs.
- AVs are projected to substantially increase traffic demand. Traditional planning studies should include scenarios that examine the sensitivity of increased demand and its impact on corridor needs.

TRAFFIC CAPACITY ANALYSIS/QUALITY OF SERVICE ANALYSIS

- Near-term analysis of AV adoption shows AVs in mixed traffic at lower levels of AV adoption do not show a decrease in segment average travel speeds.
- Mobility needs across most of I-380 in the future will warrant six to eight lanes without AVs. Higher levels of automation show a substantial increase in the efficiency of I-380 to carry higher traffic volumes, which means a future with high AV adoption would extend the period that a six-lane I-380 meets traffic operations criteria.

SAFETY ANALYSIS

- The safety analysis indicated that AVs are capable of preventing the majority of car crashes that occur on I-380 today. The number of crashes per mile will decrease by 9 percent at a 20 percent AV adoption rate and a 55 percent reduction at 85 percent adoption versus future Build conditions in the absence of AVs.

TRAVEL TIME RELIABILITY ANALYSIS

- Without AVs and without widening I-380, travelers will experience longer delays in traffic.
- With AVs and after widening I-380, travelers will experience more days without a slowdown.

FUTURE-PROOFING

- Future uncertainty needs to be considered in the design of I-380 to provide flexibility to operate under the full range of options identified in the scenario planning process.

A primary need of the overall I-380 Planning Study is to identify the future needs of I-380. The detailed analysis found in the I-380 Automated Corridor Study generated a list of recommended changes to the I-380 design to provide enhanced flexibility in the future.

Introduction

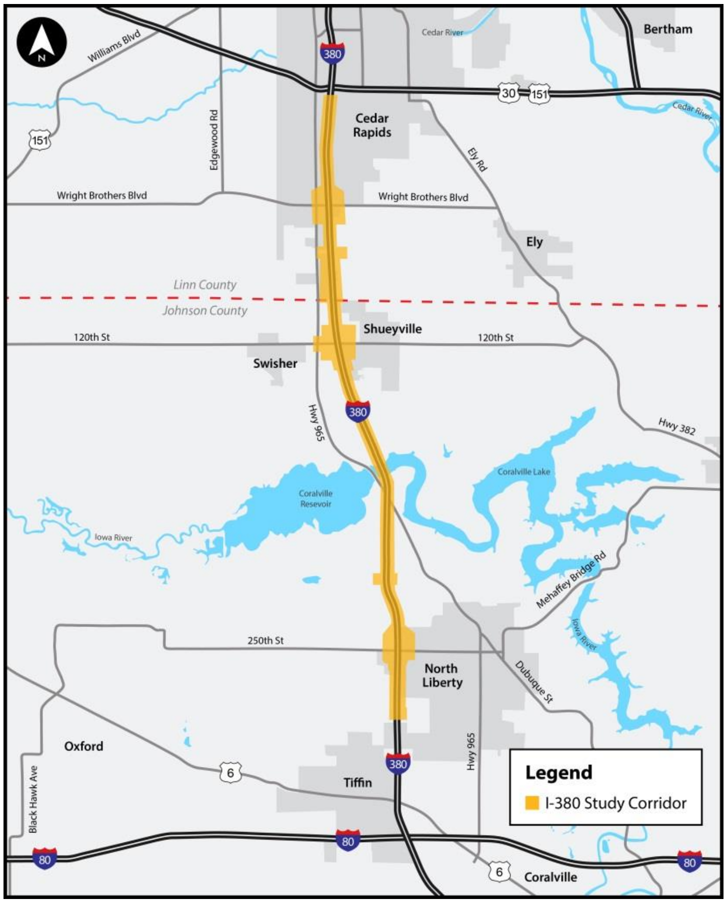
In an effort to provide a safe, efficient, and reliable transportation system, the Iowa Department of Transportation (DOT) is conducting an Interstate 380 (I-380) Planning Study to help guide the development of near- and long-term improvements to the I-380 corridor. A component of this overall planning effort is studying the impact of automated vehicles (AV), also known as connected and autonomous vehicles, and related technologies on the travels of daily commuters and the movement of freight along segments of I-380 in Johnson and Linn counties. The goals of the I-380 Automated Corridor Study include:

- Leverage existing AV knowledge
- Help understand AVs and other transformative shifts in transportation
- Prepare for AV impacts on safety, mobility and reliability in Iowa
- Consider the impact of AVs on the future I-380 design criteria

Study Purpose

Iowa DOT initiated the I-380 Planning Study to prepare a development plan for the I-380 corridor that best addresses the safety and mobility needs of all freight and passenger travelers. I-380 serves as a north-south transportation link and commuter route, covering a distance of roughly 73 miles between Waterloo and Iowa City. The focus of this planning study is the sixteen mile segment of I-380 between U.S. 30 in Cedar Rapids and Interstate 80 (I-80) in Coralville/Iowa City (see **Figure 1**). This portion of the I-380 corridor connects the second- and fourth-largest metro areas in the state of Iowa and sees recurring congestion and reduced level of service (LOS). Under current trends, these issues are anticipated to continue and worsen as the corridor grows in the future.

Figure 1. I-380 Planning Study – Study Area Map



Along the study area, I-380 faces safety and mobility challenges, including:

- Vehicle crashes and fatalities
- Growth in freight and passenger vehicle trips causing increasing congestion
- Aging pavement and bridges
- Adverse weather

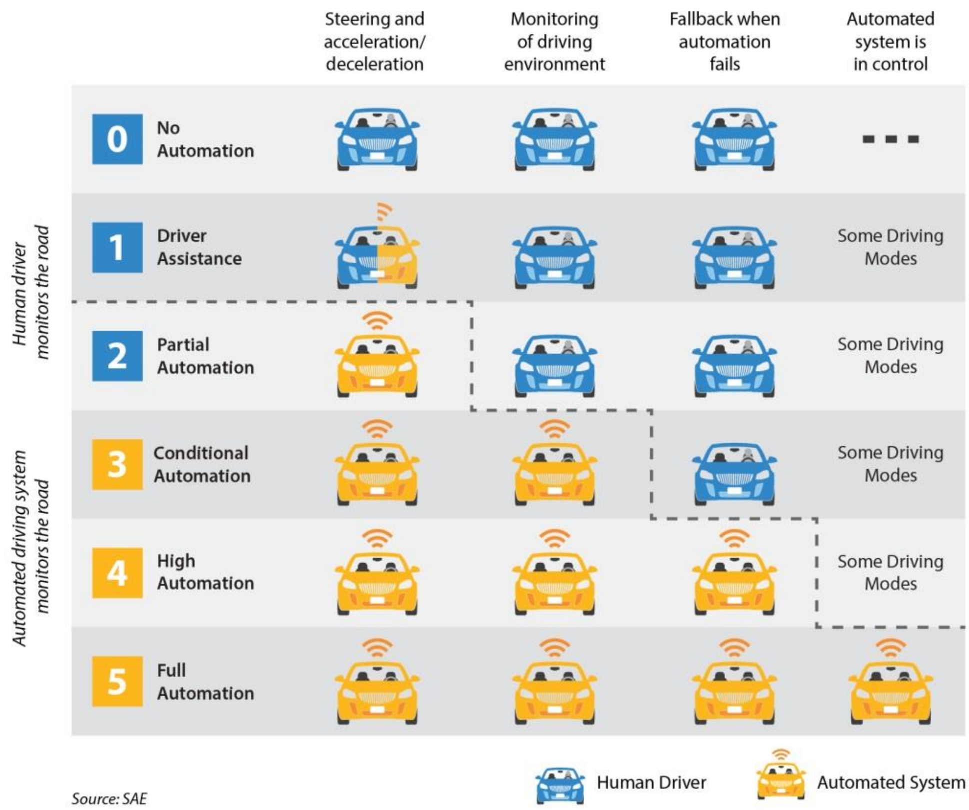
The guiding principles for the I-380 Planning Study include recognizing Iowa DOT's responsibility as a good steward, balancing the many competing needs including, but not limited to: providing a higher LOS, the costs of building and maintaining facilities, and the impacts of construction on the natural environment. Secondly, the Iowa DOT is committed to transparency throughout the planning process and intends to share the findings with and solicit feedback from the stakeholders impacted by changes in the corridor. Finally, by establishing and sharing baseline design criteria the Iowa DOT can better communicate why decisions were made and how the final layout of the interstate met these parameters.

Building on these guiding principles, the I-380 Planning Study will include an emphasis on balancing mobility and access, designing for future needs, and right-sizing the corridor. These goals are the key reasons for the I-380 Automated Corridor Study. Iowa has a vision in which advanced technologies make travelers safer and the transportation system more reliable and efficient. AVs are the primary technology poised to deliver these safety and mobility benefits.

Automated Vehicle Background

Automated vehicles are cars and trucks enabled with technology that allow systems on-board of the vehicle to control parts of the driving task under a range of circumstances. The Society of Automotive Engineers has defined a scale of vehicle automation from Level zero (no automation) to five (full automation); the higher the level the more automated the vehicle is (see **Figure 2**).

Figure 2. Levels of Automation



Level zero (no automation) means the driver has 100 percent control of the vehicle at all times. **Level one** (driver assistance) is when the vehicle assists the driver with single tasks, such as an automatic indicator light for blind spot warning. **Level two** (partial automation) takes it one step further. In this level, multiple features such as Adaptive Cruise Control, which is the automatic adjustment of speed to maintain a safe distance from the vehicles ahead, or Forward Collision Warning (FCW), the use of optical or other technologies to detect a potential upcoming crash, are used. The vehicle is making some adjustments and helping drive, but there are functions that the vehicle cannot handle without driver involvement and if trouble arises, it is the driver's responsibility to take over control of the vehicle.

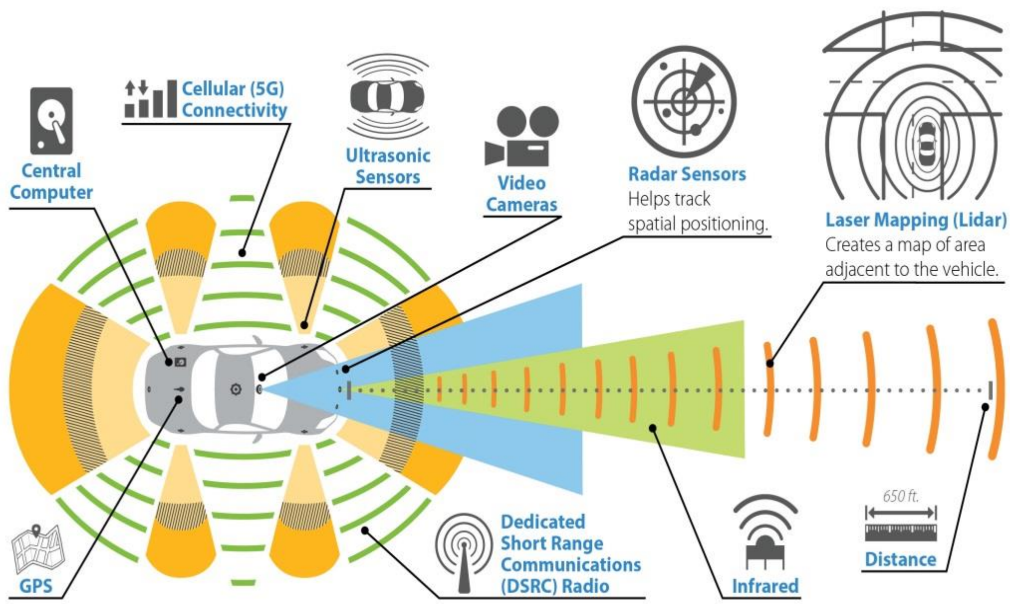
The Tesla Model S is a good example of the limited **Level three** (conditional automation) vehicles that are on the road today. In this level, the driver gives control to the vehicle in certain circumstances. It would be the driver's job to take control of the vehicle, if needed, like in the case of inclement weather.

Level four (high automation) is designed to perform all driving functions and monitor conditions of the road, the majority of the time. In this level, the driver will occasionally need to take over control of the vehicle, but most of the time on the interstate system the car will do the work for the driver.

Finally, in **Level five** (full automation) all one needs to do is buckle up, give the vehicle a destination, and the vehicle will handle the rest of the driving. An automated microtransit shuttle or the Google Waymo vehicles are examples of full automation.

Though many Level four and five technologies today are tested in highly constrained, low speed environments, the longer term vision of this technology is that high or full automation vehicles will be able to operate in mixed traffic on freeway's within the next decade. For this reason, this study considers the future users of I-380 to be a mix of manual drivers (who might use some low level automation features) and upper level AVs (future versions of Level three, four, and five automation).

Figure 3. Automated Vehicle Technology



Vehicles that drive themselves rely heavily on technologies that monitor the driving environment for obstacles, anticipate and quickly react to potential conflicts with nearby vehicles, pedestrians, and other objects, and are capable of controlling vehicle acceleration, braking and steering. Additionally, AVs utilize internal sensors, connectivity to the internet, global positioning systems (GPS), and communications with other vehicles and surrounding infrastructure to create a greater awareness of the vehicles surroundings (illustrated in **Figure 3**).

AVs hold tremendous promise for improving our overall transportation system safety and mobility, and AV research is in its early stages. Specifically, the benefits of AVs include:

- Reducing the number of crashes related to human factors and weather
- Making significant improvements to highway capacity without the need for additional construction
- Reducing aggressive driving
- Improving travel efficiency and reliability
- Improving mobility to disabled and senior citizens
- Improving fuel efficiency through vehicle drafting

Further, to recognize these benefits, agencies need to invest in enhanced infrastructure to assist AVs, building a smart corridor to support smart vehicles. The primary function of this enhanced infrastructure is to provide connectivity to keep drivers and AVs aware of approaching hazards. One aspect of this study is to identify the impacts on required and recommended infrastructure due to the emergence of AVs.

Study Approach

A multi-faceted needs analysis was conducted to account for AVs in future I-380 design needs. The project team began the study by reviewing the work on AVs conducted by Iowa DOT. Iowa's Automated Vehicle Initiative is a program that will blend AV technologies to improve mobility, safety and economic vitality for Iowa travelers and freight. A partnership between Iowa DOT, HERE of North America (HERE) (a global leader in mapping and real-time traveler information), the University of Iowa, and Iowa State University, Iowa's Automated Vehicle Initiative will develop a platform for connecting and guiding AVs based on high-definition (HD) dynamic mapping, predictive travel modeling and a cloud-based communications network. Pilot efforts have focused on I-380 and I-80 in the vicinity of Iowa City and Cedar Rapids. The goal is by 2020 to provide these supporting components as a live data feed to Level 3 and above AVs, enabling greater vehicle safety and efficiency by expanding the vehicles' awareness to situations beyond their typical sensor range. The impacts of this initiative relevant to Interstate 380 planning are discussed later in the Future-Proofing section of this memorandum. Additional details on this initiative can be found in the 2017 Automated Vehicle Technologies Project Vision Document. Work on AVs conducted by the United States DOT (USDOT) and peer agencies is included in **Appendix A – Existing Automated Vehicle Initiatives.**

Existing Conditions and Operations

Prior to consideration of the impact of AV, a baseline assessment was made concerning I-380 conditions and operations in the absence of AV technology. Full documentation of that study is provided in the **I-380 PEL Existing Conditions and Operations Tech Memo** with summaries of findings pertinent to smart corridor assessment and design listed below. Existing conditions were summarized for infrastructure condition, traffic operations, and safety.

The examination of the condition of the physical infrastructure showed that although the pavement and bridges along the I-380 corridor have been maintained, including recent resurfacing, they are beginning to show the impacts of their age. The existing pavement is typically 40 years old but is classified in good condition by the Iowa DOT. Bridges are also rated utilizing a good/fair/poor rating system and those in the study area fall into the good category. Interstate 380 was designed and constructed to the design standards of the 1970's. While most geometry components meet acceptable criteria notable exceptions include shoulder width and cross-slope. Future efforts to bring I-380 into closer alignment with current standards will likely involve trade-offs between impacts. Specifically, maintaining good median drainage patterns might force modifications to outside roadside infrastructure and slopes increasing the footprint of the facility, but if the project remains within the existing DOT lands then more cost maybe needed to address median drainage. If greater capacity is needed along I-380, widening on the existing alignment should be compared to options that shift the roadway alignment. If roadway alignment change options are preferred, then new land or right-of-way (ROW) would need to be acquired.

In the area of traffic operations, an assessment found the current four-lane cross section is at or near the limit for acceptable roadway operations and projected increases in traffic volume will exacerbate this issue. Currently there are many segments of the corridor operating at a Level of Service (LOS) C, which does not meet current Iowa DOT acceptable LOS for rural freeways. Without additional capacity (adding more lanes) the analysis predicts degraded operations with some segments approaching LOS E by 2026 and almost all segments at LOS E or F by 2040. It should be noted that the current computation of LOS includes density of vehicles (passenger cars per mile per lane), which assumes significant headway spacing is required between vehicles for drivers to maintain the higher speeds accepted on rural Interstates. However, future advances in AV technology will allow decreased headway spacing between vehicles (i.e., higher vehicle density before LOS declines) and new measures of LOS may need to be developed.

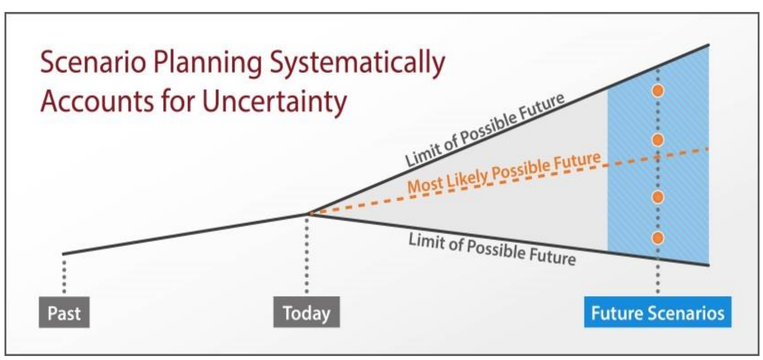
The safety analysis looked at 11 segments within the corridor and compared five-year crash data per segment. The 16-mile corridor experienced 836 crashes across mainline freeway segments, ramp segments, and ramp terminal intersections from 2011-2015 with five fatal crashes. Crashes in this corridor were predominantly single-vehicle run off-road crashes (41 percent) and rear-end (35 percent) crashes. Approximately one-quarter of crashes on the corridor involved at least a possible injury. After reviewing corridor-level crash patterns, crash activity was reviewed for individual roadway segments where segments were treated as the section of roadway between each successive ramp. For the segments analyzed, crash rates exceeded the statewide average for similar facilities at the I-380 Rest Area between 120th Street and Wright Brothers Boulevard and at the systems interchange of I-380 with I-80 and US highway 218.

From these analyses, it is evident that the need for enhancements to I-380 is near-term. While AVs hold tremendous promise to address future corridor traffic operations and safety, this planning study must balance what AVs can offer longer-term, with their more modest potential benefits in the near- to mid-term. The following sections of this document will cover two objectives for addressing I-380 needs: 1) near- to mid-term AV applications for improved traveler LOS and safety, and 2) benefits of a future enhanced I-380 that is flexible to maximize AV technology to move travelers safely and efficiently.

Planning for the Impacts of AVs

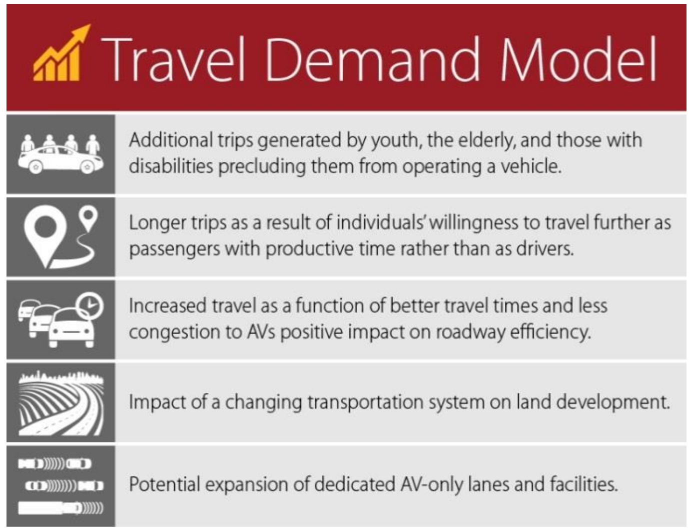
The nature of this study on AVs and advanced technologies rests on the outcome of an uncertain future. The benefits behind the technology may be extraordinarily high if AVs are commonplace or insignificant if the idea dies out. It is important that the study approach drives a set of conclusions and recommendations that are developed acknowledging the uncertainty involved, considering multiple future scenarios. Scenario planning is the approach chosen to systematically account for uncertainty (illustrated in **Figure 4**).

Figure 4. Future Scenario



This approach widens the focus from one future that represents the same trends continuing on the same path as the current day, to a number of possible futures that capture a wide variety of potential impacting factors. A study based on scenario planning can look at one future where the new technologies boom and change how our society operates and another scenario where the technology fad fades. The future's sensitivity to any trend can be investigated and with each additional future reviewed, the study's findings become more robust, preparing for a wider set of ways that the future might develop.

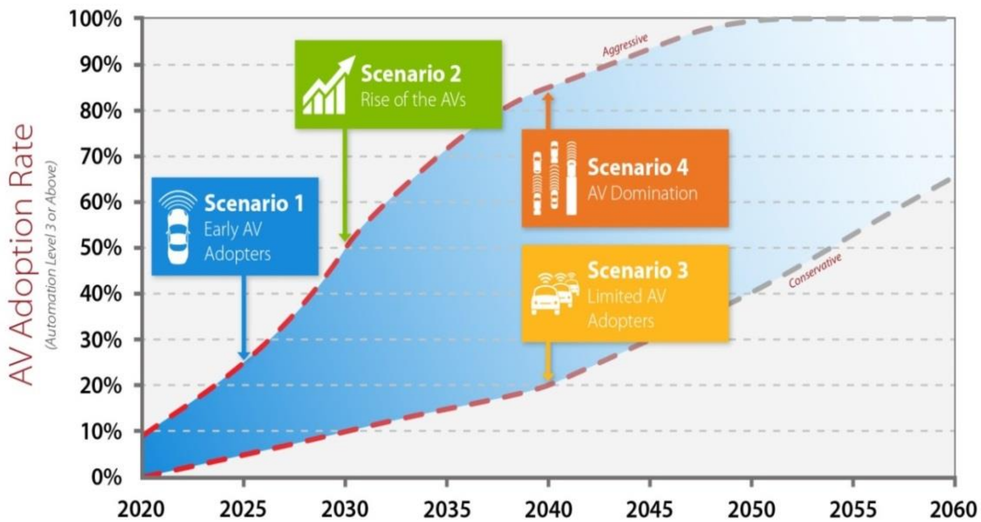
Figure 5. Travel Demand Factors Evaluated



Using a tool called the travel demand model; the study was able to look at individual trip-making behaviors to determine which behaviors will play a significant role in the impacts of AV on the I-380 corridor, which is detailed in **Appendix B** - **Travel Demand Model**. The goal of the travel demand modeling effort was to test the driving public's potential response to the emergence of AVs, and see how consistent the travel demand responses from the Iowa-specific travel demand model are compared to the national research. There are several changing behaviors and factors the model considers. Chief among those changing factors are generational differences, trip length, travel efficiency, and impacts to the overall transportation system (see **Figure 5**).

Upon review of these trends, four AV adoption scenarios were identified for further analysis along with a No-Build, non-technology scenario. **Figure 6** documents the scenarios in terms of assumptions on year of analysis and AV adoption rate.

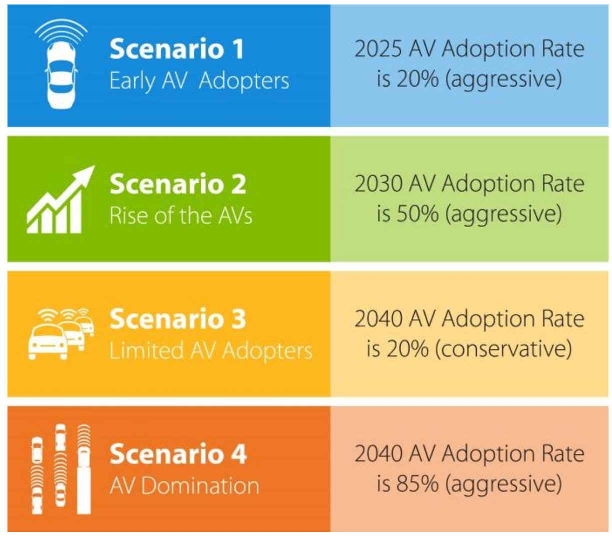
Figure 6. Automated Vehicle Adoption



The I-380 Planning Study and market adoption rates and impacts of vehicle automation are informed by industry leading research by University of Texas, University of California at Berkeley, Victoria Transportation Policy Institute and Goldman Sachs. The scenarios ranged from conservative to aggressive in market adoption.

The scenarios cover the range of anticipated AV adoption patterns based on a review of prominent research. The combination of Scenario 1 (Early AV Adopters), 2 (Rise of the AVs), and 4 (AV Domination) represent a future with aggressive AV adoption at different points in time: 2025, 2030 and 2040. These scenarios include the less dominant, trip-reducing impacts of millennial travel behavior and an aging population. Alternatively, Scenario 3 (Limited AV Adopters) represents a conservative future in which drivers adopt AV slowly and the impacts of additional travel behavior factors are not included. All four scenarios included the impact of smart truck parking, based on Iowa's involvement in the successful Mid America Association of State Transportation Officials (MAASTO) grant application to deploy the technology at key public and private truck parking areas along I-380. All scenarios are summarized in **Figure 7**. A detailed explanation of the assumptions related to the four analyzed scenarios is included in **Appendix C – Literature Review.**

Figure 7. Scenarios



Also included in all four scenarios is the assumption that I-380 will be widened statewide to six lanes. Interstate 380 has existing and near-term traffic capacity and safety needs, and even aggressive predictions for AV adoption recognize that Level 3 and above AVs will not have a majority share of the vehicle market until at least 2030. Given near-term needs that will not be foreseeably met by AV technology, the project management team decided to focus this scenario analysis on the impact of AV technology on an assumed six-lane I-380 cross section.

For these scenarios, the findings of the literature review and the results of travel demand modeling were compared to determine the change in trip frequency for I-380. The results of the travel demand model suggest that under the most likely impacts of AVs, a 100 percent AV fleet would see an increase in traffic between 14 percent and 20 percent. The high end of that range from the travel demand model analysis is quite similar to the AV trip frequency increases synthesized from literature for Scenario 4 (AV Domination). The similarity in the results from these two techniques suggests Iowa can use the travel demand model in future studies to assess the network impact of AV technology. However, the current travel demand model is not streamlined for modeling AVs and non-AV traffic efficiently, so this study set the assumed changes in trip frequency due the introduction of AV technology based on the literature review. **Table 1** presents the adjustment factor synthesized from the literature for changes in trip frequency each scenario.

Table 1. Travel Pattern Adjustment Factors

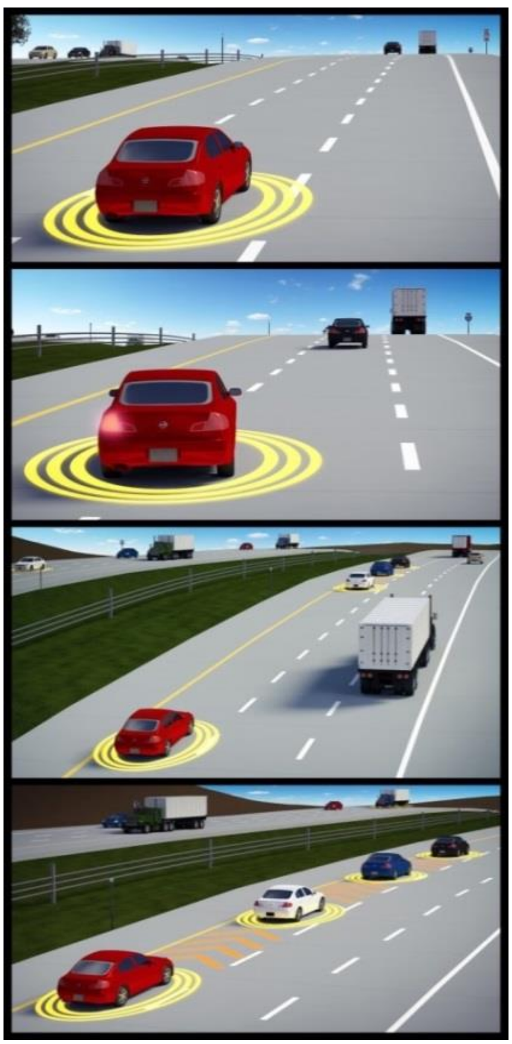
Travel Pattern	Scenario 1 (2025) Early AV Adopters (%)	Scenario 2 (2030) Rise of the AVs (%)	Scenario 3 (2040) Limited AV Adopters (%)	Scenario 4 (2040) AV Domination (%)
Change in Trip Frequency	+6%	+14%	+6%	+19%

In this study of I-380, the project team went beyond simply extrapolating the work of others and developed analysis methods that provided locally-specific estimates of the impact of AV technology mixed with manually operated vehicles on I-380. The primary factors considered as part of the I-380 needs analysis included: quality of peak traffic service, traffic safety, and travel time reliability. Each of these analyses required a methodology that captured the effects of AVs and advanced technology.

