MURIEL BOWSER
MAYOR

April 7, 2020

The Honorable Phil Mendelson Chairman
Council of the District of Columbia
1350 Pennsylvania Avenue, N.W., Suite 504
Washington, D.C. 20004

Re: DC Autonomous Vehicles Study Report

Dear Chairman Mendelson:

Pursuant to Section 6112 of the Fiscal Year 2019 Budget Support Act of 2018, effective October 30, 2018 (D.C. Law 22-168; 65 DCR 13694), the District Department of Transportation is pleased to submit the DC Autonomous Vehicle Study Report.

This report used a scenario-planning approach to develop and analyze the range of potential effects that autonomous vehicles will have on the District and the region in the future. Among many things, the results show that this transportation technology can be used to advance the District's economic growth and aid our housing affordability issues and mobility challenges for vulnerable populations.

That being said, the study finds that under all plausible scenarios of autonomous vehicle adoption and deployment, vehicle miles traveled, or VMT, in the District will increase. An increase in VMT equals an increase in congestion. The study forecasts that the additional VMT in the future will be generated by individuals who were previously traveling by other modes now traveling by autonomous vehicle and empty vehicles relocating themselves. To mitigate this rise in VMT and increased congestion, the study recommends interventions and incentives to support shared rides and alternative modes of transportation.

This report is the first step to understanding the prospective adoption trajectories of autonomous vehicle technology and the effects of each adoption scenario on the District's transit network. This study will help shape the transportation policies that may be considered in the future to best prepare for these challenges.

This study was prepared by AECOM and in consultation with DC Surface Transit for the District Department of Transportation. Please feel free to contact Director Jeff Marootian at jeff.marootian@dc.gov to discuss any questions you have regarding this report.

Sincerely,

Muriel Bowser

DCST
DC SUSTAINABLE TRANSPORTATION

DC AV Study

Final Report

4/7/2020

Prepared for DCST

Prepared by AECOM

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1.0 EXECUTIVE SUMMARY

AUTOMATED VEHICLE TECHNOLOGY IS COMING

Transportation is on the verge of a series of profound revolutions, led by advances in connectivity and automation. These technologies and the new business models and mobility options that they enable, will unlock a new era of transportation in the District and cities around the world. Automated Vehicle (AV) technologies will dramatically change how people make their daily transportation choices about where, when, and how to travel. As people and businesses adapt to these new options, AVs will transform not only transportation systems, but the structure of our cities, where people want to live, and how we chose to use space.

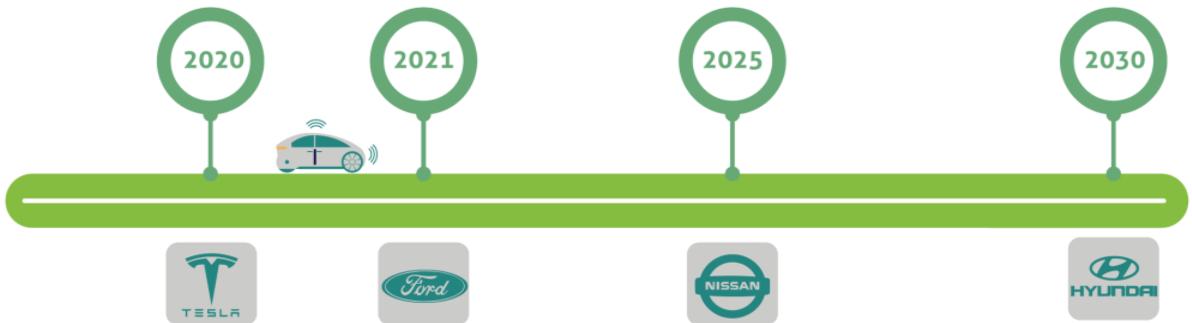


Figure 1-1: Estimates for the arrival of fully autonomous vehicles vary widely

WHEN WILL THESE CHANGES HAPPEN?

The short answer: no one knows for certain. The timing for the introduction of mostly and fully automated vehicles on urban roadways is still hotly debated in the industry (Figure 1-1 above). The speed at which they will penetrate the auto market and be adopted by consumers is even more uncertain. While the timeline is debated, major auto manufacturers, tech companies, and communications giants have put billions of dollars into research and development. It *will* happen.

AVs are not the only technology change coming to transportation, and many of these trends are interrelated. The development of one new technology will impact how the others evolve, when they are adopted and by whom, and how the transportation system of the future will function.

EMERGING TRENDS & TECHNOLOGIES

- Automated Vehicles (AV)
- Connected Vehicles (CV)
- Shared Economy
- Vehicle Electrification
- Telework
- E-commerce
- Rise of the gig-economy
- Changing demographics and preferences

Cities and states cannot "wait and see" how these technologies will play out – the potential impacts are too significant. The key is to anticipate and understand these technologies and their impacts to the extent possible, in order to guide their implementation in a way that supports the economic, social, and mobility goals of cities.

There is no question that transportation will be different in the future but forecasting these changes with certainty is all but impossible. Planning in the face of this ambiguity is challenging but must be tackled. The potential benefits are too great to miss, and the potential risks too large to ignore. Cities need to plan proactively, not simply react.

WHAT WILL CHANGE?

AVs and other emerging transportation trends could have far reaching impacts on Washington, DC and the surrounding region. Depending on how AVs are implemented, people's reactions to the new options, and how and where individuals and businesses choose to locate, a wide range of benefits and risks are possible. These variations must be guided by public policy.

Potential Benefits

- Mobility for all, especially seniors, people with disabilities and youth
- Safety, assuming predictions of AV and CV technologies are correct
- Improved traffic flows carrying more people faster
- Greater economic growth
- Fewer vehicles and less space devoted to parking them
- Improved transportation accessibility and affordability

Potential Challenges

- More driving and more people in cars with fewer people using traditional transit
- Increased congestion, including during off-peak times
- More driving leading to increaes in pollution - unless offset with electrification
- More suburban and exurban sprawl
- Over $340M in revenues generated by non-AV vehicles
- Job losses in industries related to driving

Technology cannot address these issues alone; governments, including the District, must take a strong hand to guide and shape these technologies so that they can be used to help create the future we want.

WHAT THIS STUDY DID

Because of the uncertainty surrounding the introduction, implementation, and adoption of AVs, this study used a **scenario planning** approach that looked at multiple possible versions of the future to understand what the range of potential impacts in the District could be.

Four scenarios were developed and analyzed, highlighting different options related to technology development and adoption, policies, land use changes, and mobility service options. The study looked at two scenarios with relatively low levels of government intervention, and two scenarios with stronger interventions.

Low Intervention Scenarios	High Intervention Scenarios
A: Households own Freeway Automated Vehicles	C: Strong High-Occupancy (HOV) Prioritization
B: Shared AV fleets expand quickly	D: Regional Congestion Fee

What are the four Scenarios?

An overview of some of the key elements of each of the four tested future scenarios are provided below (Figure 1-2). More detailed descriptions can be found in Section 3 of the technical report.

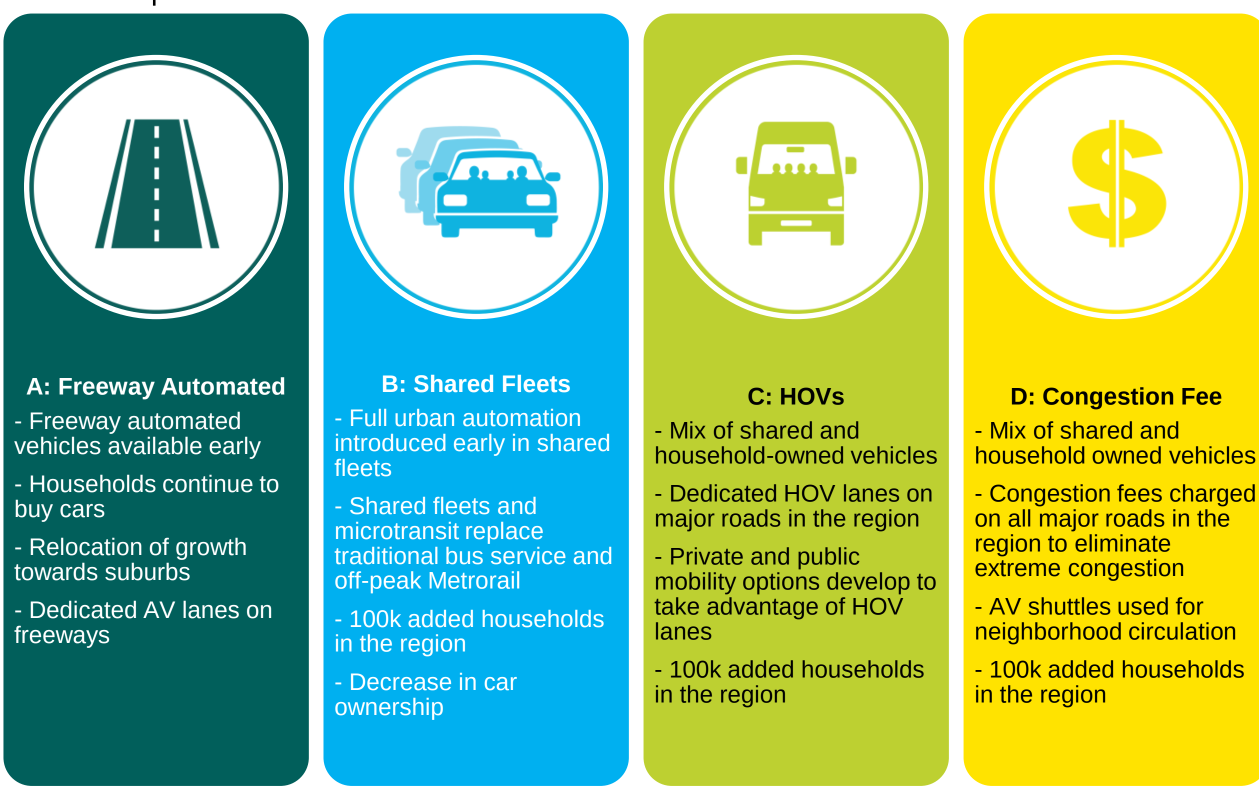


Figure 1-2: Key Elements for AV Scenarios

Throughout this report, these four AV Scenarios are compared to the future as forecast without any disruptive assumptions about AV, CV or other emerging transportation technologies. This scenario includes the existing regional forecasts developed through 2045 using the Metropolitan Washington Council of Governments (MWCOG)/Transportation Planning Board (TPB) regional travel demand forecasting model and the Round 9.1 Cooperative Land Use Forecasts. (See Section 3 and Appendix C for additional information.) Referenced as MWCOG in this document, this scenario serves as a baseline for comparison representing what the region is currently planning for, and how AVs are likely to dramatically alter that future.

WHAT THIS STUDY DID NOT DO

This study, and the four AV Scenarios analyzed, did not attempt to consider all possible futures for DC and the surrounding region. The scenarios do not reflect the most extreme futures conceivable in any direction and are neither "best case" or "worst case" scenarios. Nor does this study attempt to identify what future scenario is the most likely to occur.

Rather, the study identified four potential futures which explore a range of possible conditions for the future of AVs and other technologies. The future will not look exactly like *any* of the scenarios analyzed; that is the nature of uncertainty. But it is likely to resemble *all* of the scenarios in some way. By mapping the trajectory of these four possibilities, this study identifies the range of impacts that is most likely to occur, but it cannot guarantee those outcomes.

Where a trend is visible in all AV Scenarios, this study indicates that the trend is likely to occur. That does not mean there is no chance for the results to deviate from what is shown. New technologies that have yet to be invented, innovative marketing strategies and business models, and even political or economic shifts could alter these four different futures and their impacts on the District.

Most importantly, this analysis assumed that all four AV Scenarios maintain key public policy positions that are in place today. None of the AV Scenarios assume that Metrorail will be completely abandoned - although Scenario B comes closest to exploring this option and gives a taste of how bad congestion could get without our region's high capacity transit backbone. The AV Scenarios continue to envision DC's vibrant street life and include no provisions for transforming DC into a warren of freeways and overpasses devoid of pedestrian life – despite press articles quoting claims that this might be the way to move the most vehicles quickly.

These are not DC's current values, and this study assumes that they will not be DC's values in the future either. If the District or other area governments abandon their current transportation values to achieve other goals, the future could look very different, and substantially less promising than what is presented in this report.

WHAT DID WE LEARN?

The scenario analysis looked at the potential impacts of AVs in each of the four scenarios over a long-term time horizon. Twelve key performance metrics were identified that most accurately highlight the differences between the scenarios and current conditions. Summaries of these results are presented on the following page, and complete details of all performance metrics can be found in Section 4.0. Some key results are:

Vehicle travel will increase more than previously expected. All four of the AV Scenarios result in additional vehicle miles traveled as shown in Figure 1-3. This includes people using cars who were previously using other modes, but also includes empty vehicles that are able to relocate themselves.

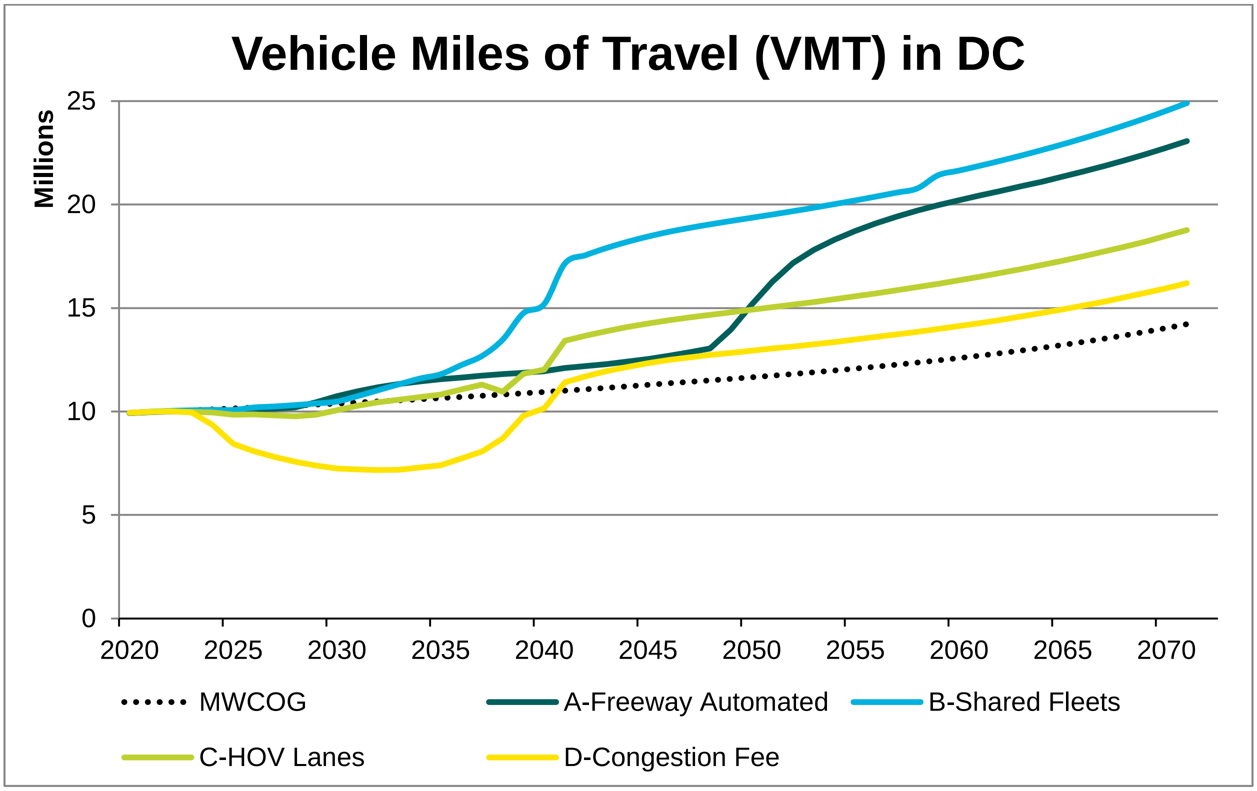


Figure 1-3: VMT in DC

Without strong public policies, congestion will likely rise significantly. Strong interventions that encourage shared rides and other modes could mitigate some of this growing congestion, but not all as shown in Figure 1-4. Although overall congestion on the network could increase, especially outside of the peak periods, interventions like dedicated HOV lanes and/or congestion pricing could actually decrease the average trip times for *people,* as shown in Table 1-1.

Table 1-1: 2045 Average Trip Times

	Average Trip Time in 2045
MWCOG	31.5 mins
A: Freeway Automated	32.3 mins
B: Shared Fleets	35.6 mins
C: HOV Lanes	29.4 mins
D: Congestion Fee	25.3 mins

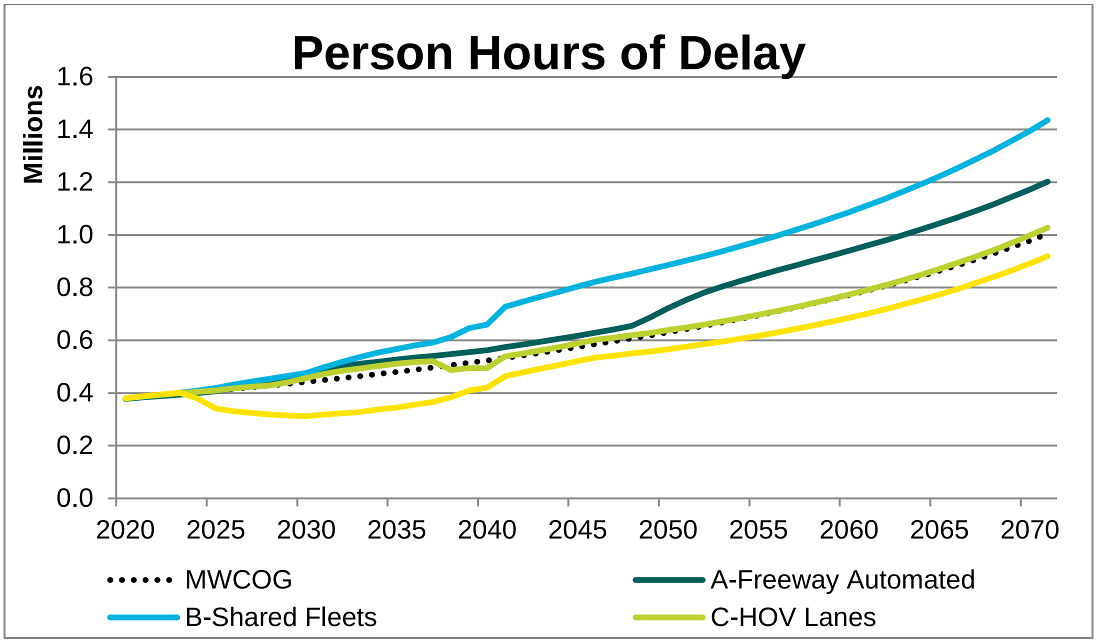


Figure 1-4: PHD in DC

With increasing VMT, ***vehicle emissions will grow rapidly unless strong action is taken to encourage vehicle electrification.*** Figure 1-5 below shows the range of emissions that might be accumulated starting in 2020 in the District. With strong early adoption of electric vehicles, more than 190 billion tons of greenhouse gas emissions could be avoided in the District alone. Far more could be avoided in the larger region.

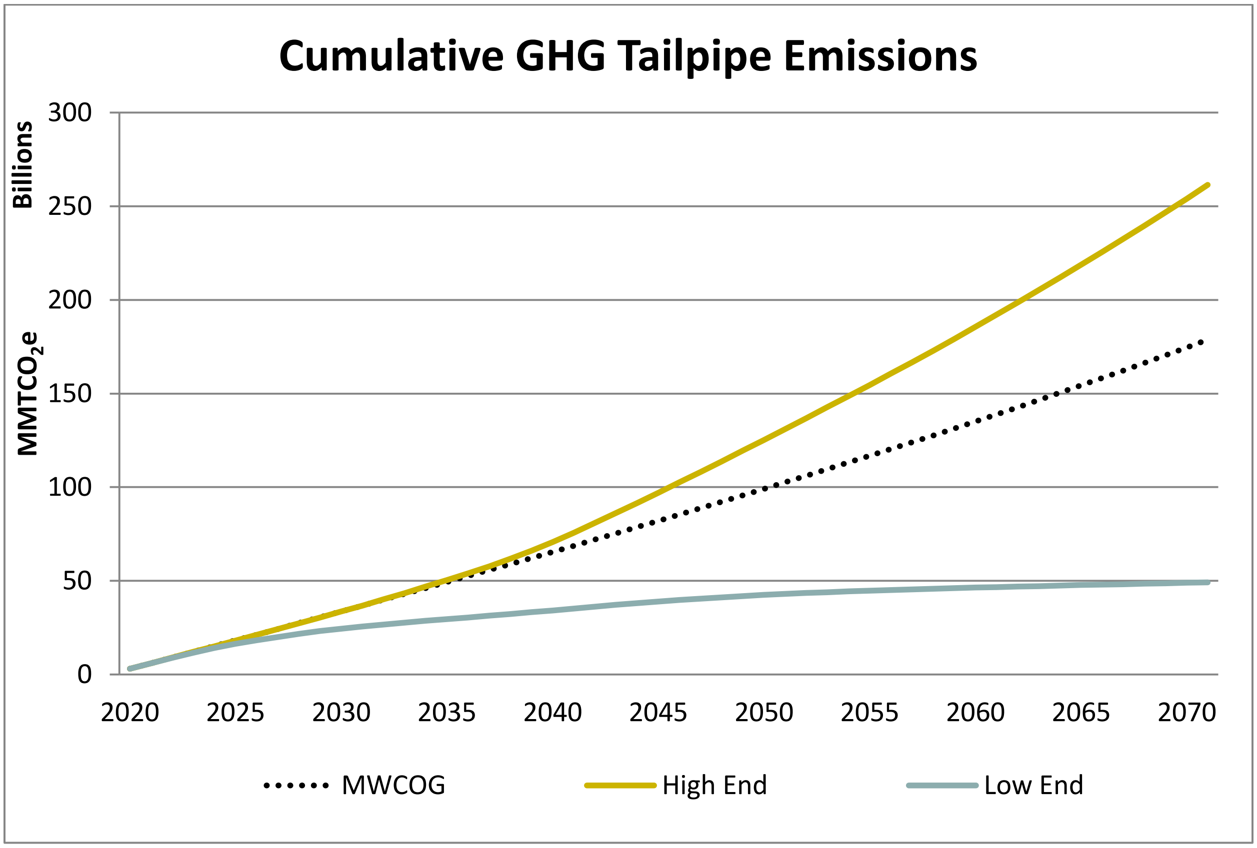


Figure 1-5: GHG Emissions in DC

The number of vehicles needed to provide mobility could decrease by more than 20 percent. In the long term, this could mean more than 120,000 fewer vehicles that need to park in DC. That means fewer parking garages, lower housing costs, and the ability to redesign parking spaces for other uses like parks.

More than $340M in annual revenues may be at risk as AVs (most likely) will not be able to speed, run red lights, or park illegally meaning they will not receive tickets. New revenue sources, particularly from congestion pricing, could mitigate these revenue sources, and potentially help pay for other transportation projects and programs. Some costs may also be eliminated, such as parking enforcement and testing new drivers for licenses. Figure 1-6 highlights how these revenue sources may change over time, and how even a low-level congestion fee could replace this lost income.

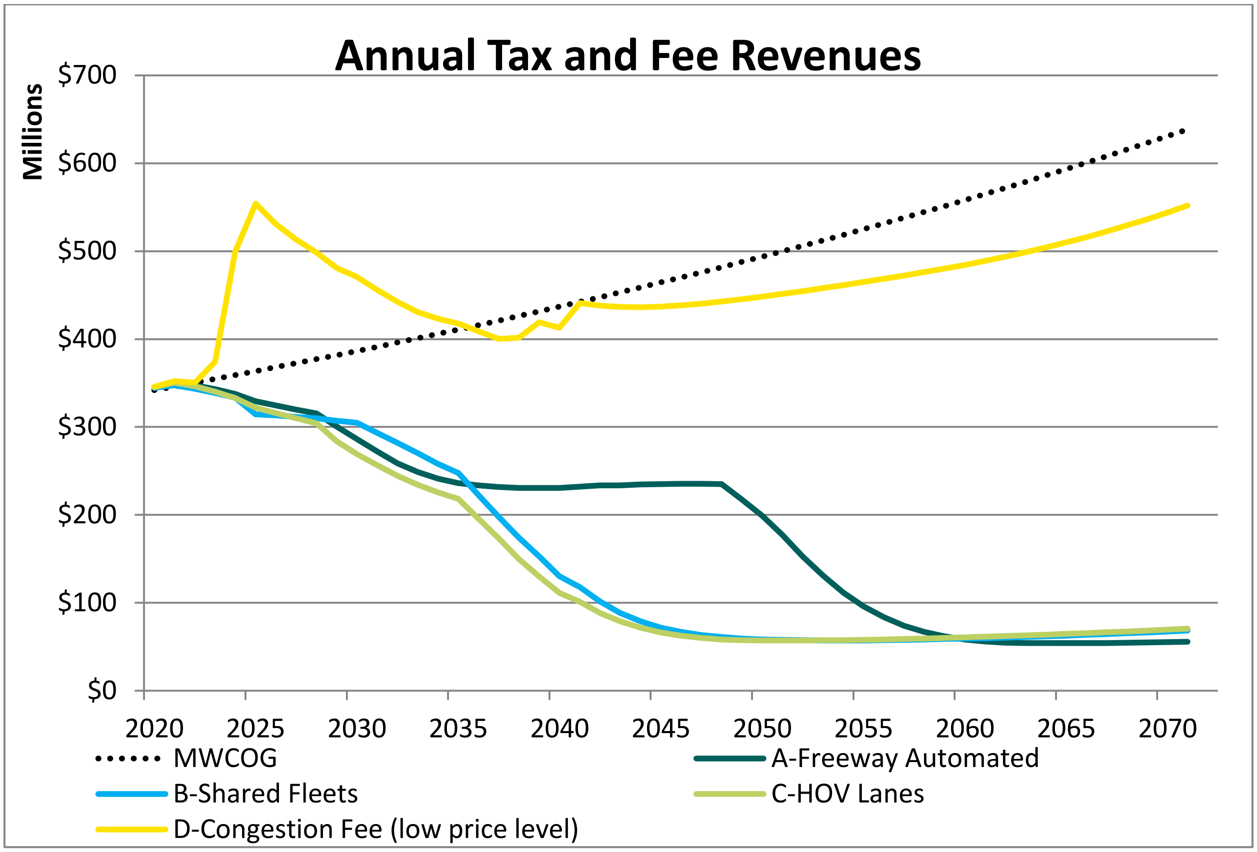


Figure 1-6: Tax and Fee Revenue Changes in DC

AV and CV technologies can save lives every year, and pump billions of dollars back into the DC economy. As shown in Figure 1-7, by helping to eliminate crashes and limit their severity, the more than $1.8 billion currently spent on insurance, emergency response, lost productivity, legal proceedings, property damage and injuries and fatalities could be put to better use. These technologies could help DC achieve its Vision Zero goals, saving more than 30 lives each year. This requires that vehicle manufacturers and technology companies ensure their products really are safer than human drivers, and avoid any trends toward more aggressive modes or products which do not prioritize the safety of all roadway users.

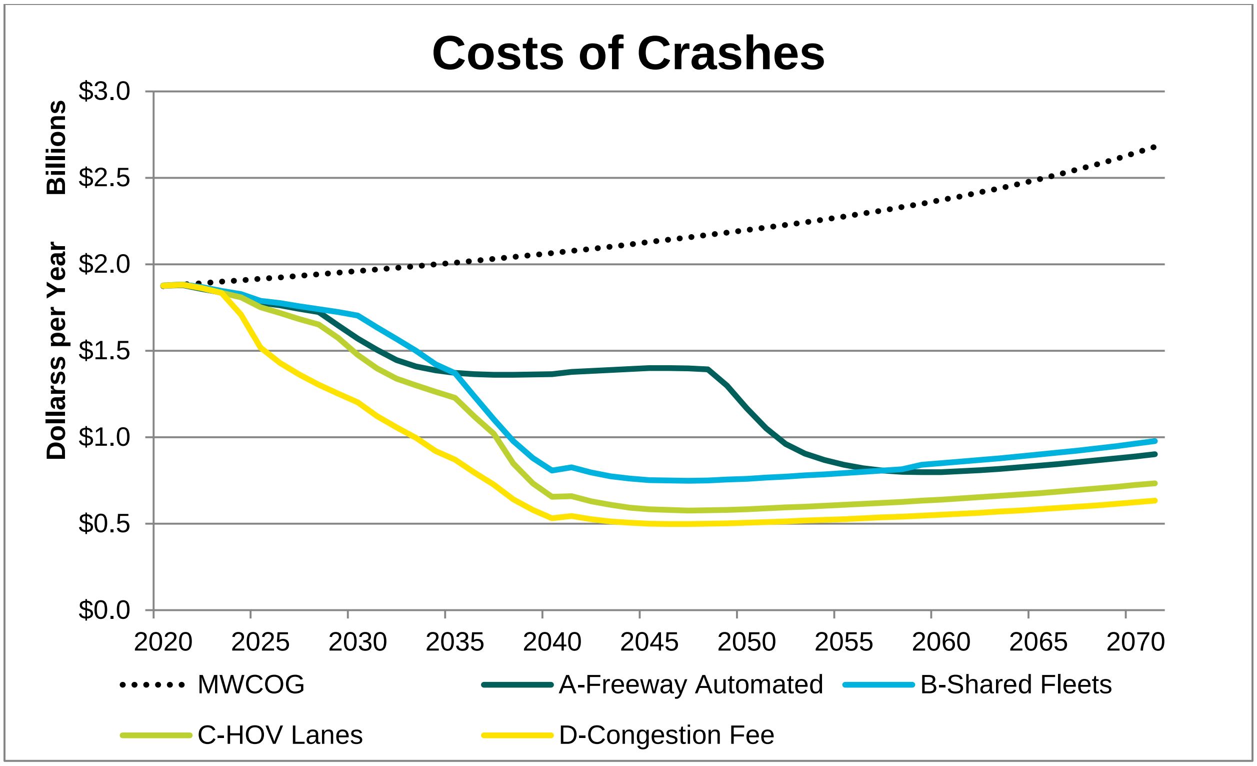


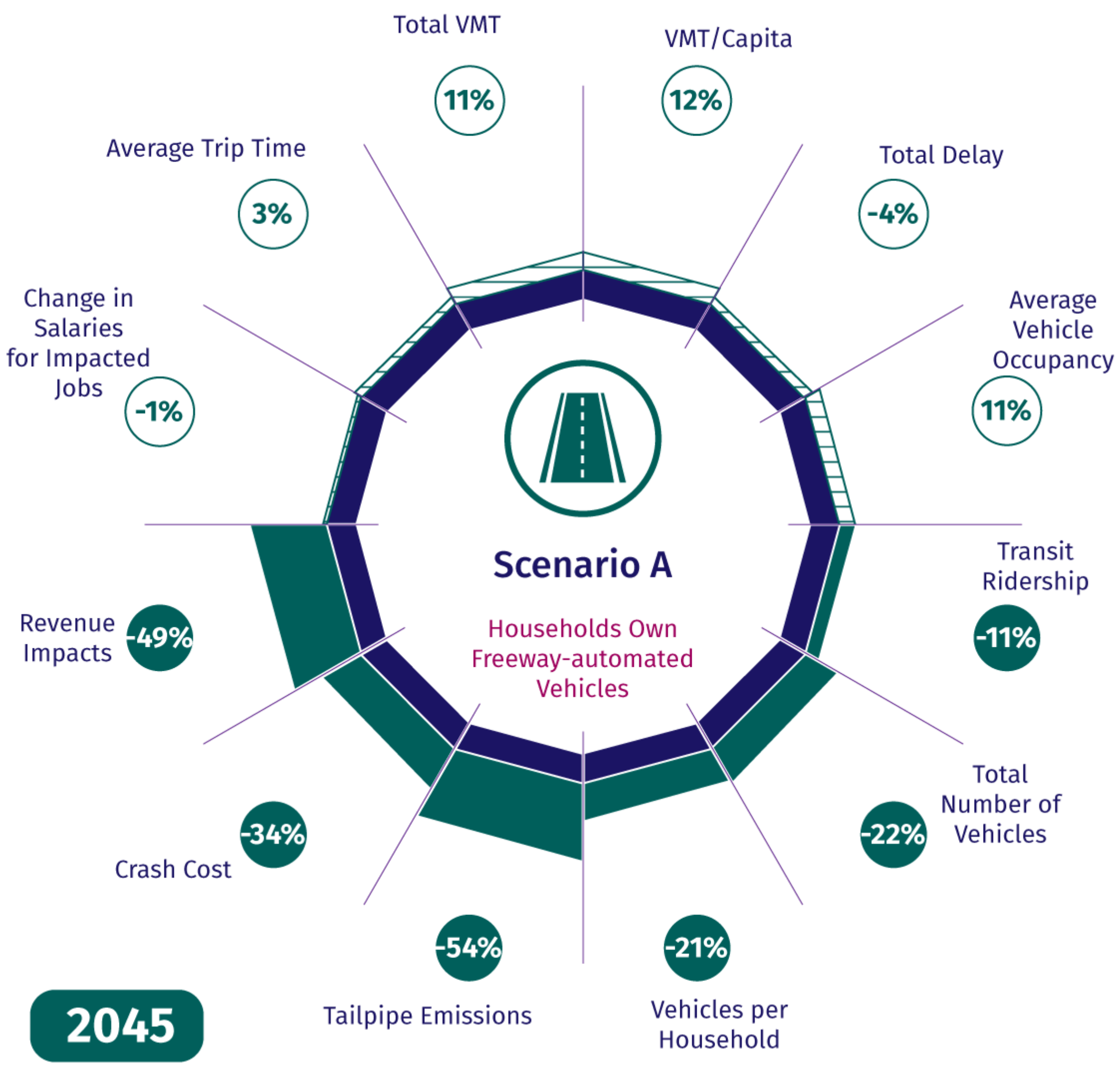
Figure 1-7: Costs of Crashes in DC

AVs can enable more people to live in walkable urban areas. DC and the larger region face a housing affordability crisis, as housing in transit-rich urban areas rises in cost and pushes people to the suburbs, or even out of the region entirely. The transportation system as currently planned cannot accommodate everyone who wants to live here, and MWCOG forecasts that by 2045 there will be 100,000 households that work in the region which have to live outside of it. But AVs and the new mobility options they enable will make it possible to accommodate more residents in the District and the region possibly with less congestion. Easy and affordable mobility could be ubiquitous across the District. AVs could open new neighborhoods to mixed use development and encourage higher densities in areas further from Metrorail stations without requiring more cars. With land reclaimed from parked cars, the District will have more space for the things its residents want: green space, affordable housing, and economic opportunities. But this type of growth and change must be implemented intentionally, with policies and interventions that encourage more efficient use of the transportation network such as dedicated HOV lanes or congestion pricing.