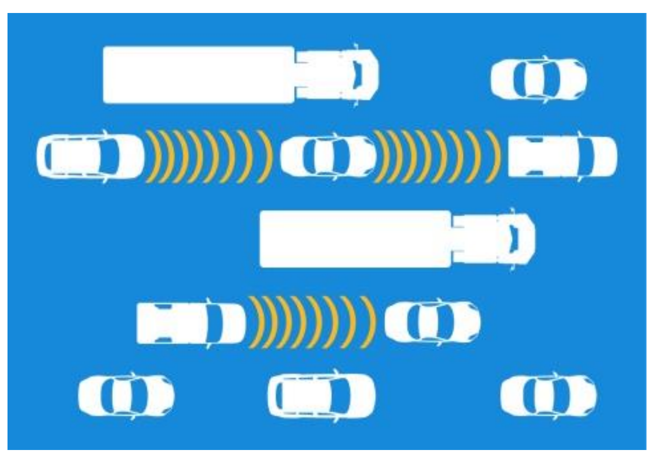
Traffic Capacity Analysis/Quality of Service

Providing high quality traffic operations is a standard of freeway design. To assess how AV technology might affect traffic operations, the project team developed a custom Vissim traffic microsimulation model, a tool for creating a digital representation of real-world traffic operations, to capture the impact of individual vehicle interactions between AVs and manual vehicles. Once AV technology enters the traffic fleet, vehicles will be able to make driving maneuvers with better awareness of their own surroundings and in cooperation with other communications-enabled vehicles. To assess AV impacts appropriately, this cooperative behavior must be added to Vissim through custom programming developed to support AV planning in Iowa.

Figure 8. Automated Vehicle Platooning Scenario



To illustrate the added value of AVs, an example of the flow of the AV simulation tool is shown in Error! eference source not found. **8**. An AV enters a three-lane section of I-380 in the model. The simulation is informed of the new AV's presence and then checks the AV's position relative to a manually-driven vehicle that is ahead of the AV – referred to as the "lead vehicle". The AV is provided a special class of driver behavior by the custom programming so that the AV can reduce his following distance behind the manual vehicle to account for the AVs near instantaneous perception-reaction time. As the AV continues, it can tell through the standard Vissim procedure that it is traveling faster than the manual vehicle and will either need to slow or change lanes. Vissim allows the AV to pass to the left of the slow vehicle and now run in the inside lane. Once in the inside lane, the AV now

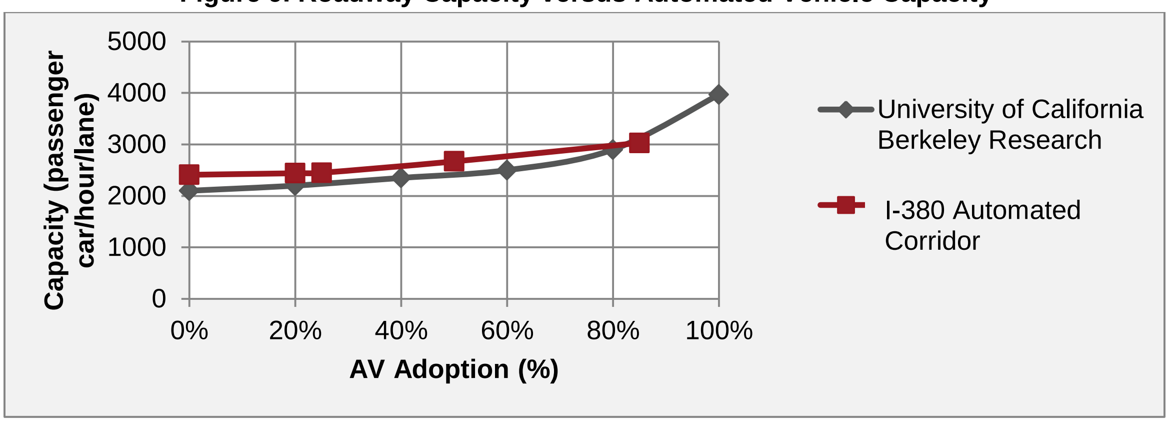


Vehicle Platooning: *AV will travel in platoons for greater efficiency, enabled by vehicle connectivity.*

has a new lead vehicle. The new lead vehicle happens to be another AV that is the rear vehicle in a platoon, or group, of three AVs. The custom programming tells the AV that it is allowed to speed up a set amount in order to catch the platoon. Once the AV reaches the back of the platoon, the custom programming allows the platoon to accept or reject this new vehicle into the platoon based on an assumed maximum platoon size of five vehicles. Because the approaching vehicle yields only a four-vehicle platoon, the new AV is allowed into the platoon and instructed by the simulation to close the spacing between itself and the vehicle in front of it and then reset its desired speed to match the platoon leader's speed. Vissim continues the simulation as if each individual vehicle is making separate driving choices, but the custom programming provides some extra cooperation between the four vehicles in the platoon, so they can for a time operate as a unit. The combination of the custom programming and Vissim run the entire analysis period operating in a similar fashion to provide that extra information to each AV. The custom programming also manages when vehicles would want to leave a platoon and reset to its original preferred speed. The custom AV simulation tool was applied to the study scenarios and AV adoption rates. See **Appendix D – Traffic Capacity Methodology and Results** for further details.

From the simulation analysis, two key findings were realized. The first key finding was that the project team identified the increased roadway capacity impact of AVs in mixed traffic. **Figure 9** shows the simulated capacity compared to adoption levels of Level 3 and above AVs, and at 85 percent AV adoption levels the capacity of a single freeway lane was found to be more than 3,000 vehicles per hour. At 100 percent adoption, researchers using a similar approach to the project team found capacities as high as 4,000 vehicles per hour, which would essentially double the amount of traffic that could be moved on a given roadway during peak traffic.

Figure 9. Roadway Capacity versus Automated Vehicle Capacity



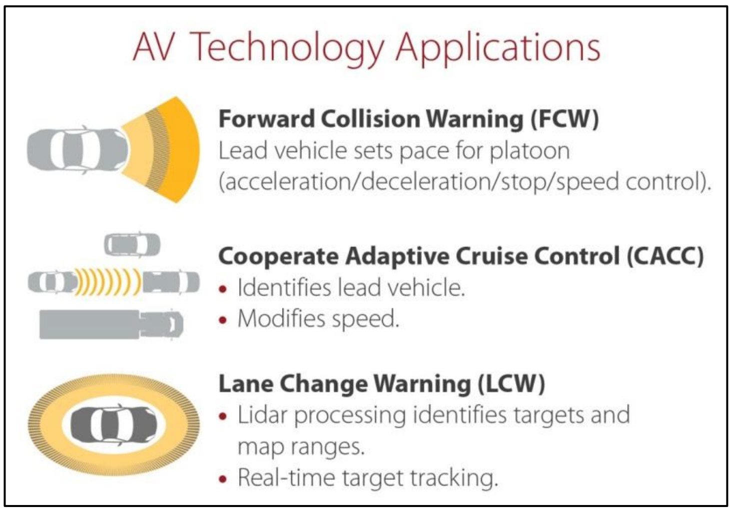
The second key finding was that the introduction of AVs changes how the quality of traffic service is measured. AVs change how transportation performance is assessed because a self-driving vehicle is less affected by how many vehicles are on the road. This density or spacing of vehicles is the key determinate of the most common freeway performance measure, level of service (LOS). In fact, AVs are expected to be designed to have connectivity features that encourage vehicles to drive in small groups or platoons. These platoons will operate with vehicles closely following a lead vehicle that is sending the trailing vehicles information about the speed to maintain, changes in roadway direction, and approaching hazards. The benefit of these dense platoons is that their space efficiency could lead to extra space for manually operated vehicles and allow Iowa DOT to provide a better-operating system with reduced need for future capacity expansion construction projects.

Densities, speeds, and demand-to-capacity ratios for multiple scenarios were compared at multiple locations. Across the board, AV technology led to higher average freeway densities, which in traditional analysis would signify a decline in the LOS score. Yet, the simulation model showed that AV technology led to higher average speeds and corresponding decreased travel times. The project team found that while the relationship between traffic volume and roadway density appears to be less relevant in the context of AVs, the analysis results show the correlation between average speeds and demand-to-capacity ratio is similar in cases with AV as it is today without AV. Consequently, future planning and preliminary design efforts that include the impact of AVs should consider using demand-to-capacity ratio as a key performance metric, understanding that the threshold for capacity per lane will increase with AVs.

Safety Analysis

AVs are capable of preventing the vast majority of car crashes that result from human error or judgment, saving tens of thousands of lives in the United States.The National Highway Traffic Safety Administration (NHTSA) has performed studies linking 94 percent of crashes to driver behavior, so AVs that mitigate driver error should be pursued to increase roadway safety. With lower level automation technologies already on the market, evidence is growing that automation features can reduce crashes.

Figure 10. AV Safety Technologies



The AV safety technologies in the research cover applications such as Forward Collision Warning (FCW), Cooperative Adaptive Cruise Control (CACC), and Lane Change Warning (LCW) as illustrated in **Figure 10**.

- FCW "system has forward-looking vehicle detection capability, using sensing technologies such as cameras, radar, and Lidar. Sensor data are processed and analyzed, and alerts are provided if a collision with another vehicle is imminent." When combined with automatic electronic braking (AEB) and/or automated steering this system could slow or stop a vehicle or shift it laterally; thereby reducing many common crash types such as rear-end crashes (Kockleman, Avery Bansal et al. 2016 pgs. 7 and 79).

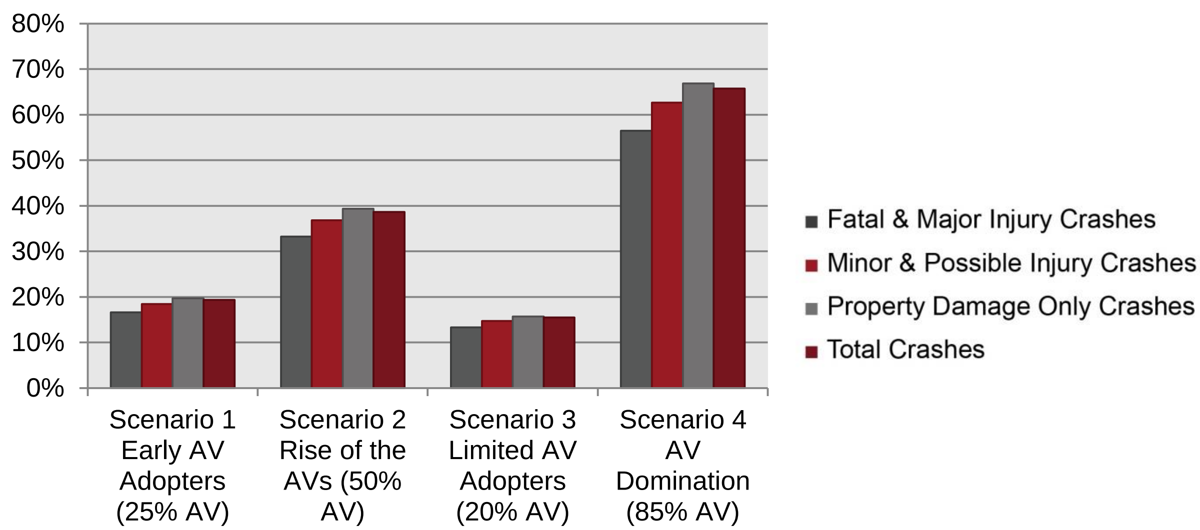
- CACC is a system that involves vehicles communicating with other vehicles behind them regarding speed and lane assignment. The technology can improve both safety and traffic flow. The safety benefits are due in part to the ability to communicate and act on that communication nearly instantaneously. The brake reaction time for a CACC-equipped vehicle following another CACC-equipped vehicle has been estimated at 0.1 second. This is substantially faster than the fastest human brake reaction time of 0.47 second.

- LCW, also known as Lane Departure Warning (LDW), technologies use sensors to detect the position and trajectory of surrounding vehicles and will warn the driver and/or take action if another vehicle poses a safety threat. It will also warn the driver and/or take action if the vehicle itself is leaving its lane in a manner that presents a safety threat. This technology is related to blind-spot monitoring and has the potential to reduce many common multi-vehicle crashes.

Research synthesized for the I-380 Automated Corridor Study looked at the crash reduction potential of a combination of automation features that would be present in AVs. The researchers also created an association between events just prior to a crash and specific automation features that would be triggered by that event, a technique called crash mapping.

It is possible to estimate an overall crash reduction for a highway segment by combining the crash mapping, an assumed reduction in crashes for each technology, and an AV adoption rate. For example, if all rear-end crashes in a segment were mapped to FCW technologies and if there was a 50 percent AV adoption rate, then the research indicates that a certain percentage of those rear-end crashes will be avoided. This same approach can be used for all crash causes, technologies and severities to yield a total crash reduction factor. **Figure 11** shows how large the crash reduction factor is expected to be on Interstate 380 due to the introduction of AV technology by scenario.

Figure 11. Safety Analysis Results



Even at 25 percent AV adoption, nearly 20 percent of existing crashes are anticipated to be eliminated by AV technology. At 85 percent AV adoption, fatalities and major injuries were projected to see a greater than 55 percent reduction and property damage only crashes were projected to see a 65 percent reduction. The potential for AVs to benefit safety is tremendous.

If the baseline condition is a future where AVs are not adopted, we should expect that over time crashes will increase in that baseline condition due to the growth of traffic/trips in the corridor. The project team considered the combined effect of this AV crash reduction factor with the anticipated growth in baseline crashes over time due to a growing number of trips on the corridor. To assess the growth in projected crashes, a crash prediction modeling approach was used. Details of the crash prediction modeling can be found in **Appendix E – Corridor Safety Methodology and Results**. **Table 2** shows the results of combining the crash prediction modeling with the AV crash reduction factor for the three scenarios occurring in year 2040 on a typical segment of rural I-380 between Iowa City and Cedar Rapids.

Table 2. Crash Prediction Results

Rural I-380 Typical Segment - Annual Predicted Crashes									
	2040 No-Build (4 Lanes)			**2040 Scenario 3 (6 Lanes)**			**2040 Scenario 4 (6 Lanes)**		
	Avg. Daily Traffic Volume	Total Crashes	Fatal & Major Injury Crashes	Avg. Daily Traffic Volume	Total Crashes	Fatal & Major Injury Crashes	Avg. Daily Traffic Volume	Total Crashes	Fatal & Major Injury Crashes.
Baseline (0% AV)	77,600	49.9	0.7	77,600	38.1	0.7	77,600	38.1	0.7
Predicted (w/ AV)				82,250	34.8	0.6	92,350	17.1	0.4
Crashes Eliminated					*3.3*	*0.1*		*21.0*	*0.3*
Percent Reduction					***9%***	***10%***		***55%***	***49%***

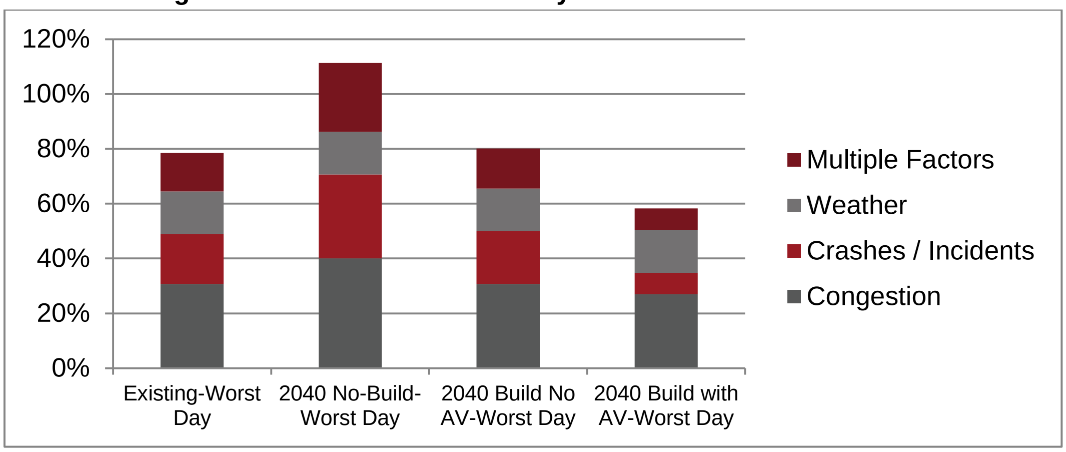
The crash prediction modeling identified that in the future, in the absence of AVs, the number of crashes on I-380 will increase due to traffic volume growth. The proposed widening on I-380 will result in a reduction in the crash rate, expressed as the number of crashes per million vehicle miles travelled, due to safety improvements that would be part of the widening project. The widening of I-380 combined with AV adoption, particularly high levels of AV adoption, is anticipated to lead to lower crashes than are experienced today, even with the number of vehicles traveling I-380 expected to grow by almost 60 percent.

Travel Time Reliability

In addition to safety and peak traffic service improvements, AVs are anticipated to provide more comprehensive improvements in traffic operations. The project team sought to capture those benefits using travel time reliability. Travel-time reliability has been defined as “the level of consistency in travel conditions over time, measured by describing the distribution of travel times that occur over a substantial period of time” (Potts, Harwood, Hutton et al. 2014). This essentially means: how do the bad congestion days or worst travel time days over a year compare with the time it takes on a normal travel day?

To understand those worst travel time days, the project team utilized research findings of several projects under the Second Strategic Highway Research Program (SHRP2) showing a cause and effect relationship between traffic volume-to-capacity ratio, the amount of time the roadway is impacted by crashes, incidents, and work zones, and the presence of severe weather. The combined effect of these factors were considered without detailed reliability modeling to qualify whether scenarios with higher levels of AV adoption lead to improved travel time reliability. Based on the travel time reliability relationships developed in the SHRP2 research, **Figure 12** charts the general trend of worst travel time days across multiple scenarios.

Figure 12. Worst Travel Time Days across Various Scenarios



Today, a worst travel time day might take about 80 percent more travel time than a day traveling without delay (at free-flow conditions). For an individual segment of I-380 that added 80 percent might add 1-2 minutes for a short trip in the southwest Cedar Rapids metro area or it could add 10 minutes for a trip between I-80 and US 30. By 2040, if I-380 is not widened the worst day travel time will likely grow by another 20-40 percent, increasing the delay of a full corridor trip up to another 5 minutes. With Build improvements to I-380 the corridor may experience similar to slightly worse (<5 percent worse) conditions compared to those seen today. However, through the adoption of AV along I-380 in conjunction with widening, the overall reliability of the corridor may benefit through an approximate 20 percent reduction in worst-case day travel time compared to today's conditions just based on the greater than 50 percent reduction in crashes/incidents and improved ratio of demand volume to available roadway capacity. However, the travel time reliability benefits of AVs may be even more impactful, especially if still developing research on AVs finds that these vehicles operate more reliably in all weather conditions.

Future-Proofing

At the conclusion of the multi-faceted scenario analysis, the planning results were applied back to the primary concern of the I-380 Planning Study; namely, designing a solution that meets the needs of I-380. The challenge in this case is designing for the uncertainty in the timing of advanced technology proliferation. The future-proofing process led to recommendations for the design of I-380 that allow the corridor to be flexible to respond to future technology and other transformative factors. The key areas addressed to balance needs with flexibility while limiting expense were:

- Mobility needs and expandability
- AV infrastructure needs
- Construction methods and materials
- Right of way needs

By considering built-in flexibility in these design areas, the proposed concept allows for the ability to better utilize the available pavement within the widened footprint when proliferation of AV technology is realized. Also, investments in communication and sensing technology will transform I-380 into a smart corridor, better able to react to traveler needs. For example, by repurposing the left shoulder and left lane areas for conditional AV use, I-380 will provide more capacity and will be less likely to breakdown due to increased traffic volumes and incidents. One illustration of how this transition could occur is represented in the changes from **Figure 3** to **Figure 14**.

Figure 13. Original I-380 Widening Concept

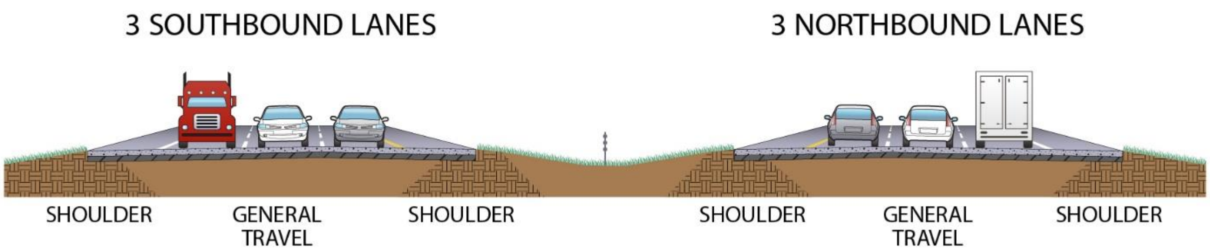
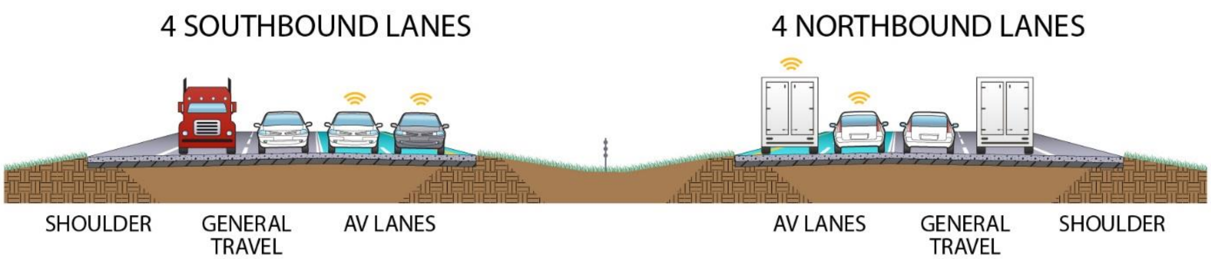


Figure 14. Preferred I-380 Widening Concept with Automated Vehicle Findings



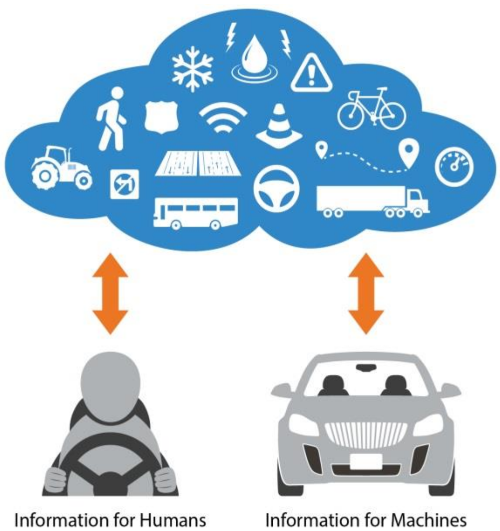
Highlights of the design considerations that would allow a seamless transition in time from the cross section in **Figure 13** to **Figure 14** include:

- Twelve-foot-wide left and right shoulders with full-depth pavement for future flexibility, including:
  - Left shoulder: Future use as a conditional shoulder/AV-only lane that could serve high-capacity transit
  - Right shoulder: Use as a safe breakdown area and maintenance of traffic in work zones
- Robust pavement design considering higher levels of heavy vehicle exposure within one path of the critical design lane
- Construct continuous fiber optic and power lines along the corridor
- Design of AV-supportive infrastructure, including:
  - Reference markers to assist AVs in acquiring positional information
  - Machine-readable signs

- Roadside equipment (5G cellular or DSRC)
- Communications infrastructure: Advanced cellular and fiber
- Detection: Cameras / video processing, sensors and processed data from AVs
- Limit fixed deployments of traveler information (e.g., Dynamic Message Signs)

All of these proposed modifications address current corridor operations, safety and reliability needs while being flexible with the introduction of AV technology.

Figure 15. Automated Vehicle Initiative Goal for Traveler Information



Source: Iowa DOT

AVs provide a growing set of benefits to traffic operations and design, and require AV-supported infrastructure. Infrastructure elements include both physical elements such as fiber and cameras and virtual elements, such as HD mapping, which provide additional sensing capabilities that work beyond the range of AV sensors and functions in all weather scenarios. AV-supported infrastructure will transition I-380 to a corridor that provides connected and cooperative information between vehicles and the roadway and roadway operator. More so than any other Iowa roadway, the I-380 corridor is being prepared for future AV use through the Iowa AV Initiative with a heavy focus on the data infrastructure needed to support AV data flow. AVs will be supported by a massive amount of traveler information and today Iowa is developing the specifications to keep that data current and available (see **Figure 15**).

Appendix F – Future Proofing and Design Considerations provides further discussion on AV-supportive infrastructure that should be considered for deployment along I-380 as AVs gain more widespread use.

Conclusions

The project team assessed the I-380 corridor for AV impacts as part of the broader I-380 Planning Study. The study approach used a three-step method of scenario planning, scenario analysis and future-proofing. Scenario planning considered the range of possible futures, and how likely trends may affect future transportation operations. Out of the scenario planning stage, four scenarios were advanced to scenario analysis. The traffic team did a detailed scenario analysis for Early AV Adoption, Rise of the AVs, Limited AV Adoption, and AV Domination in the areas of:

- Traffic capacity/quality of service
- Traffic safety
- Travel time reliability

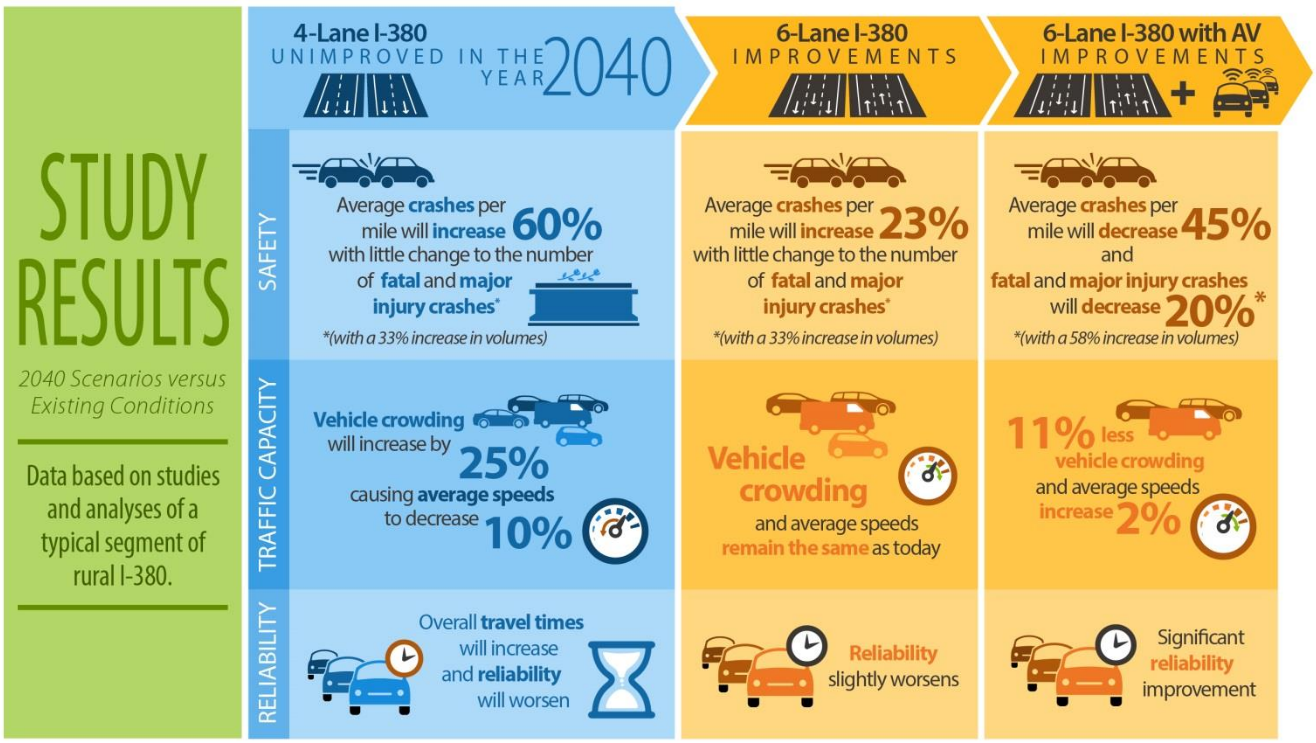
The detailed output of these scenario analyses informed the project team of the range of future design needs. Future-proofing sought to associate flexible design features with future design needs to mitigate Iowa DOT's risk of improving I-380 in a way that does not meet traveler needs.