WHAT ARE THE RESULTS?

Overall, these results show that the District, and the surrounding region can accommodate more residents if smart decisions about land use and transportation are adopted. These transportation technologies can be used to address our housing affordability issues, concerns about mobility for vulnerable populations, and continue to build on DC's strong economic growth.

Scenario A: Household own Freeway-Automated Vehicles

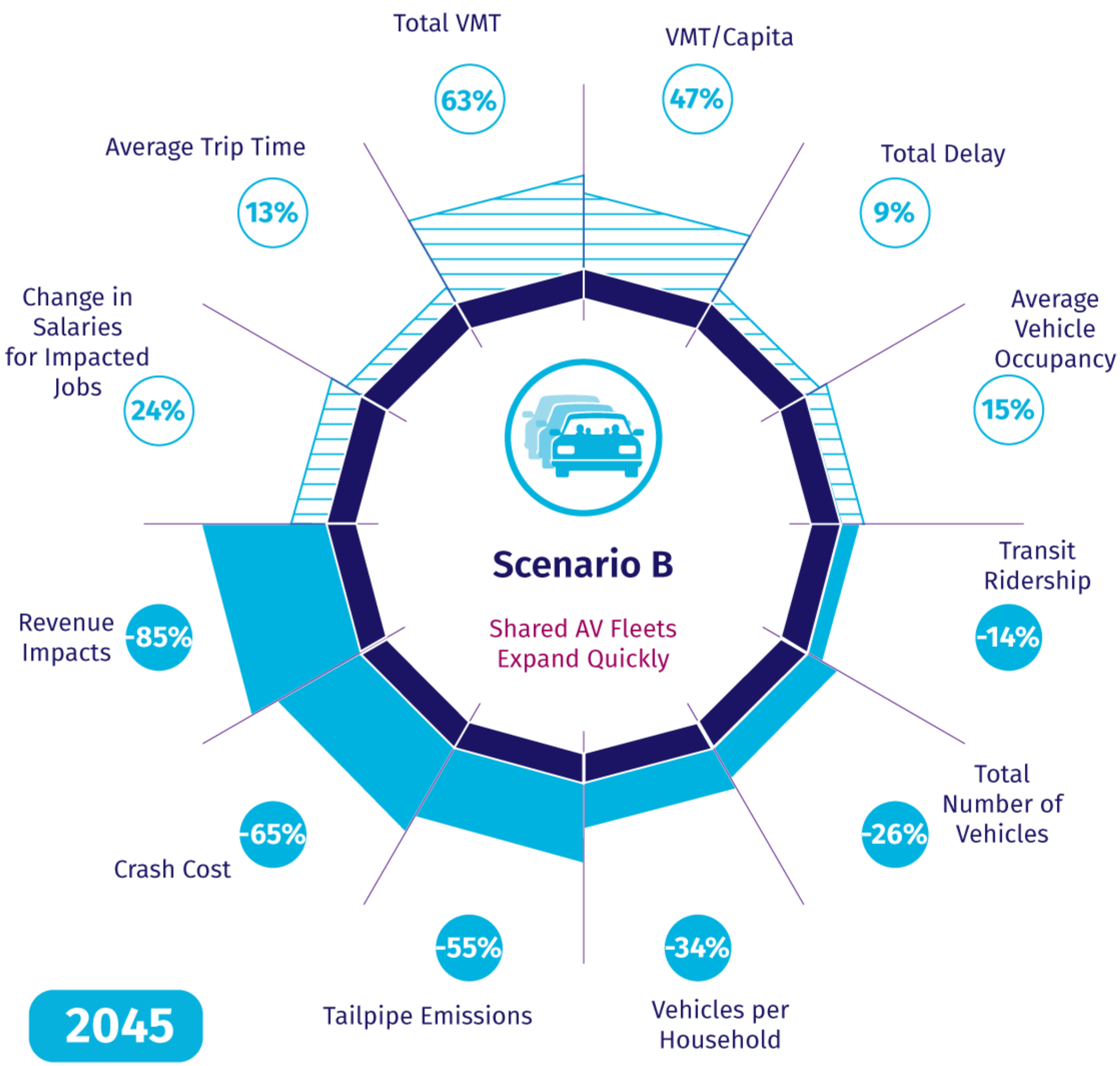


Key Findings for DC

- High levels of VMT
- Larger fleet size as people continue to buy cars
- High congestion levels and slower trip times
- Lowest transit ridership
- Highest GHG emissions of AV Scenarios
- Job loss will be slower due to delayed uptake of fully automated vehicles.
- More significant impacts in surrounding jurisdictions

A gradual development path for AVs with relatively low consumer costs is more likely to result in continued auto-ownership and auto-oriented land use. The delay in full AV capability significantly delays impacts and allows current travel patterns to entrench further. If the assumed increase in freeway capacity is not able to be achieved, then this future could result in much greater negative impacts on travel time, congestion, and equity.

Scenario B: Shared Fleets Expand Quickly

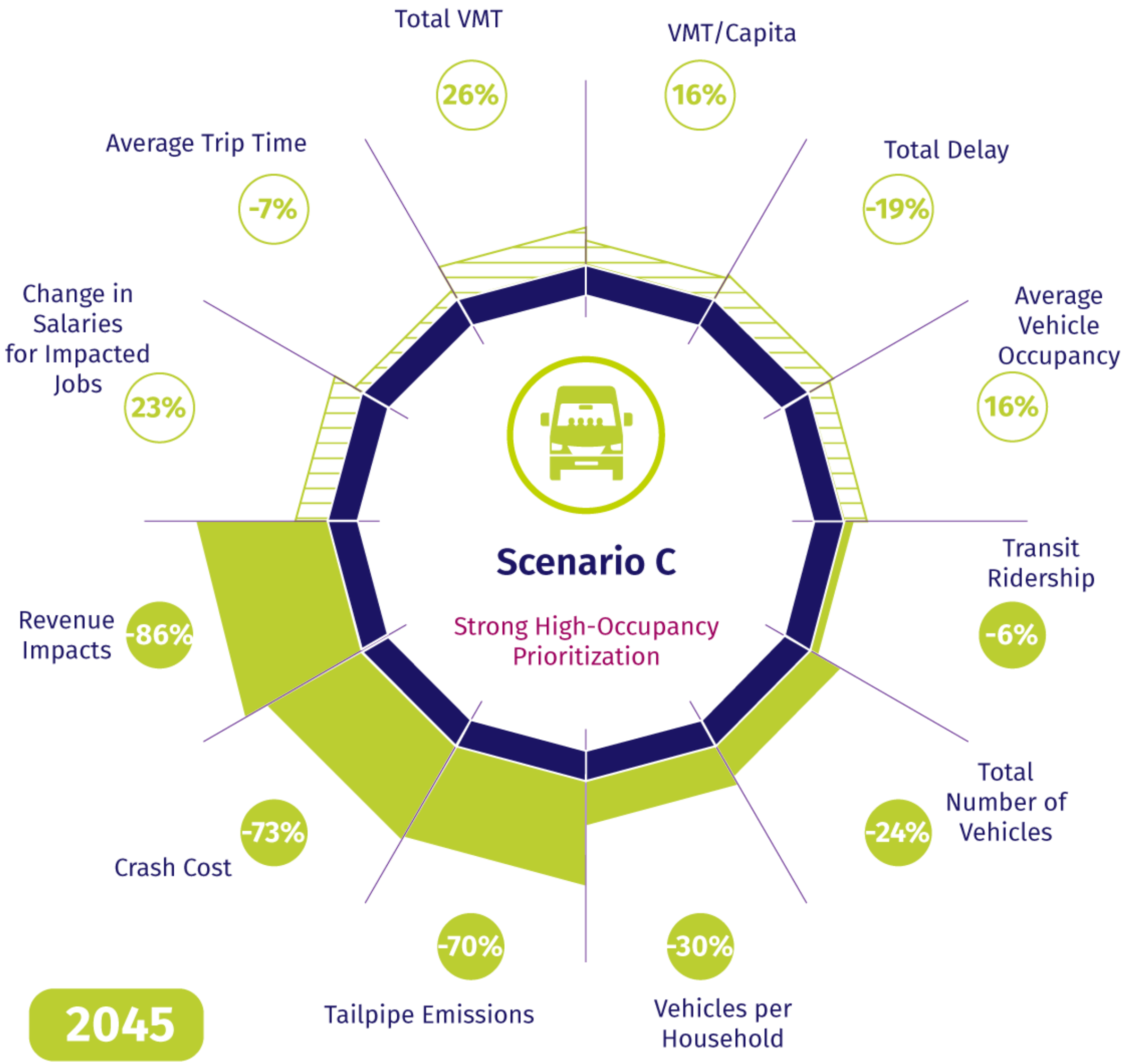


Key Findings:

- Highest levels of VMT and congestion of all scenarios
- Lowest number of vehicles needed to serve mobility needs
- Slower trips for everyone during the peak and off-peak

Unchecked, shared AVs could result in many more trips in small cars than under current conditions, impacting congestion, transit ridership, and emissions. Methods for modulating growth in VMT while maintaining mobility and accessibility must be considered. Electrification of the vehicle fleet is essential in deployment of shared vehicles in order to avoid significant increases in emissions.

Scenario C: Strong High-Occupancy Prioritization

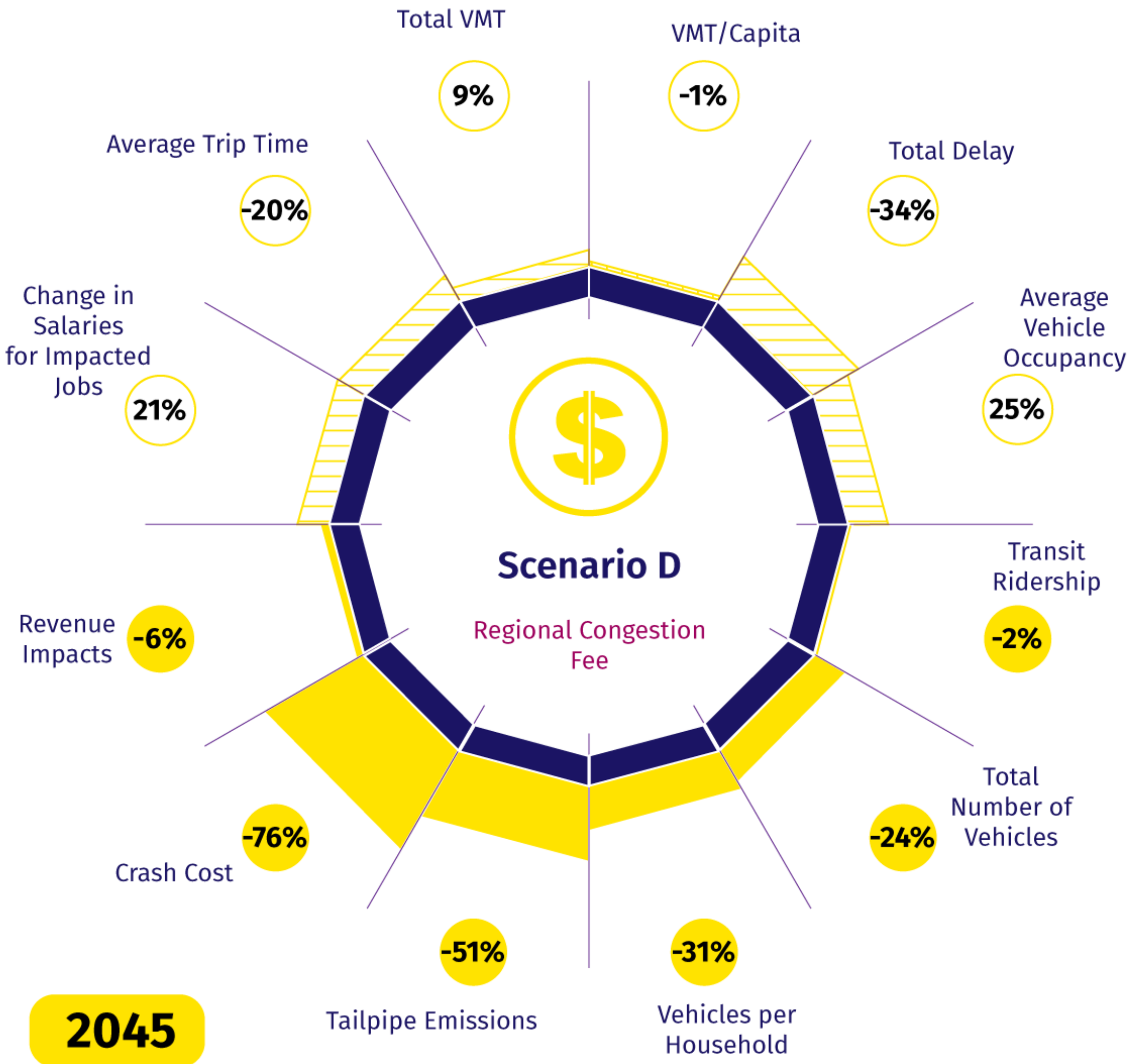


Key Findings:

- Lower growth in VMT
- Lower growth in congestion, in line with current regional forecasts despite including an additional 100,000 residents
- Relatively high transit ridership, with a broader definition of transit
- Faster travel times
- Lowest GHG emissions of any scenario tested
- Decrease in the number and severity of crashes
- Revenues may be at risk faster than in other scenarios

HOV Lanes have the potential to encourage the use of shared-ride modes, but their effectiveness will depend on pricing on the service levels offered. Providing frequent reliable service all day long in these lanes will be essential, along with identifying the best operating methods for serving the whole District whether by private or public service providers. The future definition of "transit" must be clearly identified.

Scenario D: Regional Congestion Fee



Key Findings:

- Lowest VMT growth
- Lowest congestion levels, due to implementation of congestion fee
- Highest average vehicle occupancy, as congestion pricing encourages shifts to higher occupancy modes
- Highest transit ridership
- Largest improvement in safety
- Potential to replace lost revenue with congestion fees

A strong policy of congestion pricing has the most potential to limit the growth of negative transportation externalities, such as congestion and emissions. However, additional study is necessary to identify the optimal policy option and pricing level. Consideration for low-income travelers in the whole region will need to be made to ensure that their mobility is not impaired by a congestion fee.

THE STUDY'S CONCLUSIONS

AVs and other emerging transportation technologies have the potential to help address some of the District's major transportation problems. But the technology alone will not solve every issue – and may in fact exacerbate some new challenges, like increasing VMT and spreading of congestion outside of the peak periods. Without strong guidance from planners and policy makers, the District could see few of the benefits and many of the problems. This study provides the guideposts to help ensure that does not happen.

All of the scenarios indicate that VMT is likely to rise with the widespread adoption of AVs. VMT is not a problem on its own. DC must focus on limiting growth in the externalities that arise from VMT – namely congestion, emissions, and crashes. By focusing on the problem instead of the proxy, DC can sustain high levels of mobility and economic activity while limiting the negative impacts. This study highlights several options that DC can enact to limit the negative externalities associated with additional vehicle traffic:

- **Congestion**: The major direct impact of additional travel in cars can be addressed with policies that encourage travel choices that are better for everyone. Dedicated HOV lanes can incentivize people to share rides in order to make their trip faster. Congestion pricing can make people think seriously about the total cost of their trip and make the appropriate financial decision for their situation. Any of these options will require strong policy action.
- **Emissions**: Tailpipe GHG emissions continue to grow with VMT so long as internal combustion engines remain the norm. The solution is being developed in parallel with AVs: electric vehicles. Electric Vehicles (EVs) remain a small portion of the region's vehicle fleet (less than half of one percent) but have almost unlimited potential to limit the environmental impacts of vehicle use. If people use them. DC must focus on strong policies that will encourage the proliferation of EVs – and the sooner it happens the better.
- **Crashes**: More exposure to vehicle traffic typically results in more crashes, more injuries, and more fatalities. The combination of CV and AV technologies has the potential to dramatically decrease the number of crashes in DC, saving lives, time, and billions of dollars every year. Part of the solution is policies that push for technology applications related to safety improvements, no matter how incremental.

Strong policies will result in the most dramatic improvements and will be easier to enact now before new travel behaviors get 'locked in' and new constituencies form. Most of these policies should be coordinated with the surrounding region as well, since decisions in one jurisdiction will impact travel behavior region-wide.

While this is primarily a transportation study, land use decisions have an important role in any discussion of transportation impacts. This study shows that the District can and should accommodate more residents, using AVs and other mobility options to provide access to neighborhoods that have typically been accessible predominately by car. Not only can this solution help address transportation issues in DC, it can help solve the housing affordability crisis as well.

Moving into an AV future, the District must remain strong in its priorities and commit to values about the use of road space. Pressures will mount to encourage AV implementation by making the roads “less complex” for the vehicles. These less complex roads could be achieved by separating pedestrians and bicyclists from other traffic to make urban streets more like expressways, a pressure the District must stand resolute against. None of the scenarios tested in this study contemplated such a change, and it would exacerbate the potential downsides highlighted by the results.

This study points to the fact that the time is ripe for a conversation about the future of transit in DC and the surrounding region. Public transit as we have known it over the last 40 years may not be the way forward – or more likely is not the only way forward. How the District chooses to accommodate new forms of transit will be an important decision for the future of the city, the Circulator, and WMATA. Where privately owned transit offers a market solution, is it welcomed, or discouraged? If transit agencies are no longer the only providers of mass mobility, how will they transition to their new role? These questions require serious discussion, as they have no easy answers.

Finally, it is important to note that any policies advancing or shaping AVs must prioritize equity, ensuring that services are available to and affordable for all, particularly for populations which have historically been and/or continue to be disadvantaged by transportation policy decisions. This reason alone highlights the need for strong guidance from DC government in planning and implementing the transportation systems of the future.

WHAT SHOULD BE DONE NEXT?

Based on the results of this study, a number of action recommendations are proposed. More details on each can be found in Section 5.0. The timing for all of these recommendations will be important. To ensure maximum benefits and minimal opposition many of the recommendations should be implemented before AVs and their new business models become widespread and new constituencies develop around them.

Policy Recommendations:

1. Perform a detailed analysis of alternative transportation pricing strategies and how they might be implemented.
2. Investigate, develop, and pursue policies and programs to incentivize electrification of the vehicle fleet.
3. Develop and implement programs for workforce retraining focused on jobs that are the most likely to be impacted by AVs.
4. Analyze planning and zoning requirements related to options to accommodate additional residents in DC. Re-evaluate parking minimum and maximum requirements in light of AV adoption.

5. Develop and implement programs and policies that encourage the use of high-occupancy vehicles for all types of trips to achieve goals in MoveDC and SustainableDC.

Research Recommendations:

6. Conduct a broad economic analysis of the impacts of automation and other emerging technologies on the District's economy.
7. Conduct a needs-based analysis to identify specific infrastructure investments needed to adapt to AV deployment.
8. Review and analyze policy and regulation needed to adapt to AV and other technology and services.
9. Support the updating and/or development of tools and planning processes that incorporate emerging mobility trends for the purposes of making informed investment decisions locally and regionally.

Operational and Organizational Recommendations:

10. Increase organizational capacity at DDOT with staff positions dedicated to emerging technologies.
11. Support pilot projects with other organizations or private entities including AV and CV technologies. Develop and implement an equity analysis methodology for pilots and future programs.
12. Play an active role in coordinating regional plans and policies for AVs and other emerging transportation technologies.
13. Investigate and implement connected vehicle technologies with a focus on applications that improve safety in urban environments.

Data Recommendations

Develop clear requirements for data sharing for all AV and transportation technology operators in the District, including data about service provided, operational data, and safety. Develop data sharing agreements between DC agencies and with regional entities to ensure that data is used for maximum effect. Pursue any legal and/or legislative requirements needed.

2.0 INTRODUCTION

Transportation is on the verge of a series of profound revolutions, led by advances in connectivity and automation. These technologies and the new business models and mobility options that they enable will unlock a new era of transportation in the District and cities around the world. The introduction and adoption of Automated Vehicle (AV) technologies will dramatically change how people make their daily transportation choices about where, when, and how to travel. While fully automated vehicles are the most visible technology changing transportation, AVs will converge with a number of other emerging technologies and trends over the next 20 years, including:

- Connected vehicles;
- Rise of the shared economy, including shared vehicles and shared rides;
- Environmental concerns and fuel prices;
- Electric vehicles;
- Changes to activity patterns, including telework, the gig-economy, and e-commerce;
- Freight and goods delivery;
- Changing demographics and mobility preferences; and
- Continued urbanization and population growth impacting transportation needs.

As people and businesses adapt to these new options, AVs will transform not only transportation systems, but the structure of our cities, where people want to live, and how we chose to use space. While there is no question that transportation will be different in the future, forecasting these changes with certainty is difficult because of the uncertainty related to how these emerging technologies, preferences, and business models will converge to change people's travel behaviors. How the transportation ecosystem evolves is dependent on how these opportunities are implemented:

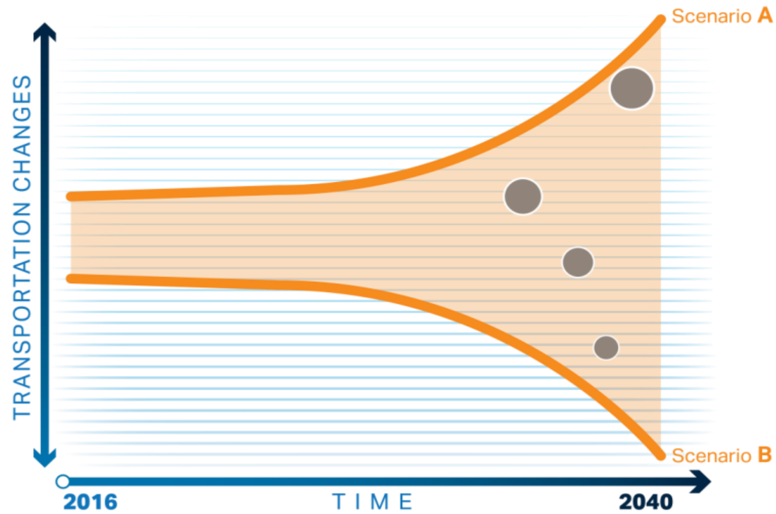
- What business models prove to be most successful?
- When will AVs and other technologies be introduced? How long will it take for them to achieve meaningful levels of market penetration?
- How will travelers and companies change their behavior to accommodate these new opportunities?

The answers to these questions and many others remain uncertain, and different answers will have different types and levels of impacts on our transportation systems. Despite these uncertainties, it is possible to gain an understanding of these changes by looking at possible implementation scenarios and analyzing the range of potential impacts. Opportunities are often accompanied by risks and unexpected consequences. This type of Scenario Planning incorporates established theories on how people make their daily travel decisions, while incorporating the new options provided by AVs and other new technologies into the system.

The Autonomous Vehicle Study Amendment Act of 2018 directed the District to undertake a study to evaluate[] and make[] recommendations regarding the effects of AVs on the District of

Columbia." Based on this analysis, the study has developed a series of recommendations about additional work that needs to be done in order to guide the implementation of AVs and other emerging transportation technology to leverage their benefits while limiting the negative repercussions.

The study began by developing four alternative future scenarios that highlight different options related to technology development and adoption, policies, land use changes, and mobility service options. These scenarios consider a range of technologies and how they will interact, along with public policy considerations in both the District and the surrounding jurisdictions. Complete descriptions of these scenarios can be found in detail in Section 3 of this report.



The further in the future we forecast, the impacts of emerging technologies and trends become increasingly more uncertain. The purpose of scenario planning is to capture the range of potential futures inside the "cone of uncertainty" to be prepared for many possibilities.

The four AV Scenarios analyzed do not attempt to represent all possible futures for DC and the surrounding region. Nor does this study attempt to identify what future scenario is the most likely to occur. Rather, the study identified four potential futures which explore a range of possible conditions for the future of AVs and other technologies. The future will not look exactly like *any* of the scenarios analyzed; that is the nature of uncertainty. But it is likely to resemble *all* of the scenarios in some way. By mapping the trajectory of these four possibilities, this study identifies the range of impacts that is most likely to occur, but it cannot guarantee those outcomes.

Most importantly, this analysis assumed that all four AV Scenarios maintain key public policy positions that are in place today. None of the AV Scenarios assume that Metrorail will be completely abandoned - although Scenario B comes closest to exploring this option and gives a taste of how bad congestion could get without our region's high capacity transit backbone. The AV Scenarios continue to envision DC's vibrant street life and include no provisions for transforming DC into a warren of freeways and overpasses devoid of pedestrian life – despite press articles suggesting that this might be the way to move the most vehicles quickly. These are not DC's current values, and this study assumes that they will not be DC's values in the future.

Traditional travel demand forecasting assumes that historic trends will continue to be true in the near future. As disruptions call that assumption into question, this analysis focuses on multiple versions of the future to the range of potential impacts. Each of the four AV Scenarios were analyzed in detail using Mobilitics, a modeling tool developed by AECOM designed specifically to understand the impacts of emerging technologies on transportation system. This process uses the MWCOG forecasts of regional land use, activity, and travel patterns as a starting point for understanding how travelers in the region get around. The model then considers the detailed scenario definitions and uses the latest in national and international research to quantify the potential impacts through a range of performance metrics. The results of this analysis are detailed in Section 4.0 of this report, and include over a dozen metrics of how congestion, jobs, municipal revenues, transit ridership, and other aspects of the transportation network will be affected by these changes.

The results of the AV Scenarios are compared to the standard MWCOG forecasts to highlight the differences between the potential outcomes, and the forecasts that the District and the region are using to make planning decisions. This level of uncertainty in the outcomes means that continual observation and careful consideration will be needed in the coming years as new technologies and business models are introduced to ensure that public policy is steering towards the desired outcomes and benefits. Where a trend is visible in all AV Scenarios, this study indicates that the trend is likely to occur. That does not mean there is no chance for the results to deviate from what is shown. New technologies that have yet to be invented, innovative marketing strategies and business models, and even political or economic shifts could alter these four different futures and their impacts on the District.

The remainder of the report is structured as follows:

- **Section 2** includes some background information and definitions that will be helpful in understanding some of the technical analysis in this document. A short glossary and definitions of AV technology is included.
- **Section 3** provides detailed descriptions of the four AV Scenarios developed as part of the study.
- **Section 4** includes the results of the analysis for the District of Columbia, including over a dozen performance metrics forecasts for 2020 through 2072.
- **Section 5** includes a set of recommendations for additional study, policy development, and operational and/or institutional changes. This section also includes recommendations about data needs for policy and safety implementation, as well as data sharing for planning and operational purposes.
- The **Appendices** include more results specific to each of the 10 DC Planning Areas, in addition summary results for a larger region covered by the area Inside the I-495 Beltway.

2.1 About This Study

2.1.1 About DCST

DC Sustainable Transportation (DCST) is a nonprofit organization which works to make DC a global leader with frequent, rapid, safe, affordable, and reliable transportation to, from, and around DC job centers. DCST brings together business, advocacy, and government entities around shared priorities for DC transportation.

DCST believes in providing all residents and workers with options to travel by transit, walking, and biking; to mitigate congestion and better manage curb space; and to prepare for mobility changes in the future with advancing technology.

More information about DCST is available at https://dcstcoalition.org/.

2.1.2 About This Study

DCST managed the Autonomous Vehicle Study under a grant from the District Department of Transportation (DDOT) and funding provided in the Autonomous Vehicles Study Amendment Act of 2018, DC Code § 50–2353.01, which provided for "a study that evaluates and makes recommendations regarding the effects of autonomous vehicles on the District, including:

"(1) The effect on the District's economy, including economic development and employment;

"(2) The impact on the District government's revenue, including motor vehicle excise taxes, motor vehicle registration fees, motor vehicle fuel taxes, residential parking permit fees, parking meter revenue, fines and fees relating to moving infractions or parking, standing, stopping, and pedestrian infractions, and commercial parking taxes;

"(3) The impact on the District's infrastructure, traffic control systems, road use, congestion, curbside management, and public space;

"(4) The impact on the District's environment and public health;

"(5) The impact on public safety in the District, including the safety of other road users such as pedestrians and bicyclists;

"(6) The impact on the District's disability community;

"(7) The impact on the various transportation modes in the District, including mass transit, shared-use vehicles, and public and private vehicles-for-hire; and

"(8) The need for and use of autonomous vehicle data, including data from autonomous vehicle manufacturers and public and private vehicle-for-hire companies."

DCST assembled an RFP Review Committee which created an RFP for a contractor to prepare the report, chose and interviewed finalists, and selected AECOM for the work. The committee then was replaced with a similar Steering Committee which met approximately monthly (sometimes more often, sometimes less) with AECOM staff to review interim progress.

The following individuals participated in the RFP Review Committee and/or the Steering Committee:

- Amanda Stout, District Department of Transportation
- Kendra Harvey, District Department of Transportation
- Anthony Cassillo, District Department of Transportation
- Marie Whittaker, Office of the Deputy Mayor for Planning and Economic Development
- Sakina Khan, DC Office of Planning
- Kristen Calkins, DC Office of Planning
- Alex Block, Downtown DC Business Improvement District
- Lexie Albie, Southwest Business Improvement District
- Galin Brooks, NoMa Business Improvement District
- Richard Ezike, Union of Concerned Scientists
- David Alpert, DC Sustainable Transportation
- Caitlin Rogger, DC Sustainable Transportation

A larger advisory committee was also created including representatives from additional government agencies, additional business groups, advocacy groups, industry, and academic experts. This committee met approximately quarterly to review major milestones in the study.

2.2 Background

This report contains a number of technical terms related to AV technology, transportation planning, and travel demand forecasting. While most are common terms used in these fields, a number are specific to the modeling methodology used for this study. To the extent possible, these terms are introduced here.

2.2.1 Types of Automated Vehicles

The most common typology for vehicle automation has been developed by the Society of Automotive Engineers (SAE). This typology divides automated vehicles into six levels based on their technical capabilities, as shown in Figure 2-1. These definitions are very useful for technical purposes, but the types of large-scale behavioral changes being analyzed in this study will not necessarily be affected by each of these gradations separately.

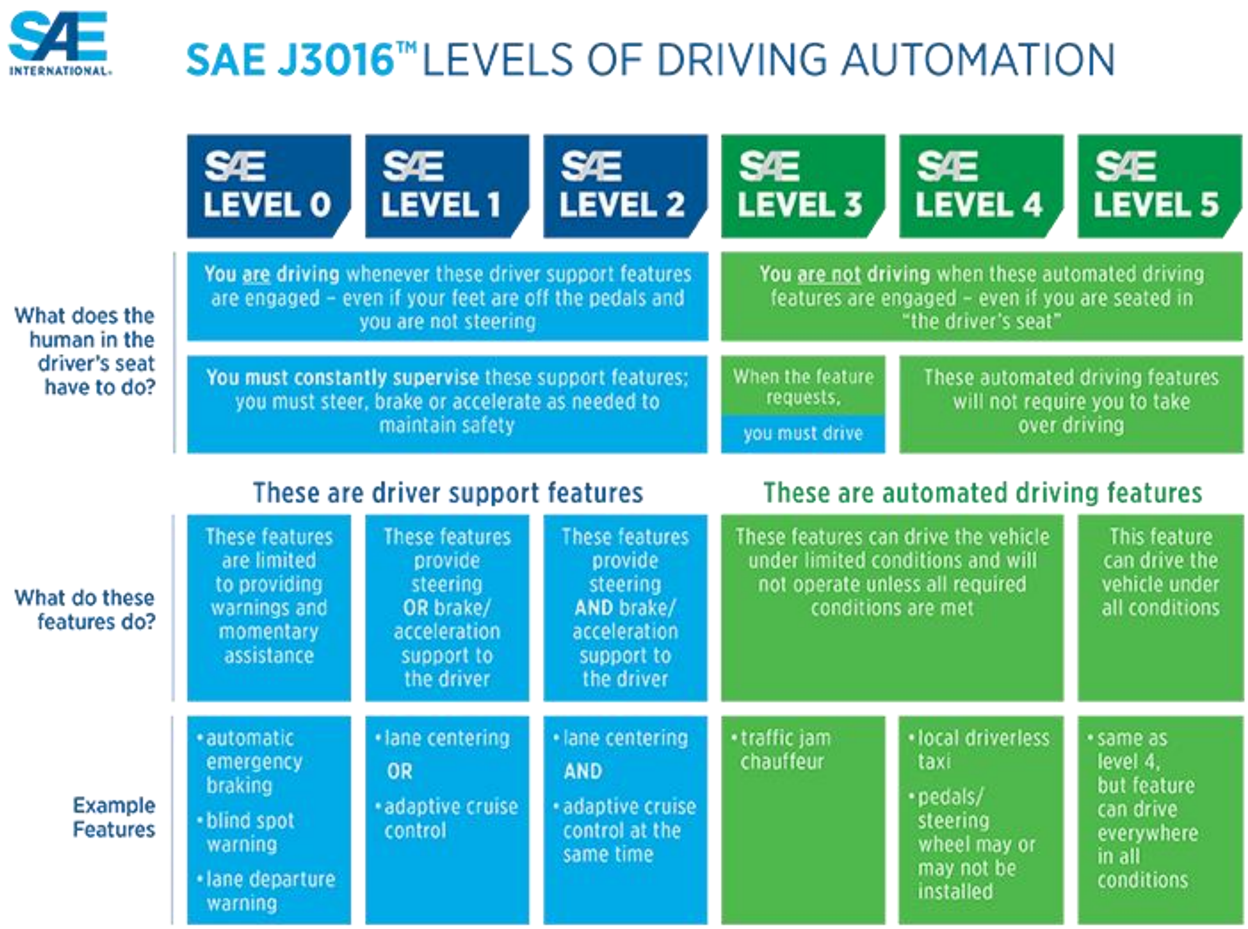


Figure 2-1: SAE Levels of Automation
Source: SAE J3016

For the purposes of this study, these Levels of Automation have been grouped into three Types of AVs that will more directly indicate when changes to trip making patterns are likely to be triggered. Table 2-1 defines these three types of AVs, and their approximate mapping with the SAE Automation Levels.

Table 2-1: AV Type Definitions

AV Type	Definition	SAE Levels of Automation
Type 1	Enhanced safety features and connectivity	0-2
Type 2	Driver assistance and automation on specified facilities	3
Type 3	Fully connected and autonomous	4-5

2.2.2 Other Terms

A few other items are used specifically throughout this report that warrant definition and clarification. Some of the language around the future of mobility is still evolving, and multiple terms can be used to represent similar concepts. Where those conflicts arise, this report has used the terminology used by authoritative sources, such as the Federal Transit Administration (FTA). Other currently accepted terms are included for reference in the definitions below.

Automated Vehicle: A vehicle that does not require a driver to operate, also known as "self-driving vehicles". There are currently six levels of automation from no automation (where a fully engaged driver is required at all times), to full autonomy (where an automated vehicle operates independently, without a human driver) as outlined in Section 2.1.1.