From this effort, many conclusions were reached about how I-380 might operate in the future at certain levels of AV adoption. Each of those findings will help Iowa DOT shape future agency policy and practices on how to deal with this emerging set of transportation technologies. Key to the study were several recommendations regarding modifications to the original I-380 design (listed above in **Future-Proofing**) and an additional study that should be completed to prepare Iowa DOT for AVs.

KEY FINDINGS

Along the study process, a number of key findings were identified by the project team. Key findings represent the key outcomes of the study in a concise manner, such that the Iowa DOT team that managed this study can share these findings with others within the agency to lead to organizational awareness and potentially change policies related to AVs. Key findings are listed below by topic area. **Figure 16** illustrates the I-380 Automated Corridor Study results.

Figure 16. I-380 Automated Corridor Study Results



Scenario Planning

AVs are projected to make up 20 percent to 85 percent of all traffic by the year 2040. The planning horizon of 2040 is less than 25 years away, thus well within the planning horizon for agency long range plans. Based on the results of this study and related efforts, agencies should standardize the practice of including AV scenario analysis in long range plans and alternatives analyses for specific corridor/site improvements. A supplemental finding is that AVs need to be considered at all levels of the design process. For example, when considering pavement design, pavements are designed to perform for up to 40 years of design life before requiring rehabilitation. By 2060, 40 years after the first segment of I-380 could be open to traffic, AVs are projected to make up 65 percent to 100 percent of all traffic. Thus, with AVs serving as the primary vehicle type, design projects need to consider how the previous design practices might change to accommodate AVs. Advances will need to be made in how bridge and pavement infrastructure are maintained and replaced with consideration of many more vehicles on the roadway.

AVs are projected to substantially increase trips compared to baseline (no-AV) scenarios, by as much as 19 percent for high levels of AV adoption on rural freeways. As traditional planning studies are conducted to identify corridor needs, studies should include scenarios that examine the sensitivity of increased demand and its impact on corridor needs. To a lesser degree, some societal impacts will change travel demand over time. Demographic trends show that the U.S. population is aging and Millennials (those born 1979 through 2000) are becoming a more dominant part of the traveling population. As research points to those two cohorts traveling less frequently, travel demand may see a less than five percent reduction in the number of trips on rural freeways.

Traffic Capacity/Quality of Service Analysis

Traffic needs for rural I-380 were assessed for a representative segment of the study area. Portions of I-380 between Iowa City and Cedar Rapids exhibit poor quality of travel today and are projected to have significant mobility needs in 2040. On portions of the corridor, the projected number of vehicles in 2040 is high enough to warrant six to eight lanes on I-380 to meet the desired design LOS alone. However, the studied scenarios with AV at various adoption rates in mixed traffic with manually operated vehicles, showed promise for increasing the capacity and quality of service over scenarios omitting technology. At high levels of AV adoption, roadway capacity was found to increase substantially even with AVs in mixed traffic with manually operated vehicles. Based on that finding, high levels of AV adoption could delay the need for additional I-380 future expansion (beyond 6 lanes) by 20 to 30 years or more over standard analyses that omit the impacts of AV.

While several of the study scenarios looked at the design year impact of AV adoption, a few scenarios were reserved for near-term analysis of the impact of AVs. The key finding from these scenarios is that AVs in mixed traffic at lower levels of AV adoption do not show a decrease in segment average travel speeds. This finding is significant because some have characterized the transition years where AVs first enter general traffic as being dominated by slow speeds due to overly cautious AV driving.

AV adoption increased the speeds on the Interstate, even though AVs also increased the number trips. As demand reaches very high levels of density, overall simulated speeds stayed higher due to consistent AV operations. As further studies confirm that LOS based on density is becoming obsolete under the rollout of AVs, the industry will have to look at modifying design guidelines that size facilities by a density-based LOS. The *Interstate 380 Planning Study Guiding Principles* set the threshold performance in the design year for I-380 at LOS B. In the long-term, I-380 may carry traffic much more dense than that criterion, but based on the AV operations analysis, freeway speeds will still provide travelers with more efficient travel times.

Safety Analysis

The safety analysis indicated that AVs are capable of preventing the majority of car crashes that occur on I-380 today. Based on the crash mapping method developed using local I-380 data:

- At 20 percent AV adoption, crash reductions of 9 percent were observed compared to Build conditions without technology.

- At 85 percent adoption, AVs yield a crash reduction of 55 percent, compared to Build conditions without technology.

It is important to note that as traffic volumes grow over time, crashes would be predicted to increase. Today, a general segment of I-380 might experience an average of roughly 31 crashes at volume of just under 60,000 vehicles per day. The high AV adoption scenario would see average daily traffic increase due to typical growth patterns and technology to almost 95,000 vehicles per day (58 percent increase), but the average annual predicted crashes would be down to 17 crashes per year (a 45 percent decrease).

A safety analysis method was applied that provides for a location-specific estimate of crashes that could be prevented using AV technology. This safety method for AV projects will help agencies study and prioritize roadways with the highest potential AV benefits.

Travel Time Reliability Analysis

AVs are expected to provide a benefit to traffic operations beyond peak hour quality of service and a reduction in the number of crashes called travel time reliability. The study applied a travel time reliability approach that considered how AVs reduce bottlenecks, reduce crashes and incidents, and potentially mitigate weather events. The method showed that without AVs or widening on I-380, those “worst travel days” are anticipated to happen more frequently, keeping drivers stuck in traffic for longer periods of time. The analysis indicated that No-Build conditions increase the delay on worst-travel days (less reliable conditions) compared to existing conditions. However, high AV adoption levels combined with I-380 widening keeps the worst-travel time days at levels below existing. This is significant because the corridor will be carrying considerably more traffic with relative growth far exceeding the amount of roadway capacity that would be added through widening.

Future-Proofing

The Iowa DOT is currently gathering high-definition mapping information and establishing data sharing processes to support the research and development of today’s emerging AV technology along the I-380 corridor. The addition of scenario planning helps inform future facility needs across a range of potential futures. Future uncertainty means the design of I-380 should be flexible to operate under the range of possible technology adoption futures identified in the project scenario planning. Future-proofing will involve the inclusion of physical and virtual infrastructure in the design and construction of I-380 improvements. The traffic capacity, safety and reliability benefits will vary depending on how the future of AV and other trends unfold over time.

Design Recommendations

A primary need of the overall I-380 Planning Study is to identify the future needs of I-380. Many of those future needs are unrelated to AVs and have been conducted as separate tasks under the larger umbrella of the I-380 Planning Study. It will take a synthesis of all of these tasks to reach a preferred design for I-380. That said, the detailed analysis of I-380 for the impacts of AVs generated a list of recommended changes to the I-380 cross section first presented in the guiding principles of the I-380 Planning Study. Recommendations include:

- Design pavement considering AVs
    - Potential impact on pavement thickness
- Design the pavement base and geogrid to extend the full width of the pavement

- 12-foot-wide left shoulder and right shoulder with full depth shoulder pavement
- Construct continuous fiber optic and power lines along the corridor
- Design of AV-supportive infrastructure
    - Reference markers to assist AVs in acquiring positional information
    - Machine-readable signs
    - Roadside equipment (5G cellular or DSRC)
    - Communications infrastructure: Advanced cellular and fiber
    - Detection: Cameras/video processing, sensors and processed data from AVs
- Limit fixed deployments of traveler information (e.g. Dynamic Message Signs)

ADDITIONAL STUDY

This automated corridor analysis has uncovered a number of key findings and design recommendations to address the potential AV impact on I-380. Yet, there are still many action items left to properly incorporate AVs into the I-380 corridor and widespread use on public roadways in general. Many of these action items fall upon the industry as a whole and are beyond the scope of designing and studying I-380. Two action items in particular are very significant to the design of I-380 for accommodating AV technology, namely:

- Develop a concept of operations for I-380 and AVs, including consideration of AV-supportive infrastructure
- Study pavement effects of truck only facilities and vehicles with little lateral movement within lanes due to lane centering

Due to the planning nature of this study, more substantive recommendations on how to design for AV operations were not completed. Future work will include the development of the concept of operations for I-380, which will provide specific technology needs on I-380 for AV-supportive infrastructure and be used for future project development, maintenance and operation of the system.

Glossary

Access – Ease of getting people and goods to or from specific locations adjacent to the roadway.

Adaptive Cruise Control (ACC) – Vehicle assistance technology that combines traditional set-speed cruise control with sensors and automatic braking to maintain a safe following distance relative to the car ahead.

Automated Vehicle – Vehicles enabled with technology that allow vehicles to control parts of the driving task, under a range of circumstances.

Automatic Electronic Braking (AEB) – Vehicle assistance technology that applies the vehicle's brakes automatically and forcibly if sensors on the vehicle recognize that a collision with the car ahead is imminent.

Cloud – Internet storage and processing available on demand, accessible from virtually any location.

Connectivity – Linkage between two separate entities; can include physical linkage between two physical locations or virtual linkages, such as communication of information between vehicles.

Dedicated Short Range Communications (DSRC) Radio – Radio capable of sharing messages 10 times a second within a fixed boundary over a specific communications band reserved for transportation.

Forward Collision Warning (FCW) – Vehicle assistance technology that audibly or visually warns a driver if sensors on the vehicle recognize that a collision with the car ahead is imminent.

Future-proofing – Flexible design of a system to build in adaptability to future trends and disruptions.

Global Positioning System (GPS) – Navigation system that provides a receiver's location if the receiver has an unobstructed line of sight to four or more positioning satellites.

Lane Change Warning (LCW) – Vehicle assistance technology that audibly or visually warns a driver if another vehicle is occupying the adjacent, target lane when a turn signal has been activated.

Lane Departure Warning (LDW) – Vehicle assistance technology that audibly or visually warns a driver if their vehicle begins to cross a painted lane line without activating a turn signal.

Level 0 Automation- A vehicle that does not possess any advanced driver-assistance technologies.

Level 1 Automation – A vehicle equipped with one or more driver assistance functions that support either steering or acceleration/deceleration of the vehicle.

Level 2 Automation – A vehicle equipped with driver assistance functions that simultaneously supports steering and acceleration/deceleration of the vehicle.

Level 3 Automation – A vehicle that can steer and accelerate/decelerate automatically and monitor the driving environment; these vehicles rely on a human driver to take over control of the vehicle if automation fails.

Level 4 Automation – A vehicle that can steer and accelerate/decelerate automatically, monitor the driving environment and have automated systems as a fallback if automation fails; these vehicles will operate in automated mode most of the time, but in certain circumstances will give control of the vehicle to a human driver.

Level 5 Automation – A vehicle that is fully controlled by automated technology with no intervention from a human driver.

Level of Service (LOS) – Traffic standard for the quality of multimodal traffic operations governed within the Highway Capacity Manual. Multiple performance measures can be converted to a scale between LOS A (high quality operations, practically unimpeded flow) and LOS F (poor quality operations, vehicles excessively delayed).

Lidar (Laser Mapping, Light Detection and Ranging) – Technology that uses laser sensing to measure the distance to objects rapidly in three dimension (3D). Individual measurements are layered together to create digital, 3D representation of the surrounding environment.

MAASTO (Mid America Association of State Transportation Officials) – Transportation organization including 10 states that collaborate to foster the development, operation and maintenance of an integrated and balanced transportation system for users within the region.

Mobility – The ability to move people or goods from place to place.

No-Build – A future alternative where no alterations/modifications are made to the transportation infrastructure.

Peak Traffic Service – Conditions during either the morning or afternoon rush hour; assessing the quality of traffic flow, often using the LOS scale.

Platoon – A group of vehicles that follow one another with close spacing and coordination of vehicle speeds.

Travel-time Reliability – The level of consistency in travel conditions over time based on the distribution of travel times observed.

Vissim Traffic Microsimulation Model – Tool for creating a digital representation of real-world traffic operations. The model uses vehicle mechanics and rules for vehicle behavior and interaction to simulate traffic flow moment by moment.

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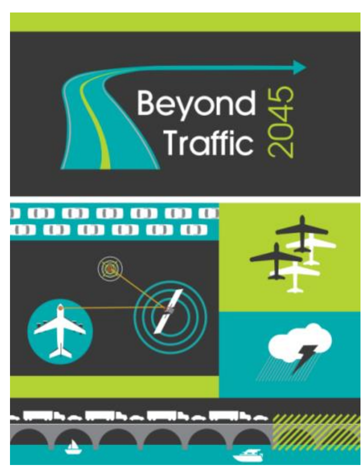
APPENDIX A – EXISTING AUTOMATED VEHICLE INITIATIVES

In planning for the future needs of Interstate 380 (I-380), a wide net was cast to draw on automated vehicle (AV) experiences across the country, especially efforts led by the U.S. Department of Transportation (USDOT).

A.1 IOWA'S AUTOMATED VEHICLE INITIATIVE

Iowa's AV Initiative is a transformational program that will blend connected and AV technologies to improve mobility, safety, and economic vitality for Iowa travelers and the freight industry. A partnership between Iowa Department of Transportation (DOT), HERE of North America (HERE) (a global leader in mapping and real-time traveler information), the University of Iowa, and Iowa State University, Iowa's AV Initiative will develop a platform for connecting and guiding automated (connected and autonomous) vehicles based on high-definition (HD) dynamic mapping, predictive travel modeling and a cloud-based communications network. The initial deployment began in 2016 and covers interstates in the Cedar Rapids and Iowa City metro areas. All covered roadways will be part of the dynamic HD map or HD Live Map, constantly sharing centimeter-level accuracy in feature information to the cloud where it can be retrieved by in-vehicle navigation systems, mobile phone applications, and eventually high-functioning AVs.

The HD Live Map is an agency-enabled layer of extra sensing capabilities that adds to the existing sensing capabilities of AVs and provide better real-time information to drivers. The HD Live Map directly addresses traffic safety, alerting vehicles to prevent end of queue and weather-related crashes. From 2010 to 2014, the Cedar Rapids – Iowa City area accounted for 5% of statewide traffic fatalities. Iowa's AV Initiative is expected to provide dramatic reductions in those numbers. Further, the cloud platform supporting the HD Live Map constantly synthesizes and communicates data, allowing AVs, first responders, Iowa State Patrol, and the statewide traffic management center to mitigate unexpected occurrences of congestion. Iowa's AV Initiative will go further than highly effective communication of recent events, going as far as to leverage big data to predict future crashes and congestion, and advise vehicles to take precautionary measures. Major program accomplishments are expected in 2017, including complete HD Live Map coverage of the program area and development of initial predictive travel models. Beyond 2017, the program is expected to continue to keep up with a growing number of AVs on Iowa's transportation infrastructure. Additional details on Iowa's AV Initiative can be found in the 2017 Automated Vehicle Technologies Project Vision Document.[1]



A.2 USDOT INITIATIVES

USDOT is undertaking several initiatives to help realize autonomous and connected vehicle (CV) implementation.

Beyond Traffic 2045

USDOT has recognized the great potential that emerging technology trends can play in making America's transportation system once again the best in the world. USDOT provides a visioning framework for the transportation system of the future in the ***Beyond Traffic 2045***

[1] https://www.iowadot.gov/pdf_files/IowaVisionDocument.pdf

report.[2] The report lays out key trends and implications to all modes of travel, including the highway system, with a significant focus on the opportunities that transportation technologies might provide. Beyond Traffic 2045 first provides some context by discussing trends in several sections:

- **How we move** discusses key demographic shifts that will affect our country between now and 2045, including population growth, aging Americans, continued growth of American mega-regions, high levels of time lost due to traffic congestion and transportation needs of the poorest Americans.
- **How we move things** outlines the growth in multimodal freight shipments, emerging opportunities, challenges and potential impacts on the economy and transportation system.
- **How we move better** covers technology opportunities and how we can take steps to leverage opportunities to improve information for travelers and safety and mobility for all modes of travel.
- **How will we adapt** discusses how we can make infrastructure more resilient and reduce the footprint of transportation, particularly in the face of climate change.
- **How we align decisions and dollars** lays out how transportation is funded, current shortfalls, and describes a path forward to build a system that serves the nation's needs.

The report then transitions from a discussion of trends to a review of system implications. It offers a multimodal perspective and acknowledges challenges such as increasing congestion, aging highways and bridges and declining revenues. The final section, ***A Better Path*****,** suggests that to address challenges, there is a set of principles that guide policy decisions ahead. Much of that discussion centers on opportunities technologies play in addressing transportation challenges ahead. The key takeaway is that USDOT expects a significant influx of transportation technologies that will change how the transportation system operates.

Intelligent Transportation Systems (ITS) Strategic Plan (2015-2019)

USDOT has conducted several research activities to promote the adoption of transportation technologies through the implementation of the ***ITS Strategic Plan 2015–2019***.[3] Strategic plan priorities are to:

- Enable safer vehicles and roadways
- Enhance mobility
- Limit environmental impacts
- Promote innovation
- Support transportation system information sharing

The *ITS Strategic Plan 2015–2019* identified six program categories as priorities for research and investment. Much of the program categories focused on various elements of automated and connected vehicles. These program categories are:

- **Connected vehicles** activities focused on adoption and deployment of CV systems, particularly: 1) Vehicle-to-vehicle (V2V) communications based on dedicated short-range communications (DSRC) technology; and 2) other CV technologies and communications enabled by DSRC or other technologies (e.g., cellular, Wi-Fi or satellite).

[2] https://www.transportation.gov/sites/dot.gov/files/docs/Draft_Beyond_Traffic_Framework.pdf
[3] www.its.dot.gov/strategicplan/

- **Automation** activities focused on automated road-vehicle system research that transfers various levels of vehicle control from the driver to the vehicle.
- **Emerging capabilities** initiative focused on evaluating emerging and long-term technologies that might transform our transportation systems.
- **Enterprise data** activities focused on integrating new, emerging transportation data sources for use in researching, measuring and managing the transportation system.
- **Interoperability** focused on developing standards and architecture to ensure Intelligent Transportation Systems (ITS) elements in vehicles, devices and infrastructure can communicate and work together.
- **Accelerating deployment** facilitating a smooth transition from the initial adoption stage to widespread deployment.

Other important USDOT publications regarding planning for a technology empowered transportation future include:

- **Smart City Challenge** is an initiative whereby USDOT pledged up to $40 million in funding to a medium-sized city, to help it leverage the opportunities technologies provide in addressing the challenges of improving mobility. In competition with 77 cities submitting applications, Columbus, Ohio, was selected as the winner of the grant. The program's goal is to help Columbus integrate innovative technologies, such as connected vehicles, traveler information, smart infrastructure, and smart sensors, into the city's transportation network. The Columbus Smart City project started in fall 2016. More details on the program are provided in **Section A.3**.
- **Regional Connected Vehicle Pilot Programs** were sponsored by the USDOT ITS Joint Program Office (JPO) to implement and test several different CV technologies. In 2016, USDOT awarded three cooperative agreements with Wyoming, New York City, and Tampa to initiate a design-build-test phase of the CV Pilot Deployment Program. Each pilot site is demonstrating different technology applications relevant to their setting, including V2V and vehicle-to-infrastructure (V2I) applications such as Forward Collision Warning (FCW), Work Zone Warning (WZW), Spot Weather Impact Warning (SWIW), Speed Compliance, Intersection Movement Assist (IMA), Pedestrian in Signalized Crosswalk, Transit Signal Priority and Red Light Violation Warning (RLVW). Additional details of these regional connected vehicle pilot tests are documented in **Section A.3**.
- **AV Proving Grounds** were designated in January 2017 by USDOT. Ten proving ground sites were selected from a pool of 60 applicants to foster innovations for safe testing of automated technology. The ten sites include:
    - City of Pittsburgh, Pennsylvania, and the Thomas D. Larson Pennsylvania Transportation Institute
    - Texas AV Proving Grounds Partnership
    - U.S. Army Aberdeen Test Center
    - American Center for Mobility (ACM) at Willow Run
    - Contra Costa Transportation Authority (CCTA) and GoMentum Station

- San Diego Association of Governments
- Iowa City/Cedar Rapids Corridor and the University of Iowa's National Advanced Driving Simulator
- University of Wisconsin-Madison
- Central Florida AV Partners
- North Carolina Turnpike Authority

- **South Eastern Michigan Connected Vehicle Test Bed** is run by the USDOT research program. It offers an environment for testing technology, applications and services to its members, an affiliation of companies and institutions collaborating to exchange information, share lessons learned and develop a common technical platform. The current test bed is in southeast Michigan, and offers a wide range of V2V and V2I testing features.
- **Connected Vehicle Safety Pilot** is a pilot project that demonstrated DSRC-based, connected vehicle safety applications for potential deployment. The pilot is testing the effectiveness of these applications under real-world conditions to determine safety effectiveness. Recent pilot projects have assessed applications on transit vehicles.
- **Dynamic Mobility Applications** take data collected from smart vehicles and devices and connects those elements to share data to benefit safety and mobility. There are six applications that are currently being advanced:
  - **Enable Advanced Traveler Information System (EnableATIS) –** working toward a framework for taking dynamic mobility data and providing advanced traveler information.
  - **Freight Advanced Traveler Information Systems (FRATIS) –** travel information, load matching and routing optimization application specific to the freight industry.
  - **Integrated Dynamic Transit Operation (IDTO) –** data and connections that increase the likelihood of riders making successful transfers between vehicles and systems, provide enhanced real-time data to both riders and system operators, and allow for dynamic ridesharing in real time via mobile devices.
  - **Intelligent Network Flow Optimization (INFLO) –** utilizing a combination of V2V and V2I deployments to provide location-specific information to drivers in an effort to harmonize speeds, warn of impending queues and operate cooperative adaptive cruise control (CACC) among vehicles in a platoon.
  - **Multi-Modal Intelligent Traffic Signal Systems (MMITSS) -** using advanced communications and data to improve mobility and facilitate the efficient travel of passenger vehicles, pedestrians, transit, freight and emergency vehicles through the system.
  - **Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) –** improves traffic safety and mobility during crashes and other highway network emergencies by focusing on incident management and responder safety. R.E.S.C.U.M.E. provides pre-arrival data to emergency responders, work zone alerts for drivers and workers and emergency communications for evacuation.

A.3 OTHER STATE PROGRAMS

Whether funded through a USDOT initiative or the vision of agency management, these state initiatives parallel Iowa's effort to speed the realization of autonomous and connected vehicle implementation. The other primary state programs include:

- **Colorado Road X** – Colorado DOT's advanced technologies incubator program will eventually support a fully connected transportation system between drivers, vehicles, infrastructure and the agency. Road X began in earnest in 2016 through the development of a project team including consulting firms CH2M Hill, AECOM, and Atkins, technology partners Panasonic, HERE, and OTTO (now owned by Uber), and local agency partners like the City of Denver. In October 2016, the Road X project demonstrated the ability for a commercial delivery to be made via a self-driving truck within specially mapped freeway corridors. The project is in the process of delivering a smart truck parking system using cellular and DSRC technologies. One of Road X's key 2017 priorities is to overhaul an active traffic management and ramp metering system on Interstate 25 with the goal of moving more traffic with greater efficiency without widening the freeway.
- **Smart Columbus** – Columbus, Ohio, was the winner of USDOT's first Smart City Challenge based on their vision of Smart Columbus. The Smart Columbus vision was based on five key tenets: access to jobs, smart logistics, connected residents, connected visitors and sustainable transportation. Once implemented, Smart Columbus will improve resident quality of life through a bundle of applications supporting more efficient mobility with a focus on equitable transportation options across social groups. Smart Columbus will provide connected vehicle and infrastructure solutions for the city's new CMAX bus rapid transit (BRT). It will also provide electric, self-driving shuttles at transit hubs to improve accessibility for the first and last mile of transit trips.
- **NYC CV Regional Pilot** – New York City was one of three original pilot projects part of the USDOT Connected Vehicle Deployment Program. The New York City pilot focused on equipping up to 8,000 vehicles that frequently travel in Midtown Manhattan and Central Brooklyn to transmit and receive connected vehicle data. The pilot also includes deploying roadside units (RSUs) to provide infrastructure-based updates to connected vehicles. Up to 100 pedestrians will wear personal devices that communicate with instrumented vehicles. New York City's goal for this pilot is to focus on unlocking potential safety improvements of connected vehicle technologies for all modes.
- **Tampa CV Regional Pilot** – Tampa Hillsboro Expressway Authority (THEA) was the second of three original pilot projects that were part of the USDOT Connected Vehicle Deployment Program. The THEA pilot focused on benefits of connected vehicle technology in improving safety and mobility during morning commutes. THEA manages reversible express lanes that bring commute traffic into downtown Tampa as the focal point of the pilot area in addition to three major downtown arterial streets. The THEA deployment includes equipped vehicles, infrastructure and pedestrians: 1,500 cars, ten buses, ten trolleys, 500 pedestrians and 40 roadside units.
- **Wyoming CV Regional Pilot** – Wyoming DOT was the final recipient of three original pilot projects that were part of the USDOT Connected Vehicle Deployment. The focus of the Wyoming pilot was to improve traveler safety on Interstate 80 (I-80), particularly considering extreme weather and commercial vehicles. The Wyoming pilot included 400 equipped trucks (mix of agency-owned and private trucks) and 75 roadside units.
- **Chattanooga CV Demonstration** – In addition to the USDOT-sponsored connected vehicle pilots, some other agencies have begun to fund their own connected vehicle pilot projects. Chattanooga, Tennessee, developed a connected vehicle pilot plan and is now undertaking portions of the project as part of an existing congestion mitigation study with funding from the State of Tennessee and the Federal Highway Administration (FHWA). The Chattanooga pilot addressed the need for transit signal priority.

- **Smart Belt Coalition** – The Ohio, Michigan and Pennsylvania DOTs, along with the Ohio Turnpike and Infrastructure Commission and the Pennsylvania Turnpike have formed a coalition focused on advancing technologies collaboratively and consistently in the tri-state area.
- **Missouri Road-to-Tomorrow** – Missouri DOT has launched a technology focused program designed to enhance the testing, adoption and promotion of new transportation technologies including new pavement design and construction, solar roadways and other innovative technologies.
- **Texas Smart State** – Cities and regions across Texas are partnering with the Texas A&M Transportation Institute, the University of Texas at Austin's Center for Transportation Research (CTR) and Southwest Research Institute (SwRI) to form the Texas AV Proving Ground Partnership. The statewide partnership has the goal of making Texas the nation's first Smart State by creating a platform for innovation to address community challenges.
- **Maricopa County Department of Transportation (MCDOT) Connected Vehicle Test Bed and SmartDrive Program** – MCDOT along with Arizona DOT and the University of Arizona collaborated to develop a CV Test Bed in Anthem, Arizona, to test the MCDOT SMARTDriveSM Program's vehicle prioritization technology.

Autonomous and Connected Vehicle Test Facilities

- **MCity** – The University of Michigan and Michigan DOT collaborated to design this 32-acre site of private testing roadways on the University's North Campus. MCity opened in July 2015 and allows AV manufacturers, after-market automation technology companies and researchers to test their vehicles on a strategically designed test bed. MCity roadways include features such as intersections, traffic signs and signals, sidewalks, benches, simulated buildings, streetlights and obstacles such as construction barriers.
- **CCTA** –CCTA is a public agency serving Contra Costa County in the San Francisco Bay Area. CCTA has taken a progressive stance toward the inclusion of future technologies, such as vehicle automation, in their long-range planning. CCTA has acquired an abandoned naval campus and opened the facility to industry testing of autonomous and connected vehicles. The vehicle testing program has been dubbed Gomentum and CCTA has established an initial vehicle automation testing program with partner OTTO, a truck-focused vehicle automation company.
- **Transportation Research Center (TRC)** – Located in Marysville, Ohio, TRC is the largest independent vehicle testing facility and proving grounds in the U.S. covering more than 4,500 acres of automotive courses and test tracks. TRC is home to National Highway Traffic Safety Administration (NHTSA) Vehicle Research and Test Center, which is the only federal vehicle research and test laboratory in the country. Recently, TRC announced a $45 million investment plan to implement new connected and autonomous vehicles testing capabilities and courses at the facility.
- **Texas Transportation Institute RELLIS Campus** – Located ten miles from Texas A&M's main campus, the RELLIS Campus provides testing facilities that accommodate a wide variety of transportation research and implementation projects, including those associated with connected and autonomous vehicles.
- **SunTrax Test Facility** – Florida DOT has recently announced a partnership with the Florida Polytechnic University to create this 2.25-mile oval track on a 400-acre site in Polk County explicitly to test emerging transportation technologies such as connected and autonomous vehicles.

A.4 EMERGING FUNDING SOURCES

Funding programs represent the public side of support behind AV evolution. Details of these funding programs continue to develop, thus details in this report may not reflect final program details.

- **AASHTO Signal Phasing and Timing (SPaT) Challenge –** AASHTO has released a draft document providing guidelines of a planned challenge to state and local agencies regarding SPaT. The SPaT message set conveys important signal timing information from the traffic signal controller to a connected or AV using DSRC. Use of SPaT could eventually lead to signal priority applications, red light violation warnings, and intelligent signal systems applications that would allow the signal to optimize its timings on the fly. AASHTO sees an opportunity to help member agencies be better prepared for connected vehicles by deploying this key communication tool. AASHTO is challenging each state to deploy at least 20 traffic signals with SPaT by 2020 and commit to operate SPaT for a minimum of ten years. AASHTO does not have a dedicated funding stream for this challenge, but, along with other members of the V2I Deployment Coalition, will provide technical guidance to agencies requesting assistance. The challenge will be effective upon approval by at least a two-thirds majority of the AASHTO Standing Committee on Highways, which had not been achieved at the time of publication of this report.
- **FAST Technology Grants** – The U.S. Congress approved the Fixing America's Surface Transportation (FAST) Act in December 2015. Included in the legislation were several funding opportunities to be competitively distributed by USDOT. One of these opportunities was the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Initiative. The ATCMTD initiative was targeted at emerging technologies that reduce congestion and improve safety. Sixty million dollars of funding was set aside by Congress for each year from 2016 through 2020. Agencies competed for up to ten awards out of the $60 million funding pool, and were required to provide 50 percent of matching funds. The winners of the 2016 program were announced in October 2016. It is anticipated that USDOT will publish a similar notice of funding opportunity for 2017 in the coming months.
- **National Institute of Standards and Technology (NIST) and U.S. Ignite Global City Teams Challenge (GCTC)** – NIST and U.S. Ignite have collaborated to create the GCTC. This provides a platform for local government representatives and technology issues.

APPENDIX B – TRAVEL DEMAND MODEL

The purpose of this memorandum is to document the potential impact of Automated Vehicles (AV) on traffic demands on the Interstate 380 (I-380) corridor between Interstate 80 (I-80) and US 30 based on travel demand model sensitivity testing. Mid-range (2025) and long-range (2040) sensitivity tests were developed to examine a range of travel behavior impacts from AVs on the corridor. This appendix summarizes the results of six aspects of the potential future transportation system including AVs, modeled utilizing the Iowa DOT's iTRAM statewide travel demand model.

B.1 INTRODUCTION

AVs promise a fundamental revolution in mobility. They are expected to make traveling safer, cheaper, more comfortable, more sustainable, and more equitable. They will open the possibility for teens, elderly and the disabled to serve as a vehicle operator. Depending on the adoption trends, they may also trigger a substantial reduction of the total vehicle fleet and substantial road capacity gains. If all those assumptions are realized, AVs will not only revolutionize transportation, but could dramatically change the urban form. By substantially reducing the real and perceived cost of travel, they may induce substantial amounts of additional travel demand and boost a new wave of suburbanization and urban sprawl. Alternatively, by reducing onsite parking needs and enabling conversions of travel lanes to bike lanes and pedestrian uses in the urban core, they may encourage a more compact urban growth pattern.

This analysis considers modeling techniques to measure the impact of AVs using the Iowa DOT's iTRAM statewide travel demand model. Since there is much uncertainty around the future of AVs, several future sensitivity tests were created to consider broad impacts of AVs on the I-380 corridor. These sensitivity tests were not created to accurately predict the future impact of AVs, but rather to develop appropriate ways of evaluating a range of potential impacts on the corridor.

B.2 SENSITIVITY TEST CONDITIONS AND FINDINGS

To model potential impacts from AVs in the I-380 corridor, six sensitivity tests were considered. The following sections explore the assumptions and steps taken to model the scenarios and discuss the results.

Condition 1: Increased mobility for individuals without driver licenses

The magnitude of person trips is assumed to change when automobiles are readily available for all people needing transportation, regardless of ability to drive. The impact of this assumption was tested with iTRAM by modifying the person trip generation rates under select scenarios as shown below.

Condition 1.1 –Trip rates for zero vehicle households were doubled.

Condition 1.2 –Trip rates set for households with more people than autos were set to match the rate of a household with similar size and area type with as many autos as people (i.e., rate for 3-person/2-auto house was set to match 3-person/3-auto house rate).

Auto and truck volume results from Conditions 1.1 and 1.2 are compared to the 2025-Baseline scenario. **Table B.1** and **Table B.2** show percent increase in volume per segment along US 30, I-380, and I-80. Both scenarios with trip generation rate increases indicate increased volumes along I-380 corridor, ranging from around zero percent to six percent.

Table B.1. Total Volume Percent Increase per Segment between Condition 1.1 and 2025-Baseline

Freeway	Location	2025-Baseline		Condition 1.1		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	9,771	15,700	9,831	15,758	0.60	0.40
	East of I-38	9,090	13,528	9,146	13,591	0.60	0.50
I-380	North of US 30	24,548	25,071	24,634	25,138	0.40	0.30
	South of US 30	20,786	19,134	20,803	19,147	0.10	0.10
	South of 120th	21,524	20,724	21,557	20,750	0.20	0.10
	South of 250th	22,499	21,518	22,559	21,463	0.30	-0.30
	South of Forevergreen	23,174	22,185	23,245	22,282	0.30	0.40
	South of I-80	21,469	18,371	21,464	18,370	0.00	0.00
I-80	West of I-380	20,917	25,619	21,002	25,649	0.40	0.10
	East of I-380	26,630	20,688	26,727	20,781	0.40	0.40

Table B.2. Total Volume Percent Increase per Segment between Condition 1.2 and 2025-Baseline

Freeway	Location	2025-BaseYear		Condition 1.2		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	9,771	15,700	10,836	16,825	10.90	7.20
	East of I-38	9,090	13,528	9,950	14,631	9.50	8.20
I-380	North of US 30	24,548	25,071	25,466	25,961	3.70	3.50
	South of US 30	20,786	19,134	21,266	19,661	2.30	2.80
	South of 120th	21,524	20,724	22,225	21,380	3.30	3.20
	South of 250th	22,499	21,518	23,456	22,333	4.30	3.80
	South of Forevergreen	23,174	22,185	24,262	23,567	4.70	6.20
	South of I-80	21,469	18,371	22,316	19,724	3.90	7.40
I-80	West of I-380	20,917	25,619	21,371	26,049	2.20	1.70
	East of I-380	26,630	20,688	27,017	21,140	1.50	2.20

Condition 2: Willingness to travel further due to no driver interaction/stress
Individuals using AVs will perceive the time in them less negatively than time spent driving in regular vehicles, assuming that being driven by a robotic car will eventually be less stressful. Rather than focusing on the road, travelers could spend time relaxing or working, perhaps reducing the disutility placed on travel time. Because travel times are perceived as shorter, people will be willing to travel further distances to work and school. They will also be willing to travel in more congested conditions at peak hours, and may take more trips to do non-mandatory activities like eating meals and shopping.

To test this scenario, magnitude of travel time coefficients was reduced by 10% in the utility expression of the iTRAM Destination choice models. In these models, travel time is interacted with the accessibility of the residence zone location. The accessibility of travelers' residence location reflects the fact that when people choose their residence location, they also effectively choose how far they are willing to travel. **Table B.3** shows reduced travel time coefficients (both linear and log transformed impedance terms) in the Home-Based Work (HBW), Home-Based Other (HBO), Non-Home-Based (NHB), Long-Distance-Work (LNGW), and Long-Distance-Non-Work (LNGNW) Destination Choice models.

Table B.3. Reduced Travel Time Coefficients

Name	Value	Reduced by 10 percent (%)
HBW Res. Accessibility x Impedance	-0.0127	-0.01143
HBW Ln (Res. Accessibility x Impedance+1)	-0.475856	-0.4282704
HBO Res. Accessibility x Impedance	-0.006703	-0.0060327
HBO Ln (Res. Accessibility x Impedance+1)	-0.391147	-0.3520323
NHB Impedance	-0.075	-0.0675
NHB Ln (Impedance + 1)	-0.706423	-0.6357807
LNGW Impedance	-0.004	-0.0036
LNGW Ln (Impedance + 1)	-0.496812	-0.4471308
LNGNW Impedance	-0.006	-0.0054
LNGNW Ln (Impedance + 1)	-1.947312	-1.7525808

Total volumes from Condition 2 are compared to 2025-Basline scenario. Total volume percent increase summary is presented in **Table B.4**. Because travel times are perceived as shorter, the total volume increased by 7-10 percent along the I-380 corridor.

Table B.4. Total Volume Percent Increase per Segment between 2025-Base and Condition 2

Freeway	Location	2025-BaseYear		Condition 2		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	9,771	15,700	10,273	16,598	5.1	5.7
	East of I-38	9,090	13,528	9,567	14,182	5.2	4.8
I-380	North of US 30	24,548	25,071	26,278	26,787	7.0	6.8
	South of US 30	20,786	19,134	22,578	20,957	8.6	9.5
	South of 120th	21,524	20,724	23,403	22,612	8.7	9.1
	South of 250th	22,499	21,518	24,561	23,572	9.2	9.5
	South of Forevergreen	23,174	22,185	25,035	24,097	8.0	8.6
	South of I-80	21,469	18,371	22,707	19,855	5.8	8.1
I-80	West of I-380	20,917	25,619	21,985	26,128	5.1	2.0
	East of I-380	26,630	20,688	27,609	21,665	3.7	4.7

Condition 3: Reduced Headways/Increased Capacity

Vehicle to Vehicle (V2V) coordination systems allow AVs to travel with much shorter headways. This technology will synchronize their operation such as the capabilities of simultaneous braking and acceleration and help them move as platoons or road trains leading to decreases in travel time and improved roadway capacity. If AVs also reduce collision rates, non-recurrent congestion would decrease as well. These and other capabilities may increase roadway capacity.

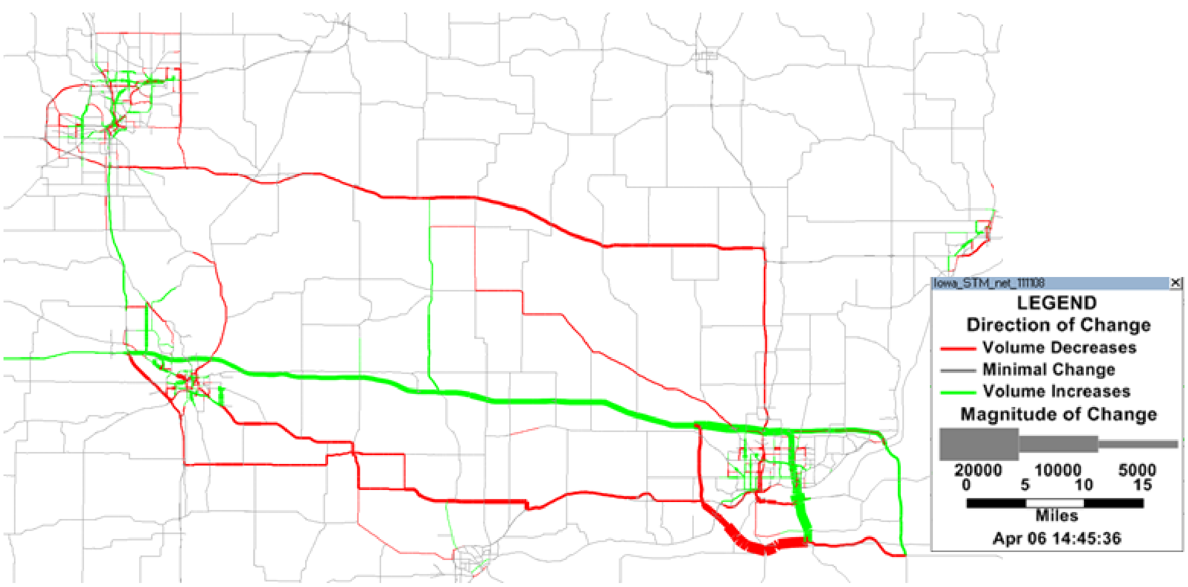
While it’s currently unclear what magnitude of capacity increase is likely, in this scenario a 25 percent increase is assumed to represent a modest result from AV adoption. All freeway and arterial capacities are increased by 25 percent.

As shown in **Table B.5** and **Figure B.1**, increased capacity resulted in a shift in traffic from the lower speed roadways to the higher speed interstate facilities. Traffic decreased by 3.5 percent to 9.5 percent on US 30, but grew by up to 13 percent on I-80 and I-380.

Table B.5. Total Volume Percent Increase per Segment between 2025-Base and Condition 3

Freeway	Location	2025-BaseYear		Condition 3		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	9,771	15,700	8,874	15,118	-9.2	-3.7
	East of I-38	9,090	13,528	8,268	12,859	-9.0	-4.9
I-380	North of US 30	24,548	25,071	24,964	25,825	1.7	3.0
	South of US 30	20,786	19,134	21,883	20,119	5.3	5.1
	South of 120th	21,524	20,724	22,436	21,710	4.2	4.8
	South of 250th	22,499	21,518	22,778	21,613	1.2	0.4
	South of Forevergreen	23,174	22,185	23,909	21,723	3.2	-2.1
	South of I-80	21,469	18,371	19,736	15,568	-8.1	-15.3
I-80	West of I-380	20,917	25,619	23,611	26,490	12.9	3.4
	East of I-380	26,630	20,688	30,136	23,194	13.2	12.1

Figure B.1. Volume Difference Plots between 2025-Base and Condition 3



Condition 4: Combined Condition

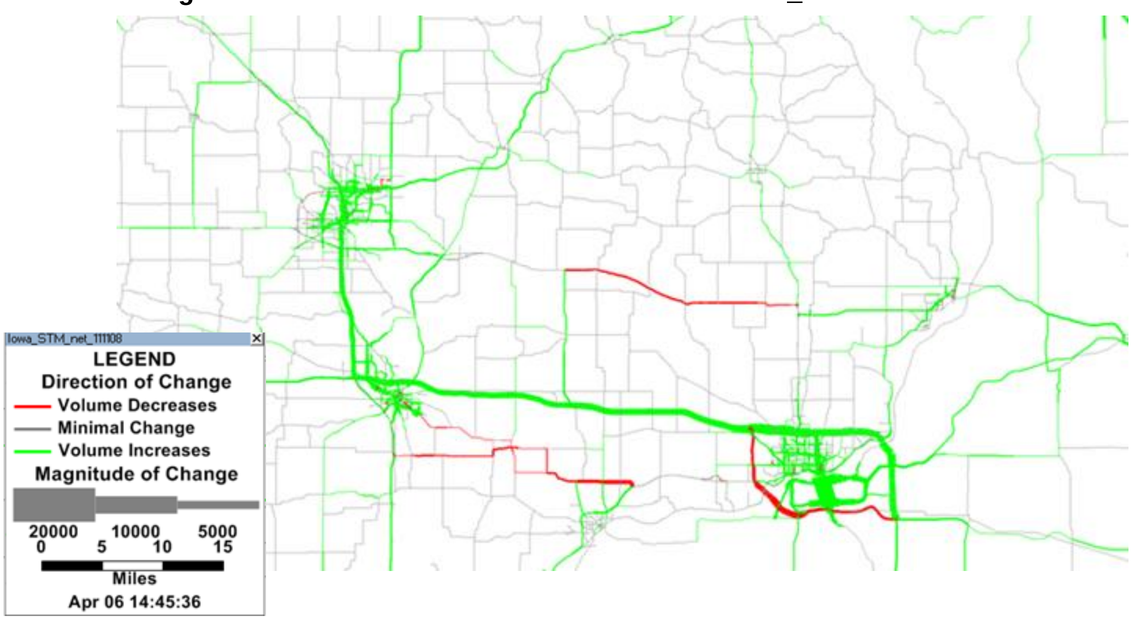
This sensitivity test combined the three test conditions described above - trip generation rates increased, travel time coefficients reduced and all freeways and major arterial capacity increased.

As shown in **Table B.6**, combining these various stand-alone AV effects is anticipated to increase volumes along I-380 by 14-20 percent. **Figure B.2** shows that with the combined scenario, AVs could lead to an overall increase in traffic on the roads.

Table B.6. Total Volume Percent Increase per Segment between 2025-Base and Condition 4

Freeway	Location	2025-BaseYear		Condition 4		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	9,771	15,700	10,524	17,353	7.7	10.5
	East of I-38	9,090	13,528	9,844	14,804	8.3	9.4
I-380	North of US 30	24,548	25,071	28,249	28,961	15.1	15.5
	South of US 30	20,786	19,134	24,920	23,005	19.9	20.2
	South of 120th	21,524	20,724	25,956	24,925	20.6	20.3
	South of 250th	22,499	21,518	26,510	25,115	17.8	16.7
	South of Forevergreen	23,174	22,185	27,411	25,328	18.3	14.2
	South of I-80	21,469	18,371	23,039	18,837	7.3	2.5
I-80	West of I-380	20,917	25,619	24,223	27,723	15.8	8.2
	East of I-380	26,630	20,688	31,149	23,947	17.0	15.8

Figure B.2. Volume Difference Plots between 2025_Base and Condition 4



Condition 5: AV impacts to land development

AVs may have complex impacts on land use in the long term. Different deployment scenarios could lead to varied land-use outcomes. AVs may either encourage more urban sprawl or more compact urban growth patterns. AVs may increase commuter willingness to travel longer distances to and from work. Households and businesses may situate farther away from urban cores in search for more affordable rent or home prices, which will provide incentive for more sprawling, low-density urban development and will generate more travel in turn. In contrast, AVs may help reduce onsite parking needs and enable road diets, especially in urban cores. This will free valuable space that can be used for redevelopment, which will then increase walkable developments and encourage more compact urban growth patterns.

To test the potential impact of AVs to land development, two test conditions were built and evaluated by reallocating projected growth in housing and employment in Linn and Johnson Counties in two different directions.

> **Condition 5.1** (Urban to Rural) – about a quarter of the county-wide growth of both housing and employment reallocated from urban areas of each county to the rural areas (keeping the total growth for each county constant).
>
> **Condition 5.2** (Rural to Urban) - the same number of houses and jobs are reallocated within each county (coming primarily from more suburban type zones) and placed within the urban core of Cedar Rapids and Iowa City.

Table B.7. Total Volume Percent Increase per Segment between 2040-Base and Condition 5.1

Freeway	Location	2040_BaseYear		Condition 5.1		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	8,975	15,992	9,244	16,461	3.0	2.9
	East of I-38	8,452	13,800	8,696	14,229	2.9	3.1
I-380	North of US 30	27,751	28,844	29,308	30,481	5.6	5.7
	South of US 30	25,813	24,003	27,420	25,522	6.2	6.3
	South of 120th	24,912	24,109	25,265	24,484	1.4	1.6
	South of 250th	26,391	24,776	26,965	25,523	2.2	3.0
	South of Forevergreen	28,546	27,399	29,210	28,888	2.3	5.4
	South of I-80	25,194	20,823	25,373	21,716	0.7	4.3
I-80	West of I-380	24,954	29,904	25,087	29,891	0.5	0.0
	East of I-380	32,592	25,515	33,300	25,705	2.2	0.7

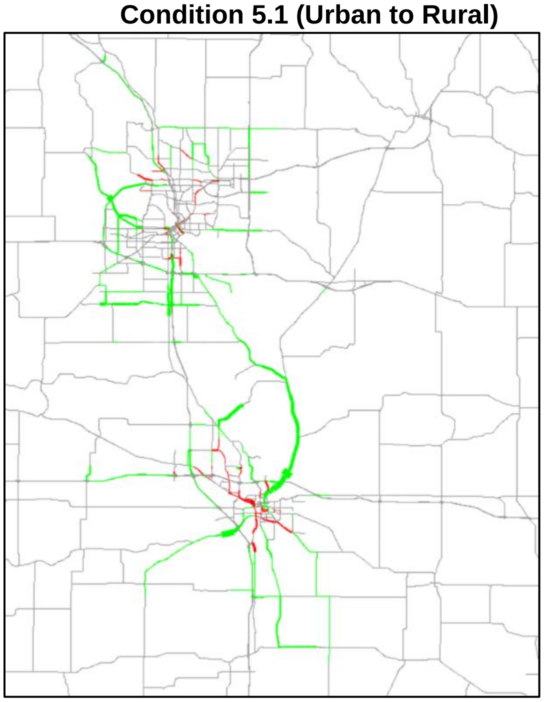
Traffic flows are compared with 2040-Basline scenario and percent changes are presented in **Table B.7** and **Table B.8**. The volume difference plot, 2040-Baseline versus Conditions 5.1 & 5.2 are depicted on **Figure B.3**. The results show that greater sprawl results in higher volumes on US 30, I-380 and I-80, while denser development results in lower volumes on these facilities.

Table B.8. Total Volume Percent Increase per Segment between 2040-Base and Condition 5.2

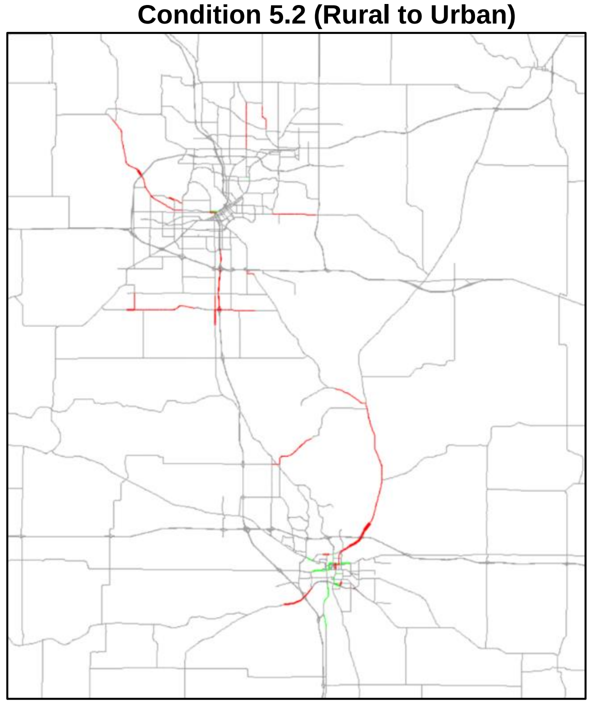
Freeway	Location	2040-BaseYear		Condition 5.2		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	8,975	15,992	8,907	15,918	-0.8	-0.5
	East of I-38	8,452	13,800	8,371	13,729	-1.0	-0.5
I-380	North of US 30	27,751	28,844	27,172	28,197	-2.1	-2.2
	South of US 30	25,813	24,003	25,193	23,349	-2.4	-2.7
	South of 120th	24,912	24,109	24,839	23,939	-0.3	-0.7
	South of 250th	26,391	24,776	26,123	24,466	-1.0	-1.3
	South of Forevergreen	28,546	27,399	28,094	27,017	-1.6	-1.4
	South of I-80	25,194	20,823	24,859	20,455	-1.3	-1.8
I-80	West of I-380	24,954	29,904	24,904	29,924	-0.2	0.1
	East of I-380	32,592	25,515	32,589	25,542	0.0	0.1

Figure B.3. Volume Difference Plots Between 2040-Base and Conditions 5.1 & 5.2

Condition 5.1 (Urban to Rural)



Condition 5.2 (Rural to Urban)



Condition 6: Automated Vehicle (AV) lane on I-380 and CRANDIC corridor
Some researchers and analysts have suggested that AV and human driven vehicle conflicts can be avoided by creating dedicated infrastructure that is only accessible with AV technology. For instance, it would be possible to set aside existing lanes or build new lanes solely dedicated for AV use - a situation similar to the current system of high occupancy/carpool lanes. For this scenario, AV-only lanes along I-380 (1-lane in each directions) and a 2-lane principal arterial within the CRANDIC facility were added between US 30 and I-80. The steps and assumptions applied to create this scenario include:

- Built AV-only lanes along I-380 (add 1-lane in each direction) and a corridor within the CRANDIC facility (2-lane principal arterial). Free-Flow speed of 100 mph is assumed on the AV-only lanes.
- Separated auto and truck trip tables (trip tables from 2025-Combined Condition) into AV and non-AV demands. Assumed 40 percent AV market penetration by 2025
- Ran all-or-nothing truck assignments with and without AV-only lanes
- Compiled the truck volumes for use as pre-loads in the AV excluded auto assignments
- Ran user equilibrium AV excluded auto assignment
- Compiled auto and truck volumes (truck volumes converted to passenger car equivalents) for use as pre-loads in the AV included auto assignments
- Added auto and truck volume (both AV and non-AV) to see the total flow in the study area.

Table B.9 summarizes the volume percent difference between 2025-Combined scenario and Condition 6.

Table B.10 shows total AV volumes per segment on AV-only lanes along I-380 and CRANDIC line.

Figure B.**Figure B.4** shows volume difference plot between 2025-Combined scenario and Condition 6. As shown in **Table B.9**, around 35 percent of the total traffic, or about 87 percent of the AV vehicles (assuming 40 percent AV market penetration), is diverted from I-380 to the AV-only lanes. Also, traffic is increased by 50.4 percent along US 30, west side of I-380, due to AVs entering US 30 from the AV-only CRANDIC corridor.