Carsharing: A service that provides members with access to an automobile for intervals of less than a day. Major carsharing business models include traditional or round-trip, which requires users to borrow and return vehicles at the same location; one-way or free-floating, which allows users to pick up a vehicle at one location and drop it off at another; and peer-to-peer (p2p), which allows car owners to earn money at times when they are not using their vehicles by making them available for rental to other carshare members.

Connected Vehicle: A vehicle (car, truck, bus, etc.) that is equipped with a wireless communication device. A connected vehicle uses any of the available wireless communication technologies to communicate with other cars on the road (vehicle-to-vehicle), roadside infrastructure (vehicle-to-infrastructure), and other travelers and the cloud.

Fixed-route System: A system of transporting individuals on which a vehicle is operated along a prescribed route according to a fixed schedule.

Household-Owned Vehicle: Used to separate vehicles owned by private citizens for their own personal travel from shared vehicle fleets accessible to the public which could potentially be publicly or private owned.

Market Penetration: The percentage of vehicles of a certain type of a roadway. This can be used to consider multiple vehicle technologies and could consider the market penetration of AVs, EVs, or CVs.

Microtransit: IT-enabled private multi-passenger transportation services, such as Bridj, Chariot, Split, and Via, that serve passengers using dynamically generated routes, and may expect passengers to make their way to and from common pick-up or drop-off points. Vehicles can range from large SUVs to vans to shuttle buses. Provides transit-like service but on a smaller, more flexible scale.

Mobility-as-a-Service: A shift away from personally-owned modes of transportation towards a multi-modal, consumer-centric model of services. This is enabled by combining transportation options from public and private transportation providers through a unified gateway that creates and manages the trip, which users can pay for with a single account.

Person-Hours of Delay: The amount of time people spend traveling above free-flow time. For example, if it would take 10 mins to make a trip in uncongested conditions and 25 minutes in traffic, the delay is 15 minutes. PHD is quantified as the delay times the number of people experiencing that delay. As a metric, PHD inherently places value only on the delay experienced by people and does not consider the impact of congestion on empty vehicles.

Ridesharing: Ridesharing involves adding passengers to a private trip in which driver and passengers share a destination. Such an arrangement provides additional transportation options for riders while allowing drivers to fill otherwise empty seats in their vehicles. Traditional forms of ridesharing include carpooling and vanpooling. This term is sometimes used to refer to ridesourcing, particularly when used by multiple passengers simultaneously (i.e. as in UberPool).

Ridesourcing: Use of online platforms to connect passengers with drivers and automate reservations, payments, and customer feedback. Riders can choose from a variety of service classes, including drivers who use personal, non-commercial, vehicles; traditional taxicabs dispatched via the providers' apps, and premium services with professional livery drivers and vehicles. Ridesourcing has become one of the most ubiquitous forms of shared mobility. These services are also commonly referred to as ride-hailing or Transportation Network Companies (TNC).

Shared fleet: A number of vehicles that are owned and operated by a central entity (private or public).

Shared-ride Services: Transportation services that are shared among users, including public transit; taxis and limos; bikesharing; carsharing (round-trip, one-way, and personal vehicle sharing); ridesharing (car-pooling, van-pooling); ridesourcing; scooter sharing; shuttle services; neighborhood jitneys; and commercial delivery vehicles providing flexible goods movement.

Transportation Network Company (TNC): See Ridesourcing.

Zero-Occupancy Vehicle (ZOV): vehicles traveling with zero passengers, such as an automated vehicle without a driver.

Zero-Occupancy Vehicle Miles Traveled (ZOVMT): the number of miles traveled by a motor vehicle for commute trips with no driver and zero passengers.

3.0 SCENARIOS AND ASSUMPTIONS

This study has developed four distinct scenarios that represent the spectrum of how Automated Vehicles (AVs) and other technologies might be implemented in DC and the surrounding region. Each of the scenarios has been developed to represent a distinct set of future conditions within the District based on a number of assumptions.

The first two scenarios have been developed as low-intervention futures in which technology is mostly allowed to develop and evolve without strong government actions to shape and control it. The second two scenarios include the implementation of District and regional policies designed to help shape the outcomes and limit the potential negative impacts of AVs. The four scenarios are described further in the sections that follow.

Low Intervention Scenarios		High Intervention Scenarios	
	A: Households own Freeway Automated Vehicles		C: Strong High-Occupancy Prioritization
	B: Shared AV fleets expand quickly	$	D: Regional Congestion Fee

This study, and the four AV Scenarios analyzed, did not attempt to consider all possible futures for DC. Nor does this study attempt to identify what future scenario is the most likely to occur. Rather, the study identified four potential futures which explore a range of possible conditions for the future of AVs and other technologies. The future will not look exactly like *any* of the scenarios analyzed; that is the nature of uncertainty. But it is likely to resemble *all* of the scenarios in some way. By mapping the trajectory of these four possibilities, this study identifies the range of impacts that is most likely to occur, but it cannot guarantee those outcomes.

For purposes of comparison and discussion, this Section outlines the assumptions made in each Scenario under thirteen categories, as outlined in Table 3-1.

Table 3-1: Categories of Scenario Assumptions

Category		Details
1	Technology Adoption	The introduction date for different levels of AV technology, and their rate of adoption into the vehicle fleet
2	Electrification	The pace of adoption of electrification of the vehicle fleet
3	Connectivity	The pace of adoption, purposes, and location of connected vehicle (CV) technology in vehicles and with infrastructure
4	Freight	The introduction date for different levels of AV technology, and their rate of adoption into the truck fleet; resulting increases in demand for long-distance truck freight and deliveries
5	Pricing Strategy	Any pricing mechanisms applied to vehicle travel
6	Roadway Usage	Dedication of roadway space to any particular mode or class of vehicles, such as high-occupancy vehicles, transit vehicles, or AVs
7	Parking	Policies associated with parking, including pricing, location, and availability for on- and off-street parking
8	Future of Transit	Modes included in the future definition of transit including the use of fixed route, demand-responsive, or large-scale ridesharing options
9	Ridesourcing	Business models, years of introduction, rate of expansion and service area definitions for automated ridesourcing services
10	Road Capacity	Vehicle throughput capacities for freeways and arterials based on the introduction of AV and CV technologies
11	Vehicle Ownership	The number of vehicles required to meet mobility needs, focusing on the number of household-owned vehicles that will be replaced with ridesourcing vehicles
12	Travel Demand	Increases or decreases in person travel demand related to mode shifts, telework, e-commerce, unmet demand from underserved groups, etc.
13	Land Use	Changes to land use growth patterns regionally, including preferences for household and job locations

While the geographic focus of each scenario is the District and how it is impacted by the set of assumptions for transportation and land use, where necessary assumptions have been made about the surrounding jurisdictions as these conditions can have major impacts on travel patterns within Washington, DC.

3.1 Area Type Definition

As in today's Washington region, future travel, development, and behavior characteristics will vary based on location. These differences are included in modeling and forecasting analysis by assigning Area Types to different locations to attempt to capture these 'type of place' characteristics. For this study, identifying differing Area Types is essential, as all assumptions about future scenarios are defined differently in different types of places. The Metropolitan Washington Council of Governments (MWCOG)/Transportation Planning Board (TPB) regional model incorporates six area types that account for differences across the region; however, most of these occur outside the District in suburban and rural communities. Because the focus of this study is on the District, with consideration for interactions with the surrounding communities, Area Types have been defined specifically for this study that better capture the differences in the types of places within the District, and still provides some variation outside of Washington, DC. The five area types used in this study to define assumptions are shown in Figure 3-1, including:

Area type 1: Downtown
Area type 2: Urban
Area type 3: Suburban Mixed
Area type 4: Suburban
Area type 5: Rural

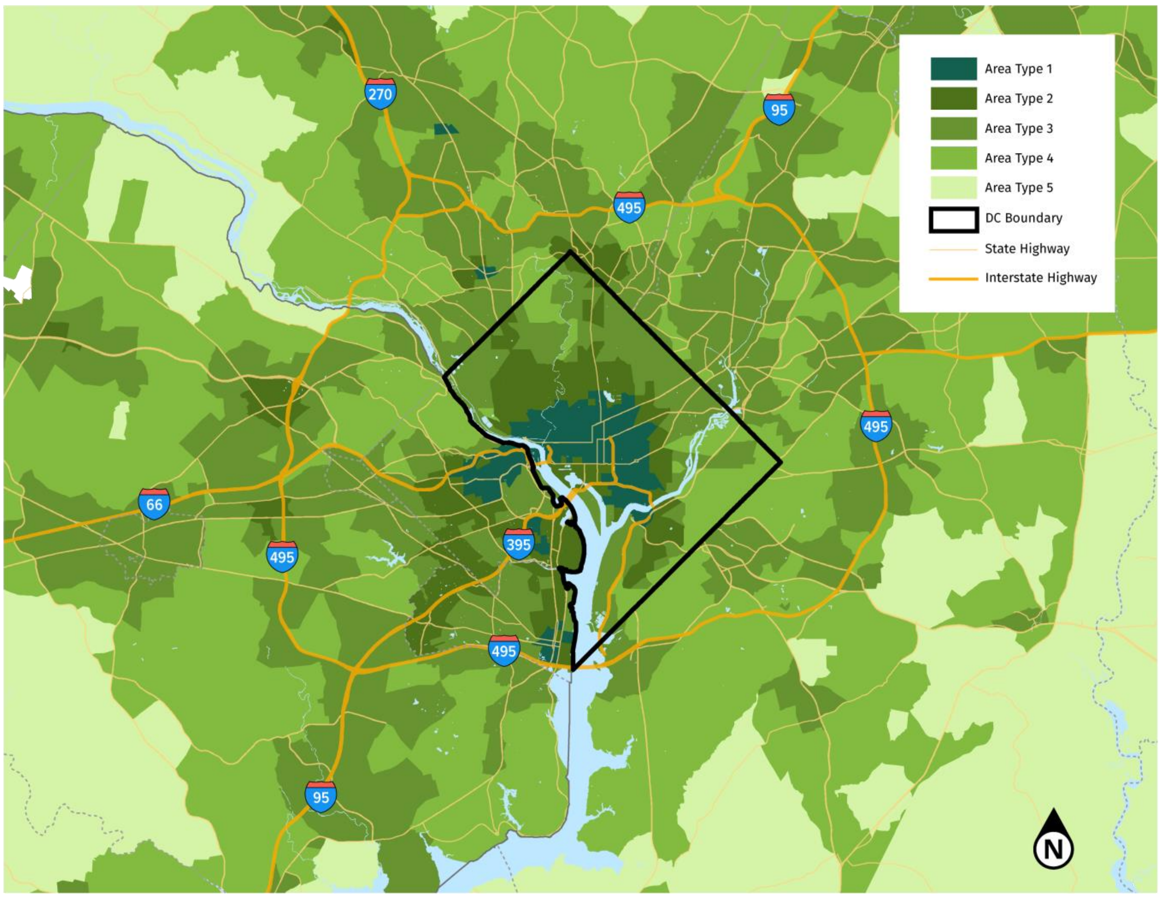


Figure 3-1: Area Type

The Area Types are defined at the Traffic Analysis Zone (TAZ) level by density of activity – a combination of jobs and residents – both within the TAZ, and within a 1-mile radius. This method is called 'floating density' and is the same method used by MWCOG to define Area Types in their model. For this study, the cutoff points for defining different Area Types have been changed, as shown in Table 3-2.

Table 3-2: Area Type Thresholds

	Employment Density (Total Emp/Sq-mi)						
Population Density (Total Pop/Sq-mi)	0-100	101-350	351-1,500	1,500-3,550	3,550-13,750	13,750-15,000	15,000+
0-750	5	5	4	3	3	3	2
750-1,500	5	4	4	3	3	3	2
1,500-3,500	5	4	4	3	3	3	2
3,500-6,000	5	4	4	3	3	2	2
6,000-10,000	4	4	4	3	3	2	2
10,000-15,000	4	4	4	3	2	2	1
15,000+	2	2	2	2	2	1	1

3.2 Scenario A – Households own freeway-automated vehicles

Scenario A explores a future in which vehicle technologies evolve with the capability to drive autonomously on freeway facilities early, and at a relatively reasonable cost. This results in these vehicles being purchased by households around the region, encouraging their proliferation in the private vehicle fleet. Connected and automated vehicle technologies also enable freeways to carry a higher number of vehicles at high market penetration rates, effectively increasing the carrying capacity of the region's freeways without widening. Based on these results, Scenario A assumes that Virginia and Maryland's Departments of Transportation dedicate freeway lanes for the exclusive use of AVs, in order to achieve higher market penetration and the associated capacity increases early to decrease congestion and avoid construction costs. Satellite parking facilities, located at major freeway exits, allow these household-owned, freeway-automated vehicles to drive most of the way into the District where their passengers will seamlessly transition to transit or ridesourcing to their final destination while their cars park themselves. This avoids painful congestion and the high cost of parking downtown.

In the future of Scenario A, it proves to be harder to develop full vehicle automation capable of operating on all roads, including urban arterials and local streets where interactions with signals, cross-traffic, bikes, and pedestrians are common. As such, full automation is introduced later and adopted more slowly into the vehicle fleet. Due to high costs associated with this technology, when they are introduced, these vehicles are initially introduced as fleets of shared vehicles that serve as on-demand transportation.

These changes encourage a shift in land use, as jobs and residents choose to locate further from the District to take advantage of lower land prices and improved traffic conditions. This is likely to cause an increase in the number of long trips occurring on the freeway network. This technology adoption path is likely to continue the paradigm of vehicles that are owned by households, although some households will be able to meet their travel needs with fewer vehicles. A more significant decrease in vehicle ownership will likely be realized in areas with widespread availability of shared vehicles.

Figure 3-2 illustrates what the future might look like in the District under these assumptions and presents a summary of the scenario assumptions by category; detailed scenario assumptions are further discussed in individual sections below.

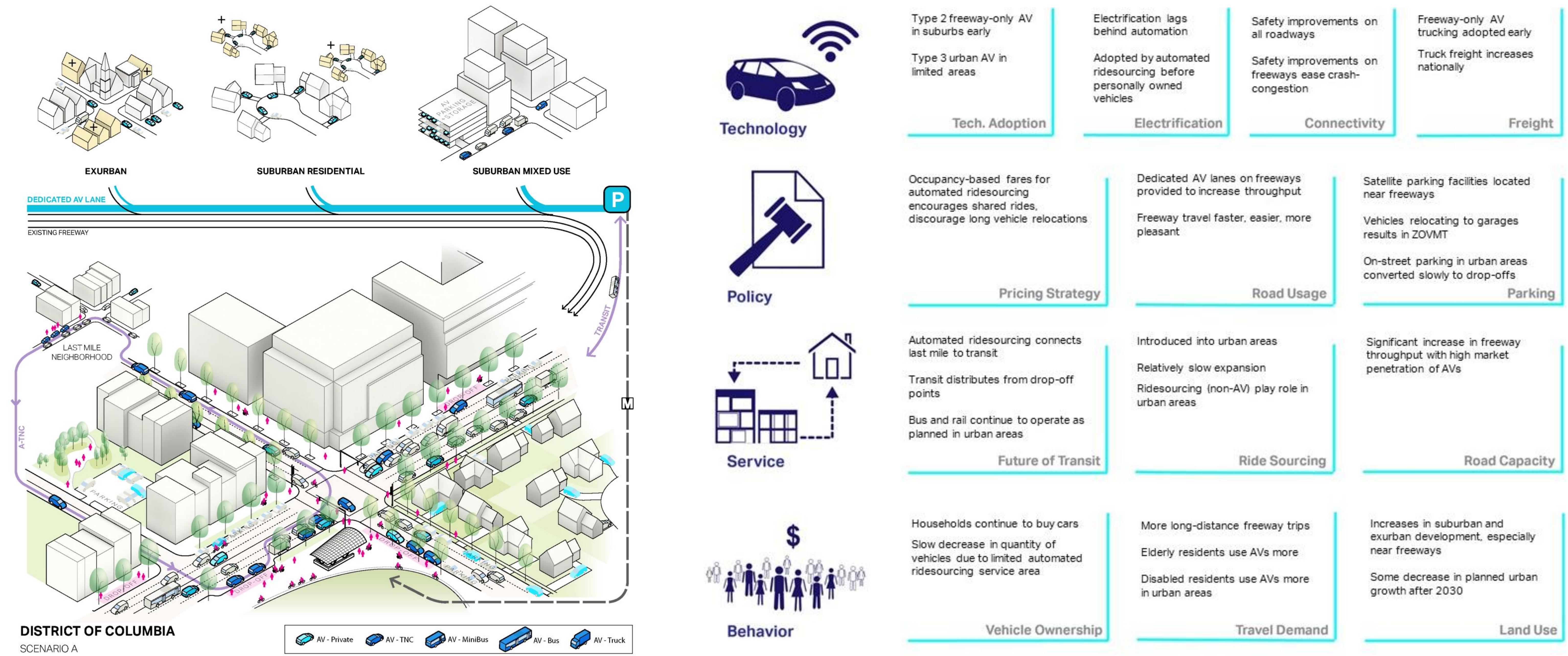


Figure 3-2: Scenario A Assumptions Summary- Households own Freeway-Automated Vehicles

3.2.1 Technology Adoption

Progression of automation technology develops sequentially in Scenario A, starting with Type 2 AVs, capable only of automated driving on freeways and other grade-separated facilities. With a relatively small surcharge, these vehicles are introduced for sale starting in 2024 with a midrange uptake path as they are purchased by households and integrated into the vehicle fleet. The household vehicle market would also expect to see an increase in Type 2 AV sales once freeway lanes are dedicated for their exclusive use on freeways (see Section 3.2.6. Road Usage).

Development of full automation capable of driving on other types of roadways proves to be technically more difficult and expensive. Therefore, Type 3 AVs are introduced in 2030, but are capable of operating only within a small geographic area. Due to their high purchase costs and the small service area, these vehicles are deployed as part of fleets. Market forces encourage technology companies to expand the Type 3 service area to serve a wider portion of the region, making them more attractive for more travelers. Over time as the purchase cost of a Type 3 vehicle decreases, they will also become more attractive in the private vehicle market.

Figure 3-3 shows how these AVs will be incorporated into the passenger car fleet in the District. With early introduction, Type 2 AVs reach a very high level of market penetration by 2039 as they are purchased by households. By that point, Type 3 AVs will still be too expensive for most of the private market, but will start to take over a larger portion of the District's passenger car fleet as shared fleets are introduced and expand. Ultimately, Type 3 AVs become the majority of the vehicle fleet by 2053.

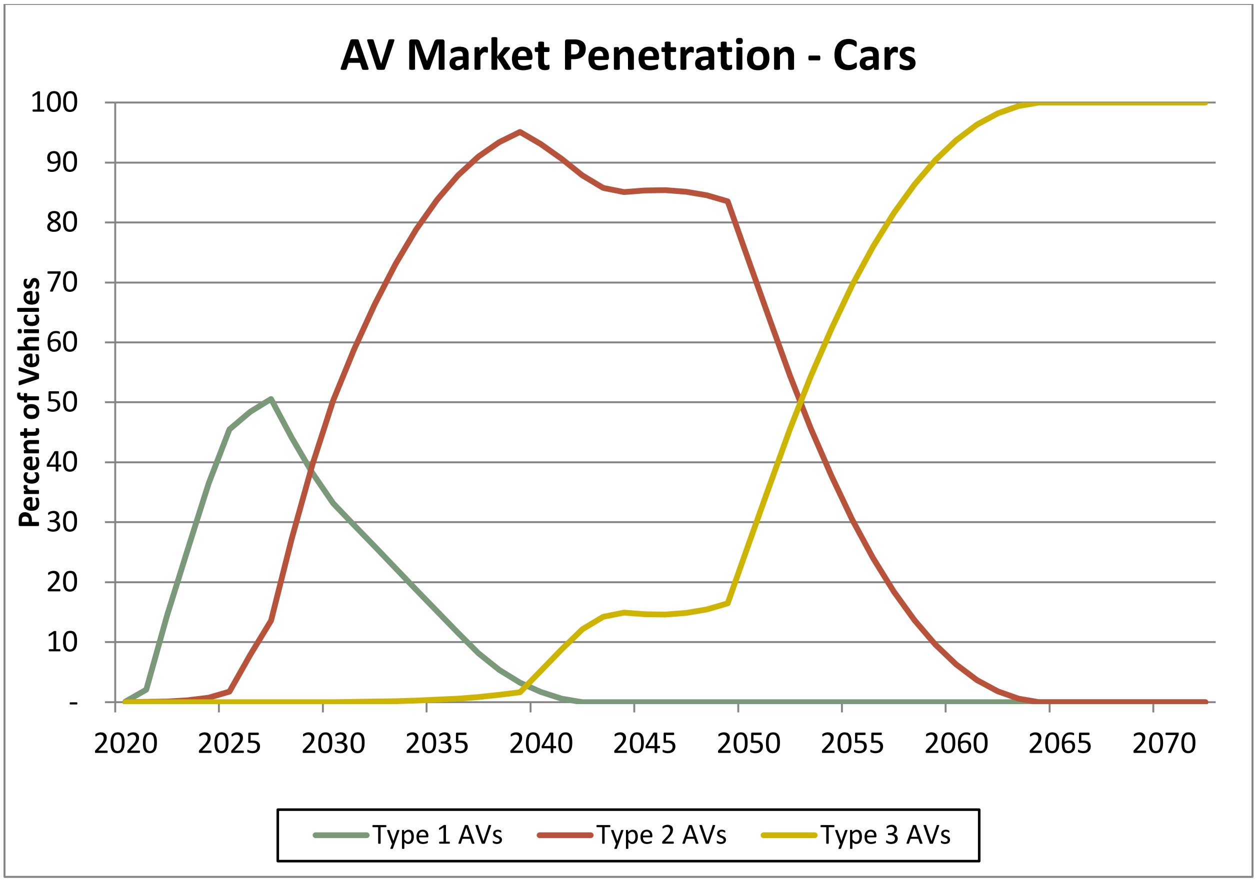


Figure 3-3: Scenario A AV Market Penetration – Cars

3.2.2 Electrification

Vehicle electrification is likely to be developed alongside automated and connected technologies; however there remains uncertainty as to how closely these technologies will be linked.

Figure 3-4 below shows the market penetration for electric vehicles in the District for all vehicles, including both household owned vehicles and shared fleet vehicles. Shared fleet vehicles are likely to see a faster pace of electrification because vehicle sharing makes electrification more palatable by eliminating much of the traditional opposition to purchasing an electric car (e.g. concerns about charging or battery range).

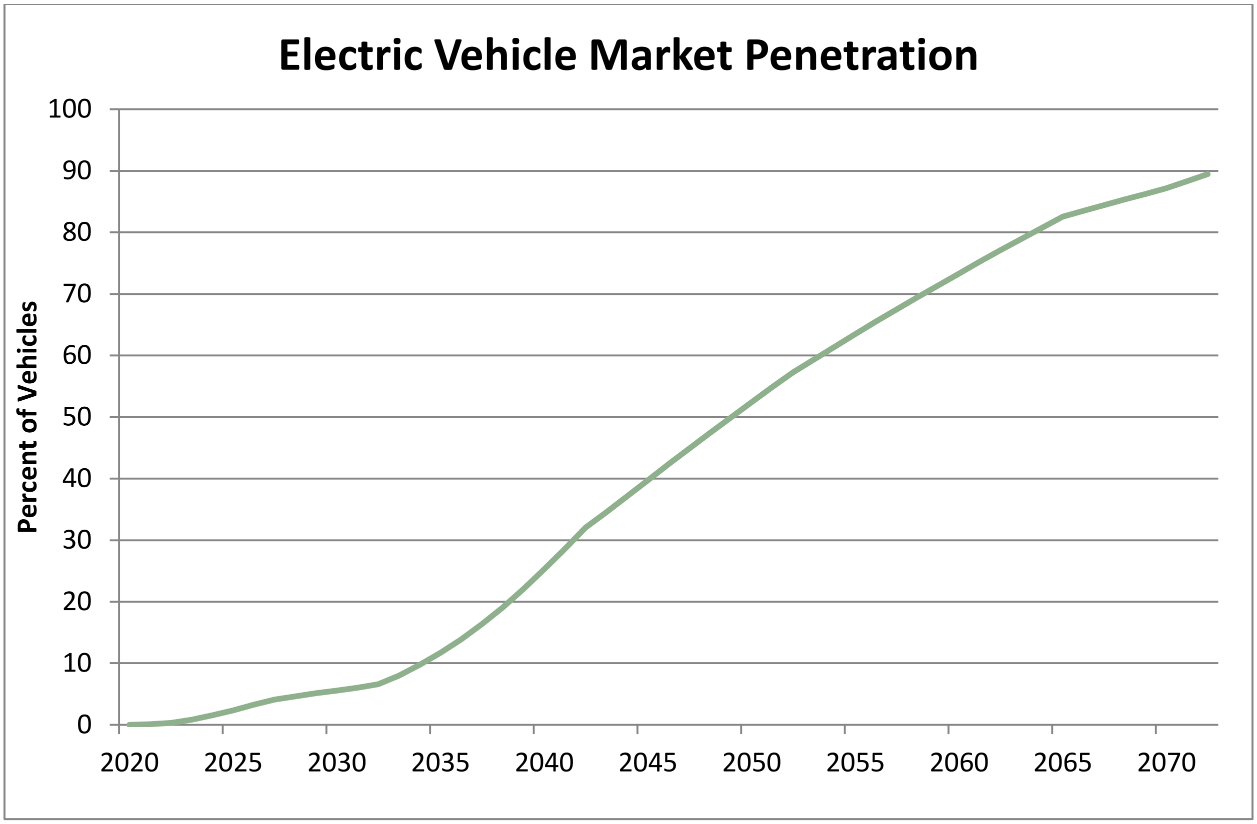


Figure 3-4: Scenario A Electric Vehicle Market Penetration

Source: AECOM, Bloomberg New Energy Finance 2018.

It should be noted that these assumptions are significantly more optimistic than those used by MWCOG in their 2019 Air Quality Conformity analysis, which uses highly conservative estimates of electrification and assumes no growth in electric vehicles above current conditions. Changes to electrification rates - driven by consumer choice, electricity prices, and/or policy and legal changes - could have significant impacts on the analysis results, specifically related to vehicle emissions.

3.2.3 Connectivity

Connected vehicle technology is often considered to be a part of vehicle automation, as it has the potential to dramatically improve roadway operations by providing drivers – or vehicles themselves in the case of AVs – with more information about roadway conditions than would otherwise be possible. This information can help vehicles prepare for difficult driving conditions, anticipate changes in traffic conditions and make necessary adjustments, and perhaps most importantly, avoid crashes and/or limit their severity. These technologies, especially when combined with automation, have great potential on freeways and surface streets. Scenario A assumes that these technologies are deployed effectively on facilities across the region, with the associated safety improvements. Further, Scenario A assumes that these safety improvements have the potential to decrease congestion on the region's freeways, as 25 percent of congestion is currently related to crashes and other traffic incidents (FHWA, 2005). In this study, all AVs of any type (1-3) are assumed to be equipped with connected vehicle technology. Figure 3-3, presented earlier in this section, therefore shows the assumed adoption rate of CV technology into the District's vehicle fleet.

3.2.4 Freight

Two elements of freight traffic will be impacted by AV technology: long-distance freight shipping and local freight deliveries. These two applications will have different impacts on travel patterns and traffic conditions and require different types of technology. Long-distance heavy-freight shipping primarily occurs on freeways, currently requiring drivers willing to work long shifts in uncomfortable circumstances. This has resulted in a significant shortage of truck drivers in the US (NPR, 2019) that could be alleviated by the introduction of Type 2 AV trucks that are capable of operating without a driver on freeways.

Labor costs account for almost 40% of truck operating costs (ATRI, 2016). By dramatically reducing labor costs, this technology could also decrease the cost of shipping freight by trucks, making it more attractive to companies and potentially increasing the amount of freight traffic occurring nationwide. Based on cost elasticities of freight traffic, Scenario A assumes a national and regional increase in long-distance freight travel of approximately 7.9 percent at 100 percent market penetration, as shown in Figure 3-5. This increase is above what would otherwise be expected due to growth.

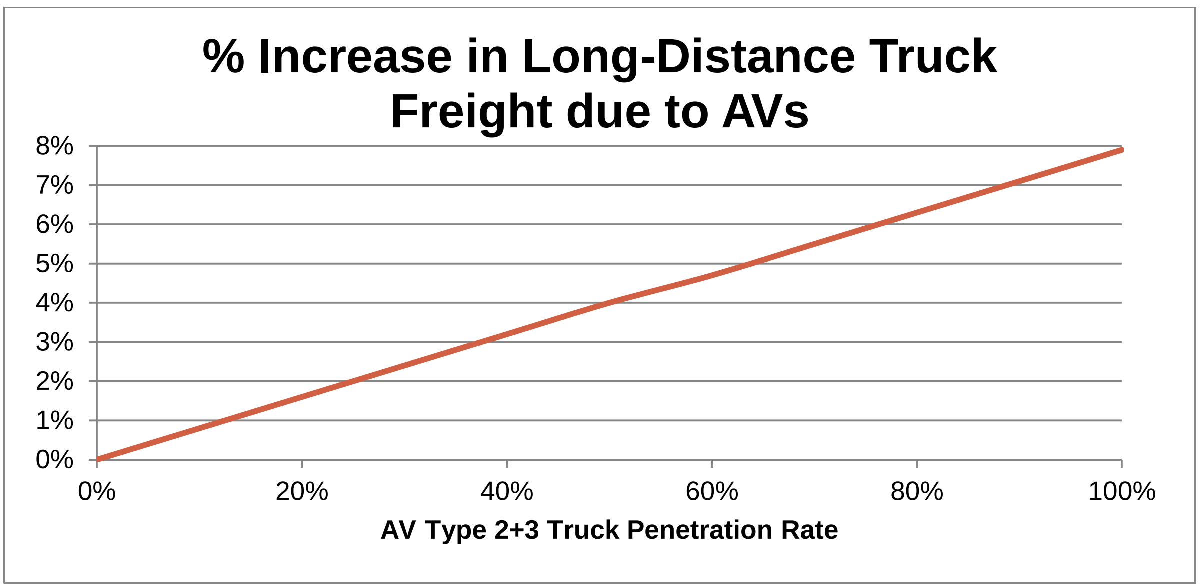


Figure 3-5: Scenario A Truck Freight Increase

Deliveries represent another major market for truck automation, as approximately 50 percent of parcel delivery costs are associated with the last mile (Joerss *et al.*, 2016). Automated deliveries, however, require Level 3 AVs (and possibly additional technology development as well) in order to navigate city streets and driveways to reach their final destination. Deliveries are already on the rise nationally, as e-commerce continues to grow in importance and the frequency of home deliveries continues to increase. This growth in deliveries is assumed to continue in the Scenario A future, but no major disruptors to this growth trajectory are assumed in this scenario, due to the later introduction of Type 3 AVs.

Scenario A assumes that Type 2 trucks will be available for sale in 2024, the same year as Type 2 passenger vehicles, although they are expected to be adopted into the fleet at a fast rate due to the attractiveness of the cost savings to the trucking industry. Scenario A assumes that Type 3 AV trucks, used for both long-distance freight and local deliveries, will only be available starting in 2042 once the Type 3 AV service area has expanded to cover a sufficiently wide portion of the region. Figure 3-6 shows the adoption of Type 2 and Type 3 AV Trucks in the District. The early introduction of Type 2 freeway-automation has a major impact on the truck fleet, which is predicted to reach full market penetration by 2035, before shifting to fully automated Type 3 trucks.

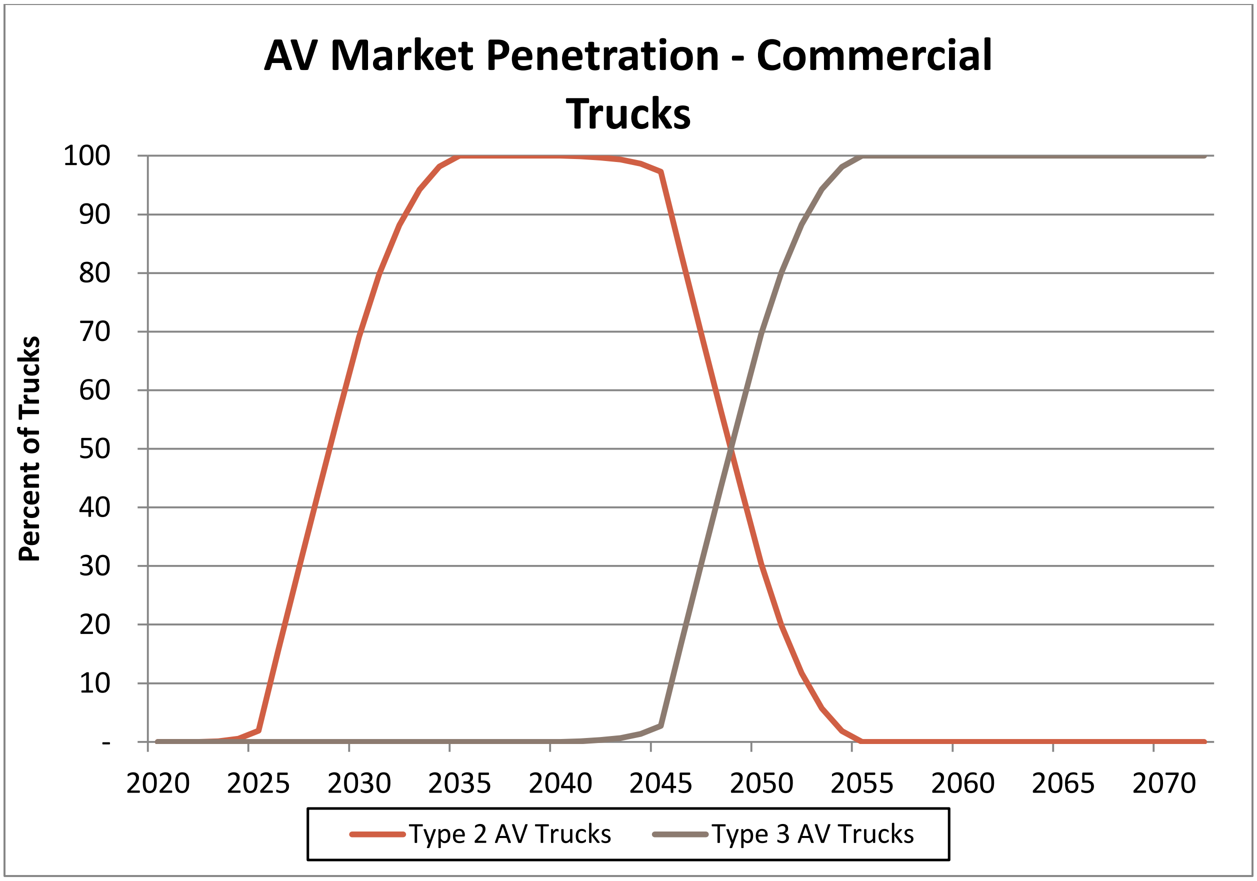


Figure 3-6: Scenario A AV Market Penetration - Trucks

3.2.5 Pricing Strategy

Scenario A does not include significant changes to pricing strategies in the future. However, in order to limit the amount of traffic caused by empty vehicle relocations, it is assumed that a small fee is charged to automated ridesourcing vehicles that are traveling without passengers.

3.2.6 Road Usage

As detailed in Section 3.2.10, one of the key assumptions in Scenario A is that significant increases in freeway capacity can be achieved at high AV market penetration rates. This assumption results in local governments not only encouraging the purchase of AVs, but also leads them to try and create these high market penetration levels as quickly as possible in order to relieve congestion without implementing cost-intensive infrastructure projects such as widening highways or constructing major mass transit expansions. In order to achieve this, Scenario A assumes that one lane on each freeway in the region will be dedicated for use by Type 2 or 3 AVs.

It is also assumed as part of Scenario A, that time spent traveling in an AV is viewed by passengers as more pleasant than time spent driving a vehicle. This has impacts on the number of people willing to drive and the distances of those trips. Section 3.2.12 includes more details on assumptions related to changing travel demand.

3.2.7 Parking

Under Scenario A, freeway driving becomes more attractive due to the proliferation of freeway-automated vehicles and dedicated AV lanes. Because these Type 2 AVs would not initially be able to relocate themselves on urban streets, parking in the District would remain a barrier to drive-alone commutes into DC. In order to avoid an influx of additional traffic on downtown streets from these commuting AVs, satellite parking facilities will be provided near/at freeway exits where AVs would drop off their owners and park, possibly for free. These parking facilities could be located directly at the freeway exit, or vehicles might have to relocate themselves back to parking facilities further from the District, as shown by way of example in Figure 3-7. So long as off-street parking continues to be made available in DC, some drivers will continue to drive into DC themselves, but it is expected the cost will still be prohibitive to many commuters.

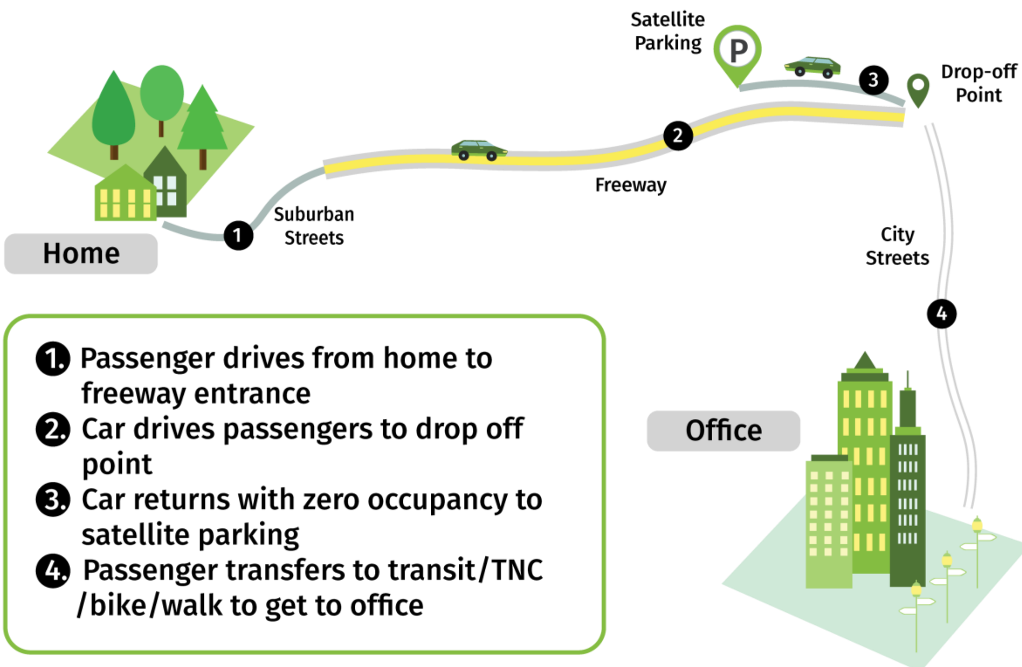


Figure 3-7: Sample Commute Pattern in Scenario A

This commute pattern does encourage some ZOVMT, while vehicles relocate to the satellite parking facilities in the morning (and vice versa in the evening for the return trip). At least some of this additional VMT will likely occur during the off-peak period and/or the off-peak direction. However, the full impact of this additional VMT will be addressed in the analysis results in Section 4.0.

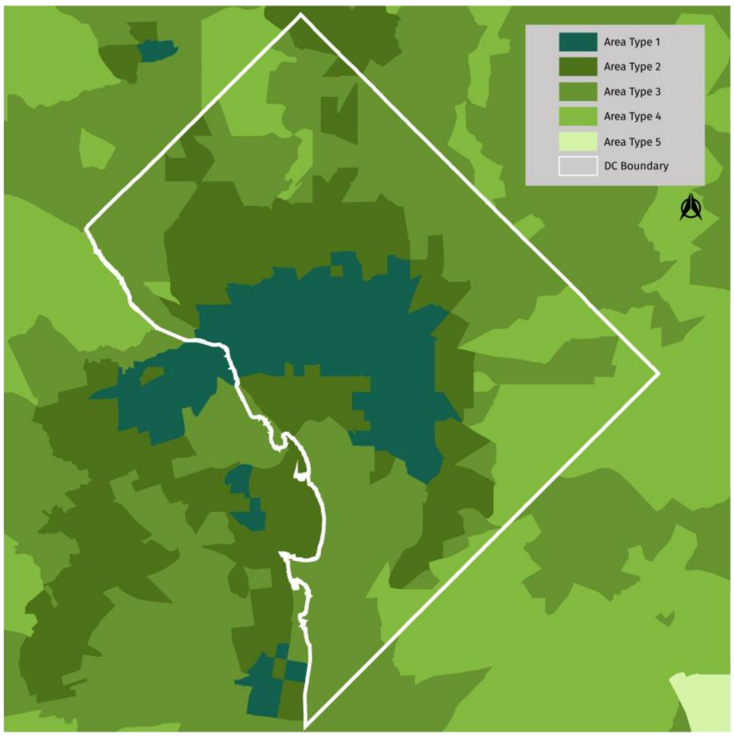
As Level 3 AVs spread across the District and the region, Scenario A also assumes that on-street parking will be converted into pick-up/drop-off locations as needed and could be freed up for other uses entirely.

3.2.8 Future of Transit

Under this scenario, AVs are used as a complement to the existing public transit system, with a particular focus on using AVs to solve first-mile/las-mile connectivity issues in areas where walking directly to public transit may not be an attractive option. Ridesourcing services – both with drivers and driverless as they are introduced and made available – would provide access to transit stations, potentially increasing ridership. Transit would also be necessary to serve the new drop-off points associated with satellite parking facilities (see Section 3.2.7 above), although these services could be provided by either public transit entities or private companies in the form of ridesourcing, microtransit, or some other business model.

3.2.9 Ridesourcing

As previously outlined in Section 0, automated ridesourcing requires the availability of Type 3 AVs to be financially viable. Scenario A assumes that this level of automation is difficult to achieve (and therefore is available later than Type 2 AVs) and requires expensive and time-consuming mapping in order to provide service in a specific geographic area. Due to their expense and limited service area, Type 3 AVs are likely to be introduced as part of ridesourcing fleets that can make the most efficient use of the vehicles. Automated Ridesourcing service would begin in the downtown area in 2025 and slowly expand outward as the technology progresses, until the whole region is served in 2040. Detailed expansion assumptions are outlined in Figure 3-8. Expansion of Automated Ridesourcing service areas is likely to spread outwards, as individual areas are mapped for inclusion in AV software.



Area Type	Expansion Timeline
Area Type 1 Downtown	beginning in 2025
Area Type 2 Urban	beginning in 2027
Area Type 3 Mixed Use Suburban	beginning in 2032
Area Type 4 Suburban	beginning in 2040
Area Type 5 Rural	beginning in 2040

Figure 3-8: DC Automated Ridesourcing Service Expansion – Scenario A

Costs for using automated ridesourcing are expected to be quite low (BCG, 2017), making them accessible to travelers of all income levels and providing the potential to affordably and realistically live a car-free lifestyle in areas that are not within walking distance to convenient transit service. It is further assumed that the ridesourcing companies structure their fares to encourage shared rides, so that they can achieve higher vehicle occupancies and have lower impacts on congestion and emissions.

3.2.10 Road Capacity

Roadway carrying capacity is assumed to see an increase in Scenario A with the introduction of both Type 2 and Type 3 AVs and connected vehicle technology. The biggest increases in capacity will occur on freeways, as concentrations of CV and AV technology allow vehicles to travel faster in congested conditions and smooth traffic through bottlenecks. A 50 percent increase in the potential carrying capacity of a freeway lane is assumed at 100 percent market penetration (Type 2 AV or higher), although the relationship between capacity and market penetration is not linear[1]. At very low levels of AV market penetration, capacity is actually likely to decrease, as AVs are likely to maintain wider separations from vehicles that they cannot communicate with than human drivers would (Arnaout *et al.*, 2011). Dedicated AV lanes are assumed to always have 100 percent market penetration.

In addition to these increases, CV and AV technologies are assumed to help alleviate congestion caused by crashes and other incidents, thus increasing the effective carrying capacity of all roadways in the region. One-quarter of congestion is caused by crashes; Table 3-3 highlights the assumptions around how many of these crashes are assumed to be removed in Scenario A, and the associated increase in carrying capacity by facility type. In this scenario, freeways are expected to see a larger investment in CV technologies, and thus will see greater capacity benefits.

Table 3-3: Effective Capacity Increases Associated with Crash Reduction – Scenario A

Facility Type	Crashes Eliminated	Effective Capacity Increase
Freeways	60%	15%
Arterials	40%	10%

The effective carrying capacities of different roadway types are shown in Figure 3-9 as a percentage of current roadway capacities.

[1] Industry estimates for capacity increases achievable with AV and CV vary widely, and in early days were as high as 5x capacity increases (USDOT, 2017). More recent literature has pulled back from these estimates somewhat, so that a 50% increase in capacity represents a middle-of-the-road assumption.

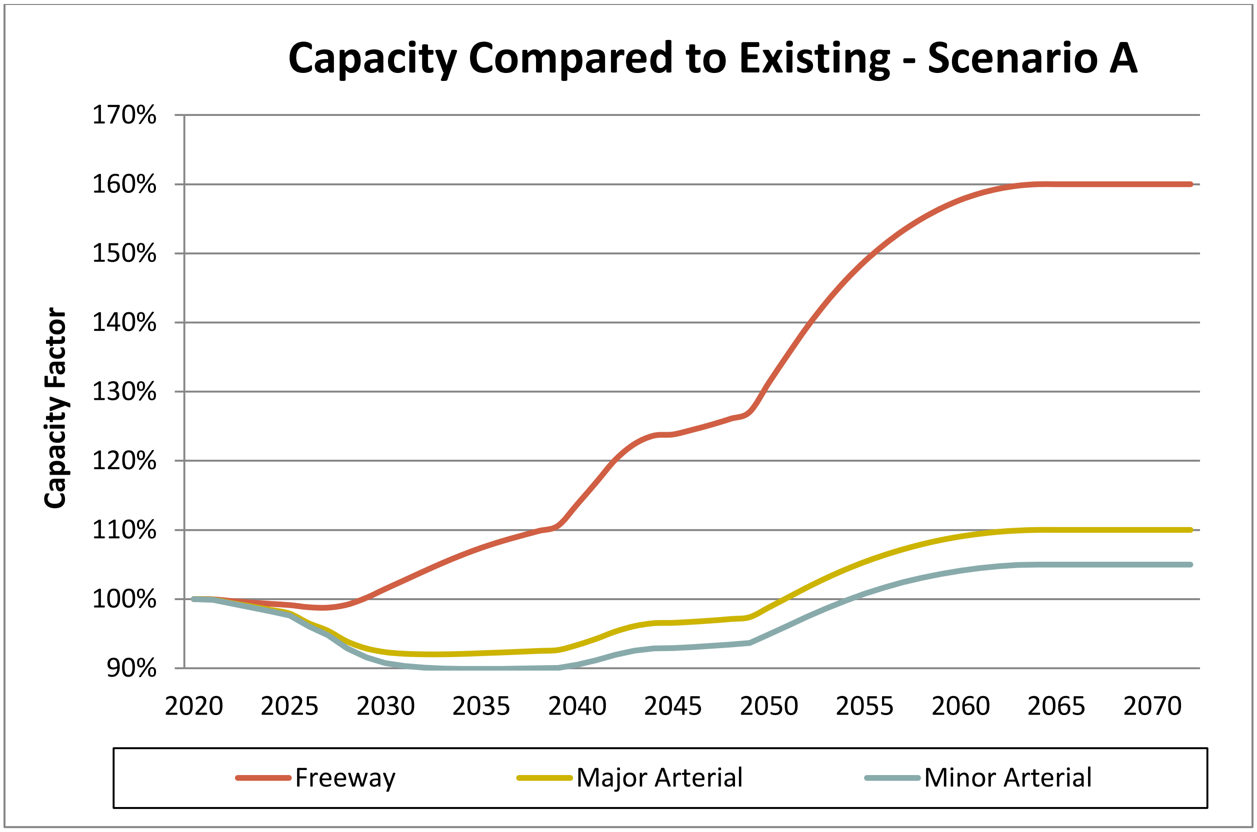


Figure 3-9: Effective Carrying Capacity as compared with current Capacity – Scenario A

3.2.11 Vehicle Ownership

In Scenario A, households will continue to purchase vehicles, as AV technology is assumed to be introduced gradually and at a reasonable consumer price. This will mean that many households, particularly in suburban and rural areas in the region, will remain reliant on their personal vehicles, although full automation may make it possible for some households to own fewer vehicles than they otherwise would.

Vehicle ownership is expected to decrease under this scenario as new mobility options make it easier and cheaper to travel without owning a car. These reductions in vehicle ownership would therefore occur in areas in which automated ridesourcing has been introduced, and are likely to occur slowly in time as their service areas expand. The assumptions account for the concept that a car owner in downtown is unlikely to give up their car until they feel comfortable that they can rely on other services to maintain their freedom and flexibility to travel when and where they want. Therefore, fewer people are willing to give up their vehicles when automated ridesourcing only serves the downtown area, than once they have expanded to the suburbs as well.

Research into carsharing provides the basis for the assumptions about vehicle ownership (Fagnant, *et al.*, 2015) which shows that in different Area Types, each shared vehicle can replace a different number of household-owned vehicles. The replacement rates are shown in Figure 3-10 below.

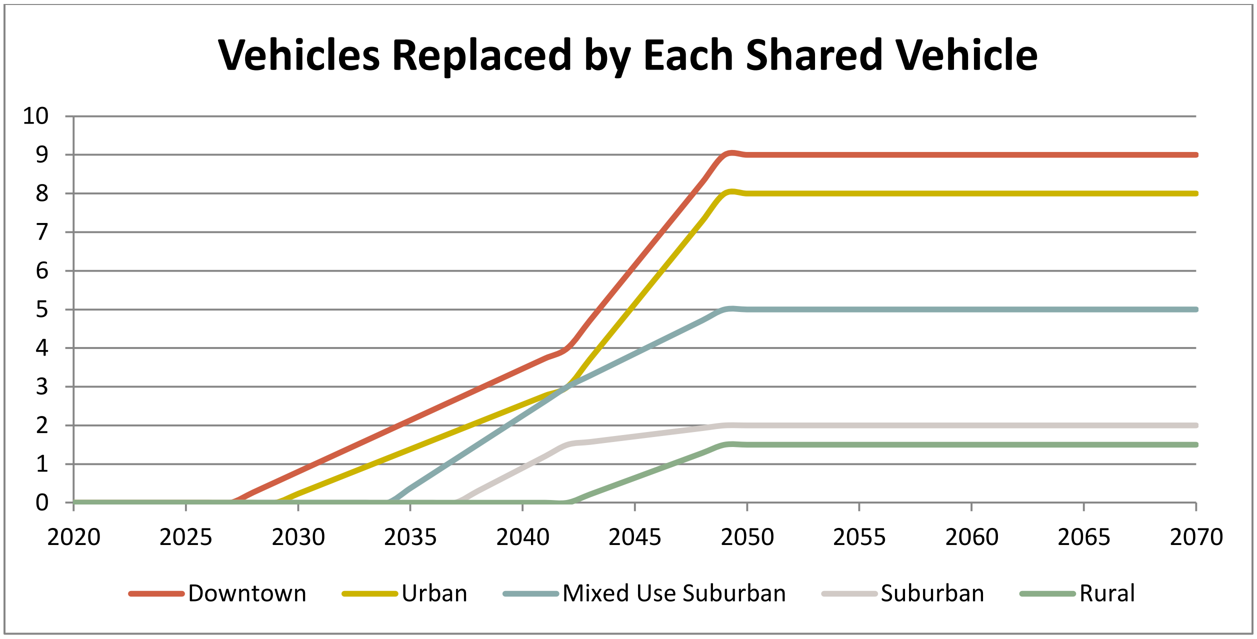


Figure 3-10: Vehicle Replacement Rates By Area Type – Scenario A

3.2.12 Travel Demand

Travel demand and travel patterns under the assumptions of Scenario A are expected to change in several ways. These changes will impact the number of trips people take (Henderson *et al.*, 2016), the length of those trips, and/or the mode of travel used (Fagnant & Kockelman, 2015; Carriea *et al.*, 2016). In addition to changes to personal travel patterns, the assumptions also consider the addition of ZOV travel behavior (Maciejewski *et al.*, 2017; Fagnant & Kockleman, 2014). The changes are outlined in Table 3-4 below; the impacts of these changes on performance metrics such as Vehicle Miles Traveled (VMT), transit ridership, and congestion are quantified in Section 4.0. These changes and impacts will vary geographically based on the service options available in each Area Type.

Table 3-4: Travel Demand Assumptions – Scenario A

Assumed Changes	Behavior
AVs make time spent in the car more pleasant (Type 2 and 3)	People are willing to drive longer distances to get to their destination More people chose vehicles over transit
Automated ridesourcing is cheaper to use than privately-owned vehicles with no ownership costs	Travelers are able to shift from transit to automated ridesourcing for particularly long transit trips
Automated ridesourcing provides mobility for people who couldn't drive previously	Disabled residents are able to increase the number of trips made Elderly residents increase the number of trips made, and are able to travel longer distances
Empty vehicles relocation	Privately-owned AVs are more likely to make long empty relocations to access satellite parking facilities Automated ridesourcing will have empty relocations to pick up passengers, but these will generally be short in order to optimize costs

3.2.13 Land Use

The assumptions included in Scenario A make driving, particularly on freeways, easier, faster, and thereby more attractive for residents in the region. The scenario envisions that these changes will make long-distance commutes less onerous, enticing more people to live further away from the region's center to take advantage of lower land prices in the region's outer suburbs and convenient access to the regional freeway network. These changes will take time to be realized, and will only start to be seen after 2030, as follows:

- 10 percent decrease in the amount of household growth currently forecast to occur between 2030 and 2045 in DC. This amounts in approximately 4,900 fewer households in the District by 2045 than are forecast for the region.
- 30 percent decrease in the amount of household growth currently forecast to occur between 2030 and 2045 in suburban communities inside the Beltway (including Arlington County, Alexandria, and portions of Fairfax, Montgomery, and Prince George's Counties). This results in approximately 24,000 fewer households in these areas.
- These 29,000 households will instead be located in suburban communities outside the beltway, resulting in a 1.2 percent increase in households (HHs) in these areas.

Figure 3-11 shows geographically where these changes in household growth were implemented throughout the region. Pink dots show locations where fewer households will be added than what is included in the MWCOG forecasts, while orange dots show locations where more households will be added.

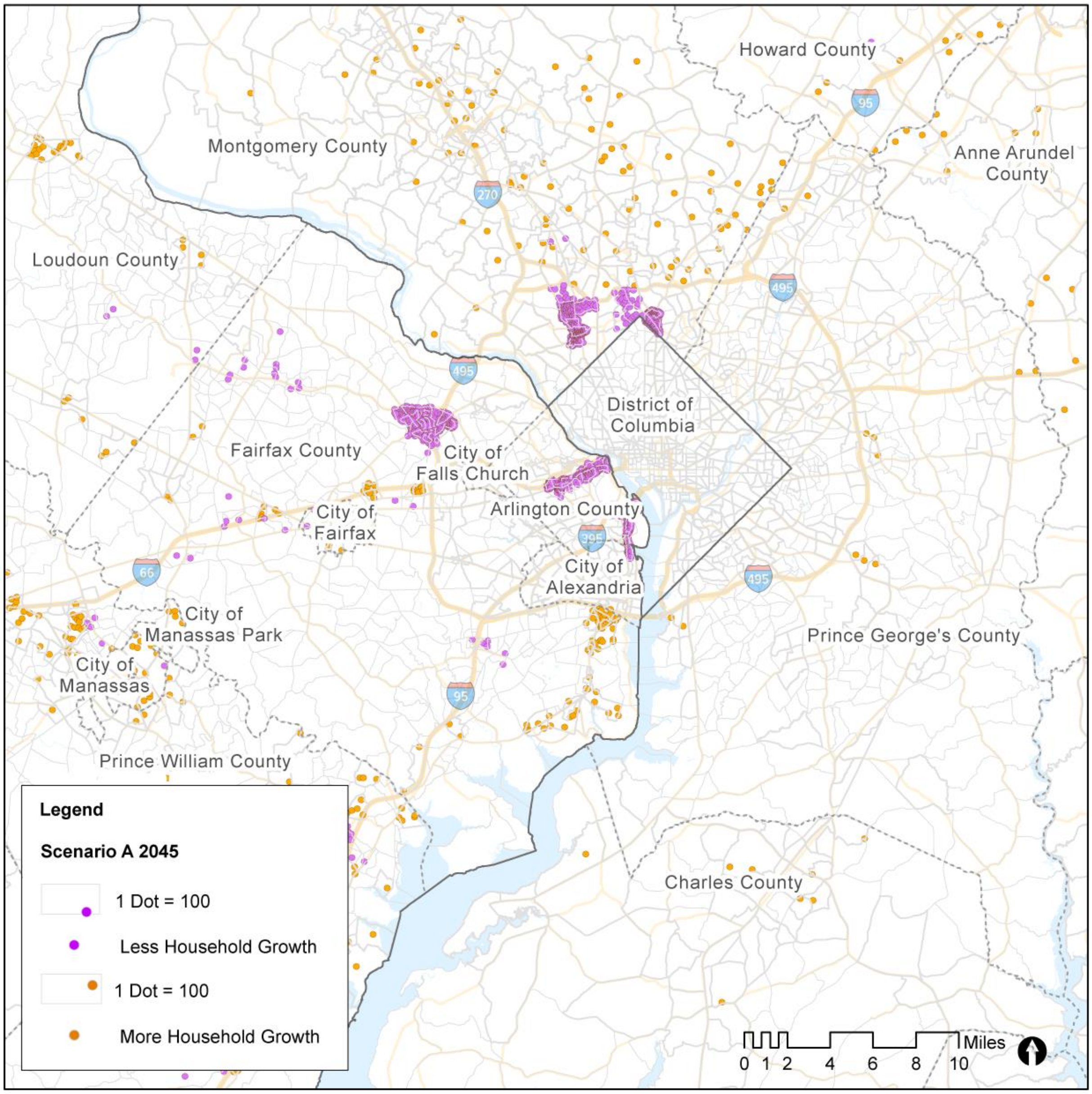


Figure 3-11: Household Growth Change

Growth in retail jobs were moved in a similar pattern to the household growth, as retail location is highly dependent on the local market. These changes are summarized in Table 3-5.

Table 3-5: 2045 Retail Job Change By Jurisdiction – Scenario A as Compared to MWCOG Forecasts

Jurisdiction	Change in Retail Jobs	
DC	-1,765	-1.5%
Montgomery County	-724	-0.7%
Prince George's County	-2,065	-2.1%
Arlington County	-1,410	-3.5%
Alexandria	-1,472	-5.8%
Fairfax County	-1,894	-1.5%
Fairfax City	184	2.6%
Falls Church	-186	-2.9%
Loudoun County	446	0.7%
Other MD	-572	-0.4%
Other VA	8,163	2.8%
Total	**2,838**	**12.0%**

Office jobs, however, are assumed to follow a different pattern of growth. The shift in residential growth towards the outer suburbs is likely to encourage companies to locate outside of the District to be closer to their employees, among other factors. However, in order to maintain a wide catchment area for potential talent, these companies primarily choose to locate in major job centers inside the Beltway – specifically in Tysons; the Rosslyn-Ballston corridor in Arlington; National Landing in Arlington/Alexandria; and Silver Spring and Bethesda in Montgomery County. These changes will take time to be realized, and will only start to be seen after 2030, as follows:

- 20 percent decrease in the amount of office job growth currently forecast to occur between 2030 and 2045 in DC. This amounts to approximately 17,000 fewer office jobs in the District by 2045 than are forecast by MWCOG.
- Decreases in the amount of office job growth currently forecast to occur between 2030 and 2045 in suburban communities outside the Beltway. A 15 percent decrease in office job growth is envisioned for outer suburban areas within a mile of a freeway, while a 30 percent decrease is assumed in outer suburban areas without easy access to the freeway network. This results in approximately 33,000 fewer jobs in these areas.
- These 50,000 office jobs were instead located in the specific job centers noted above, resulting in a 7.5 percent increase in office jobs in suburban areas inside the Beltway.

Figure 3-12 shows geographically where these changes in job growth were implemented throughout the region, including changes in both retail and office jobs. Blue dots show locations where fewer jobs will be added than what is included in the MWCOG forecasts, while red dots show locations where more jobs will be added.

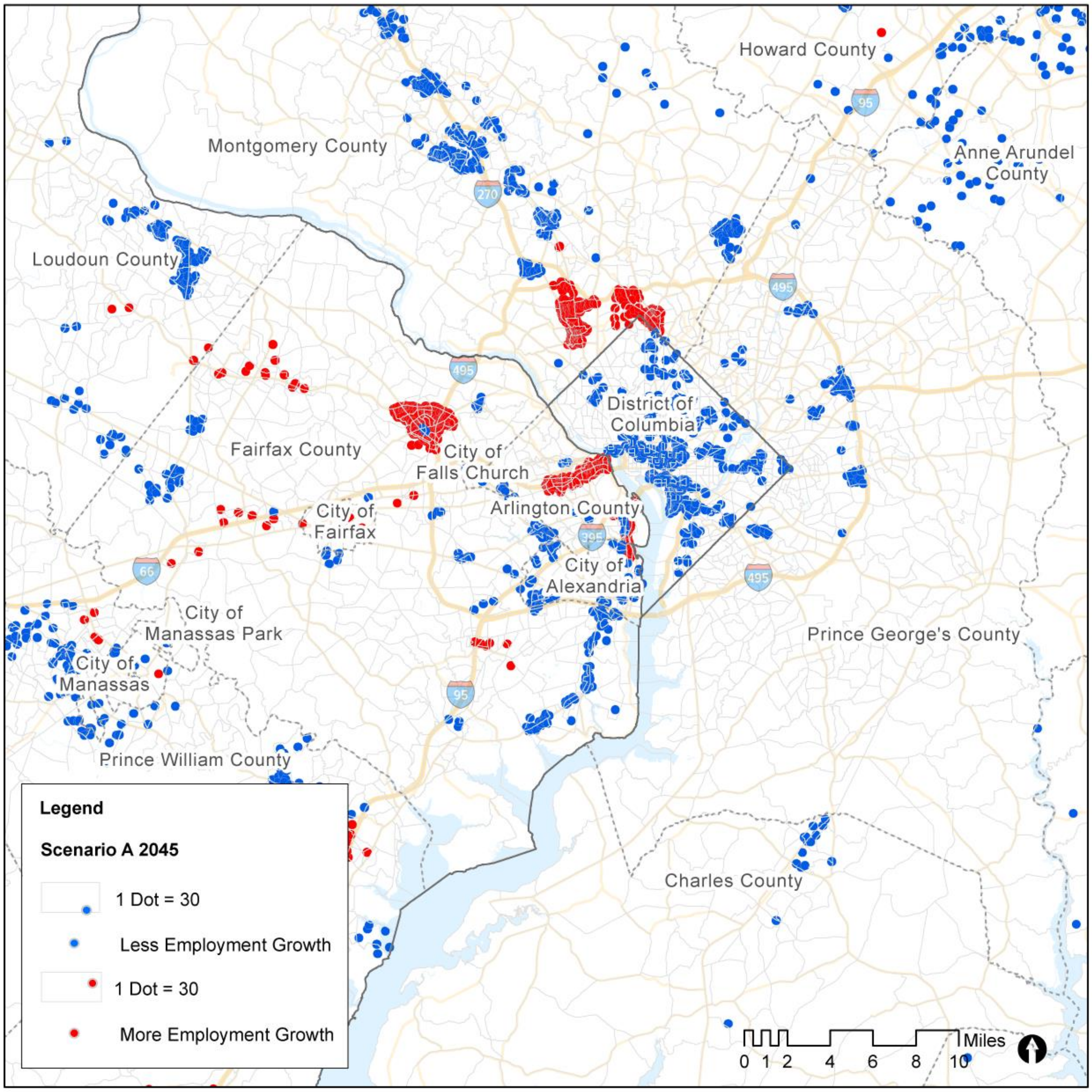


Figure 3-12: Employment Growth Change – Scenario A

No changes were assumed to the regionally forecasted growth for the other job categories (industrial and "other") included in the MWCOG Cooperative Land Use Forecasts. All of these changes result in the same regional totals for jobs and households as the regional forecasts, only their distribution is different, as shown in Table 3-6.

Table 3-6: 2045 Land Use By Jurisdiction – Scenario A

Jurisdiction	Households	Population	Retail Jobs	Office Jobs	Total Jobs
DC	406,937	977,188	113,029	817,140	1,026,648
Montgomery	461,040	1,222,022	109,102	420,555	690,880
Prince George's	375,107	991,982	94,105	90,635	399,696
Arlington	136,448	289,695	38,489	197,218	282,094
Alexandria	100,248	195,201	24,000	106,517	154,411
Fairfax County	529,136	1,423,498	121,523	664,033	897,987
Fairfax City	13,777	35,949	7,298	13,924	23,574
Falls Church	7,965	17,145	6,167	6,666	18,414
Loudoun	170,020	511,309	60,271	112,206	288,244
Other MD	426,185	1,117,568	135,415	297,236	683,157
Other VA	855,331	2,345,183	300,191	307,806	984,509
Total	**3,482,194**	**9,126,740**	**1,009,590**	**3,033,936**	**5,449,614**

3.3 Scenario B – Shared AV Fleets Expand Quickly

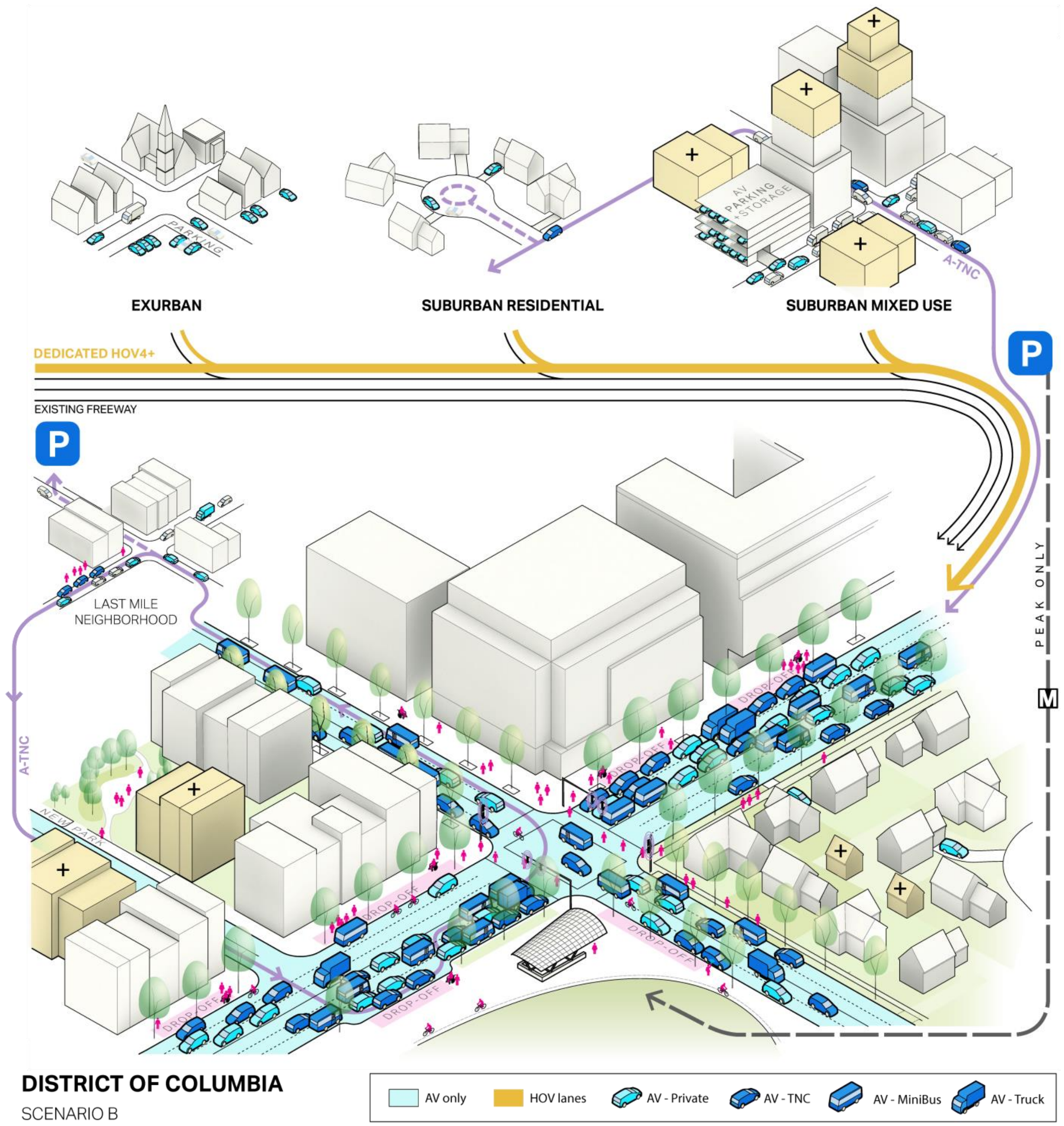
Scenario B explores a future in which AVs capable of traveling on all types of roadways, including urban streets, are introduced quickly. In this scenario, similar to Scenario A, the costs of a fully automated Type 3 vehicle remain high at introduction and will be acquired and deployed first as part of shared vehicle fleets that serve as on-demand transportation. Scenario B assumes that this AV technology expands its operating design domain quickly, with automated ridesourcing providing inexpensive, convenient service in urban and many suburban markets by 2030. These private automated ridesourcing services will offer a range of ride and vehicle options, from riding alone, to shared rides, to larger shared vans that provide higher capacity vehicles in high-demand areas. These options will offer on-demand service with minimal wait at low prices, ultimately becoming one of the preferred mobility options throughout the region. The technology is also applied to delivery vehicles, lowering the cost of parcel delivery and thereby increasing demand.