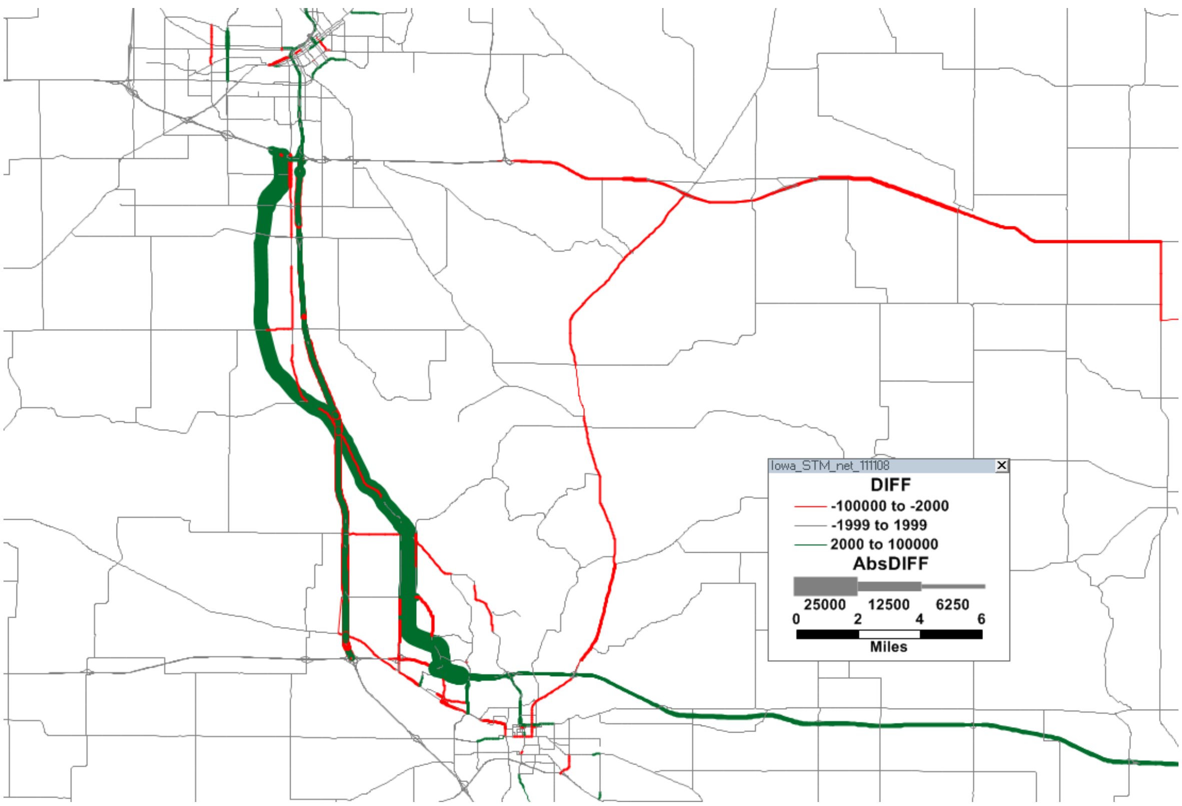
Table B.9. Total Volume Percent Change per Segment between 2025-Combined Condition versus Condition 6

Freeway	Location	2025-Combined Condition		Condition 6		Percent (%) Changes	
		AB	BA	AB	BA	AB	BA
US 30	West of I-380	10,524	17,353	15,833	16,571	50.4	-4.5
	East of I-38	9,844	14,804	9,216	14,587	-6.4	-1.5
I-380	North of US 30	28,249	28,961	32,094	32,355	13.6	11.7
	South of US 30	24,920	23,005	16,393	15,026	-34.2	-34.7
	South of 120th	25,956	24,925	16,828	16,264	-35.2	-34.7
	South of 250th	26,510	25,115	16,665	15,791	-37.1	-37.1
	South of Forevergreen	27,411	25,328	17,297	15,487	-36.9	-38.9
	South of I-80	23,039	18,837	22,932	17,797	-0.5	-5.5
I-80	West of I-380	24,223	27,723	25,271	27,660	4.3	-0.2
	East of I-380	31,149	23,947	29,887	23,864	-4.1	-0.3

Table B.10. Total Volume on AV-only Lanes

Freeway	Location	AV-only Lanes on I-380		AV-only Lanes on CRANDIC Line
		AB	BA	
I-380	South of 120th	7,046	6,872	19,068
	South of 250th	6,796	6,899	26,077
	South of Forevergreen	8,624	7,979	31,343

Figure B.4. Volume Difference Plots Between 2025-Combined Condition and Condition 6



B.3 CONCLUSIONS

Since AVs are only in the testing phase, it is difficult to precisely anticipate outcomes. Nevertheless, it is useful to roughly estimate likely impact magnitudes. In this analysis, the iTRAM model was applied to analyze the impact of AV technology on the I-380 corridor. A wide range of potential future sensitivity test conditions were considered. The results show that providing car travel for people without driver licenses increased traffic on to I-380 by up to 6 percent. Reducing perceived travel time may provide a more enjoyable traveling experience, but could facilitate longer trips; it increased traffic on I-380 by up to 10 percent. Capacity increases may improve mobility around the corridor, but could induce additional demand along on I-380. Combining the first three conditions has significant impacts, increasing traffic flow along the I-380 corridor by 14 percent to 20 percent. Changing land use patterns resulting for AVs would impact future traffic on I-380, but could increase or decrease traffic depending on the assumptions. Widespread adoption of AVs, particularly at higher levels of automation, could have significant impact on future land use. When AV-only lanes were assumed on each side of I-380 and on the CRANDIC line, around 87 percent of AV traffic and 35 percent of all traffic diverted from I-380 to AV-only lanes.

These analyses simply show that a range of reasonable assumptions about AV technology could impact the I-380 corridor in a variety of ways. The primary value in these sensitivity tests is in combining the sensitivity test findings with structured assumptions, like those in scenario planning, to make sure that the sample of scenarios analyzed all add value to the assessment of alternatives. The results of these travel demand analyses reinforce much of the research on AV adoption and related changes in travel patterns, as documented in Appendix C. The travel demand model exercise provides Iowa DOT with an opportunity to perform future network-level assessments of AV impacts, in addition to the department's current focus on analyzing AVs for corridor planning.

APPENDIX C – LITERATURE REVIEW

This appendix presents the synthesis of literature reviewed on a number of key factors anticipated to impact future travel patterns and travel performance in rural stretches of the interstate. It contains three sections. Following this introduction, the first section (**Section C.1**) provides a description of the potential factors that could affect travel conditions on Interstate 380 (I-380) based on a scan of the literature. The middle section (**Section C.2**) presents a summary of the literature review. The final section (**Section C.3**) presents the adjustment factors developed.

C.1 POTENTIAL FACTORS AFFECTING INTERSTATE 380 CORRIDOR

This section summarizes the potential factors considered and the key factors selected that may influence the I-380 Planning Study. First, the project team carried out a high-level review of the potential factors considered in Iowa's Automated Vehicle (AV) Initiative, the scope of work for the study, and other potential factors that might affect the I-380 Planning Study. Second, through discussions with Iowa Department of Transportation (Iowa DOT), the project team identified the key factors most likely and significantly to affect the Interstate 380 Planning Study. The following is a summary of the key factors selected.

Automated Vehicle (AV) Technologies involve the use of sensors and other technologies to detect the surrounding environment and carry out driving tasks. AV technologies can lead to major improvements in safety, accessibility and capacity. As a result, the level of AV technology adoption was selected as a key factor in the scenario planning.

Millennial Travel Behavior refers to the tendency of Millennials to travel less. Since 2015, Millennials (i.e., people born between 1979 and 2000) represent the largest population segment. Millennials own fewer cars and drive less than previous generations. However, it is unclear whether current millennial travel behavior represents a permanent shift in attitudes toward car ownership and driving or a short-term behavioral modification. Millennial travel behavior was selected as a key factor to consider in the scenario planning.

Aging Population corresponds to the growth in population aged 65 and above. This segment of the population continues to increase significantly, as the Baby Boom generation (i.e., people born between 1946 and 1964) enters the demographic group. Studies show that vehicle miles traveled (VMT) levels change with age, with peak levels occurring during middle age and VMT decreasing thereafter. A growing population 65 and older is expected to lead to lower travel demand per capita. Aging population was selected as a key factor for the scenario planning.

Smart Truck Parking involves the use of road signs, smartphone apps, websites, and messaging to inform truck drivers of parking availability in real time. Access to information on the availability of parking allows truckers to plan their trips. Smart truck parking is expected to reduce the number of crashes caused by driver fatigue. Also, the Mid America Association of State Transportation Officials, which includes Iowa, recently was awarded federal grant funding to develop smart truck parking. Given its high degree of likely development, smart truck parking was selected as a key factor for the scenario planning.

C.2 RESEARCH SUMMARY: EMERGING TRENDS AND TECHNOLOGY AND POTENTIAL IMPACT ON TRAVEL

This section presents the expected impacts of key factors on travel demand, capacity and safety.

AV Technologies

The literature suggests that the number of trips, Vehicle Miles Traveled (VMT), and trip length may increase as Level 3 and above AV adoption rates rise. Childress et al. (2014) finds that trip making increases by around two percent when high-income households adopt AVs and by around five percent when AVs reach 100 percent adoption. Alternatively, Kockelman, Avery, Bansal et al. (2016) finds that the number of long distance trips may increase by more than 30 percent with 100 percent AV adoption.

Estimates for the impacts of AVs on VMT are wide-ranging and vary depending on assumptions about the AV technologies adopted, AV adoption rates, opportunity costs for travel time and the elasticity of travel demand. For instance, Mackenzie, Wadud and Leiby (2014) predict that VMT may increase from four percent to 156 percent. The lower value assumes the adoption of low-level AV technologies with a low elasticity of travel demand, whereas the upper bound assumes the opposite. Alternatively, Childress et al. (2014) predicts that VMT may grow by five percent when only high-income households adopt Level 5 AVs and by 20 percent when all households adopt Level 5 AVs. That same study finds that trip length increases by about four percent when high-income households adopt AVs and by around 15 percent when all households adopt AVs.

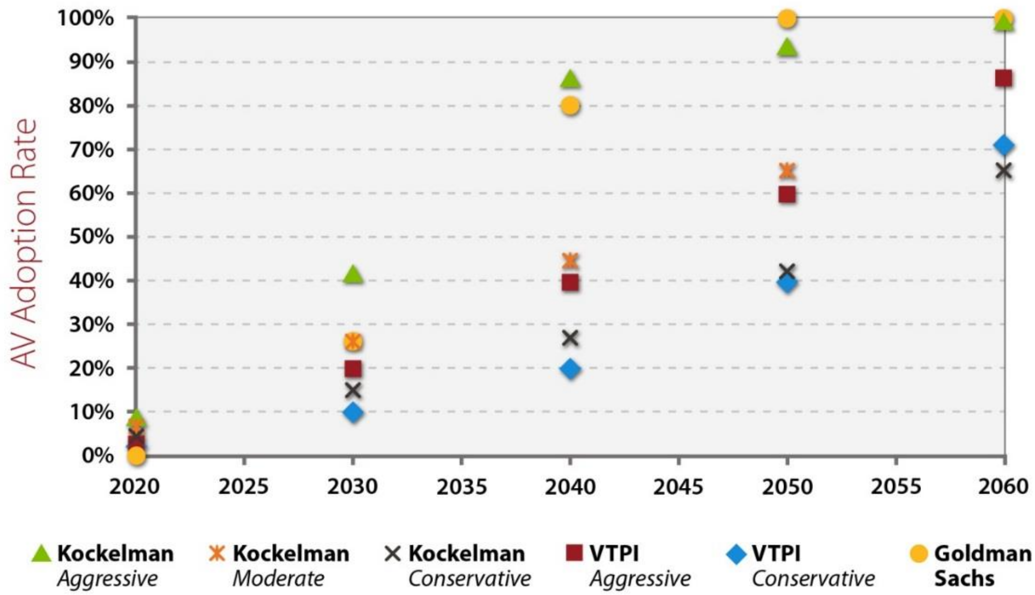
Two factors are expected to drive the increase in travel demand. First, AVs provide an underserved population access to cars. For example, elderly, children and the segment of the population with disabilities who are unable to drive will be able to increase their mobility by using AVs. Second, AVs may lead to decreases in travel time costs. AV passengers can work or carry out other activities during travel, which reduces the opportunity cost of AV travel time. As more people have access to travel in cars and as the travel time costs of driving decrease, more people will be willing and able to travel more frequently and for longer distances.

A growing penetration of AVs may also increase roadway capacity. AVs enable shorter following gaps between vehicles without reduced speeds, which result in greater roadway capacity. The expected impact of AVs on roadway capacity will depend on the levels of penetration that AVs achieve. For example, while Tientrakool, Ho and Maxemchuk (2011) find that roadway capacity can increase by around 273 percent at 100 percent adoption rate, capacity gains are significantly lower at lower AV penetration rates (e.g., 88 percent capacity gain for 80 percent penetration, and 30 percent capacity gain for 50 percent penetration).

Other studies estimate less aggressive capacity gains from AV penetration. For example, Shladover et al. (2014) finds that at 100 percent adoption of AVs, roadway capacity only increases by 80 percent, while an 80 percent adoption leads to a 50 percent increase in capacity. The studies use different assumptions for automated tasks: Shladover et al. (2014) assumes that the driver carries out braking, while Tientrakool, Ho and Maxemchuk (2011) assume that the vehicle has automatic braking.

The reliability of capacity gain estimates depend on the accuracy of forecasted AV adoption rates. **Figure C.1** summarizes forecasted AV penetration rates from various studies for 2020 to 2060 [Litman 2017, Kockelman and Bansal 2016, Archambault et al. 2015]. The figure shows that, while there is significant variation between the conservative and aggressive scenarios in some studies, there is overlap in forecasted penetration rates across the studies. This suggests that there is some consistency on what the upper and lower bounds of AV adoption may be in the future.

Figure C.1. Forecast of Automated Vehicle Penetration Rates from 2020 to 2060



AVs may lead to safety improvements. AVs may prevent many collisions caused by human error, which account for about 90 percent of collisions (The Economist 2012). Studies suggest that collision reductions may range from 14 percent (Rao and Ahari 2014) to 90 percent (Litman 2017). Reductions vary depending on what aspect of vehicle accidents each study attempts to measure. For example, Rao and Ahari (2014) measure the impact of Automated Driver Assistance Systems on crash frequency, while Eccles et al. (2012) measures multi- and single-vehicle crashes that could be mitigated by Vehicle-to-Infrastructure (V2I) communications.

Technological advances in vehicle automation and communication can reduce the economic and comprehensive costs of vehicle crashes. Kockelman and Bansal (2016) estimates the adoption of connected and AV technologies over the long term and review impacts on safety, estimated crash count and crash cost reductions through various AV technologies. The study details the crash-related gains of various AV and connectivity features and assesses near-term and long-range impacts on car crashes in Texas. A more in-depth discussion of AV safety technologies can be found in **Appendix E - Corridor Safety Methodology and Results**.

Millennial Travel Behavior

Millennial travel behavior may lead to decreases in travel demand. Millennials own fewer cars and drive less than previous generations at the same age bracket. Given this trend to date, the overall number of trips and VMT may decrease as Millennials age and make up the largest portion of the labor force. For example, McDonald (2015) finds that Millennials make 18 percent to 24 percent fewer trips compared to previous generations. Circella et al. (2015) finds that the youngest cohort of Millennials make four percent fewer trips compared to previous generations. Davis, Dutzik and Baxandall (2012) find that trips taken by drivers aged 16 to 34 dropped 15 percent from 2001 to 2009. Taken together, these and other studies indicate that the VMT for Millennials is about 16 percent to 25 percent lower than the VMT of previous generations.

Caution is necessary in using forecasts of decreased travel demand due to millennial travel behavior because there are a number of other factors involved. Trends driving lower travel demand among Millennials include being unemployed, living with parents, and living in urban areas. For example, Garikapati et al. (2016) finds that these trends represent the aftermath effects of the recession and are short term. The study explains that Millennials are lagging in adopting lifestyle patterns related to greater travel demand. The study predicts that Millennial travel behavior will converge with that of older generations once Millennials fully recover and reach the stages of life related to higher travel demand. In fact, the study finds that the travel behavior of older Millennials that reach the life stages with higher travel demand converge with those of previous generations.

Aging Population

The aging population may lead to decreases in future travel demand. The population 65 years and older will significantly increase as the Baby Boomer generation enters this demographic group. VMT falls as people retire and work trips decrease to zero. As a larger portion of the population forms the 65 and older age group, average VMT per capita is expected to decline.

The literature shows that an aging population will lead to decreases in travel demand. Hu, Choi and Wen (2012) find significantly lower travel demand in the 65 and older population compared to the 50- to 64-year-old population. They find that, on average, the 65 and older population takes 12 percent to 29 percent fewer trips and travel 28 percent to 54 percent fewer miles.

An examination of the 65 and plus population's travel behavior over time reveals that current Baby Boomers turning 65 have decreasing travel demand compared to previous generations and that this trend is expected to continue into the future. The Federal Highway Administration (FHWA) finds that per person trips of the 65 and older population fell by six percent from 2001 to 2009 (Blumenberg et al. 2013). McGuckin and Section 1909 Commission Staff (2007) forecast that VMT per capita among the 65 and older population will fall by seven percent by 2050 compared to 2000 levels.

Smart Truck Parking

Smart truck parking may lead to decreases in the number of truck collisions. Smart truck parking can reduce driver fatigue by allowing truckers to plan rest stops and reduce the amount of time spent driving under fatigue conditions. Studies find that collisions due to driver fatigue account from about two percent (Perry, Oberhart and Wagner 2015) to 15 percent (HNTB Corporation 2015) of all truck collisions. Smart truck parking may mitigate a portion of these collisions.

C.3 KEY FACTOR ADJUSTMENT FACTORS

This section presents the adjustment factors used in estimating future travel demand along I-380. Prior to discussing the adjustment factors, a brief summary of the scenarios analyzed in this study is provided. Then, the calculation of the adjustment factors used to determine the overall impacts of key factors on travel demand variables is explained.

Description of Scenarios

The project team defined four scenarios that reflect forecasted travel demand along I-380 in 2025, 2030 and 2040. **Table C.1** lists the assumptions used for each scenario.

Table C.1. Scenario Assumptions

Key Factors	Scenario 1 – Early AV Adopters	Scenario 2 – Rise of the AVs	Scenario 3 – Limited AV Adopters	Scenario 4 – AV Domination
Year of Analysis	2025	2030	2040	2040
Passenger Vehicle: Level 3+ AV Adoption	25%	50%	20%	85%
Commercial Vehicle: Level 3+ AV Adoption	25%	50%	20%	85%
Millennial Travel Behavior	Included	Included	Not Included	Included
Aging Population	Included	Included	Not Included	Included
Smart Truck Parking	Included	Included	Included	Included

Note: automated vehicle (AV)

The scenarios differ in the assumptions used for the AV adoption rate (focusing on Level 3 AV and above) and include up to three additional key factors. The combination of Scenarios 1 (Early AV Adopters), 2 (Rise of the AVs) and 4 (AV Domination) represent a future with aggressive AV adoption at different points in time: 2025, 2030 and 2040. They also include the impacts of Millennial travel behavior and an aging population. Alternatively, Scenario 3 (Limited AV Adopters) represents a conservative future in which drivers adopt AV slowly and the impacts of Millennial travel behavior and aging populations are assumed to trend back toward today’s norms for travel demand. All four scenarios include the impact of smart truck parking.

Estimated Capacity, Speed and Crash Adjustment Factors by Scenario

Adjustment factors determine the impact of key factors on travel pattern and travel performance variables including trips, VMT, capacity and crash frequency. The adjustment factors were developed in two steps. First, the expected impacts of key factors on the travel pattern and travel performance variables were determined using the values identified in the literature review. Second, the weighted average impact of the key factors on each travel pattern and travel performance variable was calculated to determine the overall impact. **Table C.2** presents the adjustment factors synthesized from the literature for each scenario.

The purpose of these adjustment factors is to provide Iowa DOT with a quick estimation reference for determining future transportation impacts of these high-level future scenarios in system planning activities. However, for the study of I-380 needs, a more in-depth analysis of traffic impacts was completed. The predominant adjustment factor used as an input in detailed traffic, safety and reliability analyses was the increase in number of trips. The increased capacity and reduced crash frequency for

I-380 were independently calculated in **Appendix D – Traffic Capacity Methodology and Results** and **Appendix E – Corridor Safety Methodology and Results**, respectively. Research indicated increases in VMT represent a key finding for future planning and conceptual analysis of freeway segments. In this study, traffic volumes were considered only at spot locations along I-380, as a result trip increases were assumed to be inclusive of the VMT increases. However, if the number of trips increase and the length of trips increase on a per trip basis, then individual segments of long distance corridors will experience higher traffic volumes than estimated in this study.

Table C.2. Adjustment Factors Synthesized from Literature Review

Travel Demand Variables	Scenario 1 – Early AV Adopters	Scenario 2 – Rise of the AVs	Scenario 3 – Limited AV Adopters	Scenario 4 – AV Domination
Trips	6%	14%	6%	19%
Vehicle Miles Traveled	9%	16%	11%	34%
Capacity	4%	22%	4%	64%
Crash Frequency[a]	-21%	-43%	-17%	-72%

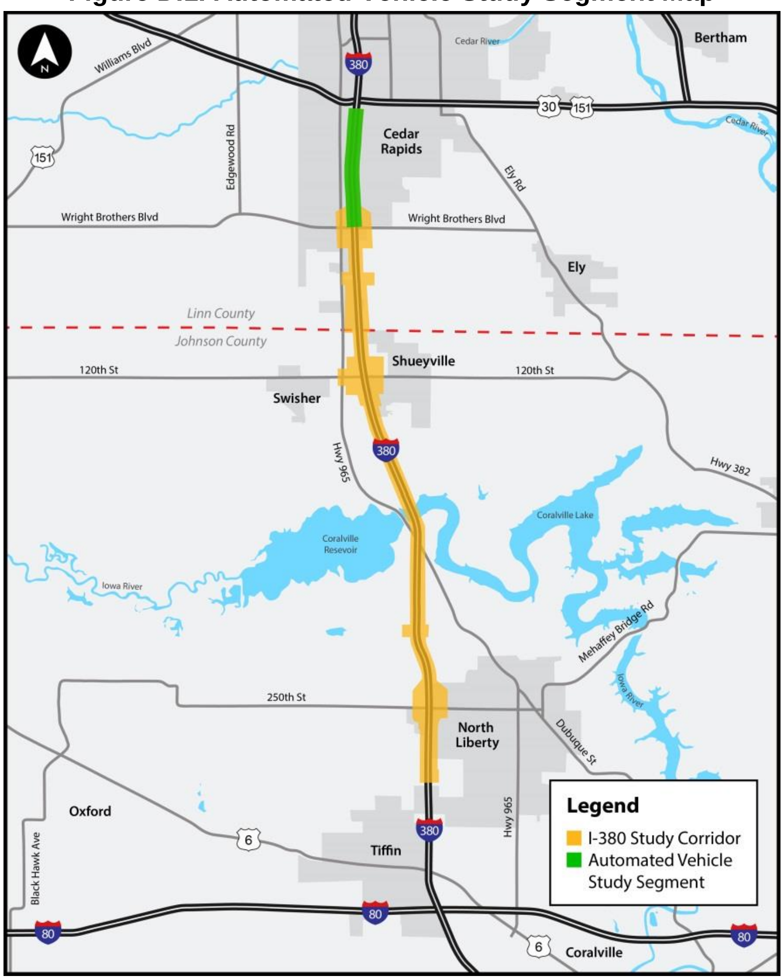
Notes: automated vehicle (AV)
[a.] Effectiveness measure based on impact of forward collision warning (FCW) and cooperative adaptive cruise control (CACC) on reducing rear end crashes.

APPENDIX D – TRAFFIC CAPACITY METHODOLOGY AND RESULTS

D.1 METHODOLOGY

The traffic capacity methodology for this study involved: 1) preparing traffic input data, 2) incorporating the research findings from **Appendix C** into a customized traffic microsimulation analysis tool, 3) developing and running the traffic microsimulation models and 4) selecting and collecting simulation-based measures of effectiveness. Traffic capacity analysis was completed for one representative segment of the Interstate 380 (I-380) corridor, namely the segment between US 30 and Wright Brothers Boulevard, as shown in **Figure D.1**.

Figure D.1. Automated Vehicle Study Segment Map



Traffic Input Data

For this study, traffic data from 2015 at automatic traffic recorder (ATR) station just north of Penn Avenue (ATR 125) was combined with estimated ADTs to identify the design hour volumes for analysis. Design hour volume is typically taken to be the 30th highest observed hourly volume. The 30th highest observed hourly volume for the year was identified to represent the design volume for the 2015 existing conditions period. The highest design hour, and thus the hour used for capacity analysis, was one hour from 5 p.m. to 6 p.m. Both northbound and southbound traffic were found to peak within the same hour, so analyzing a single hour was sufficient for this traffic analysis. The northbound design hour volume for 2015 was 2,720 and the southbound design hour volume for 2015 was 2,410.

Traffic conditions for the 30th highest observed hourly volume were also investigated to determine peaking characteristics and mix of vehicle types. Peak 15-minute data was used to establish peaking characteristics within the design hourly volume. As can be seen frequently in suburban conditions, traffic data for portions of I-380 between Cedar Rapids and Iowa City showed significant traffic flow variation over the one-hour peak period for each 15-minute time period. Based on the peaking data, the traffic analysis used a peak hour factor of 0.92.

ATR data was also used to establish the mix of vehicle types in the design hour. In traffic operations, a variety of approaches can be used to classify vehicles to capture their capabilities and/or overall impact on the traffic stream. Trucks, in particular, have significantly different operating characteristics when compared to light duty or passenger vehicles. The ATR data was used to break down traffic volumes into three classes: passenger cars, single-unit trucks and combo trucks (see **Table D.1**).

Table D.1. Traffic Volumes by Vehicle Class

Segment	Passenger Cars (%)	Single-unit Trucks (%)	Combo Trucks (%)
Northbound & Southbound	90	2	8

Customizing the Traffic Microsimulation Analysis Tool

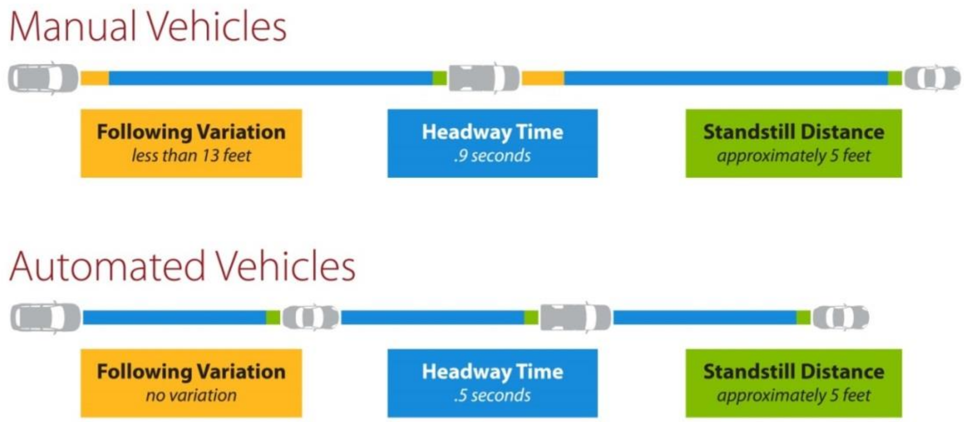
Upon development of the traffic input data, the project team looked to develop a traffic analysis tool that would properly represent the influence of automated vehicles (AVs) on traffic flow. To address study needs, the project team utilized a custom tool developed for Iowa DOT as part of the recent I-80 (I-80) Planning Study. The tool makes use of a traffic microsimulation modeling software (PTV's Vissim) that is commercially available, well-respected and capable of custom programming.

The challenge with Vissim and similar traffic microsimulation models is that the models move vehicles through the network based on individual driver behavior only (with respect for the rules of the road and traffic control devices). Once AV technology is in the traffic fleet, vehicles will be able to make driving maneuvers with better awareness of their own surroundings and in cooperation with other vehicles that are communications-enabled. To assess AV impacts appropriately, this cooperative behavior must be accounted for. The solution was to use Vissim's flexibility in allowing model developers to let other software have access to the Vissim model during the model run time. More specifically, while Vissim cannot tell an AV that it should cooperate with the vehicle in front of it, Vissim lets the modeler tell another program what is going on in the Vissim model and then that program can send information back to the AV being simulated in Vissim to change its behavior to account for cooperation.

The **Traffic Capacity Analysis** describes the flow of a vehicle in the Vissim model using customization. The combination of the custom programming and Vissim run the entire analysis period operating to provide that extra information to each AV. The custom programming also manages situations when vehicles would want to leave a platoon and how that might affect their preferred speed.

One of the key assumptions in developing this differentiation of manual-vehicle following versus AV-following behavior is in the Vissim driver behavior parameters. The driver behavior model used for this project was based on the traffic behavior model developed by Wiedemann in 1999 (standard within Vissim and called the Wiedemann 99 model). While the custom code dynamically directs the simulation that AVs in the simulation are in a platoon state, the project team specified to Vissim that the following vehicle classes always use the same research-based driver behavior parameters developed from work by researchers at the University of California at Berkeley (Cal-Berkeley; Shladover et al. [2014]). The Cal-Berkeley work was modified to apply the relative improvement in following time and following variation to the standard Wiedemann 99 car following parameters. The resultant Vissim driver behavior parameters are shown in **Figure D.2**.

Figure D.2. Vissim Driver Behavior Parameters



Another change in the common Vissim vehicle behavior was customization that represented a mixed environment between manually driven and AV traffic. Instead of using the freeway (free lane selection) default driving behavior the project team went with the right-side rule (motorized) driving behavior. The key change here is that vehicles strongly prefer to pass on the left side with slower vehicles having a tendency to move out of the fast lane if a faster, trailing vehicle approaches. The use of this lane change model was a simplification to account for the tendency of AVs and AV platoons operating at consistent high speeds compared to a portion of the manual vehicle fleet. Future enhancements to the custom AV code could address this lane changing behavior in a more sophisticated set of rules should they be necessary.

Additional future analysis of AV traffic may consider the impact of AV awareness of downstream conditions, especially considering lane selection, and AV platoon effects of ramp entrances and exits. The current analysis methodology focuses on a rural freeway facility with very low ramp volumes. For that reason, the Vissim model was customized to address a facility where lane selection is based solely on preferred speeds.

The resulting custom AV modeling tool appeared to be well-suited to capture AV influence for a number of performance metrics when combined with locally specific model parameters. To confirm the model’s capabilities, microsimulation model runs were conducted using the custom-programmed Vissim model to see if the project assumptions for AVs would show a capacity benefit similar to those identified in prior research. Capacity runs required a separate, iterative set of model runs under a variety of demand conditions before the true maximum achievable traffic volume was identified. The capacity model runs ignored the distinction between passenger cars and trucks, because capacity is typically estimated for the number of passenger cars that could pass through a lane in one hour.