One of the reasons for this preference will be the ability of households of all sizes and income levels to achieve high levels of mobility without the need to buy, maintain, or store a car. This will result in a significant decrease in vehicle ownership, particularly in the denser areas where wait times will be shorter and trip costs would likely be lower. Some households in the region will of course continue to own vehicles, and those vehicles will evolve from Type 1 through Type 3 AVs, starting with the higher-end vehicles, as owners buy new cars to replace older technology. These automated ridesourcing services will also open vehicle travel to many people who currently don't have easy access to a car, including youths, disabled residents, non-car owners, and the elderly.

As automated ridesourcing grows in market share in the District and regionally, Scenario B envisions that they are more and more in competition with transit. Slowly, governments will decide that automated ridesourcing is a more cost-effective means of providing transportation to the public and will ultimately discontinue traditional public bus service. Metrorail will continue to operate during peak periods, as the most efficient ways of moving large numbers of people into major employments centers every day.

The proliferation of mobility and access through automated ridesourcing will encourage more people to live in areas with good service levels, particularly the dense, urban areas in the District and the surrounding inner suburbs. Scenario B assumes that zoning in these areas is adjusted to accommodate this demand, with a significant increase in households located in these areas as compared to the current regional land use forecasts. Job growth is also drawn to these areas, allowing companies and their employees to take advantage of these mobility options.

Figure 3-13 illustrates what the future might look like in the District under these assumptions and presents a summary of the scenario assumptions by category; detailed scenario assumptions are further discussed in individual sections below.



DISTRICT OF COLUMBIA
SCENARIO B

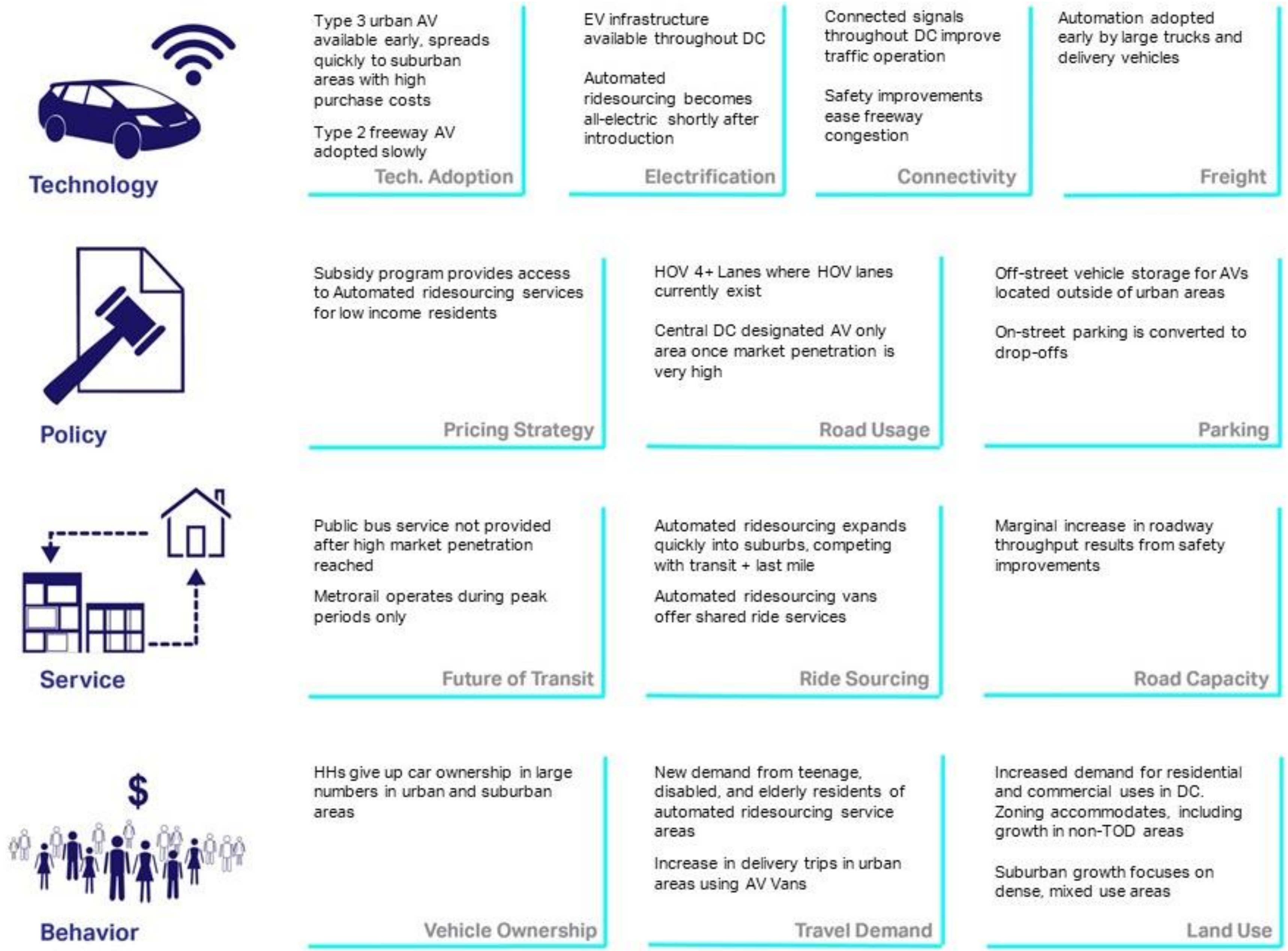


Figure 3-13: Scenario B Assumptions Summary- Shared AV Fleets Expand Quickly

3.3.1 Technology Adoption

Development of automated vehicle technology develops differently in Scenario B, with Type 3 vehicles available earlier, with capabilities for truly automated driving on all roads within a service area that grows quickly. However, these capabilities are expensive, and are therefore introduced by private companies that deploy the AVs as part of shared fleets. In this way, the owners are able to make more efficient use of their investment by using the cars all day, unlike household-owned vehicles which are typically used for approximately four percent of the day (Zimmer, 2016).

Level 2 AVs capable of driving on freeways are also introduced as a somewhat cheaper alternative to full automation. However, the cost premium associated with the technology and the wide availability of automated ridesourcing services in many areas, mean that even Level 2 AVs are adopted into the vehicle fleet relatively slowly. Ultimately, prices on Level 2 and Level 3 AVs will come down enough to make purchase by a larger segment of the population viable. However, as discussed in Sections 3.3.9 and 3.3.11, the early establishment and expansion of automated ridesourcing will lead many residents, particularly in dense urban and suburban areas to become reliant on a lifestyle that does not include car ownership. Even as they become more affordable, many people will choose to remain car-free, limiting the market for privately owned AVs to areas where service is less ubiquitous or to people who strongly prefer not to share.

Figure 3-14 shows how these AVs will be incorporated into the vehicle fleet in the District. Type 2 vehicles are introduced for sale in 2024, at which point they slowly start to be integrated in the vehicle fleet, peaking at 70 percent in 2037. Type 3 AVs become available for general purchase in 2027, shortly after their introduction as shared vehicles downtown. They remain a very small portion of the vehicle fleet until 2037, at which point technology capabilities expand to cover the entire metropolitan region; this advance makes them much more attractive for purchase and encourages residents to give up car ownership in large numbers. Residents remain unlikely to purchase them while costs remain prohibitive, but as costs come down, Type 3 becomes the dominant type of vehicle region-wide. Ultimately, Type 3 AVs become the majority of the vehicle fleet by 2042.

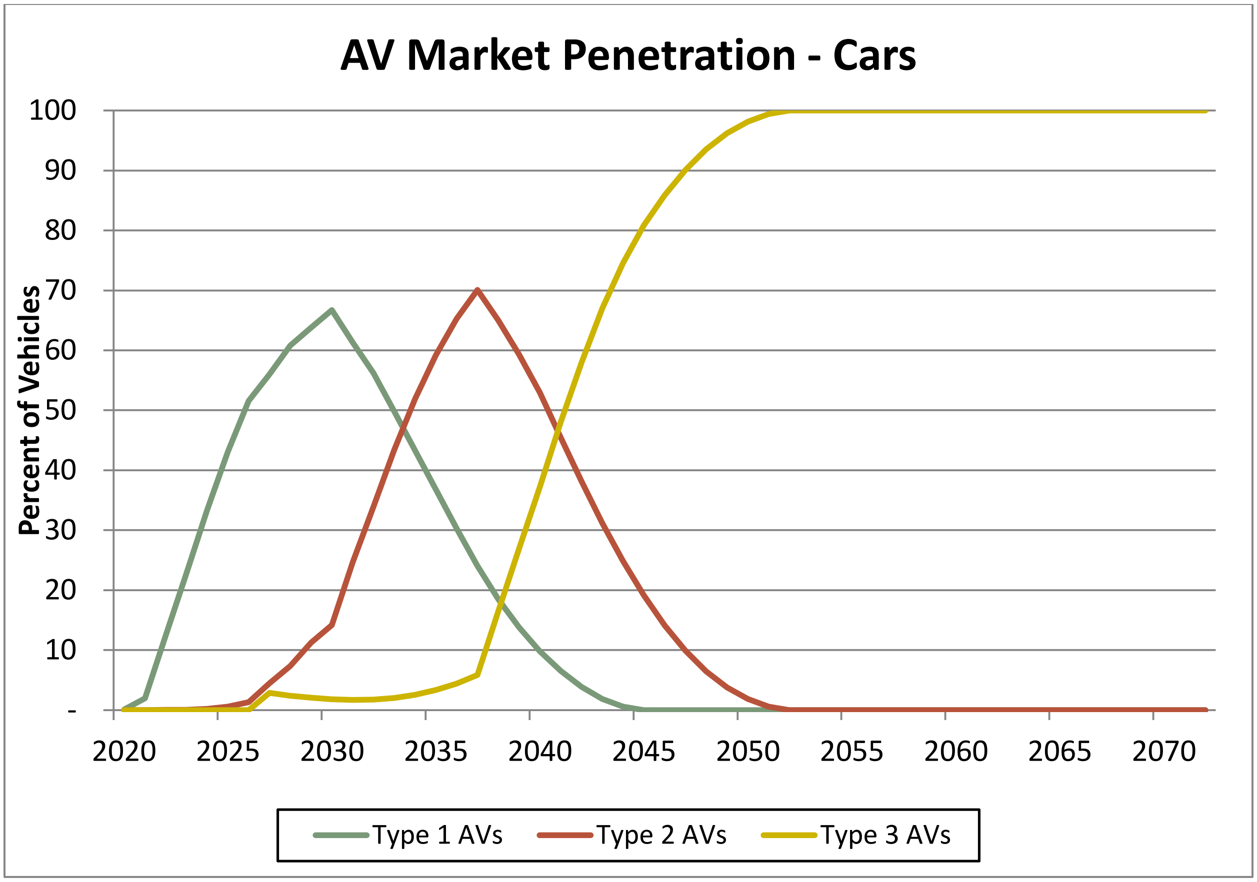


Figure 3-14: Scenario B AV Market Penetration - Cars

3.3.2 Electrification

Vehicle electrification is likely to be developed alongside automated and connected technologies, however there remains uncertainty as to how closely these technologies will be linked. Figure 3-15 shows the market penetration for electric vehicles in the District for all vehicles, including both household owned vehicles and shared fleet vehicles. Because it may be more straightforward to electrify a fleet of vehicles than for an individual vehicle owner to switch to an electric vehicle, all automated ridesourcing vehicles are expected to be electric by 2030. Various policy options such as incentives or mandates for electric vehicles could help achieve these assumptions.

It should be noted that these assumptions are significantly more optimistic than those used by MWCOG in their 2019 Air Quality Conformity analysis, which uses highly conservative estimates of electrification and assumes no growth in electric vehicle share above current conditions. Changes to electrification rates - driven by consumer choice, electricity prices, and/or policy and legal changes - could have significant impacts on the analysis results, specifically related to vehicle emissions as discussed further in Section 4.0.

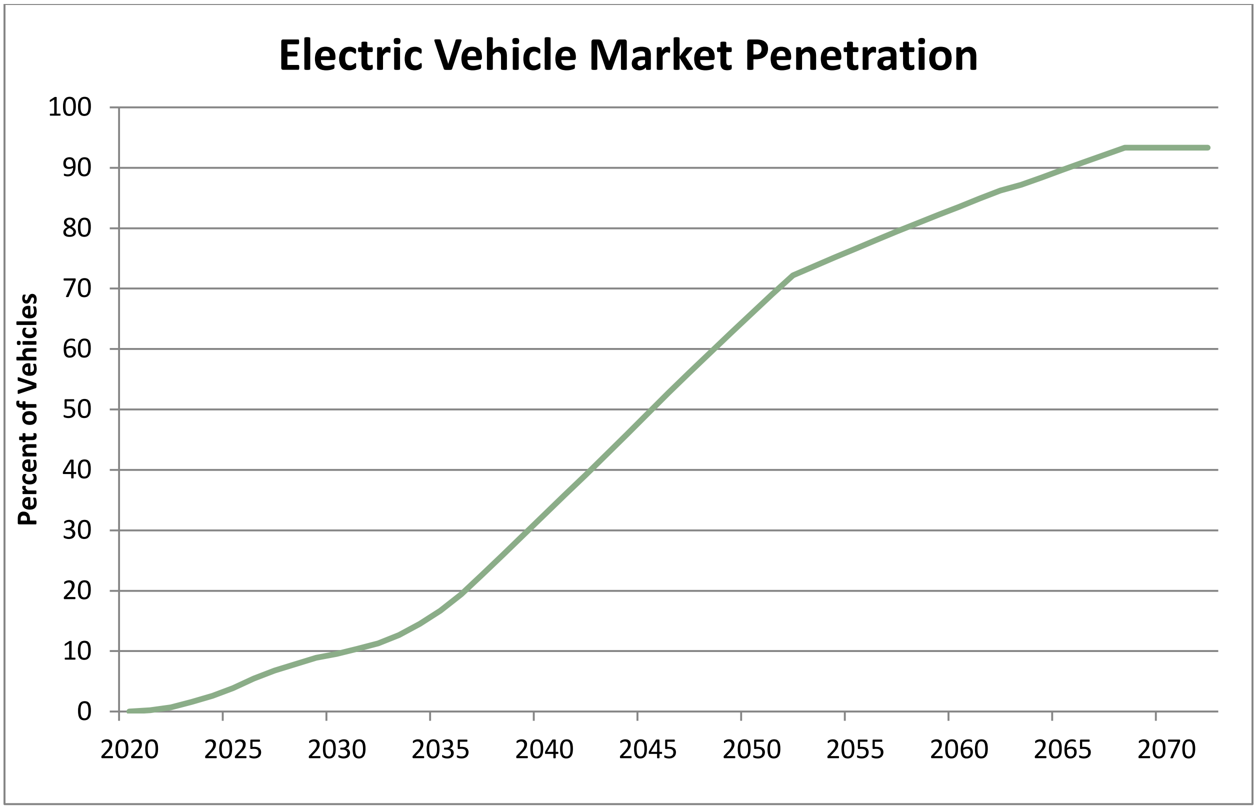


Figure 3-15: Scenario B Electric Vehicle Market Penetration

3.3.3 Connectivity

Connected vehicle technology is often considered to be a part of vehicle automation, as it has the potential to dramatically improve roadway operations by providing drivers – or vehicles themselves in the case of AVs – with more information about roadway conditions than would otherwise be possible. This information can help vehicles prepare for difficult driving conditions, anticipate changes in traffic conditions and make necessary adjustments, and perhaps most importantly, avoid crashes and/or limit their severity.

Connectivity has additional possibilities on surface streets, where connected vehicles could potentially communicate with connected signals, traffic signs, or a centralized traffic control center. This could not only enhance safety, but could improve traffic operations during congestion and increase the throughput of urban roads and intersections. These technologies, especially when combined with automation, have great potential on freeways and surface streets.

Scenario B assumes that these technologies are deployed effectively on freeway facilities across the region, with the associated safety improvements. Further, Scenario B assumes that connected signals will be deployed across the District in order to improve traffic operations throughout the day. During congested times this system will be used to optimize traffic flow throughout the city. As a result, congestion will decrease on all connected roadway facilities as throughput on surface roads increases, and congestion caused by crashes is dramatically decreased on freeways (25 percent of congestion is currently related to crashes). In this study, all AVs of any type (1-3) are assumed to be equipped with connected vehicle technology. Figure 3-14 (presented earlier in this Section) therefore also shows the assumed adoption rate of CV technology into the District's vehicle fleet.

3.3.4 Freight

Two elements of freight traffic will be impacted by AV technology: long-distance freight shipping and local freight deliveries. These two applications will have different impacts on travel patterns and traffic conditions, and require different types of technology. Long-distance heavy-freight shipping primarily occurs on freeways, while deliveries occur more on urban streets and local roadways in trucks that are smaller in size. Both types of freight business models could see substantial changes to their cost structures and productivity with the adoption of AVs and the elimination (or repurposing) of the driver. If even a portion of these cost reductions are passed on to consumers, we could see significant increases in both long-distance truck traffic (at Type 2 automation and above) and parcel delivery (at Type 3 automation only).

Based on cost elasticities of freight traffic, Scenario B assumes a national and regional increase in both long-distance freight and local delivery traffic. These increases over time are shown in Figure 3-16 and are above what would otherwise be expected due to growth..

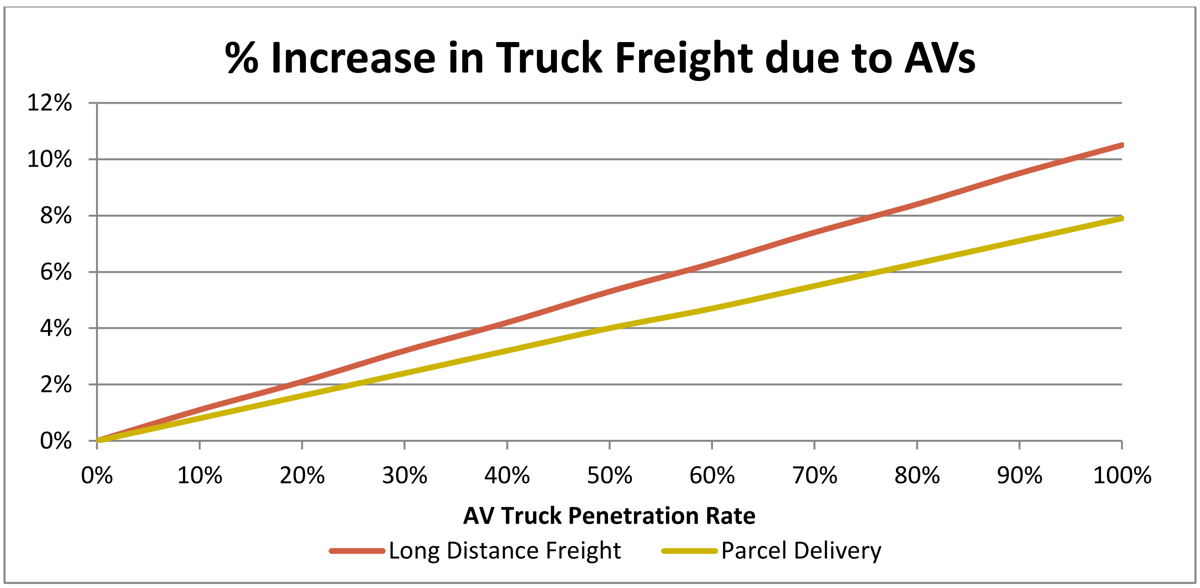


Figure 3-16: Scenario B Truck Freight Increases

Scenario B assumes that Type 2 trucks will be available for operations in 2024, the same year as Type 2 passenger vehicles, although they are expected to be adopted into the fleet at a faster rate due to the attractiveness of the cost savings. Scenario B assumes that Type 3 AV trucks, used for both long-distance freight and local deliveries, will only be available starting in 2032. This delay when compared with passenger vehicles accounts for the added safety precautions and costs associated with automating much larger vehicles. Figure 3-17 shows the adoption of Type 2 and Type 3 AV Trucks in the District. While truck fleets are able to integrate freeway automation fairly quickly, they will also quickly be replaced by Type 3 AV trucks, which would reach full market penetration by 2047.

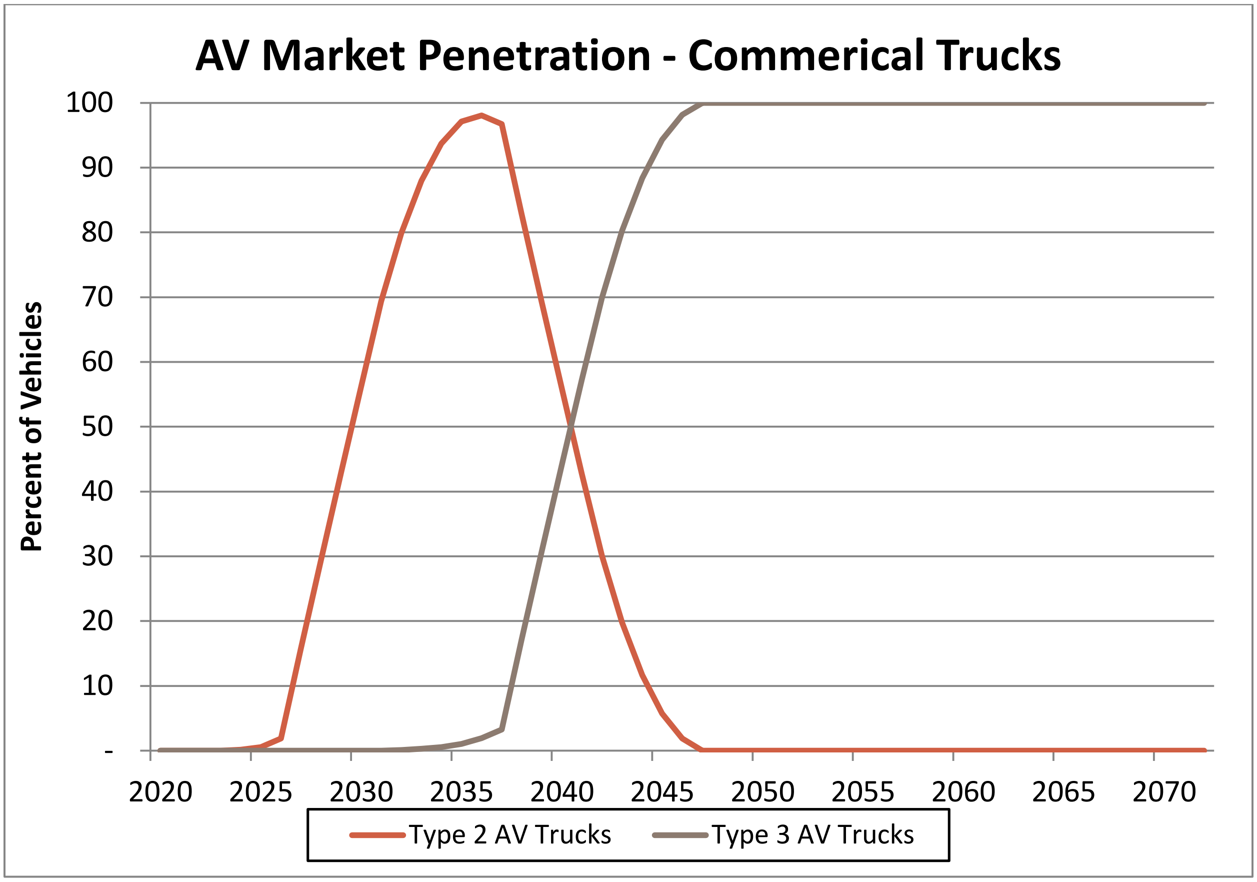


Figure 3-17: Scenario B AV Market Penetration - Trucks

3.3.5 Pricing Strategy

Under the assumptions of Scenario B, the majority of urban mobility would be provided by shared vehicles, operated as part of automated ridesourcing services. These services are most likely to be owned by private companies, although it would be possible for these fleets to be owned and operated by public entities as well. The Scenario definition does not dictate who owns these services, but it is assumed that these entities charge a market-based price for use. Despite estimated costs of less than 75 cents per mile, these services might still be cost-prohibitive for some users. Therefore, Scenario B assumes that the District will implement a subsidy program for low income users, to ensure their ability to access and benefit from these new mobility options.

3.3.6 Road Usage

Scenario B includes two assumed changes to how roadway space will be used, as compared to the current plans for the region. First, the scenario assumes that all planned and existing HOV lanes in the region will be transitioned to HOV4+ by 2045. This would accommodate shared-ride ridesourcing, including smaller vehicles and larger ones that might take the place of traditional transit service on regional freeways with HOV lanes (e.g. I-395, I-66, I-270).

The second change would be to limit vehicle traffic in central DC to only AVs once market penetration in the District is sufficiently high. Based on the technology adoption rates provided previously in Figure 3-14, DC would reach 80 percent Type 3 AV adoption by 2045. This restriction is assumed to be in place starting in 2045, when the vast majority of vehicles in DC would be able to access this area. This policy would help achieve safety goals in the District, enable increased throughput, and improve traffic operations by not having to accommodate both human-driven vehicles and vehicles with varying levels of automation. The assumed extents of this dedicated AV-only area are shown in Figure 3-18.

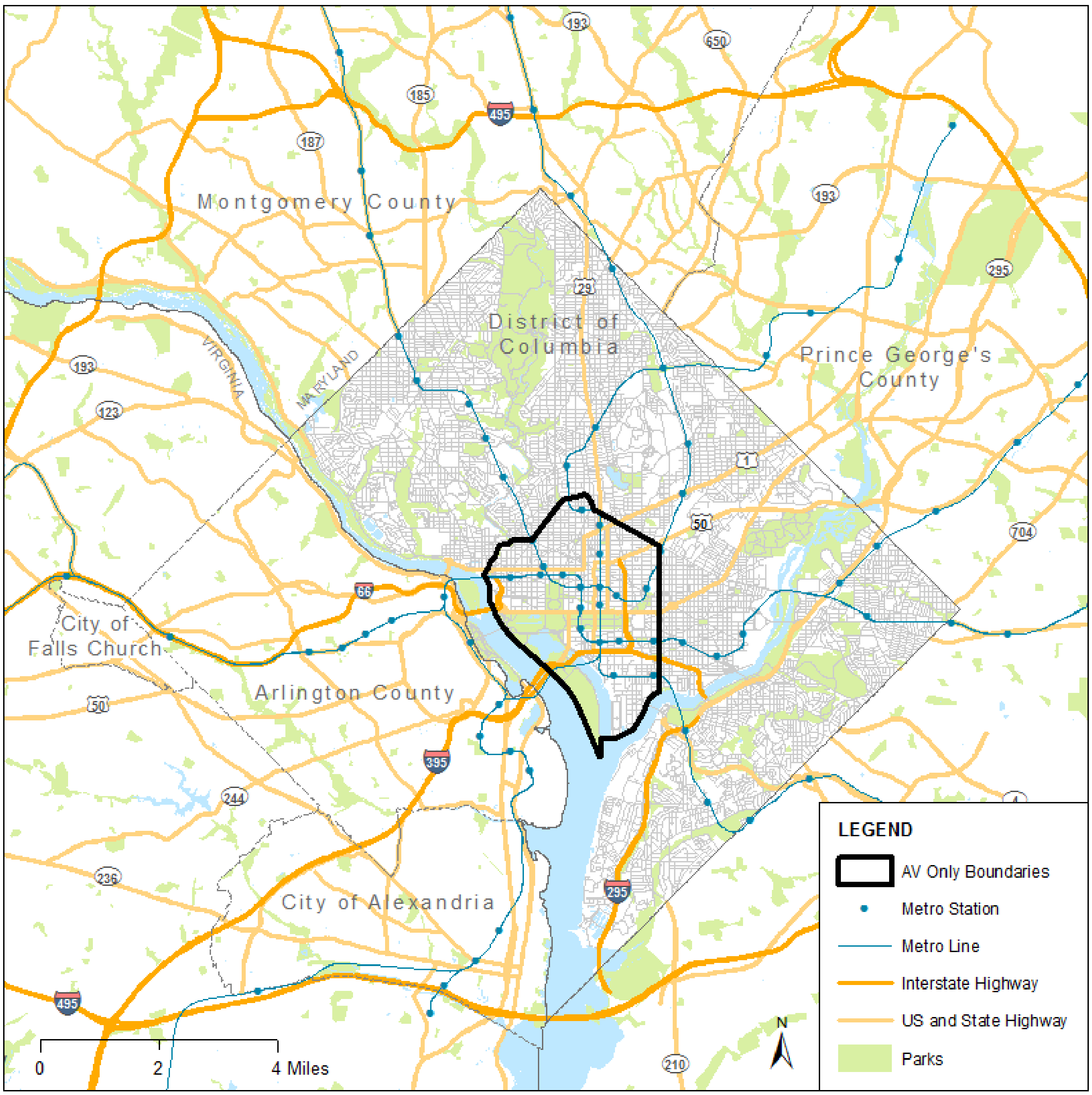


Figure 3-18: Assumed Boundary of AV-Only Area in Scenario B

3.3.7 Parking

Under Scenario B, the urban areas inside and surrounding the District will become increasingly reliant on shared fleets of AVs of all sizes. Vehicle ownership will decrease significantly over time, as shared mobility and Mobility-as-a-Service make it possible for people to get around cheaply and conveniently without owning a car. As such, the need for parking is expected to decrease in urban areas. (More detail about this change can be found in the Results in Section 4.0.) Shared vehicles will still require parking, but those parking facilities will be fewer, smaller, and will not be located in high-cost, high-demand urban areas. Scenario B assumes that both District policy and market-based cost incentives will cause AV storage to be located outside of urban areas. This will necessitate some amount of ZOVMT as the vehicles relocate to/from storage locations, but will also open up space currently devoted to parking for other uses. This is assumed to be true in urban commercial and residential area in the District.

On-street parking needs will also be significantly diminished by the new mobility paradigm, with far fewer people needing to park a personal vehicle nearby. As vehicle ownership decreases, on-street parking will also be converted to other uses, including well-designed pick-up/drop-off points that will help make automated ridesourcing safe, convenient, and easy for users District-wide. Other uses, such as widened sidewalks, green space, and/or dedicated lanes for specific modes could also be implemented.

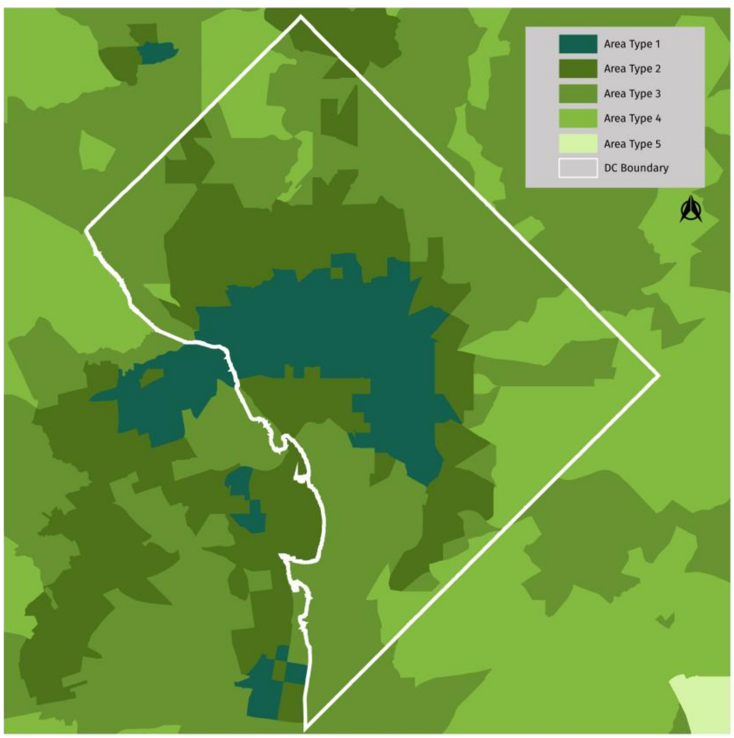
3.3.8 Future of Transit

Scenario B assumes that the AV technology expands its service area quickly, with automated ridesourcing providing inexpensive, convenient service in urban and many suburban markets by 2030. These private services will use a range of ride and vehicle options, from riding alone, to shared rides, to larger shared vans that provide higher capacity vehicles in high-demand areas. These options will offer on-demand service with minimal wait at low prices ultimately becoming one of the preferred mobility options throughout the region.

As automated ridesourcing grows in market share in the District and regionally, Scenario B envisions that they are more and more in competition with public transit. Slowly, governments will decide that automated ridesourcing is a more cost-effective means of providing transportation to the public and will ultimately discontinue traditional fixed-route public bus service. Metrorail will continue to operate during peak periods, as the most efficient ways of moving large numbers of people into major employments centers every day. Many of the automated ridesourcing applications may be considered to be a form of 'transit' in the future, as many will incorporate the sharing of rides and may even include fixed routes on certain corridors. The precise definition of what these systems would look like or how they would operate has not been identified as part of this study. However, Scenario B does assume that all residents in the region would be able to access automated ridesourcing services, based on the service area expansion outlined in Section 3.3.9. These services are assumed to be relatively cheap, and to be on-demand, so as to maximize convenience and minimize wait times.

3.3.9 Ridesourcing

As previously outlined, Type 3 AVs are introduced early in Scenario B, but with a high purchase cost that makes them best suited for use in shared fleets or automated ridesourcing services where these assets can be used more efficiently. These services are introduced as early as 2022 in downtown DC, and the mapping and processing technologies advance quickly, allowing for rapid expansion into suburban areas until the whole region is served b 2035. Detailed expansion assumptions are outlined in Figure 3-19. Expansion of automated ridesourcing service areas is likely to spread smoothly outwards, as individual areas are mapped for inclusion in AV software. During actual implementation, policy should ensure that the service area covers all eight wards in a fair and equitable way.



Area Type	Expansion Timeline
Area Type 1 Downtown	beginning in 2022
Area Type 2 Urban	beginning in 2024
Area Type 3 Mixed Use Suburban	beginning in 2027
Area Type 4 Suburban	beginning in 2030
Area Type 5 Rural	beginning in 2035

Figure 3-19: DC Automated Ridesourcing Service Expansion – Scenario B

3.3.10 Road Capacity

Improvements to safety and a decrease in crashes are assumed to be the main sources of roadway throughput enhancement in Scenario B. These improvements are associated more with the CV and driver assistance features found in Type 1 vehicles. One-quarter of congestion is caused by crashes; Table 3-7 highlights the assumptions around how many of these crashes are assumed to be removed in Scenario B, and the associated increase in carrying capacity by facility type.