After completing the capacity model runs, the resulting simulation-derived capacities were compared to the Cal-Berkeley research findings previously introduced, as shown in **Figure D.3**. Interstate 380 project model shows a bias from Cal-Berkeley results due to the project model's uncalibrated state that uses ideal assumptions for capacity and the contrasting, calibrated nature of the Cal-Berkeley study. However, the results of this test show a similar trend between the project model and the Cal-Berkeley results between AV adoption rates of 25 percent and 85 percent. Above 85 percent, the Cal-Berkeley results show a significant benefit to AV efficiency that was beyond the scope of the project model.

Looking at the project model results compared to the AV adoption levels tested (see **Table D.2**); the results show an 11 percent capacity increase per lane at 50 percent AV adoption and a 26 percent capacity increase per lane at 85 percent AV adoption. The project findings show that AVs and other studied factors increase travel demand by 14 percent at 50 percent AV adoption and by 19 percent at 85 percent AV adoption. Thus, some of the increased capacity will be used to serve induced AV travelers. Yet, those increases in travel demand are dispersed over all travel lanes, while capacity benefits are shown as an increase per lane. The result is that with high levels of AV adoption, the six-lane widening of I-380 was analyzed as providing total capacity at nearly the same level as an eight-lane freeway without AV technology.

Figure D.3. Simulated Freeway Capacity versus Automated Vehicle Adoption

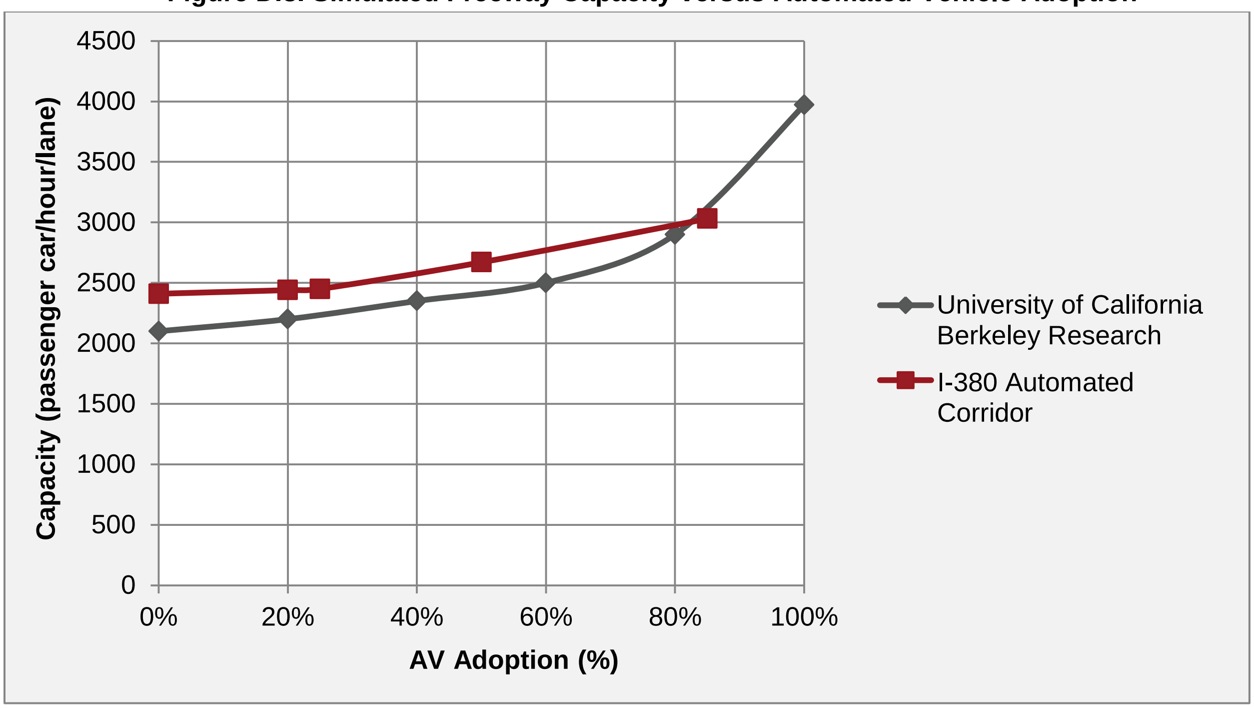


Table D.2. Traffic Capacity Increase

% Automated Vehicle Adoption	Capacity (passenger car/mile/lane)	Percent increase in capacity per lane (%)
0	2,410	+0
20	2,440	+1
25	2,450	+2
50	2,670	+11
85	3,030	+26

Microsimulation Model Development

In conjunction with development and testing of the Vissim customization, the existing conditions roadway network was developed in Vissim. Creation of the existing conditions network involved the use of links and connectors drawn on an aerial background to represent the four-lane freeway. Network links used for evaluation were drawn from the entrance ramp gore to the successive exit ramp gore. The alignment of the evaluation area was drawn to match the horizontal alignment of the freeway. Though a curve exists in the freeway alignment it was not deemed to require a reduced speed area.

Upstream of the freeway links for evaluation, a set of long, straight freeway links was created to allow for vehicle positioning and vehicle platoon formation prior to reaching the evaluation area. These upstream freeway links were connected to the evaluation links via a short connector that uses Vissim defaults for lane change distance and emergency stopping distance. Even though the upstream positioning/platooning area passes ramp gore points, the project team perpetuated an existing AV modeling tool that does not model ramp connections. As opportunities arise to update the AV modeling tool to consider the influence of ramps, that level of added detail will help determine any merge/diverge/ weaving benefits that are attributable to AV technology. For this study, benefits are for the portion of the roadway assumed to be operating in isolation from ramp traffic.

After the development of the simulation network, traffic controls were specified in the model. Given the nature of this simulation model as a set of isolated freeway links, traffic control was minimal, and mostly consisted of providing vehicles with the speed limit of 70 miles per hour (mph) in study segments. Vissim does not specifically utilize speed limits or speed limit signs as model elements; as a result the speed limit given to simulated vehicles was in the form of desired speed decisions. The desired speed for vehicles was specified as a distribution for different vehicle types. The desired speed distributions were developed based on INRIX XD data purchased as a yearly profile by Iowa DOT along with some supplemental data on truck speed distributions from Iowa DOT sensors. Passenger cars were given a desired distribution of speeds ranging from 58 to 83 mph and heavy trucks were given desired speeds ranging from 51 to 76 mph, which were consistent across all five segments. A different set of speed controls were given to AVs, which represent a lower level of speed variability. In the absence of surrounding AVs, an AV was given the range of desired speed distribution between 65 and 70 mph. If an AV was near another AV, then the platooning logic would modify the AVs desired speed. Approaching a platoon, the AV could utilize a five percent increase in desired speed to catch the platoon. Upon joining the platoon, AV desired speeds are set to create a single platoon-wide desired speed based on platoon leader's preference. No other traffic controls were used in the model.

Vehicle inputs, previously described, needed to be supplemented to account for Vissim's more detailed understanding of vehicle type and size. The 13-class FHWA system was used to identify size variation in vehicles and provided additional granularity over the three-class system previously discussed as part of the traffic input development. The Vissim model vehicle types were originally based on the PTV North American standard vehicle mix, but data from the 13-class counts was used to update the relative proportions of each vehicle type to match conditions on I-380.

The final element of a base Vissim model is underlying driver behavior. Driving behavior defaults in Vissim are often calibrated to match existing roadway performance data. In this proof-of-concept model for testing the impacts of AVs, calibration was not undertaken. As shown previously, by not including calibration, the project model likely overstates the capacity of low AV adoption conditions. However, the model showed appropriate sensitivity to relative improvements in capacity at levels of AV adoption between 25 percent and 85 percent. Also, at higher levels of AV adoption, the benefits of calibration are reduced due to fewer human drivers in the traffic mix. Thus, the use of an uncalibrated model for this particular planning study likely provides a conservative analysis of the capacity benefits of AV traffic. Use of a calibrated model would be recommended to support detailed AV technology corridor design.

To convert the existing conditions Vissim model to represent other scenarios, Vissim's built-in scenario management tools were used. The scenario management tools let one master input file act as the basis for multiple scenario input files where each of the scenario input files could be modified from the base to represent changes in input data and network geometry. Specific modifications of each scenario, aside from existing conditions, are documented in the scenario sub-sections of the following section. Due to the high level nature of the future forecasting for this project, many of the patterns from the existing conditions model were expected to remain the same in each scenario, including:

- Design hourly traffic volume peaking characteristics as they relate to daily traffic volumes
- Peaking characteristics within the peak hour of traffic
- Proportions of heavy vehicles compared to total daily truck volume
- Desired speeds (outside those that change during the model runtime due to the custom scripting)

Traffic Analysis Performance Measures

Simulated conditions were assessed for each of the analysis segments based on measures of effectiveness pulled from the custom-programed Vissim model. Measures of effectiveness considered for this study include:

- Density
- Capacity (maximum achievable traffic volume)
- Demand-to-capacity ratio
- Travel time and speed

Metrics considered are briefly described below.

Density is the measure of vehicle crowding that has long been used to assess the level of service (LOS) of freeway facilities. Density is measured as the number of vehicles in a lane in a one-mile segment. Density is very sensitive to traffic volume and also considers the speed that traffic volume moves at. AVs will encourage greater densities, but the research findings show that density is not as undesirable for AVs as it is to manual drivers.

Capacity is a measure of mobility that most frequently considers a roadway's adequacy to handle traffic demand at peak conditions. Consider an empty freeway; if the road conditions and weather do not pose an issue, the first vehicle on the empty freeway is going to travel at the speed that feels most comfortable to them. If they are on their way to work, school, an appointment or a delivery, that driver will probably travel at the speed limit or above. Then consider more vehicles joining that first vehicle on the roadway. As the number of vehicles increase, each individual driver has to moderate their behavior and speed to avoid getting too close to the other vehicles. For certain levels of traffic, vehicles are spread out enough that travelers can all maintain high speeds, but eventually all vehicles start to have to slow a noticeable amount. If the number of vehicles on the freeway keeps increasing, individual vehicles face greater strain in traveling the roadway until the steady, slowing flow of vehicles eventually breaks down, a traffic jam forms, and everyone stuck in the traffic jam experiences stop-and-go conditions.

Capacity is typically defined as the threshold just before the traffic jam forms where the maximum number of vehicles can traverse a section of roadway. Thus, if any additional vehicles try to traverse a roadway that is already at capacity, then the flow of traffic starts to jam up and not all vehicles wishing to use the roadway will be able to get to their destination until the traffic jam clears. Technology and AVs have been postulated to significantly increase capacity.

Demand-to-capacity ratio is a metric commonly used in planning-level applications to compare the adequacy of multiple facilities that do not share the same number of lanes or functional classification. By normalizing the traffic demand by the capacity, or maximum volume that can be served, the analysis can draw comparisons between the need of two different locations or project alternatives.

In analyzing transportation technology impacts, demand-to-capacity ratio can be an insightful metric because technology can cause variations in both the demand and supply for travel. The potential being that in some future technology cases, the demand for travel may grow at a much greater rate than the increase in transportation capacity. The demand-to-capacity ratio inherently compares both factors, informing the analysis as to whether the capacity is adequate and if any reserve or unused capacity remains that could serve latent demand should it materialize.

Demand-to-capacity ratio is also a pseudo-density metric. If your demand-to-capacity ratio is 1.0 then all the space that can be used is full. While density, as traditionally defined, does not account for some of the impacts of AV traffic, demand-to-capacity ratio does take those factors into account. The trouble with using demand-to-capacity ratio is that the transportation industry has rarely defined acceptable levels of demand-to-capacity ratio for similar types of study as this one.

Travel time and speed are straightforward, intuitive and user-centric metrics that capture the average time it takes travelers to traverse a freeway segment or the average speed at which the segment is traversed. Travel time under typical conditions is a product of the facility's free-flow or natural speed and the traffic volume the facility carries. At higher traffic volumes, speeds begin to drop as the slowest vehicles in the traffic stream start to impact more vehicles due to limits in the opportunity to pass.

It is assumed that the target speeds of AVs will be programmed to be near the average speeds for a segment in consideration of safety. If the AVs are then going to mirror human operated vehicle behavior, the question becomes whether having AVs in the fleet mix increase or decrease average vehicle speeds, and correspondingly, travel times. Because capacity is likely increasing due to technology, the impact of AVs may be that speeds do not decrease until higher volume levels. However, there is a potential that the

AV benefits can only be realized if AVs are given their own separate lanes or if the slowest vehicles are restricted from certain travel lanes.

Microsimulation runs were setup to capture average vehicle speeds across the studied freeway segments. An average travel time can be estimated from the known length of the segment and the average speeds collected. The microsimulation results are provided as average speeds due to the nature of this study not making assumptions about the trip length of vehicles on the freeway segment. However, if a performance threshold were to be set based on user expectations, travel time or the travel time per mile (known as travel rate) could be established through a user survey or synthesis of existing research and surveys on traveler’s value of time.

D.2 TRAFFIC CAPACITY RESULTS

Existing Conditions

The count-based traffic volumes described in the existing model development were simulated. The existing conditions simulation assumed zero percent AV traffic because AVs are considered a future technology. The results show portions of the corridor have densities in LOS C or D range, which would be below the preferable standard of LOS B. This density based indication of vehicle crowding partially confirms the need for improvements to I-380.

Future Baseline (2040 No-Build) Conditions

Traffic volumes for 2040 No-Build conditions were developed using a growth ratio from comparing 2040 No-Build projected average daily traffic volumes to 2014 existing average daily traffic volumes. No modifications were made to the model geometry or traffic control (i.e., no I-380 widening was assumed in the baseline scenario). For 2040 No-Build conditions, zero percent AV traffic was modeled for this scenario to act as a baseline for comparison against the four future AV scenarios.

The results show significant degradation of traffic service based on density and speed, with traffic performance exhibiting LOS E. Without improvements to I-380, even rural travel between these two metro areas may experience traffic jams due to extreme crowding.

Scenario 1 – Early AV Adopters (2025 25 percent AV)

Traffic volumes for 2025 daily conditions for a six-lane I-380 were estimated by straight-line interpolation between 2015 and forecasted 2040 Build daily volumes. Traffic volumes for 2025 peak hour Build conditions were developed using a growth ratio from comparing 2025 Build projected average daily traffic volumes to 2015 existing average daily traffic volumes. The design hour volumes were then inflated by the research-based trip increase factor of 1.06 based on 25 percent AV adoption, Millennial travel behavior and impact of aging population.

Modifications were necessary to turn the existing roadway model into a build condition. An interior, third lane was added to the model and was treated as a passenger car and passenger AV-only lane based on the current line of planning for I-380 that would only allow trucks in the right two lanes after I-380 expansion. For the **Early AV Adopters** scenario, 25 percent of all simulated vehicles were coded as either AV cars or AV trucks.

The results show the combined effect of widening of I-380 and 25 percent AV adoption. Compared to existing conditions, speeds are higher in all locations, which would be expected due to the freeway widening. The significance in the context of AV technology is that some early studies have raised the concern that safety-focused early AV operations may lead to overly cautious driving and lower vehicle speeds. At this time, the custom Vissim and underlying research do not suggest a speed drop at lower levels of adoption.

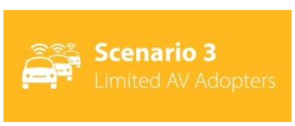
Scenario 2 – Rise of the AVs (2030 50 percent AV)

Traffic volumes for 2030 daily conditions for six-lane Interstate 380 were estimated by straight-line interpolation between 2015 and 2040 Build daily volumes. Traffic volumes for 2030 peak hour Build conditions were developed using a growth ratio from comparing 2030 Build projected average daily traffic volumes to 2015 existing average daily traffic volumes. The design hour volumes were then inflated by the research-based trip increase factor of 1.14 based on 50 percent AV adoption, Millennial travel behavior and impact of aging population.

Modifications were necessary to turn the existing roadway model into a build condition. As with Scenario 1, an interior, third lane was added to the model and was treated as a passenger car and passenger AV only lane. For the **Rise of the AVs** scenario, 50 percent of all simulated vehicles were coded as either AV cars or AV trucks.

The results show that the five years of additional traffic growth and induced traffic from the doubling in AV adoption has led to limited increases in average speeds. This stabilization of speeds reflects that in the Rise of the AVs scenario traffic is flowing smoothly since more of that traffic is in vehicle platoons.

Scenario 3 – Limited AV Adopters (2040 20 percent AV)



Daily traffic volumes for 2040 Build conditions were developed and provided to the study team. Traffic volumes for 2040 peak hour Build conditions were developed using a growth ratio comparing 2040 Build projected average daily traffic volumes to 2015 existing average daily traffic volumes. The design hour volumes were then inflated by the research-based trip increase factor of 1.06 based on 20 percent AV adoption as the only factor considered.

Modifications were necessary to turn the existing roadway model into a build condition. As with Scenarios 1 and 2, an interior, third lane was added to the model and was treated as a passenger car and passenger AV only lane. For the **Limited AV Adopters** scenario, 20 percent of all simulated vehicles were coded as either AV cars or AV trucks.

The results show that ten additional years of traffic growth since the Rise of the AVs scenario have started a ten percent decline in speeds. Traffic is more crowded, but only 20 percent of vehicles can leverage platooning technology to reduce the negative effects of crowding.

Scenario 4 – AV Domination (2040 85 percent AV)

Daily traffic volumes for 2040 Build conditions were developed and provided by Iowa DOT Systems Planning. Traffic volumes for 2040 peak hour Build conditions were developed using a growth ratio from comparing 2040 Build projected average daily traffic volumes to 2014 existing average daily traffic volumes. The design hour volumes were then inflated by the research-based trip increase factor of 1.19 based on 85 percent AV adoption, impact of aging population, and Millennial travel behavior.

Modifications were necessary to turn the existing roadway model into a build condition. As with the previous three scenarios, an interior, third lane was added to the model and was treated as a passenger car and passenger AV only lane. For the AV Domination scenario, 85 percent of all simulated vehicles were coded as either AV cars or AV trucks.

The results show that speeds have stayed nearly constant to the Rise of the AVs scenario even though the analysis periods are ten years apart. The growth in vehicle crowding (demand-to-capacity ratio) in that last ten years is obvious, but most vehicles are AV in this scenario, so crowding is a limited concern. The AV Domination scenario results indicate a trend that traffic operations appear stable well beyond the traditional traffic breakdown point.

Conclusions/Comparison of Scenarios

Results from the existing conditions simulation, future 2040 No-Build simulation, and the four scenarios are summarized in **Table D.3** providing focus on contrasts between the varying scenarios. Density is shown for all scenarios for reference.

The segment analyzed between Wright Brothers Boulevard and U.S. 30 (**Table D.3**) experiences traffic volumes that represent 71 percent of available capacity. Interstate 380 widening provides a major improvement in these segments, by decreasing the demand-to-capacity ratio to 57 percent. The influence of high-levels of AV adoption is an additional decrease in demand-to-capacity ratio to 50 percent and average speeds higher than existing conditions.

Interstate 380 represents a facility that traditional HCM analysis suggests widening from six lanes to eight lanes to accommodate traffic density thresholds customary for freeway planning. The segment's simulated speeds at low levels of automation (Limited AV Adopters) still show high freeway speeds even though densities have reached an unacceptable LOS. The project team recommends a six-lane freeway section for I-380 through the study area for the 2040 design year.

A visual comparison of the traffic behavior with and without AV is found in **Figures D.4** and **D.5**.

Figure D.4. I-380 without Automated Vehicles

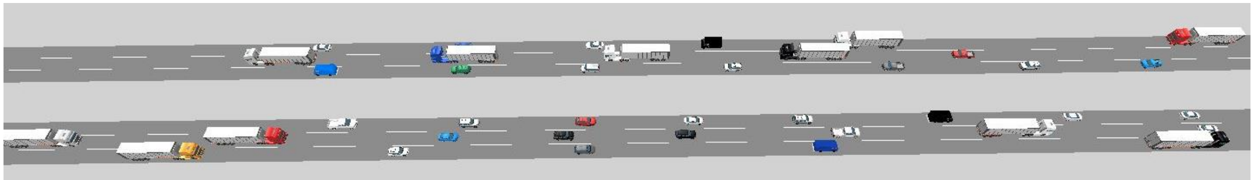


Figure D.5. I-380 with Automated Vehicles

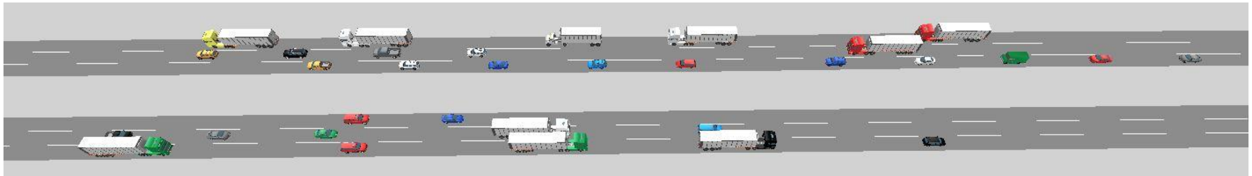


Table D.3. Summary of Segment Results

Worst Case Direction	Volume (passenger car equivalents)	AV %	Average Speed (mph)	Average Density (passenger car / mile / lane)	Demand to Capacity Ratio
Existing	2,720	0	65.5	20.8	0.57
2025 Scenario 1 Early AV Adopters	3,360	25	66.3	18.2	0.43
2030 Scenario 2 Rise of the AVs	3,880	50	66.3	20.9	0.45
2040 No-Build	3,420	0	58.9	32.8	0.70
2040 Scenario 3 Limited AV Adopters	4,080	20	65.2	22.4	0.52
2040 Scenario 4 AV Domination	4,580	85	66.7	24.5	0.47

Notes: automated vehicle (AV); miles per hour (mph)

Overall, the traffic capacity analysis identified several key elements of the challenges facing I-380 and concerning AV operations in mixed traffic with manually operated vehicles.

- The existing conditions analysis for I-380 showed average traffic speeds decreasing based on increasing traffic density. Because AV technology is not expected to reach high levels of adoption for more than a decade, a more traditional capacity improvement is necessary to improve the operations on I-380.
- The evaluation of low adoption levels of AV in mixed traffic with manual vehicles shows that the introduction of AVs leads to higher average speeds due to more free space for the manual vehicles and harmonized speeds between AVs.
- The high levels of AV adoption show the extreme benefit of high speeds even in very crowded conditions due to the 26 percent capacity gain per lane identified at 85 percent AV adoption.

Collectively, these findings suggest Iowa DOT can experience major traffic operational improvements on I-380 through enabling the I-380 corridor to support AV.

APPENDIX E – CORRIDOR SAFETY METHODOLOGY AND RESULTS

E.1 METHODOLOGY

This section describes the methodology used to assess the impact of the four Automated Vehicle (AV) scenarios on safety. Existing conditions of the rural Interstate 380 (I-380) corridor between Iowa City and Cedar Rapids were reviewed to estimate the potential impacts of AV technology on I-380. Then to illustrate the combined impact of AV technology and anticipated traffic growth and corridor widening, a segment of rural I-380 between US 30 and Wright Brothers Boulevard was selected for analyzing future alternatives. Recent AV safety research and Highway Safety Manual crash prediction methods were used to forecast the expected crashes for each of the future scenarios. Predictions were also developed for no-AV adoption conditions for comparison purposes.

AV Safety Research and Crash Modification Factors

Recent research related to AV safety was examined and a recent research document was identified, which showed promise for predicting the safety benefits of AV safety technologies: *Implications of Connected and Automated Vehicles on the Safety and Operations of Roadway Networks: A Final Report* (Kockelman, Avery, Bansal et al. 2016). This report used the 2013 National Automotive Sampling System (NASS) General Estimates System (GES) crash database and mapped pre-crash events to specific safety technologies.

Table E.1 shows which rural freeway-related pre-crash events were mapped to each of the safety technologies. For example, on the I-380 corridor between US 30 and the future Forevergreen Road interchange there were 59 crashes that were identified as “ran off road – straight” crashes. These crashes were mapped to the Road Departure Crash Warning (RDCW) and Lane-Keeping Assistance (LKA) technologies, which would have engaged if present to attempt to prevent those crashes. Also, on the I-380 corridor between US 30 and the future Forevergreen Road interchange there were 46 animal crashes. Those crashes were mapped to the AEB and Electronic Stability Control (ESC) technologies that would have engaged to attempt to prevent those crashes. While the crash mapping in the Kockelman, Avery, Bansal et al. 2016 study was completed using light-duty vehicle crashes only, the results were applied to all crashes in this Interstate 380 study. Non rural freeway pre-crash events such as running a red light or pedalcyclist crashes have been removed to simplify the table.

Table E.1. Mapping of Rural Freeway Pre-Crash Scenarios to Safety Technologies Based on 2013 General Estimates System

No.	Pre-Crash Scenario	Mapping Safety Applications
1	Vehicle failure	Control Loss Warning (CLW)
2	Control loss with prior vehicle action	
3	Control loss without prior vehicle action	
6	Road edge departure with prior vehicle maneuver	Road Departure Crash Warning (RDCW) and Lane-Keeping Assistance (LKA)
7	Road edge departure without prior vehicle maneuver	
8	Road edge departure while backing up	
9	Animal crash with prior vehicle maneuver	Automatic Emergency Braking (AEB) and Electronic Stability Control (ESC)
10	Animal crash without prior vehicle maneuver	
15	Backing up into another vehicle	Backup Collision Intervention (BCI)
16	Vehicle(s) turning – same direction	Blind Spot Warning (BSW) and Lane Change Warning (LCW)
17	Vehicle(s) changing lanes – same direction	
18	Vehicle(s) drifting – same direction	
20	Vehicle(s) making a maneuver – opposite direction	Do Not Pass Warning (DNPW)
21	Vehicle(s) not making a maneuver – opposite direction	
22	Following vehicle making a maneuver	Forward Collision Warning (FCW) and Cooperative Adaptive Cruise Control (CACC)
23	Lead vehicle accelerating	
24	Lead vehicle moving at lower constant speed	
25	Lead vehicle decelerating	
26	Lead vehicle stopped	
29	Left turn across path/opposite direction at non-signalized junctions	Cooperative Intersection Collision Avoidance System (CICAS)
30	Straight crossing paths at non-signalized junctions	
31	Vehicle(s) turning at non-signalized junctions	
32	Evasive action with prior vehicle maneuver	AEB and ESC
33	Evasive action without prior vehicle maneuver	
34	Non-collision incident	None
35	Object crash with prior vehicle maneuver	AEB and ESC
36	Object crash without prior vehicle maneuver	
37	Other	Combined Impacts of Safety Applications

Source: Kockleman, Avery, Bansal et al. 2016
Notes: Non rural freeway pre-crash events have been removed to simplify the table. The crash mapping was completed using light-duty vehicle crashes only.

The Kockleman, Avery, Bansal et al. 2016 research assumed effectiveness for each of the safety technologies in reducing crashes of different severities. The assumed effectiveness for 100 percent AV adoption is shown in **Table E.2** and is divided into three possible safety scenarios: conservative (least crash reduction), moderate, and aggressive (greatest crash reduction). The moderate scenario assumes an approximately ten percent increase in safety technology effectiveness over the baseline conservative scenario. The aggressive scenario assumes a further ten percent increase in effectiveness over the moderate scenario, creating a 20 percent range for possible safety technology effectiveness outcomes. The moderate scenario represents the middle of that range and was selected as a reasonable effectiveness estimate for this project. It also assumed that the safety technology benefits are linear with increasing AV adoption.