Table 3-7: Effective Capacity Increases Associated with Crash Reduction – Scenario B

Facility Type	Crashes Eliminated	Effective Capacity Increase
Freeways	60%	15%
Arterials	40%	10%

Connectivity and higher levels of automation will yield additional throughput increases on arterial streets through the implementation of connected signals (see Section 3.3.3). An additional five percent improvement in carrying capacity is assumed on arterial roads throughout DC, although the relationship between capacity and market penetration is not linear. At very low levels of AV market penetration, capacity is actually likely to decrease, as AVs are likely to maintain wider separations from vehicles that they cannot communicate with human drivers (Arnaout *et al.*, 2011). The effective carrying capacities of different roadway types are shown in Figure 3-20 as a percentage of current roadway capacities.

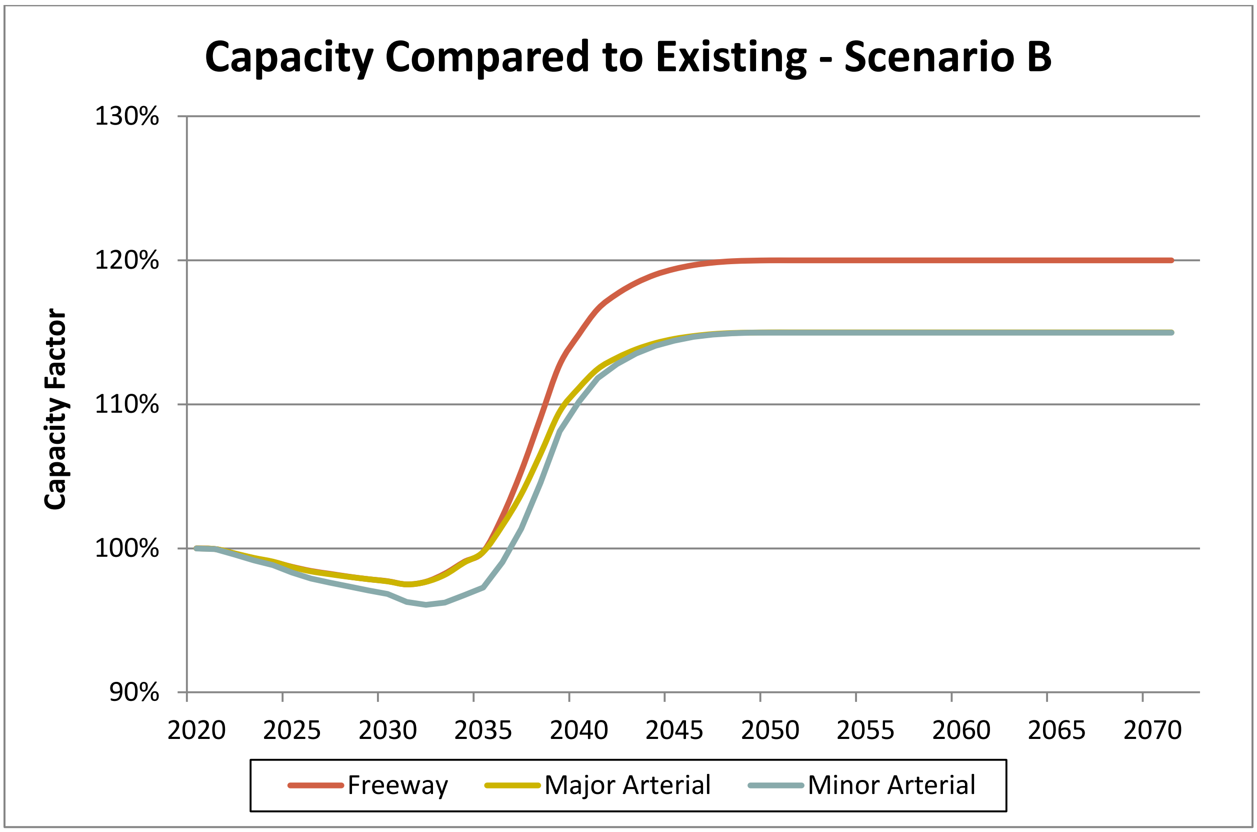


Figure 3-20: Effective Carrying Capacity as compared with current Capacity – Scenario B

3.3.11 Vehicle Ownership

In Scenario B, the early introduction of Type 3 AVs with a high cost premium results in their initial adoption into shared vehicle fleets, instead of being purchased by individuals. These fleets, deployed as automated ridesourcing and Mobility-as-a-Service make it attractive, easy, and inexpensive for residents in dense urban and suburban areas to live without a car. Many residents in these areas will choose not to own a car. Residents in some of the less dense suburban areas would continue to purchase vehicles, and will purchase Type 2 and 3 AVs as prices on those vehicles come down over time. However, households may be able to decrease the number of vehicles that they own, as one AV could serve multiple members of the same family during a day, while some trips could be served by ridesourcing.

Vehicle ownership is expected to decrease significantly under this scenario. These reductions in vehicle ownership would therefore occur in areas in which automated ridesourcing services have been introduced and grow over time as the automated ridesourcing service areas expand. The assumptions account for the concept that a car owner in downtown is unlikely to give up their car until they feel comfortable that they can rely on other services to maintain their freedom and flexibility to travel affordably when and where they want. Therefore, fewer people are willing to give up their vehicles when automated ridesourcing only serves the downtown area than once they have expanded to the suburbs as well.

Research into carsharing provides the basis for the assumptions about vehicle ownership (Fagnant, *et al.*, 2015) which shows that in different Area Types, each shared vehicle can replace a different number of household-owned vehicles. The replacement rates are shown in Figure 3-21 below.

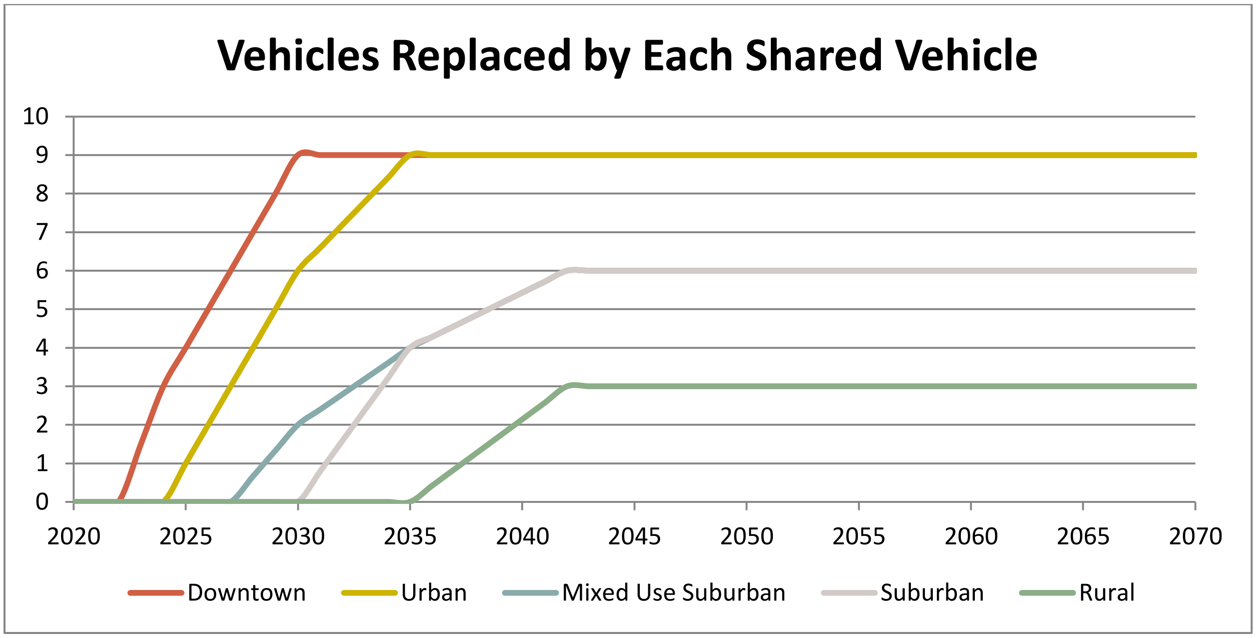


Figure 3-21: Vehicle Replacement Rate By Area Type – Scenario B

3.3.12 Travel Demand

Travel demand and travel patterns under the assumptions of Scenario B are expected to change in several ways. These changes will impact the number of trips people take (Henderson *et al.*, 2016), the length of those trips, and/or the mode of travel used (Fagnant & Kockelman, 2015; Carriea *et al.*, 2016). In addition to changes to personal travel patterns, the assumptions also consider the addition of ZOV travel behavior (Maciejewski *et al.*, 2017; Fagnant & Kockleman, 2014). The changes are outlined in Table 3-8 below; the impacts of these changes on performance metrics such as VMT, transit ridership, and congestion are quantified in Section 4.0. These changes and impacts will vary geographically based on the service options available in each Area Type.

Table 3-8: Travel Demand Assumptions – Scenario B

Assumed Changes	Behavior
Discontinuation of traditional bus service and off-peak Metrorail service	Most people shift travel from traditional public transit to automated ridesourcing services in large and small vehicles
Automated ridesourcing is cheaper to use than privately-owned vehicles with no ownership costs	Significant number of travelers are able to shift from transit to automated ridesourcing services for particularly long transit trips
Automated ridersourcing provides mobility for people who couldn't drive previously	Disabled residents are able to increase the number of trips made Elderly residents increase the number of trips made Youth are able to travel independently of their parents
Empty vehicles relocation	Automated ridesourcing services will have empty relocations to pick up passengers, but generally short in order to optimize costs

3.3.13 Land Use

The assumptions included in Scenario B rely on AVs and other technologies to provide on-demand mobility services around the region. These services provide cheap, responsive alternatives to owning a car or relying on traditional fixed-route transit. To take advantage of car-free living and these new mobility options, people will choose to live in the denser, mixed-use communities inside the Beltway.

The MWCOG Cooperative Land Use forecasts for the region result in an imbalance between residents and employment; MWCOG estimates that the excess jobs are filled by 100,000 households outside of the region commuting in each day. Scenario B assumes that these households are able to be accommodated within the region due to a wide range of changes included in the Scenario. Zoning requirements and regulations would need to be revisited to make these Land Use assumptions possible in reality, and Scenario B assumes that these changes take place in order to allow more housing in these areas. Specifically, 100,000 households are added to the District and the inner suburbs between 2030 and 2045, as outlined in Table 3-9 below:

Table 3-9: Change in Households compared to MWCOG 2045 Land Use Forecasts – Scenario B

Jurisdiction	Change in Households Compared to MWCOG Forecasts	
	#	%
DC	49,996	12.1%
Montgomery County	7,740	1.7%
Prince George's County	12,442	3.3%
Arlington	10,879	7.7%
Alexandria	8,120	7.6%
Fairfax County	10,179	1.9%
Falls Church	628	7.7%
Other MD	0	0%
Other VA	0	0%
Grand Total	**99,984**	**2.9%**

Households outside the Beltway remain the same as in the MWCOG Cooperative Land Use Forecasts. Figure 3-22 shows geographically where these changes in household growth were implemented. As shown, only areas inside the Beltway experience any change in households as compared to the MWCOG forecasts, and all of these areas experience more growth as illustrated by the orange dots.

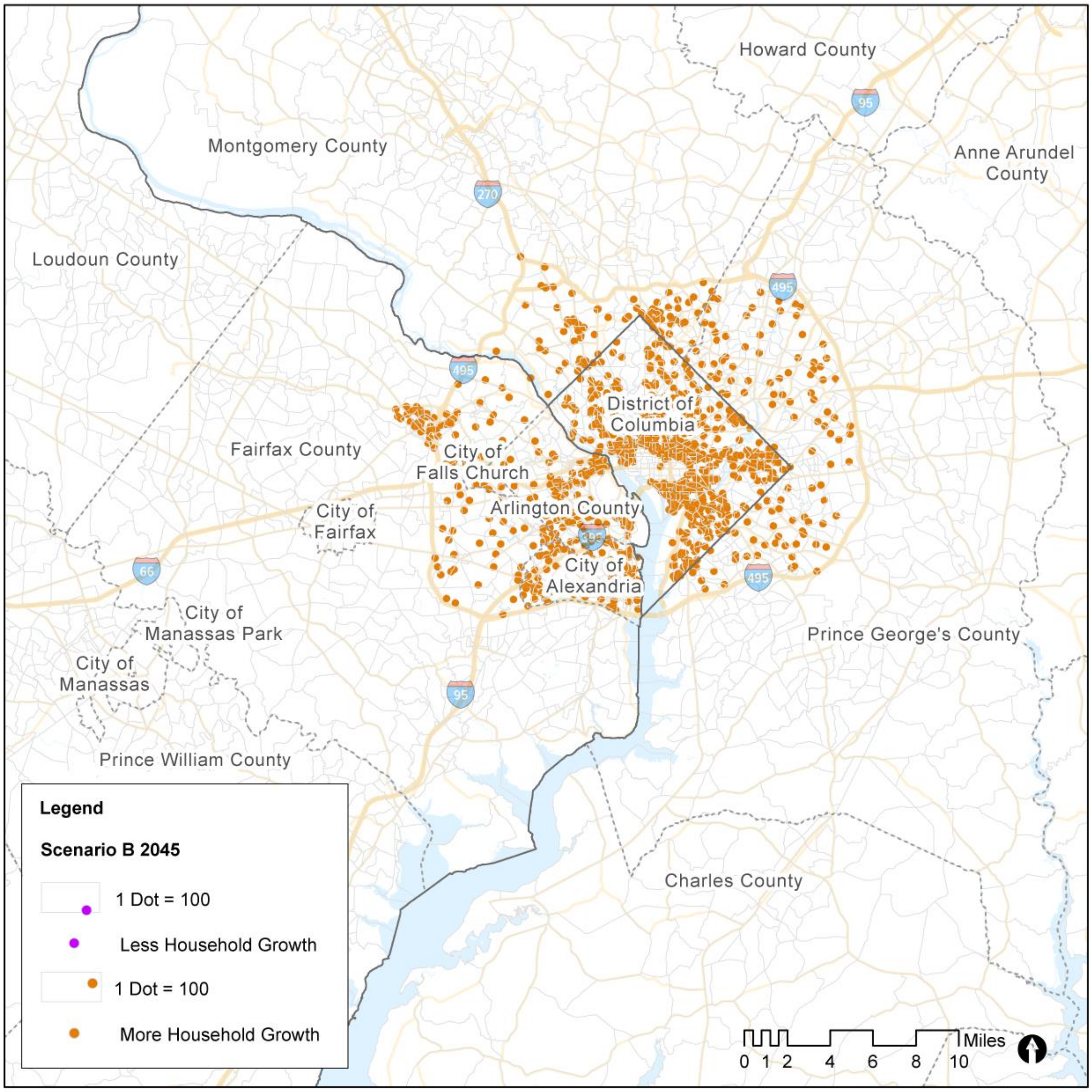


Figure 3-22: Household Growth Change – Scenario B

No additional retail jobs were added in Scenario B, which assumes the same retail distribution as in the MWCOG Cooperative Land Use Forecasts.

Office jobs are assumed to follow a similar pattern of growth to households, as more companies also locate in dense, mixed-use areas so that their employees can take advantage of the new transportation options. While the total regional office jobs remain consistent with the MWCOG Cooperative Land Use Forecasts, the growth in jobs after 2030 is relocated as follows:

- 30 percent decrease in the amount of office job growth currently forecast to occur between 2030 and 2045 in the suburbs outside of the Beltway. This amounts in approximately 57,000 fewer office jobs in these areas by 2045 than are currently forecast by the region.

- Half of this relocated growth in office jobs (28,500 jobs) is assumed to be relocated to the District of Columbia, representing a 3.4 percent increase over the MWCOG Cooperative Forecasts.
- The remaining job growth (28,500 jobs) will be relocated to major job centers inside the Beltway – specifically in Tysons Corner in Fairfax County; the Rosslyn-Ballston corridor in Arlington; National Landing in Arlington/Alexandria; and Silver Spring and Bethesda in Montgomery County.

Figure 3-23 shows geographically where these changes in job growth were implemented throughout the region. Blue dots show locations where fewer jobs will be added than what is included in the MWCOG forecasts, while red dots show locations where more jobs will be added.

No changes were assumed to the regionally forecasted growth for the other job categories (“industrial” and “other”) included in the MWCOG Cooperative Land Use Forecasts.

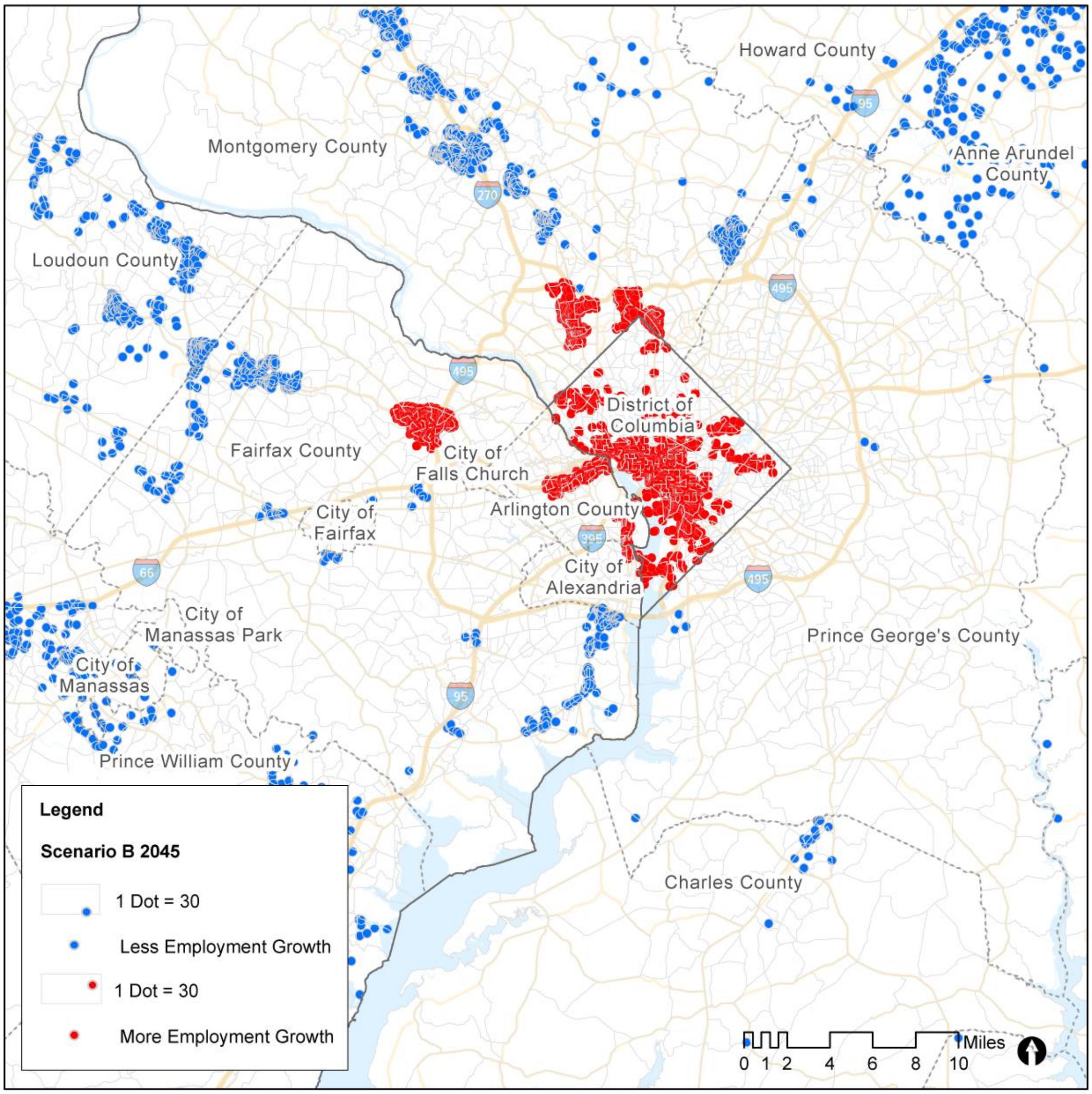


Figure 3-23: Employment Growth Change – Scenario B

The results of these changes to land use forecasts are summarized in Table 3-10.

Table 3-10: Scenario B 2045 Land Use Assumptions by Jurisdiction

Jurisdiction	Households	Population	Retail Jobs	Office Jobs	Total Jobs
DC	411,872	987,213	114,794	834,122	1,045,390
Montgomery	461,916	1,223,345	109,826	407,725	678,753
Prince George's	376,787	995,874	96,170	91,024	402,145
Arlington	141,843	301,167	39,899	182,776	269,064
Alexandria	107,082	208,451	25,472	105,730	155,095
Fairfax County	528,093	1,416,818	123,417	654,016	889,863
Fairfax City	13,470	35,166	7,114	13,964	23,429
Falls Church	8,205	17,611	6,353	6,666	18,600
Loudoun	168,671	507,398	59,825	115,571	291,165
Other MD	424,270	1,112,622	134,807	302,745	688,052
Other VA	845,383	2,317,965	296,357	319,595	992,447
Total	**3,487,592**	**9,123,630**	**1,014,034**	**3,033,934**	**5,454,003**

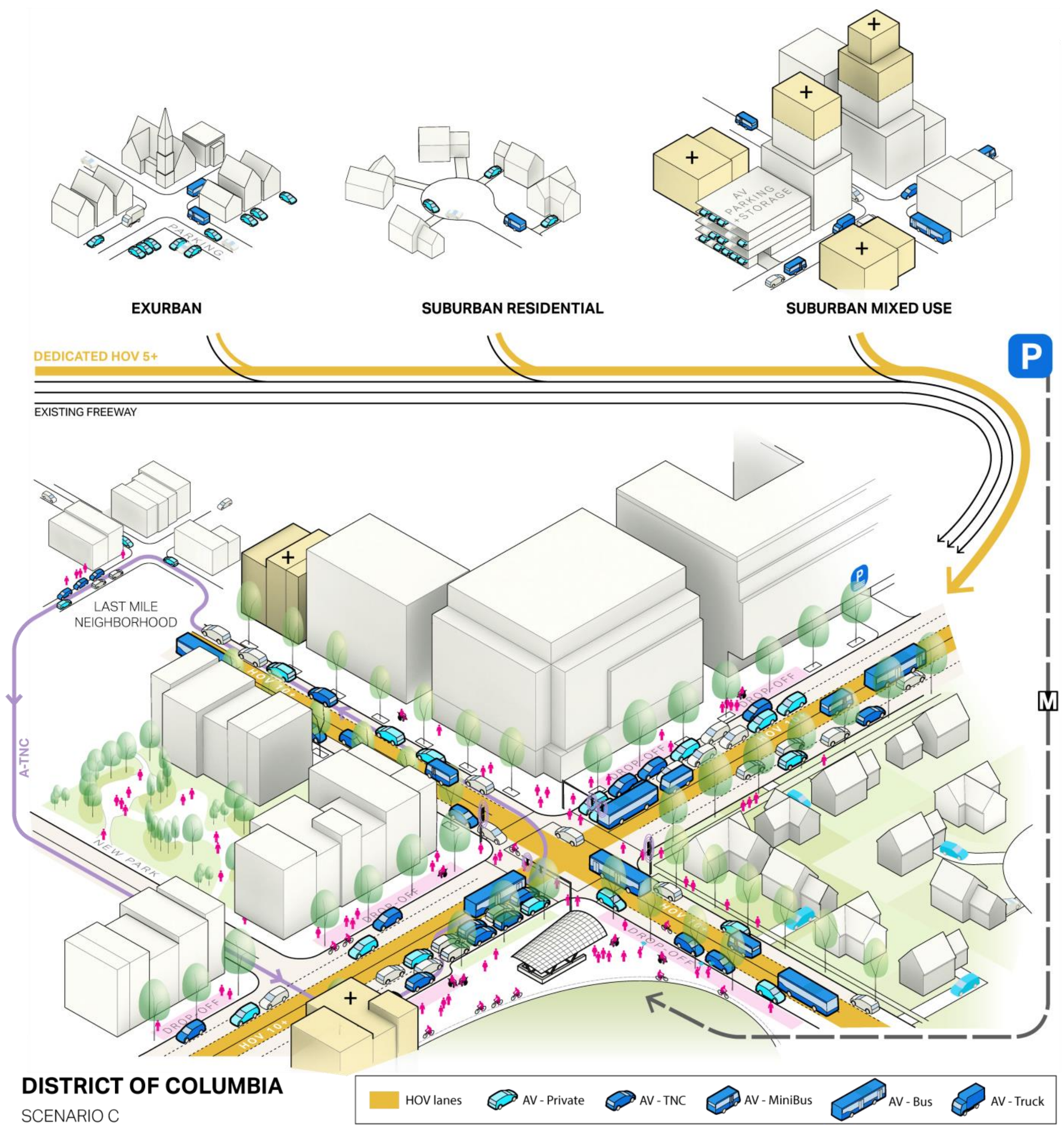
3.4 Scenario C – Strong High-Occupancy Prioritization

Scenario C explores a future in which the full range of AV technologies are incorporated into the region's mobility system. Type 2 AVs capable of traveling independently on freeways are introduced into the fleet early, beginning in 2022, and incorporated into the vehicle fleet as residents purchase and replace their cars. Shortly thereafter, Type 3 AVs are introduced, although for a short while they remain too expensive to be purchased by most individuals. As such, in the initial years, these vehicles will be incorporated only into shared fleets. The competing business models of household-owned and shared AVs will each prove attractive to different segments of the population. Some decreases in vehicle ownership will be expected, with more significant impacts in the more urban areas. The technology will also be applied to heavy trucks, resulting in an increase in truck freight in the region.

In order to encourage the use of high occupancy travel modes, Scenario C assumes that dedicated high-occupancy lanes are provided on freeways and major arterials throughout the region. These high occupancy lanes will be accessible to any vehicles with the requisite number passengers, including buses on fixed routes, microtransit, or large automated ridesourcing vehicles. These lanes will provide a speed advantage when compared with the general-purpose lanes, enticing the use of high occupancy vehicles. This speed advantage will also encourage companies to provide shared-ride services, and to structure their business models, vehicle sizing, and routing algorithms to ensure high occupancy levels during congested time periods.

The proliferation of mobility access through automated ridesourcing will encourage more people to live in areas with good service levels, particularly the dense, urban areas in the District and the surrounding inner suburbs. Scenario C assumes that zoning in these areas is adjusted to accommodate this demand, with a significant increase in households located in these areas as compared to the current regional land use forecasts. Job growth is also drawn to these areas, allowing companies and their employees to take advantage of these mobility options.

Figure 3-24 illustrates what the future might look like in the District under these assumptions and presents a summary of the scenario assumptions by category; detailed scenario assumptions are further discussed in individual sections below.


EXURBAN
SUBURBAN RESIDENTIAL
SUBURBAN MIXED USE
AV PARKING + STORAGE
DEDICATED HOV 5+
EXISTING FREEWAY
P
M
LAST MILE NEIGHBORHOOD
A-TNC
DISTRICT OF COLUMBIA
SCENARIO C
HOV lanes
AV - Private
AV - TNC
AV - MiniBus
AV - Bus
AV - Truck

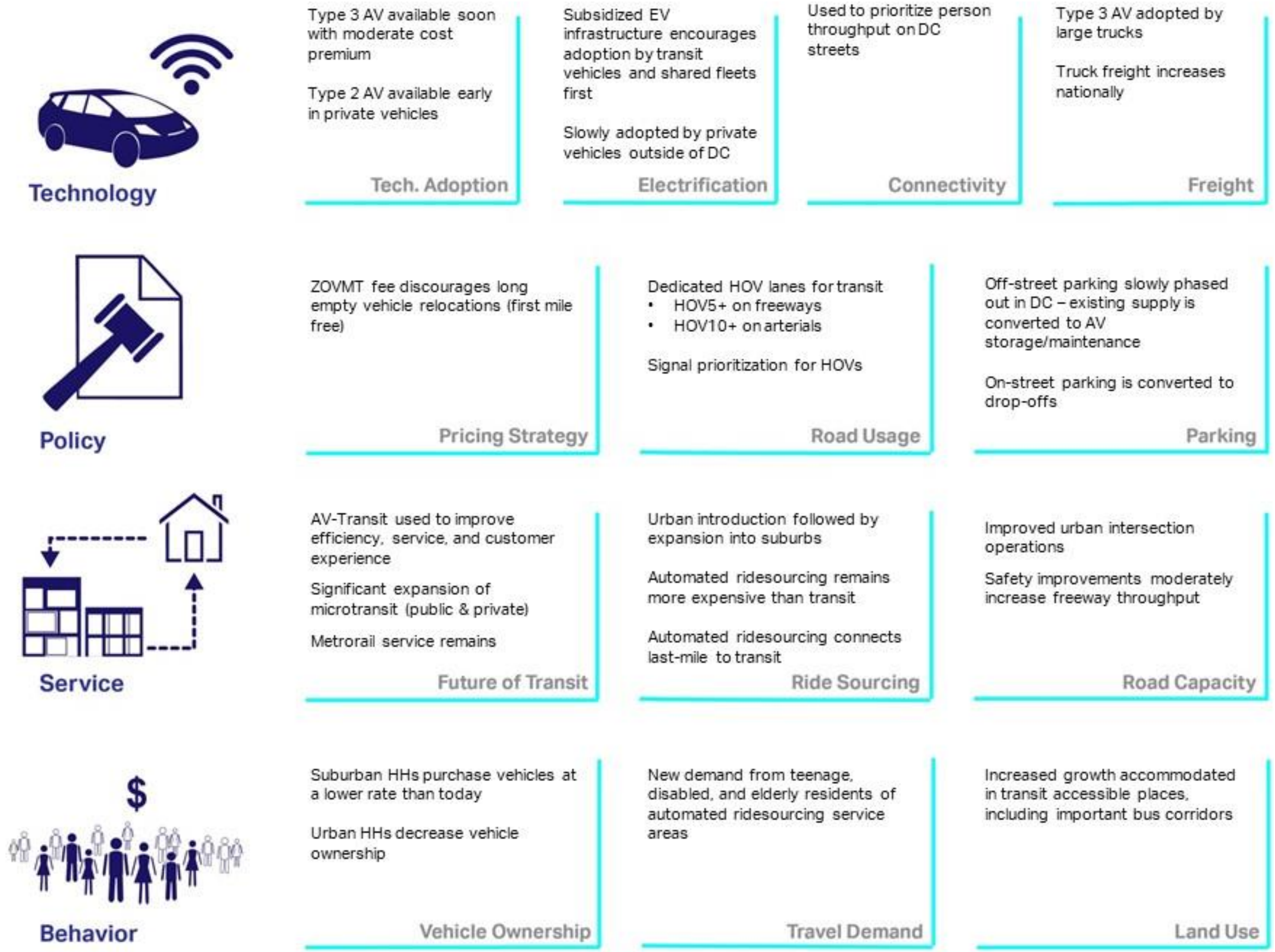


Figure 3-24: Scenario C Assumptions Summary- Strong High-Occupancy Prioritization

3.4.1 Technology Adoption

Development of automated vehicle technology in Scenario C includes the introduction and evolution of both Type 2 Type 3 vehicles. Type 2 vehicles, capable of independent driving on freeways, are available for sale in 2022 with some higher costs. Over time, these costs come down, and Type 2 AVs are incorporated into the private vehicle fleet as people buy new cars. Type 3 AVs with the capability to travel urban streets are introduced a little later in 2025 and are initially able to only serve a limited area. Relatively high costs coupled with this limited service area mean that initially, Type 3 AVs are only really used in shared vehicle fleets. As costs come down and service areas expand (see Section 3.4.9), individuals start to purchase Type 3 vehicles in areas where vehicle ownership is attractive.

Figure 3-25 shows how these AVs will be incorporated into the vehicle fleet in the District. Type 2 vehicles are introduced for sale in 2024, at which point they start to be integrated into the vehicle fleet, peaking at 73 percent in 2037. Type 3 AVs become available for general purchase in 2031, six years after their introduction as shared vehicles downtown. They remain a very small portion of the vehicle fleet until 2036, at which point technology capabilities expand to cover the entire metropolitan region; this advance makes them much more attractive for purchase and to encourage residents in some areas to give up car ownership. Residents remain unlikely to purchase them while costs remain prohibitive, but as costs come down, Type 3 becomes the dominant type of vehicle region-wide. Ultimately, Type 3 AVs become the majority of the vehicle fleet by 2042.

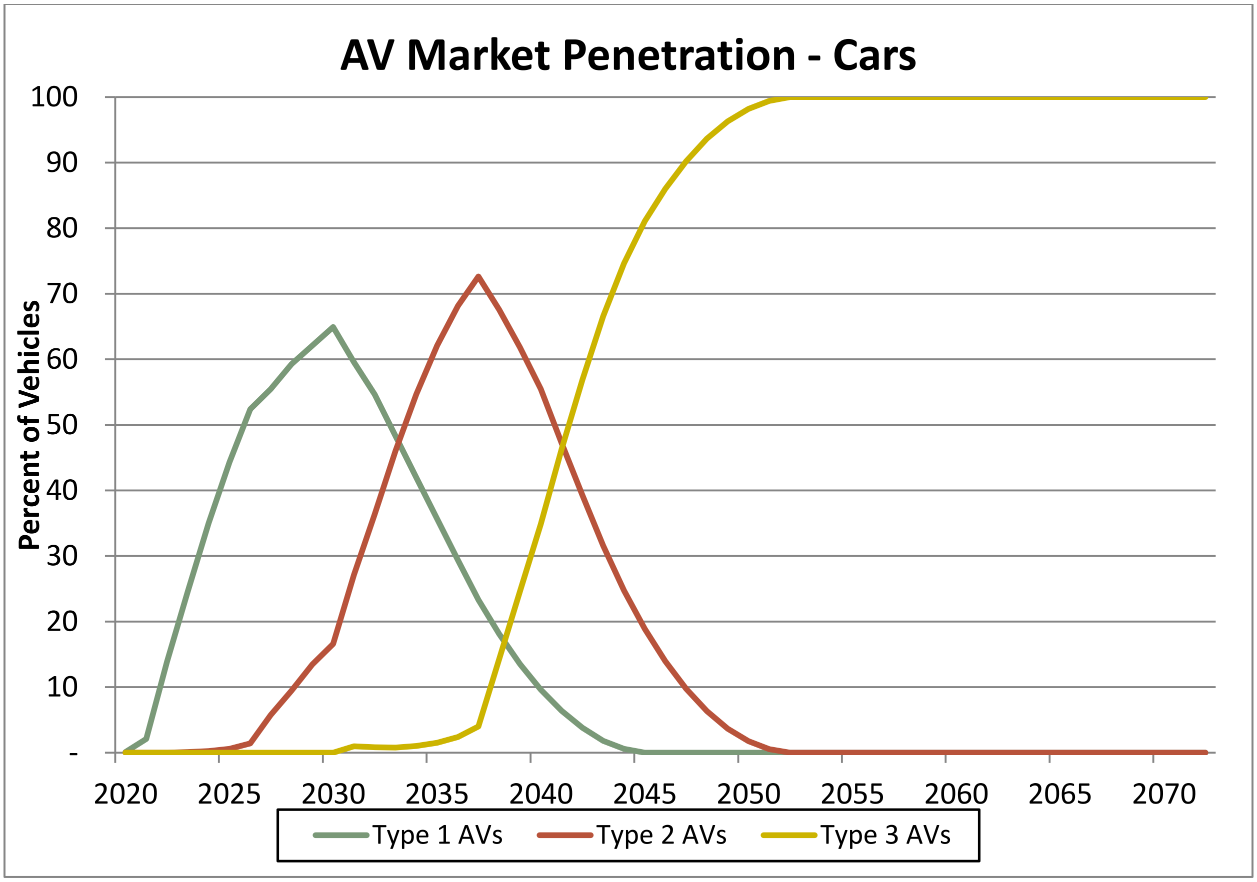


Figure 3-25: Scenario C AV Market Penetration - Cars

3.4.2 Electrification

Vehicle electrification is likely to be developed alongside automated and connected technologies; however, there remains uncertainty as to how closely these technologies will be linked. Figure 3-26 shows the market penetration for electric vehicles in the District for all vehicles, including both household owned vehicles and shared fleet vehicles. Because it may be more straightforward to electrify a fleet of vehicles than for an individual vehicle owner to switch to an electric vehicle, all automated ridesourcing vehicles are expected to be electric by 2030. Household-owned vehicles will be much slower to adopt battery electric propulsion, and will reach 35 percent market penetration by 2040.

It should be noted that these assumptions are significantly more optimistic than those used by MWCOG in their 2019 Air Quality Conformity analysis, which uses highly conservative estimates of electrification and assumes no growth in electric vehicle share above current conditions. Changes to electrification rates - driven by consumer choice, electricity prices, and/or policy and legal changes - could have significant impacts on the analysis results, specifically related to vehicle emissions.

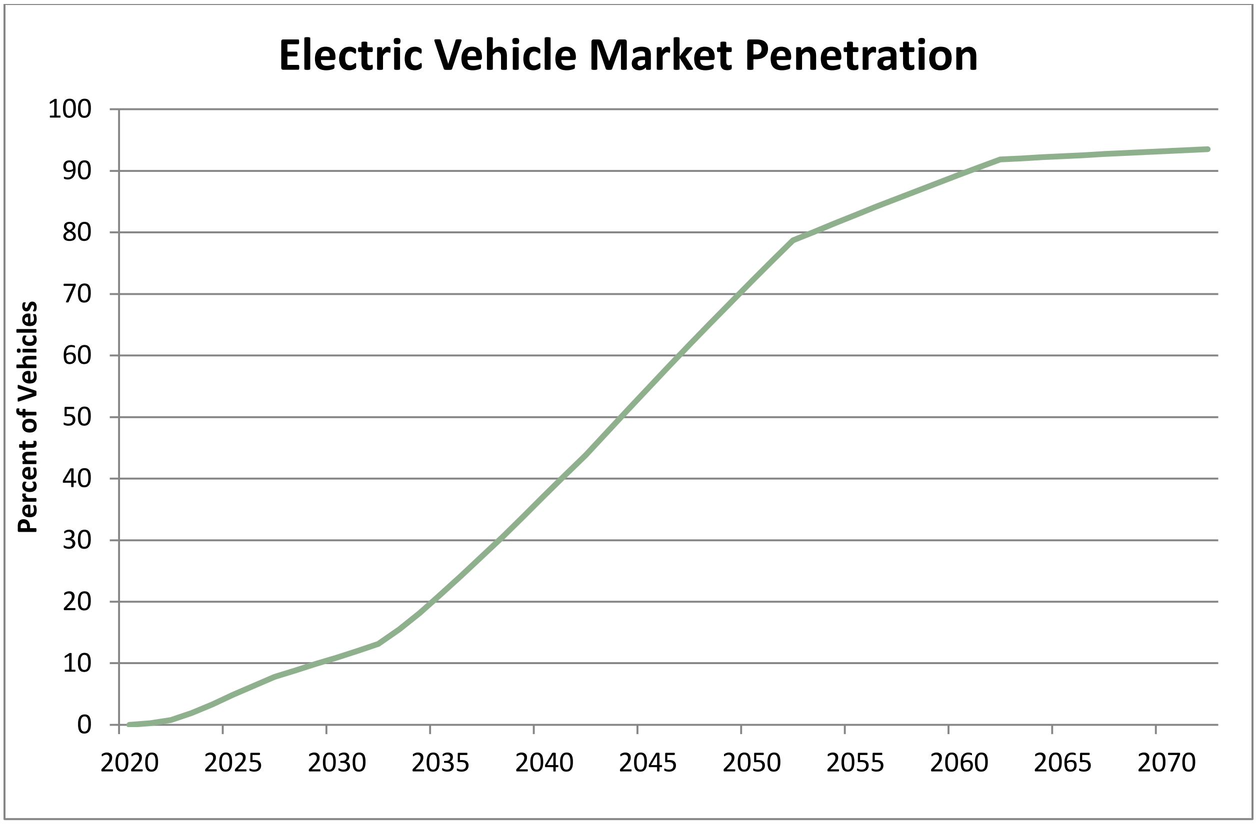


Figure 3-26: Scenario C Electric Vehicle Market Penetration

3.4.3 Connectivity

Connected vehicle technology is often considered to be a part of vehicle automation, as it has the potential to dramatically improve roadway operations by providing drivers – or vehicles themselves in the case of AVs – with more information about roadway conditions than would otherwise be possible. This information can help vehicles prepare for difficult driving conditions, anticipate changes in traffic conditions and make necessary adjustments, and perhaps most importantly, avoid crashes and/or limit their severity.

Connectivity has additional possibilities on surface streets, where connected vehicles could potentially communicate with connected signals, traffic signs, or a centralized traffic control center. This could not only enhance safety but could also improve traffic operations during congestion and increase the throughput of urban roads and intersections. These technologies, especially when combined with automation, have great potential on freeways and surface streets.

In coordination with the assumptions around prioritizing high-occupancy vehicles, Scenario C assumes that connected vehicle technologies are used in the District to improve person throughput on DC's roads. While the specific connected applications are not identified as part of this scenario analysis, some options could include signal prioritization based on occupancy levels, dynamic routing at a city-wide level that optimizes person-throughput, fully or partially reversible facilities, and others that may not have been imagined yet. As a result, congestion will decrease on all connected roadway facilities as throughput on surface roads increases and congestion caused by crashes is dramatically decreased.

In this study, all AVs of any type (1-3) are assumed to be equipped with connected vehicle technology. Figure 3-25, presented earlier, therefore also shows the assumed adoption rate of CV technology into the District's vehicle fleet.

3.4.4 Freight

Two elements of freight traffic will be impacted by AV technology: long-distance freight shipping and local freight deliveries. These two applications will have different impacts on travel patterns and traffic conditions and require different types of technology. Long-distance heavy-freight shipping primarily occurs on freeways, currently requiring drivers willing to work long shifts in uncomfortable circumstances. Labor costs account for almost 40 percent of truck operating costs (ATRI, 2016). By dramatically reducing labor costs, this technology could also decrease the cost of shipping freight by trucks, making it more attractive to companies and increasing the amount of freight traffic occurring nationwide. Based on cost elasticities of freight shipping, Scenario C assumes a national and regional increase in long-distance freight travel of approximately 10.5 percent at 100 percent market penetration, as shown in Figure 3-27. This increase is above what would otherwise be expected due to growth.

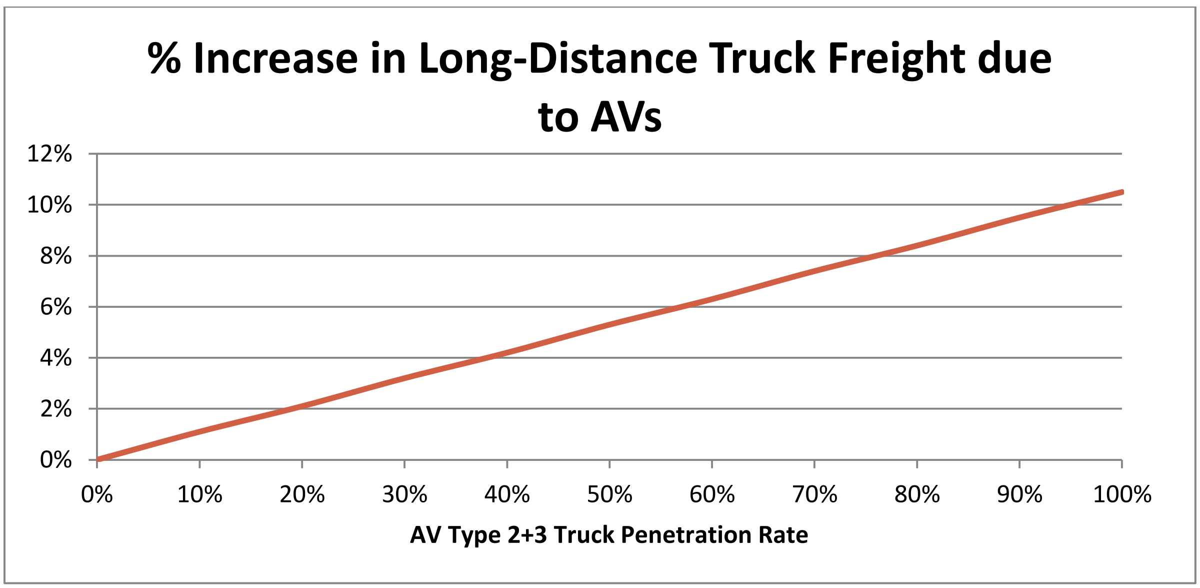


Figure 3-27: Scenario C Truck Freight Increases

Deliveries represent another major market for truck automation, as approximately 50 percent of parcel delivery costs are associated with the last mile (Joerss *et al.*, 2016). Automated deliveries require Level 3 AVs in order to navigate city streets and driveways, and are assumed to still require a human presence to off-load packages at their final destination. Deliveries are already on the rise nationally, as e-commerce continues to grow in importance and the frequency of home deliveries rises. This growth in deliveries is assumed to continue in Scenario C, but no major disruptors to this growth trajectory are assumed in this scenario.

Scenario C assumes that Type 2 trucks will be available for operations in 2024, two years after Type 2 passenger vehicles. They are expected to be adopted into the fleet at a fast rate due to the attractiveness of the cost savings to the trucking industry. Scenario C assumes that Type 3 AV trucks, used for both long-distance freight and local deliveries, will be available starting in 2034. Figure 3-28 shows the adoption of Type 2 and Type 3 AV Trucks in the District. The early introduction of Type 2 freeway-automation has a major impact on the truck fleet, which is predicted to peak at over 97 percent of the truck fleet in 2036, before shifting to fully automated Type 3 trucks.

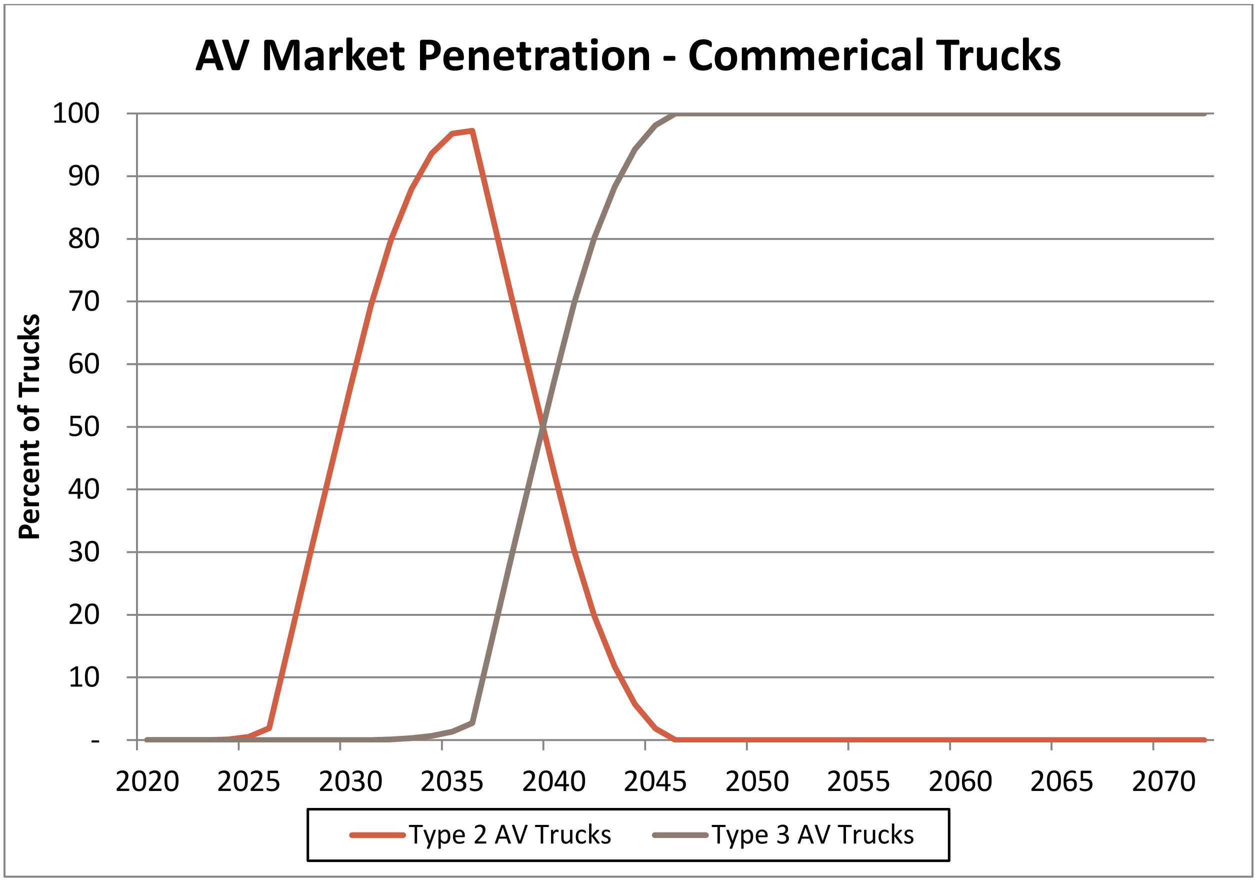


Figure 3-28: Scenario C AV Market Penetration - Trucks

3.4.5 Pricing Strategy

Scenario C does not include significant changes to pricing strategies in the future. However, in order to limit the amount of traffic caused by empty vehicle relocations, it is assumed that a fee is charged to vehicles that are traveling more than a mile without passengers. This fee would be applied equally to privately owned and shared vehicles.

3.4.6 Road Usage

One of the major policy interventions in Scenario C is the provision of dedicated high-occupancy vehicle (HOV) lanes on major facilities across the region. All freeways inside the Beltway are assumed to have one lane accessible to HOV5+ vehicles, including buses and mini-buses, and larger automated ridesourcing vehicles. Major arterials will have one lane dedicated to HOV10+ vehicles, including publicly and privately-owned vehicles that operate transit or microtransit services. These lanes, combined with the connected vehicle technologies are assumed to provide a significant speed benefit compared to the general purpose lanes, saving travelers approximately 20 percent of their travel time during congested time periods.

These time savings will encourage passengers to use high-occupancy services in order to save time. These restrictions will also encourage microtransit and automated ridesourcing companies to offer services in larger vehicles, both to encourage use by customers who want faster travel. Private companies will also likely develop algorithms and incentives to maintain high occupancy in their vehicles. Dedicated lanes will also speed up public transit buses, not only making them more attractive to customers but more cost efficient to operate as well.

3.4.7 Parking

Under Scenario C, parking needs in the urban areas inside and surrounding the District will decrease as residents in these areas come to rely increasingly on shared fleets of AVs of all sizes. Vehicle ownership will decrease over time, as these shared mobility options make it possible for people to get around cheaply and conveniently without owning a car. As such, the need for parking is expected to decrease in urban areas. (More detail about this change can be found in the results in Section 4.0.) Shared vehicles will still require parking, but those parking facilities will be fewer, smaller, and not located in high-cost, high-demand urban areas. Scenario C assumes that DC policy will not allow the construction of new off-street parking in urban areas, and any existing off-street parking will be transitioned to use as AV storage, maintenance, and fueling. This will limit the amount of ZOVMT occurring as empty vehicles relocate themselves.

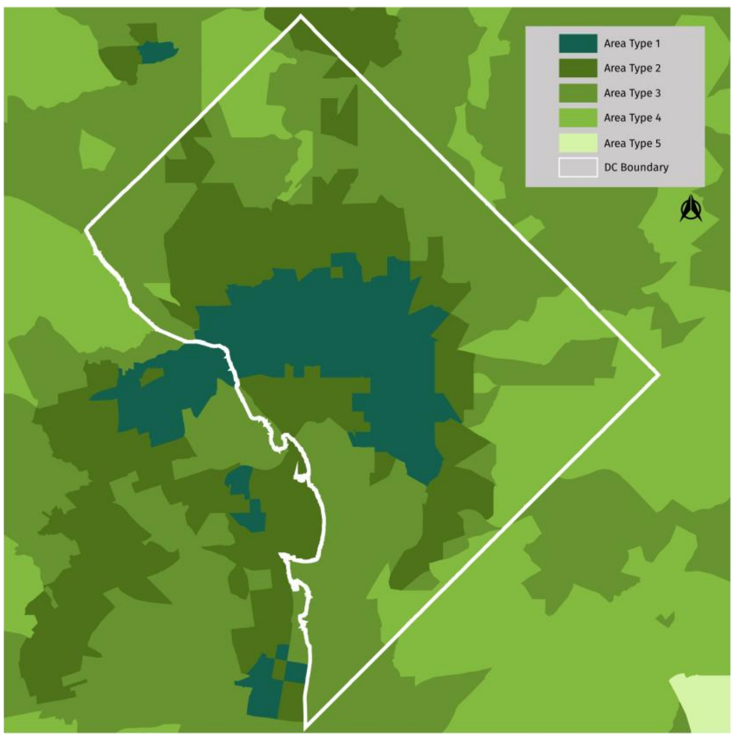
On-street parking needs will also be significantly diminished by the new mobility paradigm, with fewer people needing to park a personal vehicle nearby. As vehicle ownership decreases, on-street parking will also be converted to other uses, including well-designed pick-up/drop-off points that will help make automated ridesourcing and microtransit services safe, convenient, and easy for users District-wide. Other uses, such as widened sidewalks, green space, and/or dedicated lanes for specific modes, could also be implemented.

3.4.8 Future of Transit

Scenario C assumes that the definition of transit expands to incorporate a wide range of high-capacity service offerings from the public and private sectors. Microtransit will be introduced in neighborhoods where traditional fixed route service can't be provided cost-effectively or where the market supports door-to-door on-demand options. These services are likely to be operated in larger vehicles than the other tested scenarios, so that they can take advantage of the dedicated HOV lanes throughout the region. Microtransit and automated ridesourcing will also provide first-mile/last-mile connections to Metrorail and Commuter Rail services.

3.4.9 Ridesourcing

As previously outlined, Type 3 AVs are introduced in 2025, but with a high purchase cost that makes them best suited for use in shared fleets or automated ridesourcing services where these assets can be used more efficiently. Automated ridesourcing services are introduced in downtown DC, although the mapping and processing technologies advance quickly, allowing for expansion into suburban areas until the whole region is served by 2036. Detailed expansion assumptions are outlined in Figure 3-29. Expansion of automated ridesourcing service areas is likely to spread outwards, as individual areas are mapped for inclusion in AV software. During actual implementation, policy should ensure that the service area covers all eight wards in a fair and equitable way.



Area Type	Expansion Timeline
Area Type 1 Downtown	beginning in 2025
Area Type 2 Urban	beginning in 2027
Area Type 3 Mixed Use Suburban	beginning in 2030
Area Type 4 Suburban	beginning in 2032
Area Type 5 Rural	beginning in 2036

Figure 3-29: DC Automated Ridesourcing Service Expansion – Scenario C

3.4.10 Road Capacity

Improvements to safety and a decrease in crashes are assumed to be the main sources of roadway throughput enhancement in Scenario C. These improvements are associated with both connectivity and automation technologies, and their combination. One-quarter of congestion is caused by crashes; Table 3-11 highlights the assumptions around how many of these crashes are assumed to be removed in Scenario C, and the associated increase in carrying capacity by facility type.

Table 3-11: Effective Capacity Increases Associated with Crash Reduction – Scenario B

Facility Type	Crashes Eliminated	Effective Capacity Increase
Freeways	40%	10%
Arterials	60%	15%

In addition, higher levels of automation will allow for additional increases in roadway throughput. Freeway throughput is expected to see only a marginal improvement due to automation in Scenario C. Surface roadways will see a greater increase in throughput due to implementation of connected signals and other improvements outlined in Section 3.4.3. The relationship between capacity and market penetration is not linear, as shown in Figure 3-30. At very low levels of AV market penetration, capacity is likely to decrease, as AVs are likely to maintain wider separations from vehicles that they cannot communicate with than human drivers would (Arnaout *et al.*, 2011).

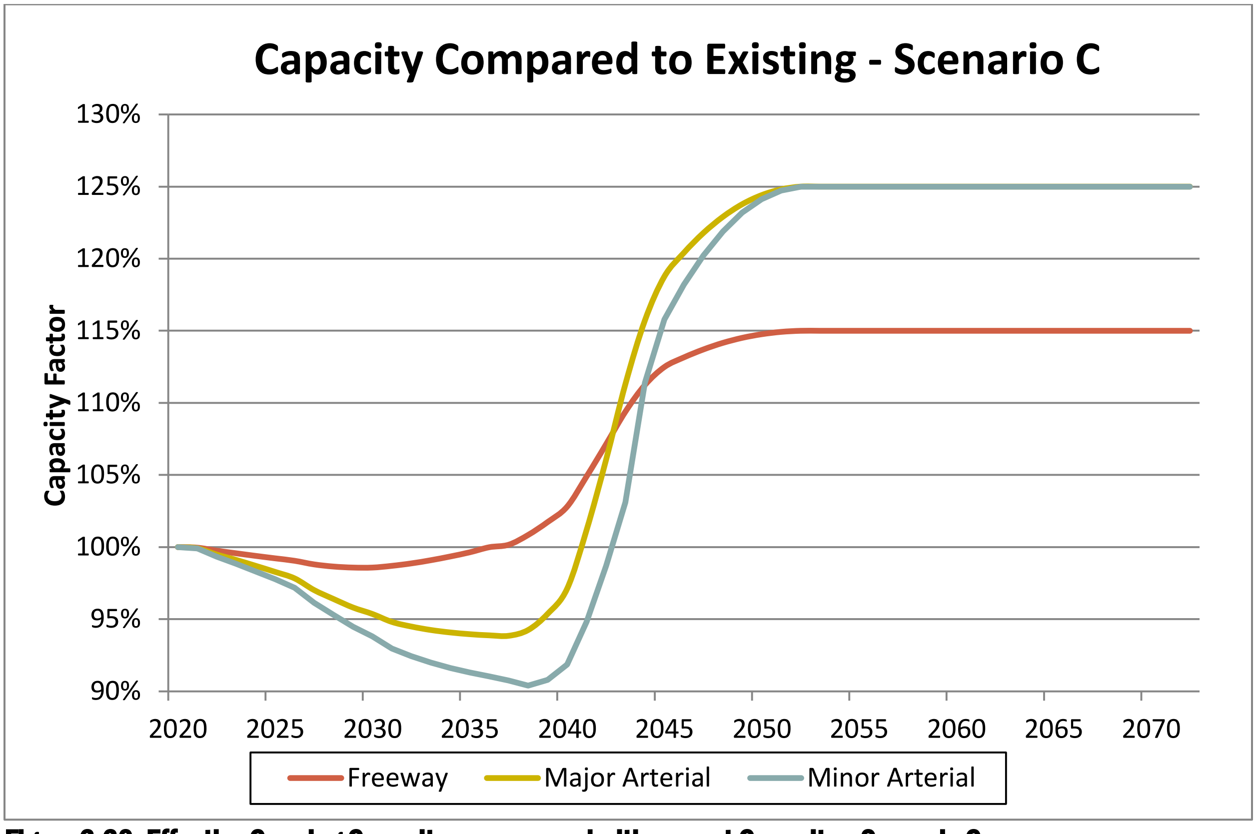


Figure 3-30: Effective Carrying Capacity as compared with current Capacity – Scenario C

3.4.11 Vehicle Ownership

In Scenario C, AVs will be available both for purchase and for use via shared vehicle fleets. These vehicles will be introduced at a cost premium that will make them unattainable for most people for several years. However, as costs decrease over time, some households will continue to purchase cars, albeit fewer vehicles per household than today. These households are more likely to be located in the less dense suburbs and decreases in vehicle ownership will only take place once prices have fallen significantly and automated ridesourcing services have expanded sufficiently to provide good alternatives for suburban trips.

Vehicle ownership in urban areas will decrease more significantly as automated ridesourcing and microtransit provide competitive, convenient, fast alternatives to car ownership. These reductions in vehicle ownership would therefore occur in areas in which automated ridesourcing have been introduced, and are likely to occur slowly in time as the service areas expand. The assumptions account for the concept that a car owner in downtown is unlikely to give up their car until they feel comfortable that they can rely on other services to maintain their freedom and flexibility to travel when and where they want. Therefore, fewer people are willing to give up their vehicles when automated ridesourcing only serves the downtown area than once they have expanded to the suburbs.

Research into carsharing provides the basis for the assumptions about vehicle ownership (Fagnant, *et al.*, 2015) which shows that in different Area Types, each shared vehicle can replace a different number of household-owned vehicles. The replacement rates are shown in Figure 3-31 below.

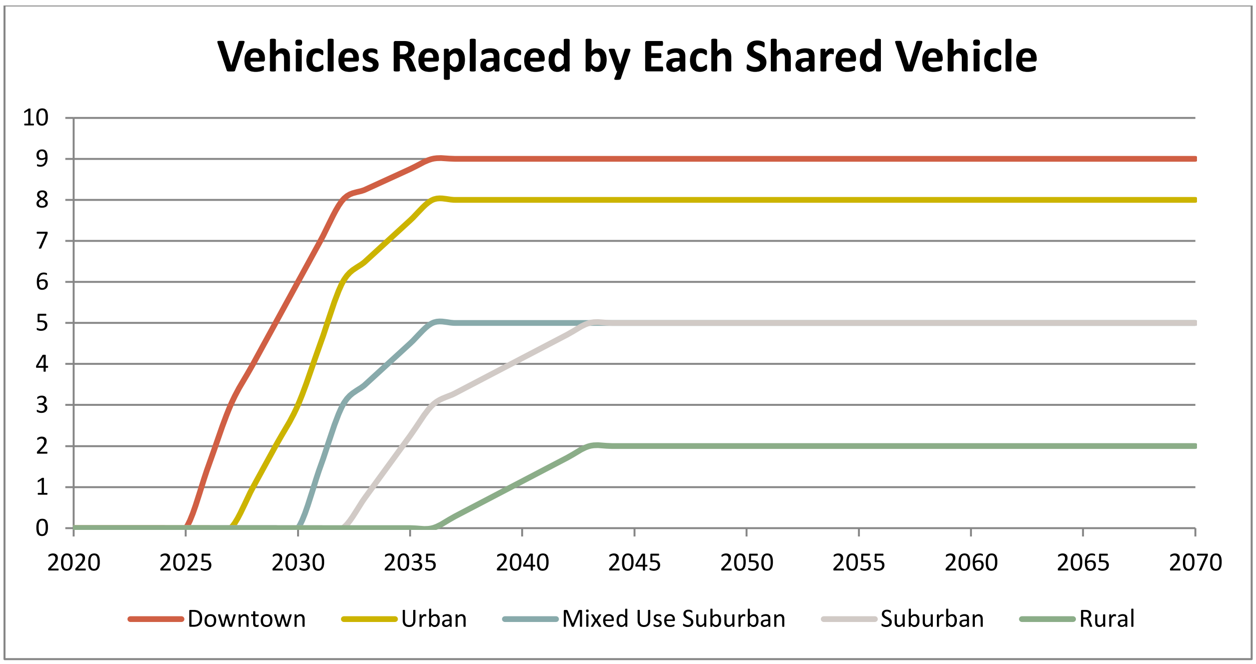


Figure 3-31: Vehicle Replacement Rate by Area Type – Scenario C

3.4.12 Travel Demand

Travel demand and travel patterns under the assumptions of Scenario C are expected to change in several ways. These changes will impact the number of trips people take (Henderson *et al.*, 2016), the length of those trips, and/or the mode of travel used (Fagnant & Kockelman, 2015; Carriea *et al.*, 2016). In addition to changes to personal travel patterns, the assumptions also consider the addition of ZOV travel behavior (Maciejewski *et al.*, 2017; Fagnant & Kockelman, 2014). The changes are outlined in the table below; the impacts of these changes on performance metrics such as VMT, transit ridership, and congestion are quantified in Section 4.0. These changes and impacts will vary geographically based on the service options available in each Area Type.

Table 3-12: Travel Demand Assumptions – Scenario C

Assumed Changes	Behavior
AVs make time spent in the car more pleasant (Type 2 and 3)	People are willing to drive longer distances to get to their destination More people chose vehicles over transit
Automated ridesourcing is cheaper to use than privately-owned vehicles with no ownership costs	Travelers shift from transit or privately-owned vehicle to automated ridesourcing services
Automated ridesourcing provides mobility for people who couldn't drive previously	Disabled residents are able to increase the number of trips made Elderly residents increase the number of trips made, and are able to travel longer distances
Empty vehicle relocation	Automated ridesourcing services will have empty relocations to pick up passengers, but generally short in order to optimize costs AV storage facilities limit the amount of ZOVMT for relocating vehicles

3.4.13 Land Use

The assumptions included in Scenario C focus on the effects of speeding up high-occupancy vehicles and their ability to provide mobility for travelers around the region. The availability of these mobility services and the presence of a speed advantage encourage people to live in the denser, mixed use communities inside the Beltway where they can take advantage of them.

The MWCOG Cooperative Land Use forecasts for the region result in an imbalance between residents and employment; MWCOG estimates that the excess jobs are filled by 100,000 households outside of the region that commute into the region every day. Scenario C assumes that these households are able to be accommodated within the region due to a wide range of changes included in the scenario. Zoning requirements and regulation would need to be revisited to make these Land Use assumptions possible in reality, and Scenario C assumes that these changes take place in order to allow more housing in these areas. Specifically, 100,000 households are added to the District and the inner suburbs between 2030 and 2045 as shown in Table 3-13.

Table 3-13: Change in Households compared to MWCOG 2045 Land Use Forecasts – Scenario C

Jurisdiction	Change in Households Compared to MWCOG Forecasts	
	#	%
DC	37,505	9.1%
Montgomery County	11,247	2.4%
Prince George's County	11,824	3.1%
Arlington	12,421	8.8%
Alexandria	12,025	11.2%
Fairfax County	14,045	2.7%
Falls Church	940	11.5%
All other jurisdictions	0	0%
Grand Total	**100,000**	**2.9%**

Households outside the Beltway remain the same as in the MWCOG Cooperative Land Use Forecasts. Figure 3-32 shows geographically where these changes in household growth were implemented which includes additional households in the jurisdictions inside the Beltway as compared to the MWCOG forecasts.

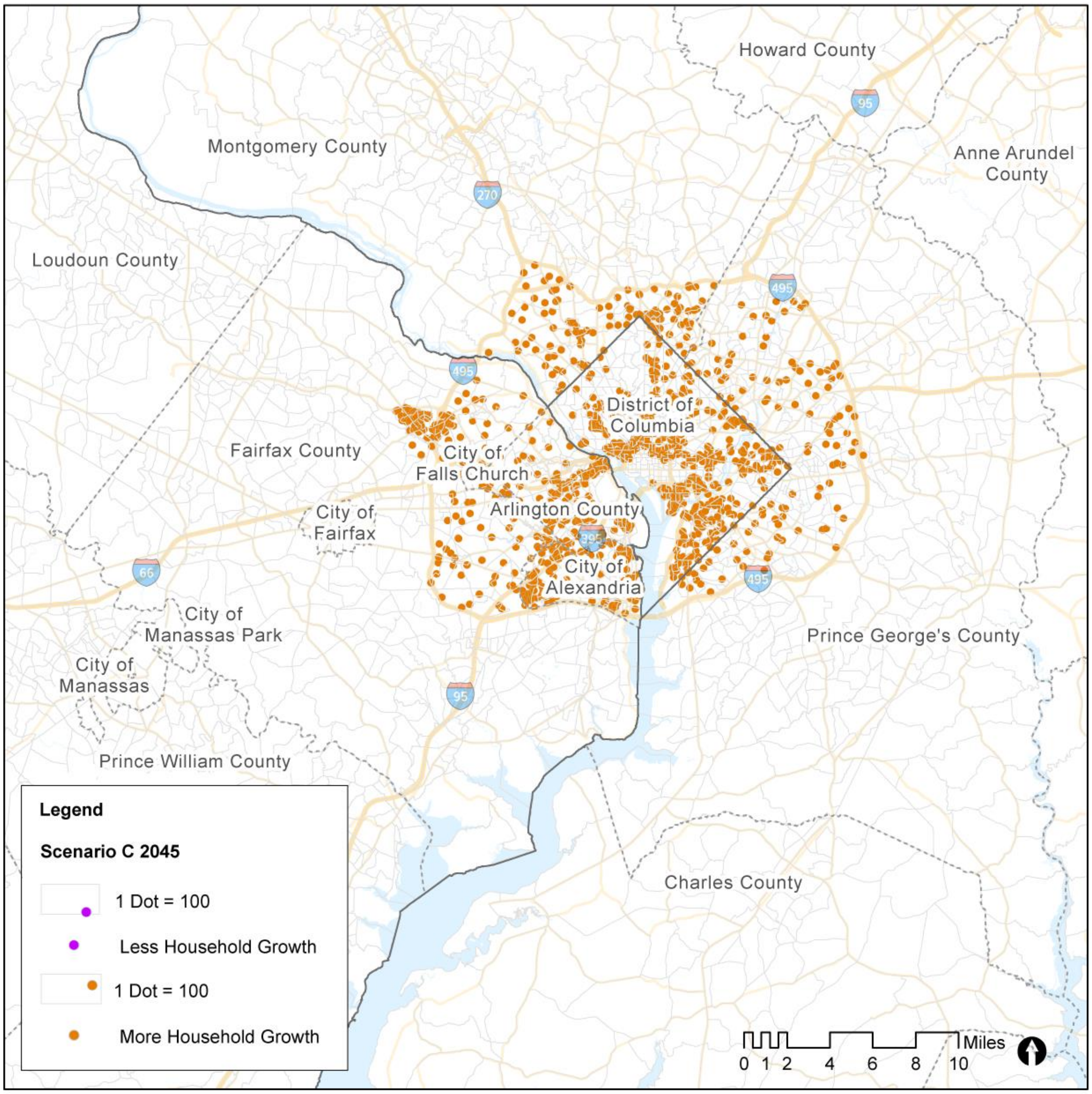


Figure 3-32: Household Growth Change – Scenario C

Office jobs are assumed to follow a pattern of growth to household growth as more companies locate in DC so that their employees can take advantage of the new transportation options. While the total regional office jobs remain consistent with the MWCOG Cooperative Land Use Forecasts, the growth in jobs after 2030 is relocated as follows:

- 20 percent decrease in the amount of office job growth currently forecast to occur between 2030 and 2045 in the suburbs outside of the Beltway. This amounts in approximately 17,000 fewer office jobs in these areas by 2045 than are currently forecast by the region.