Table E.2. Effectiveness Assumptions of Safety Applications in Three Scenarios

Safety Application	Scenario: Conservative						Scenario: Moderate						Scenario: Aggressive					
	K	A	B	C	O	U	K	A	B	C	O	U	K	A	B	C	O	U
Forward Collision Warning & Cooperative Adaptive Cruise Control	0.7	0.8	0.9	1	1	0.3	0.8	0.9	1	1	1	0.4	0.9	1	1	1	1	0.5
Cooperative Intersection Collision Avoidance System	0.5	0.6	0.7	0.8	0.9	0.3	0.6	0.7	0.8	0.9	1	0.4	0.8	0.9	1	1	1	0.5
Control Loss Warning	0.4	0.5	0.6	0.7	0.8	0.3	0.5	0.6	0.7	0.8	0.9	0.4	0.6	0.7	0.9	1	1	0.5
Road Departure Crash Warning & Lane-Keeping Assistance	0.3	0.4	0.5	0.6	0.7	0.3	0.5	0.6	0.7	0.8	0.9	0.4	0.7	0.8	1	1	1	0.5
Self Parking Valet System	0.6	0.7	0.8	0.9	1	0.3	0.7	0.8	0.9	1	1	0.4	0.8	0.9	1	1	1	0.5
Blind Spot Warning & Lane Change Warning	0.7	0.8	0.9	1	1	0.3	0.8	0.9	1	1	1	0.4	0.9	1	1	1	1	0.5
Do Not Pass Warning	0.6	0.7	0.8	0.9	1	0.3	0.7	0.8	0.9	1	1	0.4	0.8	0.9	1	1	1	0.5
Automatic Emergency Braking & Electronic Stability Control	0.3	0.4	0.5	0.6	0.7	0.3	0.4	0.5	0.6	0.7	0.8	0.4	0.5	0.6	0.7	0.8	0.9	0.5
Vehicle 2 Pedestrian	0.4	0.5	0.6	0.7	0.8	0.3	0.5	0.6	0.7	0.8	0.9	0.4	0.6	0.7	0.7	0.8	1	0.5
Backup Collision Intervention	0.7	0.8	0.9	1	1	0.3	0.8	0.9	1	1	1	0.4	0.9	1	1	1	1	0.5
Vehicle 2 Pedacyclist	0.3	0.4	0.5	0.8	0.7	0.3	0.4	0.5	0.6	0.7	0.8	0.4	0.5	0.6	0.7	0.8	0.9	0.5
Combined Impacts of Safety Applications	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5

KEY:
(K) fatality; **(A)** incapacitating injury; **(B)** non-incapacitating injury; **(C)** possible injury; (**O)** no apparent injury/property-damage only; **(U)** severity unknown
Red = low impact (0 to 0.4)
Yellow = medium impact (0.5 to 0.9)
Green = high impact (1)

Source: Kockleman, Avery, Bansal et al. 2016

By combining the crash mapping, an assumed reduction in crashes for each technology and an AV adoption rate it is possible to estimate an overall Crash Modification Factor (CMF) for a highway segment.

For example, if all crashes in a segment were mapped to FCW and CACC technologies and if there was a 50 percent AV adoption, then using the moderate scenario a 40 percent reduction in fatal crashes, 45 percent reduction in major injury crashes, and a 50 percent reduction in all other crashes would be expected. This same approach can be used for all crash causes/technologies and severities to yield a total crash reduction CMF, which can be applied to the predicted crashes for each analysis scenario.

Crash/Technology Mapping and CMFs for I-380

The process used above was applied to the I-380 corridor between US 30 and the future Forevergreen Road interchange. The Iowa crash data did not have the exact same pre-crash event information; however, the crash causation information provided a reasonable proxy. **Table E.3** shows how the I-380 crash data was mapped to a pre-crash scenario and thereby to a safety application. By using this process the majority of all observed crashes occurring on the corridor over the five-year, 2011 to 2015, time period could be mapped to a technology (499 of 510 crashes were mapped to a technology, with 11 unassigned). The most common crash causes on the corridor were: following too close, swerving/evasive action, ran-off-road (straight road), driving too fast for conditions, and animals.

Table E.3. Crash Mapping

Major Cause	Pre-Crash Scenario	Safety Application
Followed too close	Leading vehicle/following vehicle actions	FCW and CACC
Driving too fast for conditions	Loss of control/vehicle failure	CLW
Lost control	Loss of control/vehicle failure	CLW
Equipment failure	Loss of control/vehicle failure	CLW
Crossed centerline	Road edge departure	RDCW and LKA
Crossed median	Road edge departure	RDCW and LKA
Ran off road – straight	Road edge departure	RDCW and LKA
Ran off road – left	Road edge departure	RDCW and LKA
Illegally parked/unattended	Road edge departure	RDCW and LKA
Failed to yield right-of-way	Lane change/drifting	BSW and LCW
Improper or erratic lane changing	Lane change/drifting	BSW and LCW
Animal	Animal	AEB and ESC
Driver distraction: reaching for object(s)	Evasive action	AEB and ESC
Driver distraction: inattentive	Evasive action	AEB and ESC
Over correcting/over steering	Evasive action	AEB and ESC
Swerving/evasive action	Evasive Action	AEB and ESC
Improper backing	Backing	BCI

Key:
FCW and CACC – Forward Collision Warning and Cooperative Adaptive Cruise Control
CLW – Control Loss Warning
RDCW and LKA – Road Departure Crash Warning and Lane-Keeping Assistance
BSW and LCW – Blind Spot Warning and Lane Change Warning
AEB and ESC – Automatic Emergency Braking and Electronic Stability Control
BCI – Backup Collision Intervention

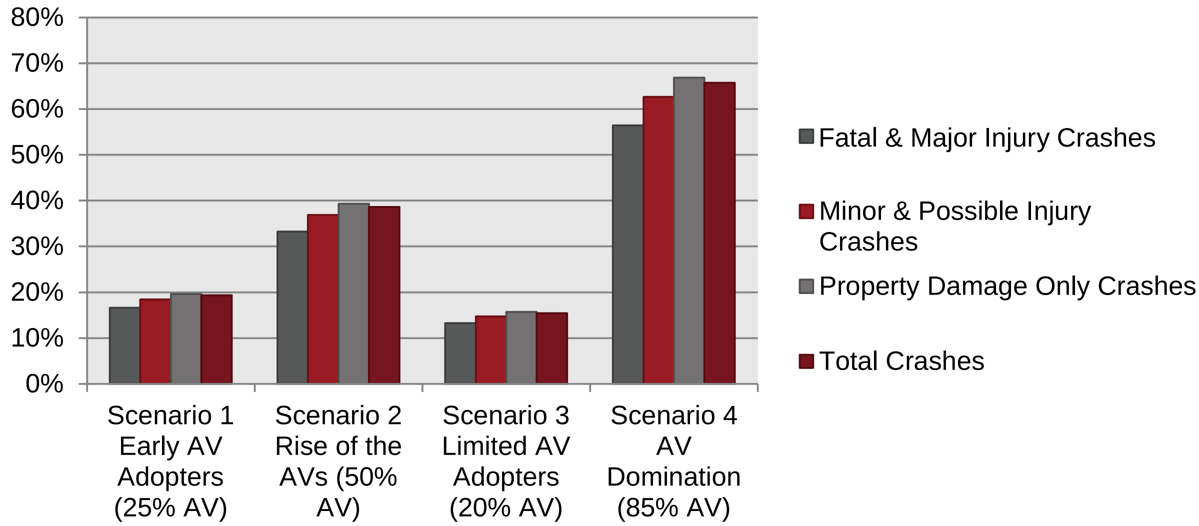
The CMFs that resulted from the I-380 crash mapping and then assigning a crash reduction factor by severity (using the moderate category from the Kockelman, Avery, Bansal et al. 2016 research) resulted in the CMFs shown in **Table E.4** and **Figure E.1**.

Table E.4 Resulting Crash Modification Factors by Scenario for I-380 Corridor

Scenario	Year	AV Adoption (%)	Crash Reduction by Severity (%)			
			K and A	B and C	O	Total
1: Early AV Adopters	2025	25	16.6	18.4	19.7	19.3
2: Rise of the AVs	2030	50	33.2	36.9	39.3	38.6
3: Limited AV Adopters	2040	20	13.3	14.7	15.7	15.5
4: AV Domination	2040	85	56.5	62.6	66.8	65.7

Notes: AV = automated vehicle; K=Fatal; A=Incapacitating Injury; B=Non-incapacitating Injury; C=Possible Injury; O=Property Damage Only

Figure E.1. Crash Reductions by Scenario and Severity – I-380 Corridor

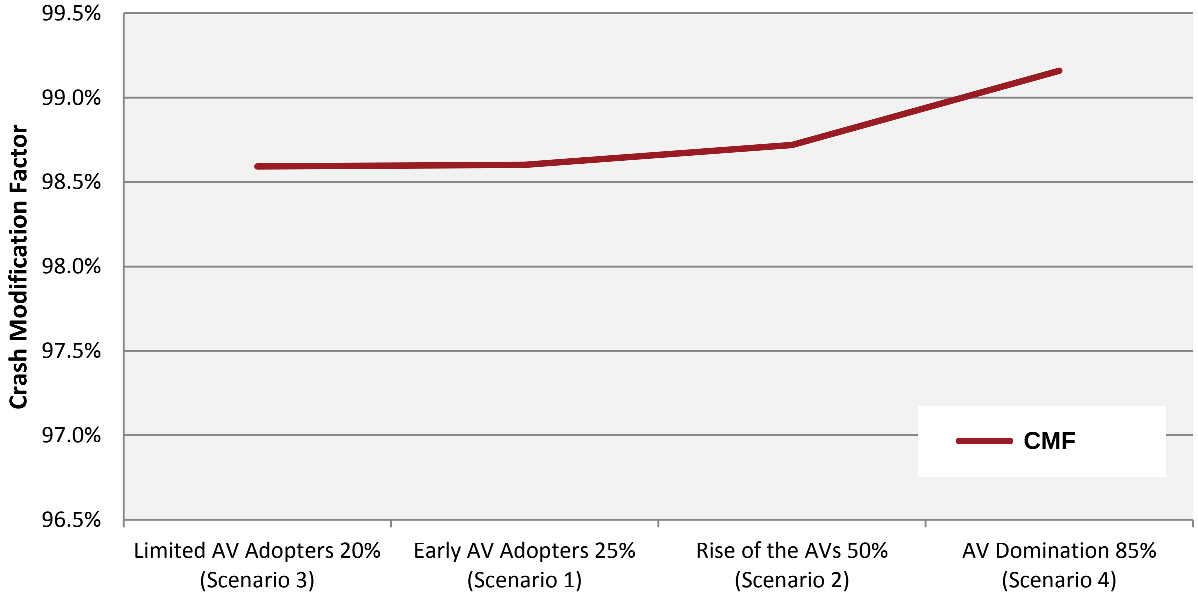


Smart Truck Parking

A second set of CMFs were applied for the proposed Smart Truck Parking project that is being implemented in Iowa and several other Midwestern states. Smart Truck Parking is a system that uses road signs, smartphone apps, websites, and messaging to inform truck drivers of parking availability in real time. Access to this information will allow truck drivers to better plan their trips and find a place to rest when they are tired. Smart Truck Parking is intended to reduce crashes related to driver fatigue. Several background documents were examined to determine the most appropriate CMF for this improvement. The value selected was an eight percent crash reduction applied to all crashes involving a heavy truck (tractor trailers). This value is in line with the overall trend of the data on this topic.

While the eight percent CMF was applied to all crashes with one of more trucks involved, it was reduced to account for the percentage of trucks assumed to be automated. Therefore, as the AV adoption increased, the Smart Truck Parking benefit decreased. The resulting crash modification factors by scenario and AV adoption are shown in **Figure E.2.**

Figure E.2. Smart Truck Parking Crash Modification Factors for I-380



E.2 SAFETY RESULTS

Existing Conditions

Crash data for 2011-2015 was analyzed for I-380 between the future Forevergreen Road interchange and US 30. Examining this data was helpful for understanding the crash types and trends within the study area. The detailed crash cause and truck involvement data were then used as discussed previously for determining the crash modification factors for AV safety technologies and Smart Truck Parking.

The corridor analyzed had a total of 510 crashes during the five-year period. **Figure E.3** shows the crash percentages by severity for the corridor.

Figure E.3. Crash Severity (2011-2015)

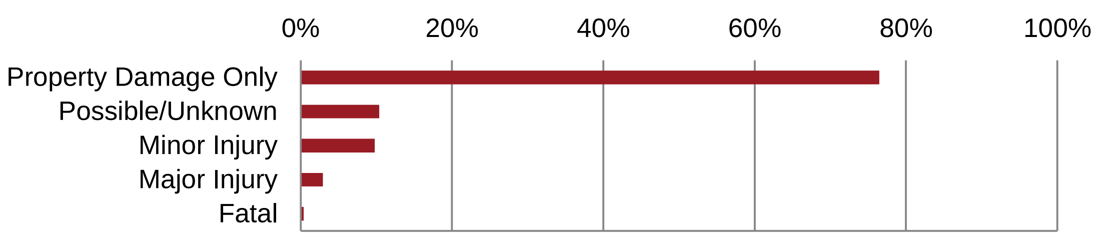


Figure E.4 and E.5 shows several crash characteristics, such as major cause and weather. One of the most common crash causes was reported as follows too closely, which is consistent with the high speed, high traffic volume nature of the corridor. Other commonly reported causes include ran off road – straight and swerving/evasive action, which are both common crash types for high-speed, limited-access facilities such as I-380. The majority of crashes occurred during clear weather conditions; however, snow-related crashes were also common. Given the amount of snow typically experienced in this area, these snow-related crashes are not unexpected.

Figure E.4. Major Causes of Crash Characteristics

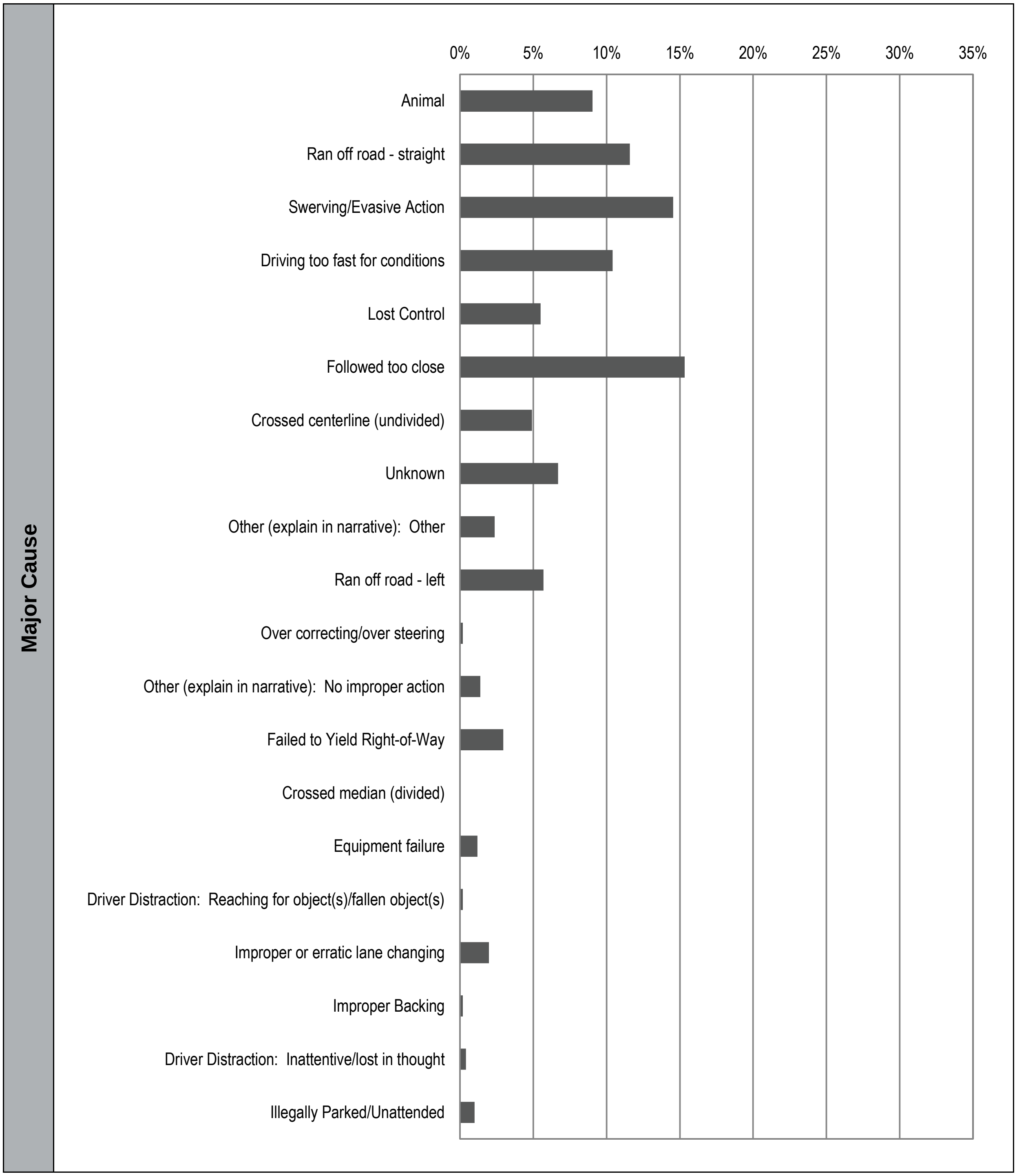
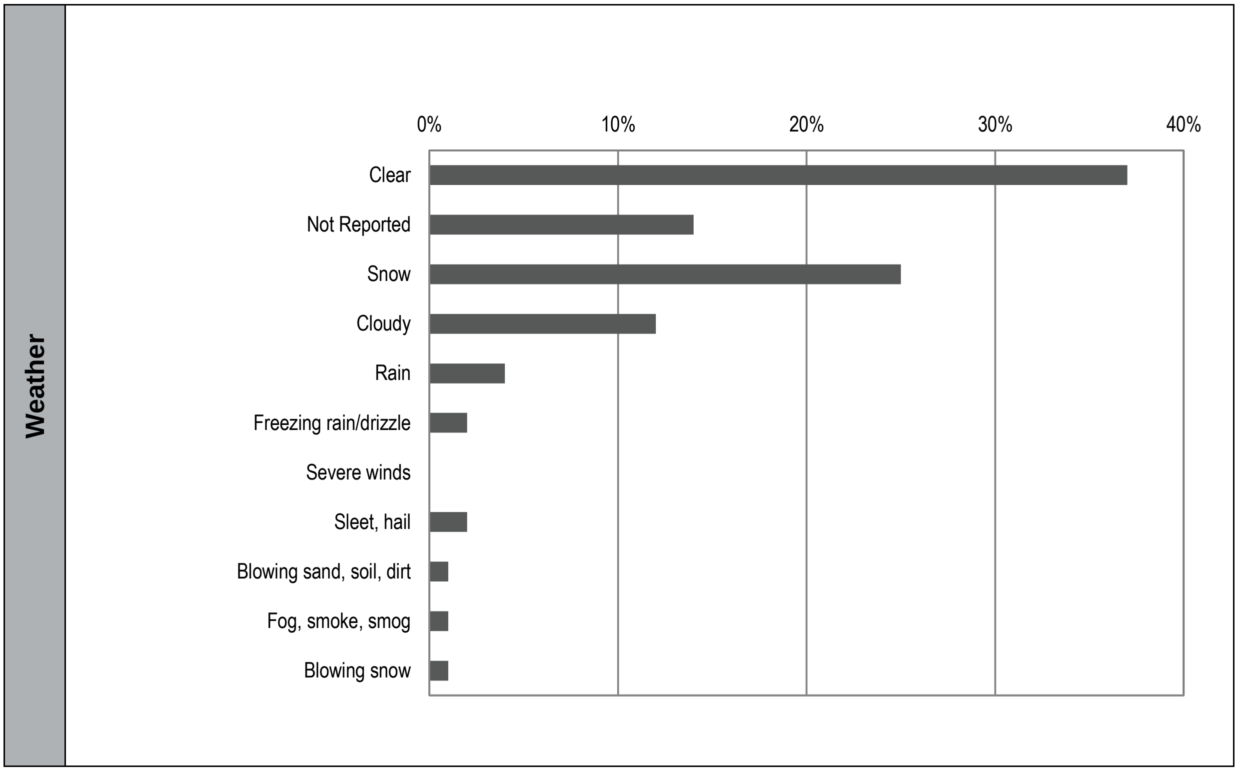


Figure E.5. Weather-related Crash Characteristics



The crash rate (crashes per 100 million vehicle miles travelled [VMT]) for the corridor was calculated to be 39.6 for the period from 2011-2015. This rate falls below the statewide average rate for rural interstates, which is 51.0 for the period from 2012-2016, which is the most recent statewide data available. The fatal and injury crash rate was also calculated (excludes possible injuries). For the corridor that rate was calculated to be 5.20. This fatal and injury rate does not exceed the statewide rate of 5.42 for the 5-year period.

Interstate 380 Study Segment

After taking stock of existing crash patterns on the corridor, detailed crash prediction modeling was conducted on a representative segment of the corridor. The segment chosen was between US 30 and Wright Brothers Boulevard in Linn County on the southern portion of the Cedar Rapids metro area. From 2011-2015 this segment experienced 57 total crashes including 11 fatal and injury crashes.

The segment is two miles long with a single, large radius curve near the 76th Avenue SW overpass. The roadway also includes continuous cable barrier and rumble strips on inside and outside shoulders. Typical to the corridor, this segment has narrower than standard inside shoulders. Based on data from the Iowa DOT Interactive Map Portal, the 2015 average annual daily traffic (AADT) on this segment is 58,400 with 14 percent trucks.

The remainder of this analysis focuses on this short segment, but findings along this segment would be indicative of more general trends along the corridor, like the frequency of increased crashes due to baseline traffic growth and the high-level impact of AVs.

Safety Performance Functions

Safety performance functions (SPFs) were used to predict the number of crashes on the study segment. The team utilized equations published in the Highway Safety Manual (HSM) 2014 Supplement. The analysis ignored the influence of ramps at adjacent interchanges, focusing on assessing crashes related to the typical cross section of I-380. Existing crash history was not incorporated using the Empirical Bayes technique as is common practice when predicting changes in crash behavior between conditions that differ significantly from existing. Iowa's calibration factors (shown below) for rural mainline freeway segments were utilized.

- Rural Freeway Multiple-Vehicle Fatal and Injury SPF – 1.08
- Rural Freeway Multiple-Vehicle Property Damage Only – 1.67
- Rural Freeway Single-Vehicle Fatal and Injury – 0.64
- Rural Freeway Single-Vehicle Property Damage Only – 1.16

Future Baseline Conditions

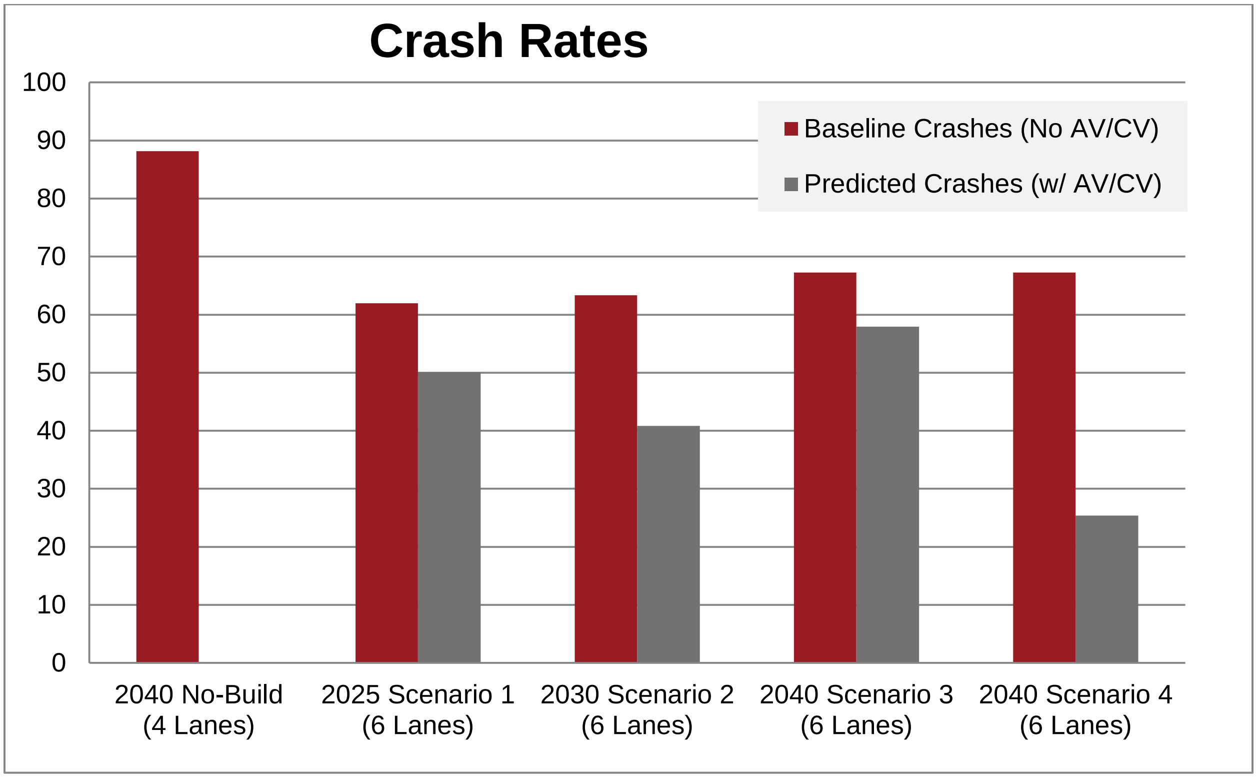
The 2040 No-Build scenario assumes no freeway widening and zero percent AV adoption. Using the HSM method, the baseline predicted crashes in 2040 for the No-Build scenario was 49.9 total crashes (0.7 fatal and major injury crashes) on the segment between US 30 and Wright Brothers Blvd as shown in **Table E.5**, alongside the four AV scenarios. The resulting crash rate was 88 total crashes per 100 million VMT and 1.2 fatal and major injury crashes per 100 MVM as shown in **Figure E.6**.

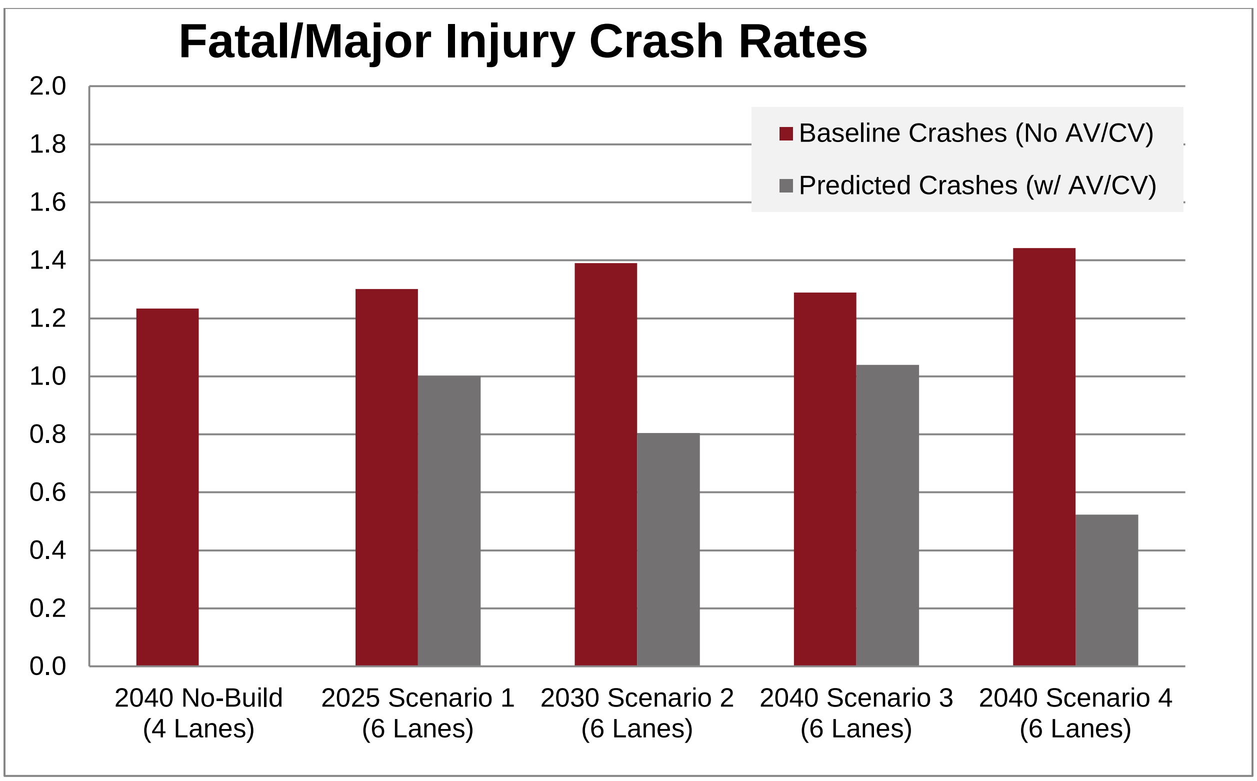
Table E.5. Predicted Crash Results

Segment 1 Total Predicted Crashes - ISU Method															
	2040 No-Build (4 Lanes)			2025 Scenario 1 (6 Lanes)			2030 Scenario 2 (6 Lanes)			2040 Scenario 3 (6 Lanes)			2040 Scenario 4 (6 Lanes)		
	ADT	Total Crashes	Fatal & Maj. Inj.	ADT	Total Crashes	Fatal & Maj. Inj.	ADT	Total Crashes	Fatal & Maj. Inj.	ADT	Total Crashes	Fatal & Maj. Inj.	ADT	Total Crashes	Fatal & Maj. Inj.
Baseline (0% AV)	77,600	49.9	0.7	63,390	28.7	0.6	68,500	31.7	0.6	77,600	38.1	0.7	77,600	38.1	0.7
Predicted (w/ AV)				67,750	24.8	0.5	78,100	23.3	0.5	82,250	34.8	0.6	92,350	17.1	0.4
Crashes Eliminated					*3.9*	*0.1*		*8.4*	*0.2*		*3.3*	*0.1*		*21.0*	*0.3*
% Reduction					**14%**	**11%**		**27%**	**25%**		**9%**	**10%**		**55%**	**49%**

Notes: AV = automated vehicle; ADT = average daily traffic

Figure E.6. Predicted Crash Rate Results





Scenario 1 – Early AV Adopters (2025 25 percent AV)

Scenario 1 – Early AV Adopters is the near-term (2025) scenario, which assumes 25 percent AV adoption. With this assumption, the number of predicted crashes on the analyzed segment is 24.8 (0.5 Fatal and Major Injury – (F&MI)). These values are 14 percent lower than the baseline 2025 total crashes assuming no AV adoption, and 11 percent lower than the baseline F&MI crashes. It is useful to note that these crash reductions occur even with an increase in volume and therefore crash exposure in the AV scenarios. To account for the change in volumes, crash rates were calculated. The crash rates go down even further from 62 crashes per 100 MVM to 50 crashes per 100 MVM as shown in **Figure E.6**, a 19 percent reduction for total crash rates. F&MI crash rates decrease from 1.3 crashes per 100 MVM to 1.0 crashes per 100 MVM, a 23 percent reduction.

Scenario 2 – Rise of the AVs (2030 50 percent AV)

Scenario 2 – Rise of the AVs is the mid-year (2030) scenario, and assumes 50 percent AV adoption. With this assumption, the number of predicted crashes on the analyzed segment is 23.3 (0.5 F&MI). These values are 27 percent lower than the baseline 2030 total crashes assuming no AV adoption, and 25 percent lower than the baseline F&MI crashes. The crash rates go down even further from 63 crashes per 100 MVM to 41 crashes per 100 MVM as shown in **Figure E.6**, a 36 percent reduction for total crash rates. F&MI crash rates decrease from 1.4 crashes per 100 MVM to 0.8 crashes per 100 MVM, a 42 percent reduction.

Limited AV Adopters (2040 20 percent AV)

Scenario 3 – Limited AV Adopters is the long-term, low-penetration scenario, which assumes only 20 percent AV adoption by 2040. For this scenario the predicted number of crashes was calculated to be 34.8 on the analyzed segment. This is a 9 percent reduction on each segment in comparison to the 2040 baseline numbers. The F&MI crashes decrease by approximately 10 percent. The crash rates go down even further from 67 crashes per 100 MVM to 58 crashes per 100 MVM as shown in **Figure E.6**, a 14 percent reduction for total crash rates. F&MI crash rates decrease from 1.3 crashes per 100 MVM to 1.0 crashes per 100 MVM, a 23 percent reduction.

In this scenario, the predicted 34.8 total crashes is a 15.2 crash improvement over 2040 No-Build conditions, but most of that crash improvement is related to the widening and modernizing of Interstate 380 with only 3.3 total crashes being reduced due to AV technology.

Scenario 4 – AV Domination (2040 85 percent AV)

Scenario 4 – AV Domination is the long-term, high-penetration scenario, which assumes 85 percent AV adoption by 2040. This scenario yields the highest safety benefits, as the number of total predicted crashes decreases from 38.1 to 17.1 (55 percent reduction) on the segment analyzed. The F&MI crashes decrease by 49 percent. Crash rates are also significantly improved in this scenario. The crash rates go down even further from 67 crashes per 100 MVM to 25 crashes per 100 MVM as shown in **Figure E.6**, a 63 percent reduction. F&MI crash rates decrease from 1.4 crashes per 100 MVM to 0.5 crashes per 100 MVM, a 64 percent reduction.

Safety Summary

Interstate 380 experiences substantial crash activity today as is typical for a high-volume, high-speed corridor. With worsening congestion, 2040 No-Build conditions are predicted to experience 88 crashes per 100 million VMT, well in excess of statewide averages. Based on the four scenarios analyzed, widening of I-380 alone (independent of AV fleet penetration) would bring significant crash rate benefits, lowering the crash rate to 67 crashes per 100 million VMT. These benefits are based on reduced congestion and enhanced shoulder width. The results assume widening does not induce more traffic to the corridor by 2040 than the No-Build condition.

While the widening does show an improvement of No-Build conditions in 2040 crash rates, the analysis still points to a rate of 67 crashes per 100 million VMT. However, with AVs, the analysis shows a drastic reduction in crash rates, ranging from 58 down to 25 crashes per 100 million VMT, and between 14 and 62 percent improvement over No-Build. Should I-380 be widened and AV scenarios play out as projected, **Table E.5** shows between 15.1 and 32.8 total crashes per year could be eliminated compared to the forecasted 2040 No-Build condition for the segment analyzed (US 30 to Wright Brothers Boulevard). Similarly, between 0.1 and 0.3 fatal and major injury crashes per year could be eliminated comparing the 2040 Build scenarios to No-Build as shown in **Table E.5**.

APPENDIX F – FUTURE PROOFING AND DESIGN CONSIDERATIONS

Future-proofing is the process of anticipating the future and designing in a way which, to the greatest degree possible, minimizes the need to replace or abandon today's investments for newer or more effective ones in the future. The Iowa DOT has recognized the potential benefits of AV technology in terms of mobility, roadway safety, and freight movement and has begun making investments to facilitate the development of tools which will enable early adoption of AV technologies along the Interstate 380 (I-380) corridor. To ensure that any investments made to increase the capacity of the system continue to provide long-term value, the Iowa DOT should endeavor to include future-proofing principals in the planning and construction of the I-380 corridor.

The Iowa DOT has recognized enablers (physical and virtual infrastructure components) as critical elements in the gathering and dissemination of data to AV's. As part of the Automated Vehicles Technologies Initiative, the Iowa DOT and partners HERE, the University of Iowa and Iowa State University are working to provide information in a format that is understandable and actionable by either humans and/or vehicles. In order to provide this information, the Iowa DOT will need to collect data from both infrastructure and passing vehicles. The Iowa DOT is also currently investing in permanent and temporary Intelligent Transportation Systems (ITS), Intelligent Work Zone (IWZ) and back-of-queue technology projects throughout the state and along portions of the study corridor. The data that the infrastructure and equipment projects are capable of collecting (e.g., speed, volume) are examples of the types of information that the AV project could provide to drivers in the future (e.g., crash ahead, right lane closed). Future-proofing considerations may help in determining which additional technologies and supporting infrastructure should be pursued and point toward opportunities to leverage investments made on one project to benefit future efforts, both known and unknown. Planning for upcoming corridor roadway construction projects could include elements which support the infrastructure needs of AV data collection, distribution, and communications. Selecting open architectures, avoiding the use of proprietary technology and building in scalability to allow for the addition of new devices are examples of ways the Iowa DOT can start the process of future proofing today.

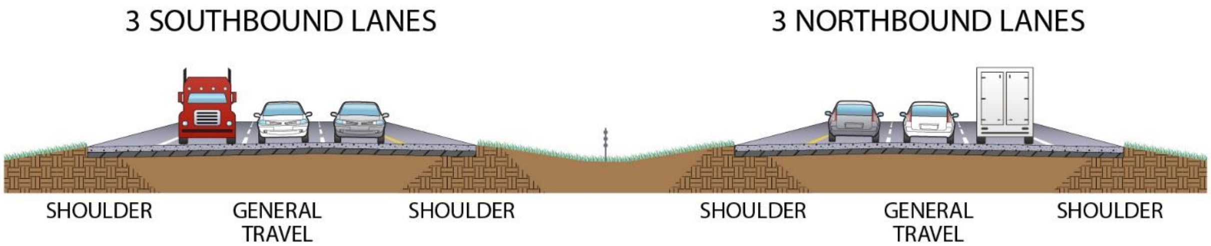
Prior to this I-380 PEL Study, the Iowa DOT conducted a planning effort for the rural portions of I-80. The I-80 study was used as a starting point for the future-proofing portion of this study. Although both studies involve rural segments of interstates there are notable differences which impact the future-proofing recommendations of this document. As an example, I-380 is the primary commuter route between the state's second and fourth largest metropolitan areas and has a much different mix of passenger vehicles and truck traffic than the I-80 study area. The existing technology infrastructure, current AV efforts, and the projected growth in volume along the corridor were also considered. These differences, along with the relatively short distance of the corridor study area, led the study team to a different lane utilization recommendation.

To future-proof a rural interstate corridor, the project team identified four main focus areas:

- Mobility needs and expandability
- Automated vehicle (AV) infrastructure needs
- Construction methods and materials
- Right of way needs

The baseline to consider these future-proofing focus areas against was the proposed Interstate 80 (I-80) cross section identified in the *I-380 Planning Study Guiding Principles* document (see **Figure F.1**).

Figure F.1. Interstate 380 Planning Study Guiding Principles Cross Section



The proposed concept has the following features:

- 12-foot-wide outside shoulder
- Three 12-foot-wide travel lanes
- 12-foot-wide inside shoulder that could be converted to a fourth travel lane in the future
- Space for a future inside shoulder to be paved during a later expansion
- 82-foot-wide median from the inside of travel lanes in each direction

Based on this baseline concept, the project team considered design modifications that meet the traffic and safety analysis needs previously defined while providing greater flexibility to the Iowa Department of Transportation (DOT).

F.1 - MOBILITY NEEDS AND EXPANDABILITY

Today, portions of I-380 are already experiencing vehicle crowding or density at levels exceeding desirable guidelines**.** By 2040, a traditional density analysis that incorporates forecasts of future corridor vehicle demand growth shows the need to expand to eight lanes. With that level of expansion needed even by the project horizon year, Iowa DOT developed an I-380 cross section that reserves space in the median for expansion to the inside. Under this template cross section, the initial major construction to widen I-80 to six lanes (including replacing existing overhead bridges with longer structures) can be accomplished so that an eventual transition to eight lanes requires only placing a future inside shoulder section.

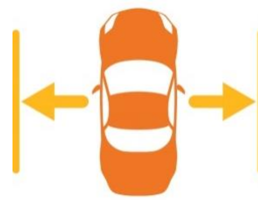
As identified in the traffic capacity section, traffic capacity analysis of mixed manual and AV was assessed for performance based on average freeway speeds and demand-to-capacity ratio. Review of the typical segment analyzed show the peak hour demand-to-capacity ratio at 0.50. At that level of congestion, average segment speeds under high-levels of automation are still high higher than existing conditions. Based on these performance measures, the project team suggests mixed manual and AV traffic can operate efficiently on the proposed six-lane section.

The project team sought to identify how far beyond the year 2040 the facility could still operate efficiently without additional lanes (beyond the lanes recommended for the build condition). To develop this estimate, the project team assumed traffic volumes would grow linearly each year and developed a threshold for acceptable performance of demand-to-capacity ratio equal to 0.80. Between the years of 2060 and 2070, it is estimated that a typical segment of rural I-380 would potentially exceed the threshold of acceptable operations.

Based on this distant year where I-380 conditions would be expected to reach an unacceptable level, the idea of providing future expandability within this design may not be as important as providing future lane flexibility. By looking at lane flexibility, the issue becomes whether the proposed pavement can handle traffic under diverse conditions, such as lane width and shoulder need and use. The key components to lane flexibility are:

Lane Width

AVs and trucks are designed to lane center. That means whether the lane is 10 feet wide or 12 feet wide, the vehicles run in a track down the center of the lane, minimizing vehicle oscillation and related safety concerns. The primary determining factor in lane width for AVs only would be vehicle width though other factors may apply, especially in the case of retrofitting an existing lane to AV only traffic.



With future-proofing, the design flexibility must consider conservative scenarios that will accommodate lane widths suitable to AVs and manually driven vehicles. The project team recommends a design that uses 12-foot-wide lanes for the three opening day travel lanes in each direction. In the future, lane widths may narrow if lane-centering were to become standard, potentially as low as 10 feet wide while still accommodating some oversized trucks.

Shoulder Need and Use

A growing number of agencies nationally and internationally have begun to utilize shoulders for some active traffic in highly monitored urban areas instead of reserving the shoulder area exclusively for vehicle breakdowns. With AV capabilities, the future may lead to more conditional use of rural shoulders through the built-in communications abilities of AV traffic.

With active traffic on the shoulders, the pavement design of the shoulders should provide more pavement depth than would be needed on a refuge-only type of shoulder. The project team evaluated whether both shoulders would need this type of more robust pavement design. The key factor was that manual truck traffic would be the most likely user of the right or outside-most travel lane. Given the potential safety risk of a truck breakdown and likelihood that traffic in the right lane will not be capable receiving active traffic communications, the project team recommends keeping the right shoulder as a refuge area only.

On the other hand, AV traffic will operate most efficiently in lanes other than the right or outside-most lane. Because that will put AV traffic closer to the inside shoulder, the inside shoulder is a better choice for conditional use. Because no special lane use signs will be provided, the occupants of the shoulder when conditionally open would be AVs. AVs will still have the potential to breakdown, but AVs also can respond to unexpected breakdowns more readily, which means that the left shoulder's use could become much more like a traffic lane than a shoulder, except when there is a vehicle breakdown. In that case, the inside shoulder could eventually be striped, signed and designated as an AV only lane.

One other potential use of the inside shoulder for greater mobility is the potential for agencies to deploy rapid transit and/or dynamic ridesharing using the inside shoulder as a guideway. Unlike the prior I-80 study, I-380 serves recurring commuter trips that are well suited to transit. As AV and other supportive technologies improve multimodal options, the I-380 corridor could open up the inside shoulder for those transit/ride-share vehicles to encourage fewer single-occupant vehicle trips that use freeway space inefficiently.

Considering the distant timeframe for expandability needs and the discussion on the flexibility benefits of AVs on lane width and shoulder need and use, the project team recommends that Iowa DOT consider providing future expandability (beyond 2040) by utilizing the inside shoulder as a AV dedicated travel lane, providing a total of eight lanes on I-380. Iowa DOT confirmed that the proposed typical median width for I-380 was based on constructability, and will remain as proposed in the *I-380 Planning Study Guiding Principles*.

F.2 - AUTOMATED VEHICLE INFRASTRUCTURE NEEDS

Although the I-380 corridor has sufficient infrastructure (e.g., communications and electrical service) to support the needs of existing roadside technology, future technology applications will likely require improvements to support their functionality. An example is the existing fiber optic communications along the corridor. The Iowa DOT currently utilizes two strands of fiber to facilitate connectivity to roadside devices (e.g., cameras), statewide access to the Cedar Rapids ITS network, Iowa DOT staff access to email, and other communications applications. The Iowa DOT is able to utilize a single strand to accomplish connectivity between devices and buildings with the second strand acting as a backbone connection between network hubs. To provide the network redundancy, resiliency and reliability required to support AV operations, additional communications capacity will be required. This additional capacity can be accomplished by installing fiber optic cable during roadway construction or as an alternate future proofing strategy, installing vacant conduit to provide a raceway for future cable installations. This section will explore various other options for consideration when planning future improvements to the corridor.

AVs are being developed within the confined conditions of car manufacturing facilities and private testing grounds. Outside those private testing grounds, public agencies invest in and maintain the transportation system that AVs will need to operate on. Consequently, agencies are preparing for and making investments in technology upgrades with AVs in mind, setting the stage for a smart corridor. The project team reviewed what future-proofing items are needed in the design of the I-380 expansion to help the AVs achieve their potential.

The first AV-supportive design consideration is the installation of reference markers to provide precise location information to AV's. This technology could involve the use of laser light (LiDAR) plus known points to obtain positional information (LiDAR is currently utilized for Adaptive Cruise Control, Emergency Brake Assist, and other AV applications). By establishing known reference locations (similar to National Geodetic Society monuments), combined with the high definition mapping information provided by a service such as the Iowa DOT's AV Initiative, a vehicle could determine its position in relation to these known points. In order to provide accurate location information utilizing LiDAR, an AV would need to simultaneously view a minimum of three known reference markers which will influence both the location and density of reference marker installations. Consideration should be given to the issue of occlusion from adjacent vehicles (specifically from truck traffic) when determining the appropriate location for marker installations. The project team recommends that the Iowa DOT consider reference marker installations in the interstate median and along the outside shoulder (preferably outside of the clear zone) at approximately 0.25 mile spacing. The project team suggests coordination with the automaker industry on the exact specification and spacing for designing GPS reference markers. The GPS reference markers are anticipated to be the size of a small sign.

Another AV-supportive design consideration is machine-readable signs. The current use of signage on public roadways is optimized for human comprehension and design of signs follows the guidance of the *Manual on Uniform Traffic Control Devices* (MUTCD). For AVs, the use of signs may still be appropriate to inform the AV of upcoming changes in roadway nature or traits. However, signs likely cannot be optimized for human users and AVs simultaneously given how differently the two process information. Because signs will still be needed for human users on the road, the project team recommends using signs designed with hidden, machine-readable content under the more typical, MUTCD compliant sign message. Determining how to add this machine-readable content to signs will take cooperation with the automotive industry and sign fabricators. The project team at this early stage did not identify any specific need for additional, AV-only signs as part of this work. Iowa DOT design of signage plans can focus on choosing sign locations that meet their traditional criteria, but will have to consider the new AV messaging that will be added to typical signage. Alternatively, Iowa's plans for continuous data feeds into AVs may fully serve the need of AV information, which means typical roadway signage could be used as currently deployed until such a time as no longer necessary (all vehicles capable of capturing signage virtually).

Another AV-supportive design element is roadside equipment (RSE). RSE is agency-owned communications and processing infrastructure that help the agency monitor local traffic operating conditions and provide safety information to AVs. RSE house vehicle-to-infrastructure (V2I) communications devices, like dedicated short range communications (DSRC) radio and computer processing power to turn raw data from passing AVs into information that can be acted upon by automated processes in the RSE or sent to the traffic management center (TMC). For example, RSE will be collecting information like the number of AV signals in a period of time, which helps Iowa DOT understand if the roadway is experiencing crowding. Further, RSE could gather messages from AVs that signify that a vehicle is disabled in the roadway. That message could then lead to the actions, such as contacting the proper emergency medical services (EMS) and instructing vehicles approaching the blocked lane to move to the next open lane.

The Iowa DOT's current preferred alternative to agency owned DSRC communications is the utilization of cellular connectivity. While the introduction of 5G cellular technology will provide the opportunity for reliable high-speed connectivity by more devices, there are several limitations of the technology to consider. One such limitation is the need for relatively short baselines to each tower. This requirement for closer proximity to the roadway may impact the DOT's right-of-way policies, specifically as related to utility accommodation. Another potential limitation is saturation of the cellular network during peak conditions (e.g., during an incident or special event). Relying on the availability of non-agency owned communications network may reduce the efficacy of information sharing, potentially during an incident which is a situation that would most benefit from the distribution of information to and from vehicles.

RSE was originally thought to be physical infrastructure. Advances in computing power, storage in the cloud and evolving cellular communication strength and speed are challenging that thought. By the time agencies act upon widespread use of RSE, the RSE could be all virtual infrastructures. The project team suggests a plan for RSE be developed that allows flexibility for use of either virtual or physical RSE.

The infrastructure elements recommended to support this smart corridor are continuous fiber optic lines and continuous power lines. Including these two lines continuously during the initial construction of I-380 would provide that base layer for future RSE and minimize later disruption to I-380 traffic for supplying communications and power. During design consideration should also be given to providing advanced cellular capabilities and improved vehicle and environmental sensors. The specific needs and design of infrastructure for certain sections of the I-380 corridor will vary and should be determined through the systems engineering process.

Beyond this corridor, Iowa's Automated Vehicle Initiative has advanced the understanding that agencies must consider the data side of AV infrastructure. Currently, Iowa's research and design efforts have focused on formatting their data for trial use by low level AVs using a subscription service to receive messages like "stopped traffic ahead". As Iowa DOT advances this project, higher level AVs will be able to receive a real-time map update to track a condition, like a vehicle stopped in the outer lane a half-mile ahead. To keep pace with these map updates, additional infrastructure may be needed to collect, structure, and analyze the AV data and push the data to AV users.

F.3 - CONSTRUCTION METHODS AND MATERIALS

The project team looked at construction methods and materials from an AV perspective. The biggest challenge in the area of construction materials is how AVs may indirectly increase the burden on pavement and material strength. The project team believes that impact of AVs on pavement design is an understudied future-proofing issue in the study's literature review. The project team's best course of action for capturing impacts of AVs on pavement design was through coordination with Iowa DOT's materials and pavement engineers.

While AVs may prove challenging to pavement and material design, AVs could bring agency savings and efficiency in how they impact construction methods. The project team did not identify any key recommendations for construction methods during the initial construction of I-380 because AVs are still limited, but future road work could be streamlined to take advantage of AVs ability to receive dynamic information and fit within narrower lanes.

Pavement Design

Based on the project team's analysis findings and literature review, Iowa DOT's pavement design and materials engineer provided the project team with considerations from a materials point of view. One primary takeaway for the project team was how including pavement design in the future-proofing process leads to an even larger range of uncertain futures. This is because pavements are typically designed to accommodate a 40-year design life. From the aggressive and conservative AV trends identified in the literature, that would mean by the time the pavement's useful life is complete the facility may handle between 65 percent and 100 percent AV traffic. Iowa DOT's perspective on that increased uncertainty is that the pavement design for I-380 should aim toward higher projections of future traffic to avoid designing the pavement to a lower assumed level of traffic and having pavement deteriorate prematurely. Also, Iowa DOT recommended typical assumptions on lane distribution of vehicles and trucks should be re-visited. The current assumption for a design lane is that it carries 60 percent of the total trucks for a six-lane freeway. For AVs, it is recommended that the design lane be analyzed assuming 70 percent to 80 percent of all trucks utilize a single lane. Additionally, a review of truck-only facilities could be conducted as a future activity to assess if the design of those facilities is consistent with Iowa DOT's experience and assumed impact of AVs.

Iowa DOT thinks that AVs may provide a benefit in concrete pavement design in the consistency of vehicle wheel paths. Because concrete pavements tend to fail due to edge stress, vehicle wheel paths that never wander to the pavement edge would reduce that edge stress. However, more study may be needed on the topic because vehicles with zero wander may create a new critical location for material failure. Even with the potential benefits to edge stress due to AVs paths, a conservative pavement design might provide a 12-foot-wide lane for a 10-foot-wide left travel lane without an adjacent shoulder. This is consistent with earlier lane width recommendations developed by the project team due to mobility needs and expandability.

The pavement design discussion also focused on the concept that AVs may lead to active use of both travel lanes and shoulder areas. The conservative materials design strategy to account for that variability in lane use would be a consistent base design under the full width of the travel lane and shoulder pavement. Also, under the base, Iowa DOT would likely use geogrid for the full width across the travel lanes and shoulders. The use of geogrid would increase pavement strength, but may require added drainage expense to make sure subdrains were properly placed.

An additional set of pavement design considerations relates to how future AVs lanes are placed. With AVs, there can be great flexibility in lane use because updates to lane use can be communicated directly to the vehicle. Yet, that freedom to virtually re-establish the lane lines at varying locations runs into a problem with pavement wear. Concrete pavements wear especially at the joints, so moving a lane in a way that placed the vehicle wheel path over a joint line would be a detriment to the pavement life. Likewise, the placement of future lanes in comparison to rumble strip locations is critical in concrete pavements, so a future lane change does not require passing over the rumble strips.

F.4 - RIGHT OF WAY NEEDS

The primary future-proofing consideration in the area of right of way needs is to develop a right-sized right of way design for the I-380 expansion. Right of way needs were developed at the planning level of study, based on an assumed constant width for the length of the project with a normal or typical cross section. Development of the cross section was driven by the previous future-proofing areas of mobility needs and expandability, AV infrastructure needs and construction methods and materials. The combination of those elements set the design pavement width and the median width between the travel lanes in each direction. Detailed design (performed as a future task) will determine if more right of way is needed on one side of the roadway or the other based on construction strategy and any spot improvements to I-380’s alignment.

In the future as AV adoption rates rise to 100 percent adoption, AV technology may lead to designs requiring narrower right of way. With dedicated AV lanes, AVs could be accommodated in narrower lanes and research suggests they will experience lower levels of road departures. These road departures are a primary reason behind current practices to provide gradually sloping roadsides.

F.5 - POTENTIAL STATEWIDE FUTURE-PROOFING APPLICATIONS

In order to determine future-proofing applications for rural I-380, the project team conducted a high-level review of potential future-proofing applications. The list of applications is provided to document the findings of this high-level review. The list was originally developed as part of the statewide rural I-80 assessment, but was amended due to added commuter concerns related to extremely peaked travel that can be better handled through modal strategies. Corridor planning in urban areas, or high-level agency planning that tracks emerging trends should consider further development of this list.

AV Strategies

- Communications backhaul (e.g., fiber)
- Enhanced cellular coverage (micro/pico towers)
- Roadside equipment
- Continuous power along the corridor
- Map-supportive infrastructure
  - GPS reference markers
  - Lane-level work zone database
  - Lane-level incident database

Management Strategies

- Speed harmonization/variable speed limits
- Dynamic shoulder lanes
- Dynamic passing lanes
- Variable lane restrictions
- Dynamic striping
- Flexible striping
- En-route traveler information
- Highway Helper
- End-of-Queue warning

Pavement Strategies

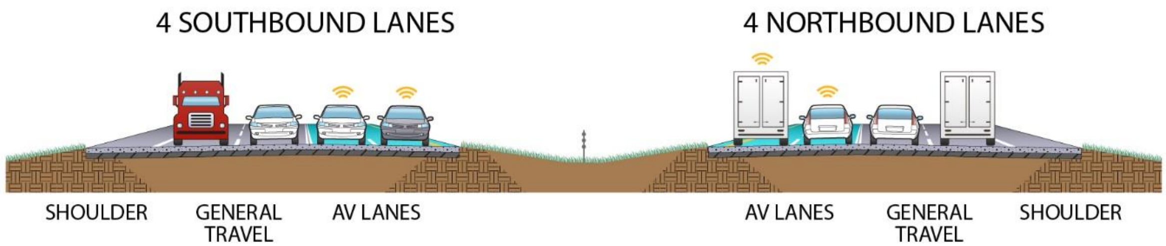
- Full depth shoulders
- Higher density pavements for truck lanes
- Pavement health monitoring systems
- Self-healing pavements

Modal Strategies

- Dynamic rideshare (with park and ride)
- Automated express bus
- Bus/High-Occupancy Vehicle (HOV) on dynamic shoulder
- En-route traveler information
- Integrated corridor management

F.6 – FUTURE-PROOFING DESIGN CONCEPT

Figure F.2. Preferred I-380 Widening Concept with Automated Vehicle Findings



Highlights of the design considerations that would allow a seamless transition in time from the cross section in **Figure F.1** to **Figure F.2** include:

- Twelve-foot-wide left and right shoulders with full depth pavement for future flexibility
    - Left shoulder: Future use as a conditional shoulder/AV-only lane that could serve high-capacity transit
    - Right shoulder: Use as a safe breakdown area and maintenance of traffic in work zones
- Robust pavement design considering higher levels of heavy vehicle exposure within one path of the critical design lane.
- Construct continuous fiber optic and power lines along the corridor
- Design of AV-supportive infrastructure
    - Reference markers to assist AVs in acquiring positional information
    - Machine-readable signs
    - Roadside equipment (5G cellular or DSRC)
    - Communications infrastructure: Advanced cellular and fiber
    - Detection: Cameras/video processing, sensors and processed data from AVs
- Limit fixed deployments of traveler information (e.g. Dynamic Message Signs)

F.7 - FUTURE-PROOFING SUMMARY

The design of roadways will change significantly as roadways adapt to support AV use. Because the future is unclear on how AVs will enter the existing vehicle mix, the best current strategy is to maintain flexibility. Additionally, agencies can make smart corridor investments, including vehicle and environmental sensors and communications equipment to prepare for a future where vehicles, infrastructure and agency traffic managers more seamlessly communicate and adjust to changing roadway conditions. The project team's future-proofing recommendations lay out key design considerations that may improve Iowa DOT's flexibility to safely and efficiently move both manually-operated cars and trucks and their AV counterparts.