- This job growth (17,000 office jobs) will be relocated inside DC, representing an increase of 2.0 percent by 2045.

Figure 3-33 shows geographically where these changes in job growth would be implemented throughout the region. Blue dots show locations where fewer jobs will be added than what is included in the MWCOG forecasts, while red dots show locations where more jobs will be added.

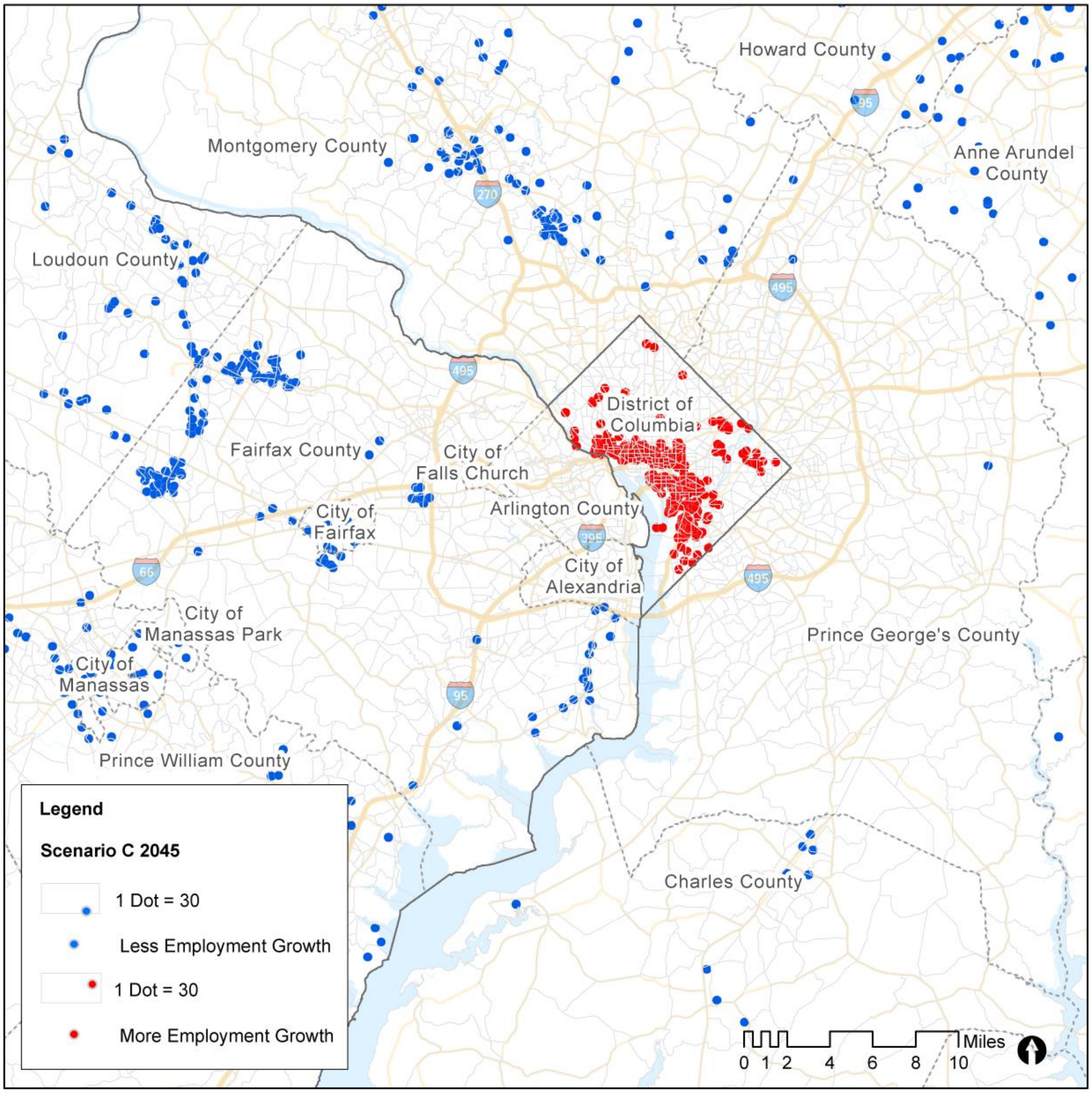


Figure 3-33: Office Job Growth Change – Scenario C

No additional retail jobs were added in Scenario C, which assumes the same retail distribution as in the MWCOG Cooperative Land Use Forecasts. No changes were assumed to the regionally forecasted growth for the other job categories (industrial and "other") included in the

MWCOG Cooperative Land Use Forecasts. The results of these changes to land use forecasts are summarized in Table 3-14.

Table 3-14: Scenario C 2045 Land Use Assumptions by Jurisdiction

Jurisdiction	Households	Population	Retail Jobs	Office Jobs	Total Jobs
DC	449,377	1,073,095	114,794	851,095	1,062,363
Montgomery	473,163	1,250,680	109,826	404,809	675,837
Prince George's	388,611	1,026,774	96,170	90,741	401,862
Arlington	154,264	327,752	39,899	182,776	269,064
Alexandria	119,107	231,621	25,472	105,730	155,095
Fairfax County	542,138	1,450,995	123,417	650,433	886,280
Fairfax City	13,470	35,166	7,114	13,714	23,179
Falls Church	9,145	19,622	6,353	6,666	18,600
Loudoun	168,671	507,398	59,825	114,310	289,904
Other MD	424,270	1,112,622	134,807	300,110	685,417
Other VA	845,383	2,317,965	296,357	313,546	986,398
Total	**3,587,599**	**9,353,690**	**1,014,034**	**3,033,930**	**5,453,999**

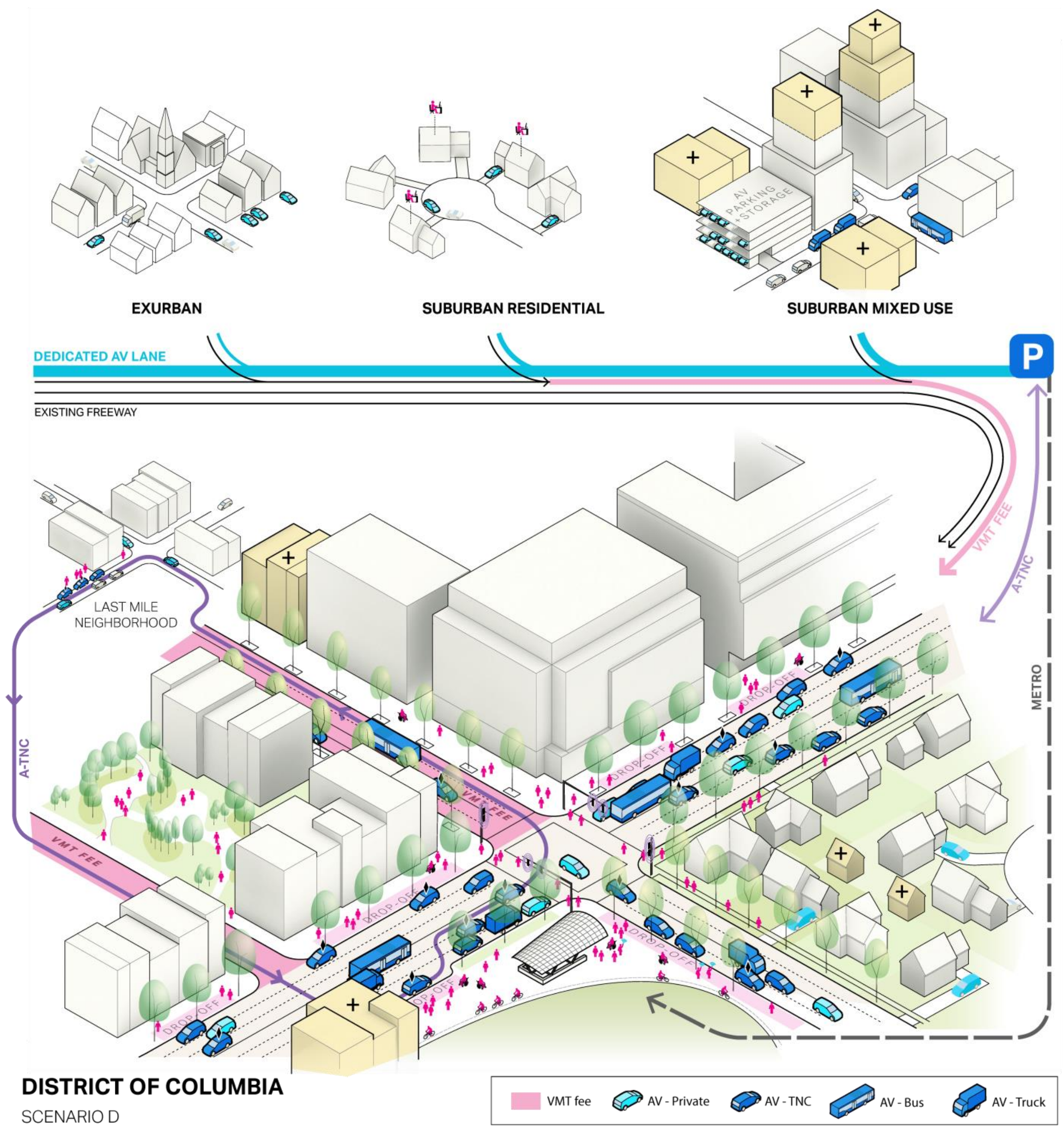
3.5 Scenario D – Regional Congestion Fee

Scenario D is similar in many ways to Scenario C, as it also explores a future in which the full range of AV technologies are incorporated into the region's mobility system. Type 2 AVs capable of traveling independently on freeways are introduced into the fleet early beginning in 2022, although their high costs and limited capabilities mean that they are incorporated into the vehicle fleet rather slowly, as travelers prefer the flexibility of Type 3 AVs. The introduction of Type 3 AVs at a high cost means that they are initially used only as part of shared vehicle fleets. They then begin to be purchased by higher-income households as the prices decrease. The competing business models of household-owned and shared AVs will each prove attractive to different segments of the population. Some decreases in vehicle ownership will be expected, with more significant impacts in the more urban areas. The technology will also be applied to heavy trucks and delivery vehicles, resulting in an increase in truck freight in the region.

Scenario D looks to achieve congestion relief in the region by pricing roadway capacity through a regional congestion fee. This congestion fee is envisioned as a regional effort that applies dynamic pricing on all congested freeways and major arterials in the region. The fee would be charged at any point during the day when congestion occurs and is not envisioned as being limited to the traditional peak periods. In addition to limiting congestion, this fee would also encourage the use of high-occupancy mobility options, as they would allow passengers to split the fee between more people, essentially lowering the cost. The fee will also discourage empty vehicles from driving unnecessarily on facilities without excess capacity, encouraging automated ridesourcing and household owned AVs from long vehicle relocations or from spending a lot of time circling.

The proliferation of AVs that are household-owned combined with almost ubiquitous access to automated ridesourcing will have competing impacts on residential preferences. Some residents will prefer to take advantage of lower land prices in the suburban and exurban communities outside the Beltway in an attempt to avoid paying congestion fees as much as possible. Other residents will choose to locate in denser, mixed use areas where they can take advantage of shared mobility options, transit services, and walk/bike/scoot to the extent possible. On both ends of the spectrum, Scenario D will see an increase in telework compared to the other scenarios, as both urban and suburban residents elect to avoid paying congestion fees altogether.

Figure 3-34 illustrates what the future might look like in the District under these assumptions and presents a summary of the scenario assumptions by category; detailed scenario assumptions are further discussed in individual sections below.



DISTRICT OF COLUMBIA
SCENARIO D

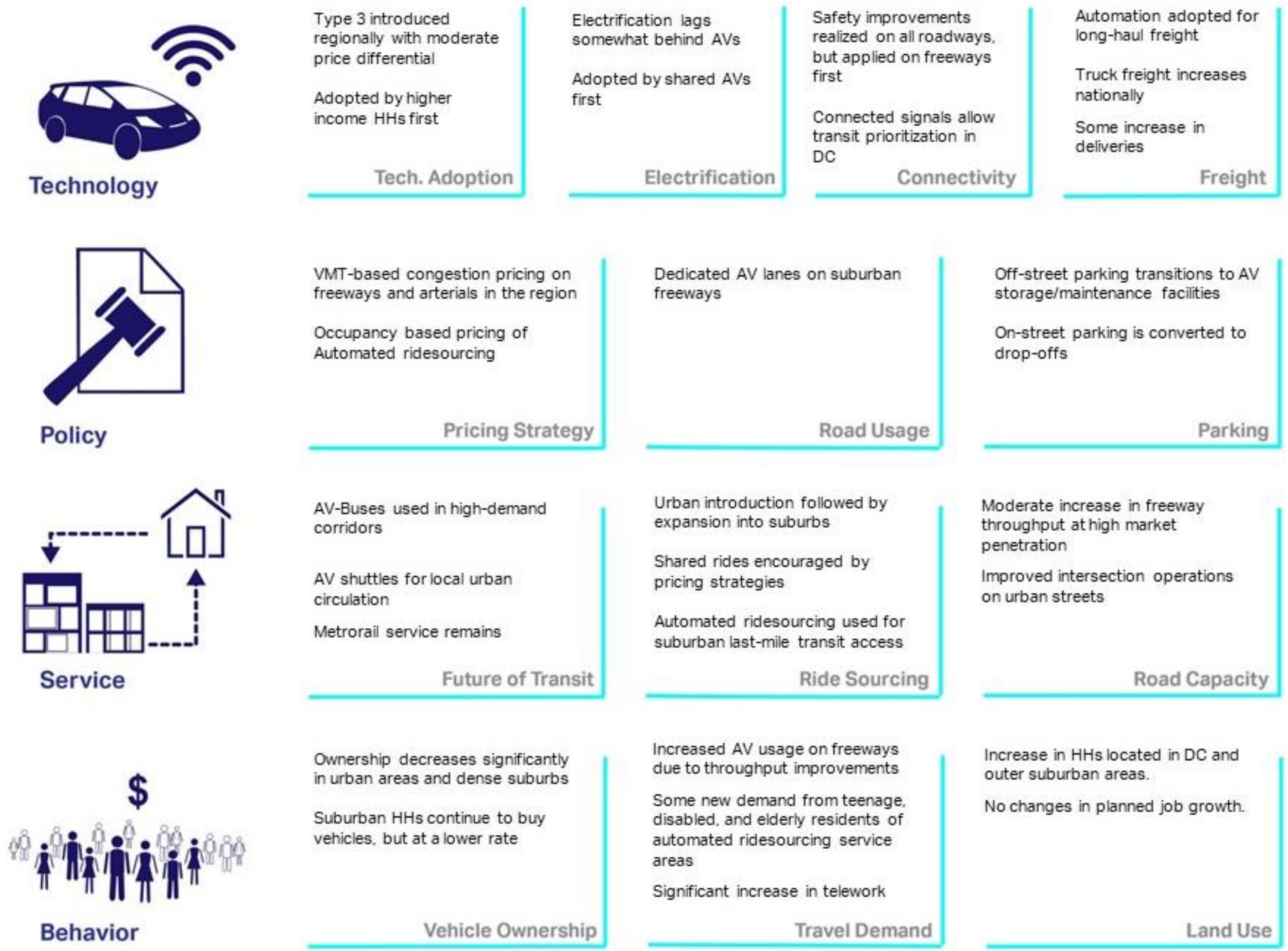


Figure 3-34: Scenario D Assumptions Summary- Regional Congestion Fee

3.5.1 Technology Adoption

Development of automated vehicle technology in Scenario D includes the introduction and evolution of both Type 2 and Type 3 vehicles. Type 2 vehicles, capable of independent driving on freeways, are available for sale in 2022 with significantly higher costs. Over time, these costs come down, but not before Type 3 vehicles and affordable automated ridesourcing service has been introduced in 2025. These other options limit the attractiveness and adoption of Type 2 AVs into the vehicle fleet. Relatively high costs coupled with a limited service area mean that initially, Type 3 AVs are only really used in shared vehicle fleets. As costs come down and service areas expand (see Section 3.5.9), individuals start to purchase Type 3 AVs in areas where vehicle ownership is attractive.

Figure 3-35 shows how these AVs will be incorporated into the vehicle fleet in the District. Type 2 vehicles are introduced for sale in 2024, at which point they start to be integrated into the vehicle fleet, peaking at 69 percent in 2036. Type 3 AVs become available for general purchase in 2031, six years after their introduction as shared vehicles downtown. They remain a very small portion of the vehicle fleet until 2036, at which point technology capabilities expand to cover the entire metropolitan region; this advance makes them much more attractive for purchase and to encourage residents in some areas to give up car ownership. Residents remain unlikely to purchase them while costs remain prohibitive, but as costs come down, Type 3 becomes the dominant type of vehicle region-wide. Ultimately, Type 3 AVs become the majority of the vehicle fleet by 2039.

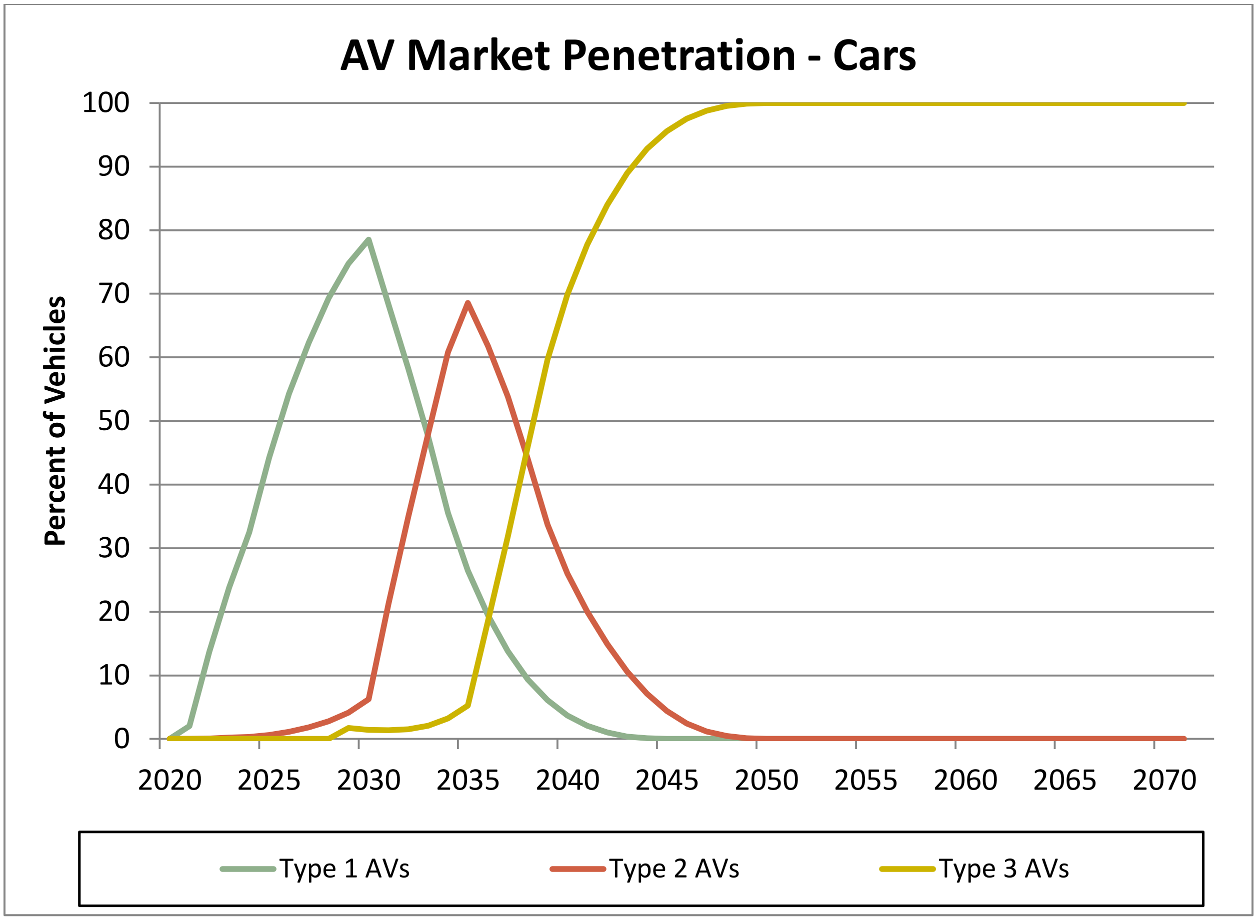


Figure 3-35: Scenario D AV Market Penetration - Cars

3.5.2 Electrification

Vehicle electrification is likely to be developed alongside automated and connected technologies, however there remains uncertainty as to how closely these technologies will be linked. Figure 3-36 below shows the market penetration for electric vehicles in the District for all vehicles, including both household owned vehicles and shared fleet vehicles. Shared fleet vehicles are likely to see a faster pace of electrification because vehicle sharing makes electrification more palatable by eliminating many of the traditional opposition to purchasing an electric car (e.g. concerns about charging or battery range).

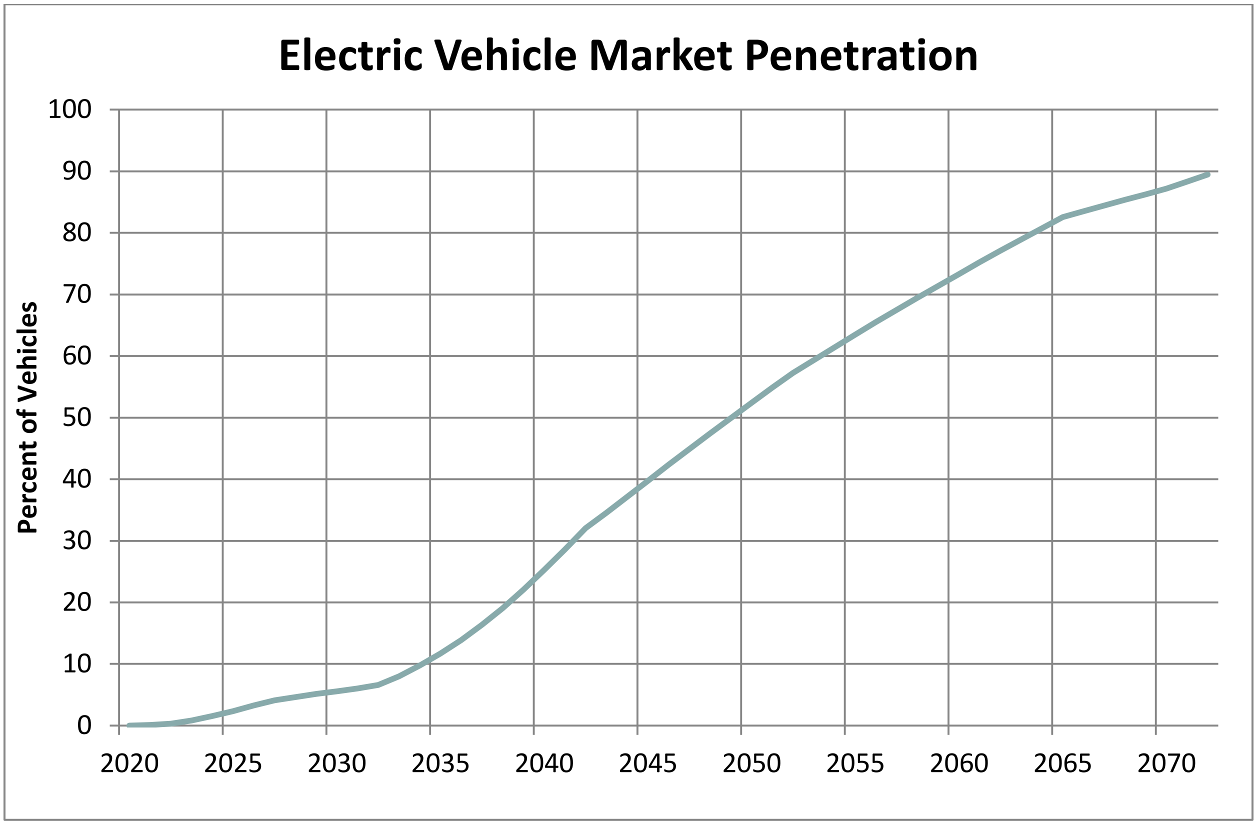


Figure 3-36: Scenario D Electric Vehicle Market Penetration

It should be noted that these assumptions about the pace of electrification are significantly more optimistic than those used by MWCOG in their 2019 Air Quality Conformity analysis, which uses highly conservative estimates of electrification and assumes no growth in electric vehicles above current conditions. Changes to electrification rates - driven by consumer choice, electricity prices, and/or policy and legal changes - could have significant impacts on the analysis results, specifically related to vehicle emissions as discussed further in Section 4.0.

3.5.3 Connectivity

Connected vehicle technology is often considered to be a part of vehicle automation, as it has the potential to dramatically improve roadway operations by providing drivers – or vehicles themselves in the case of AVs – with more information about roadway conditions than would otherwise be possible. This information can help vehicles prepare for difficult driving conditions, anticipate changes in traffic conditions and make necessary adjustments, and perhaps most importantly, avoid crashes and/or limit their severity. These technologies, especially when combined with automation, have great potential on freeways and surface streets. Scenario C assumes that these technologies are deployed effectively on facilities across the region, although they will be implemented first on freeways. Further, Scenario C assumes that these safety improvements have the potential to decrease congestion on the region's freeways, as 25 percent of congestion is currently related to crashes and other traffic incidents (FHWA, 2005). In this study, all AVs of any type (1-3) are assumed to be equipped with connected vehicle technology. Figure 3-35, presented earlier, therefore shows the assumed adoption rate of CV technology into the District's vehicle fleet.

3.5.4 Freight

Two elements of freight traffic will be impacted by AV technology: long-distance freight shipping and local freight deliveries. These two applications will have different impacts on travel patterns and traffic conditions and require different types of technology. Long-distance heavy-freight shipping primarily occurs on freeways, while deliveries occur more on urban streets and local roadways in trucks that are smaller in size. Both types of freight business models could see substantial changes to their cost structures and productivity with the adoption of AVs and the elimination (or repurposing) of the driver. If even a portion of these cost reductions are passed on to consumers, significant increases in both long-distance truck traffic (at Type 2 automation and above) and parcel delivery (at Type 3 automation only) would be likely.

Based on cost elasticities of freight traffic, Scenario D assumes a national and regional increase in both long-distance freight and local delivery traffic. These increases over time are shown in Figure 3-37, and are above what would otherwise be expected due to growth.

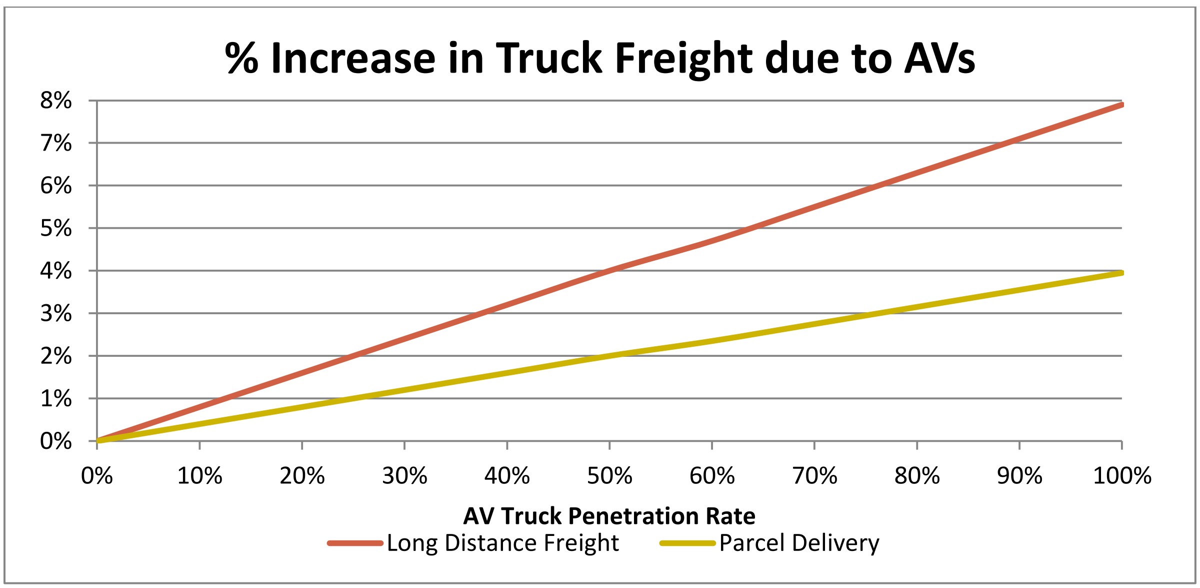


Figure 3-37: Scenario D Truck Freight Increases

Scenario D assumes that Type 2 trucks will be available for operations in 2024, two years after the introduction of Type 2 passenger vehicles. They are expected to be adopted into the fleet at a faster rate than passenger vehicles due to the attractiveness of the cost savings to freight companies. Scenario D assumes that Type 3 AV trucks, used for both long-distance freight and local deliveries, will be available starting in 2034. This delay when compared with passenger vehicles accounts for the added safety precautions and costs associated with automating much larger vehicles. Figure 3-38 shows the adoption of Type 2 and Type 3 AV Trucks in the District. While truck fleets are able to integrate freeway automation fairly quickly, they will ultimately be replaced by Type 3 AV trucks, which would reach full market penetration by 2054.

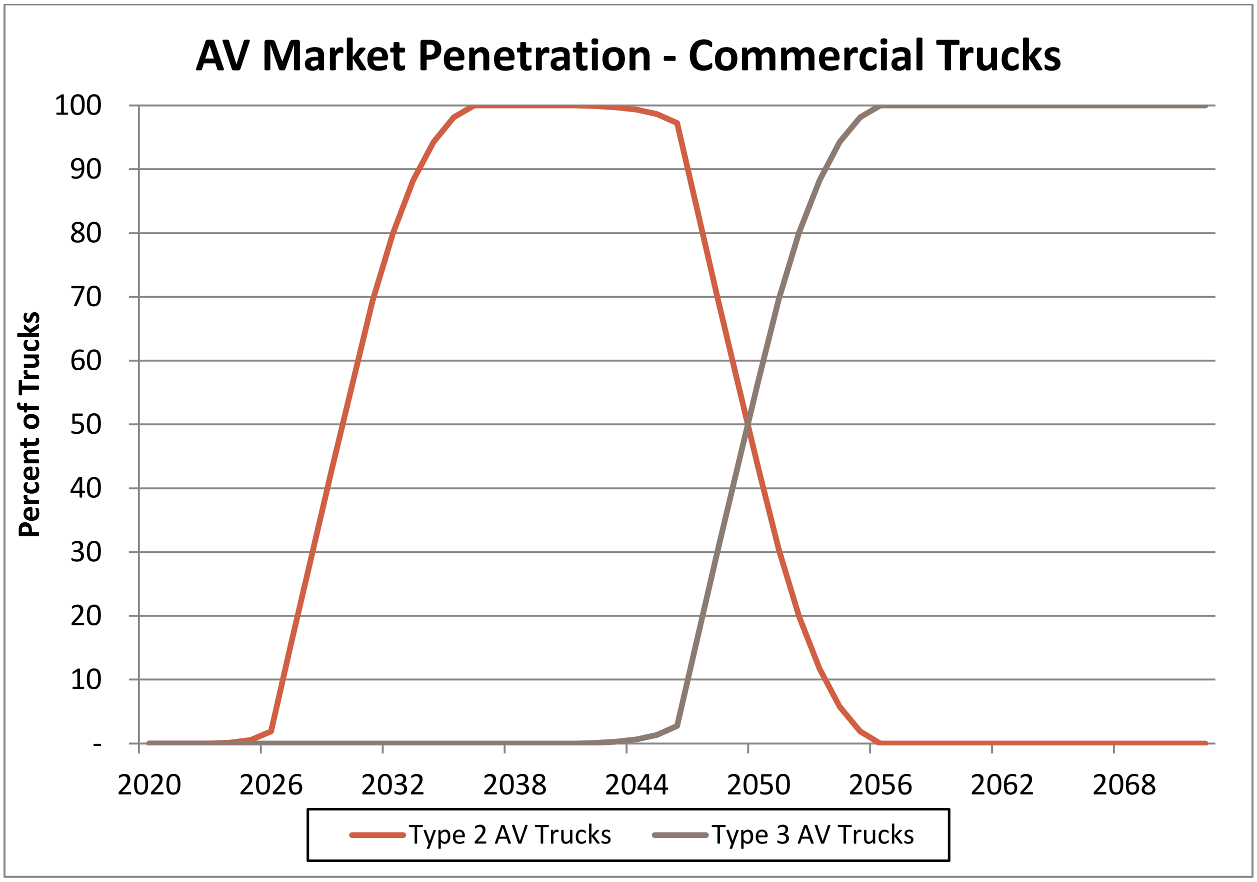


Figure 3-38: Scenario D AV Market Penetration - Trucks

3.5.5 Pricing Strategy

One of the defining characteristics of Scenario D is its implementation of a regional congestion pricing fee. This congestion fee would be designed and implemented to have a range of benefits for the region as a whole and for the District in particular. Some of these potential benefits include:

- Reducing congestion by encouraging use of options to driving alone during peak periods;
- Reducing the amount of VMT added to the region's roadways due to AVs;
- Increasing the use of transit and other high-occupancy modes during congested time periods;
- Improve travel time reliability for all roadway users, including transit vehicles; and
- Reducing tailpipe emissions regionally.

Under Scenario D, a congestion fee is applied to all freeways and major arterials regionally that experience significant congestion at any time of day. A significant level of congestion would need to occur during any 15-minute time period in order for a fee to go into effect; significant congestion for this scenario is defined as any travel that takes more than 50 percent longer than free-flow travel time. Dynamic pricing would allow for different levels of charges based on the level of congestion. Travelers in vehicles with more than one passenger would still be charged the congestion fee but would be able to share the charge among all passengers. ZOV AVs would be charged extra for traveling on congested facilities.

A congestion fee that achieves these goals could be designed and implemented in a number of ways; for the purposes of this study, some broad assumptions were made about one possible way. More complete study on the design of a congestion pricing strategy, and the correct amount of charge necessary to impel the desired levels of behavioral change will be necessary. This scenario analysis also does not consider the hardware and software that would be required in order to implement this type of pricing strategy in the region; these costs and limitations would need additional study as well.

3.5.6 Road Usage

As detailed in Section 3.5.10, Scenario D assumes that moderate increases in freeway capacity can be achieved at high AV market penetration rates. This assumption results in suburban governments not only encouraging the purchase of AVs but leads them to try to create these high market penetration levels as quickly as possible in order to relieve freeway congestion without widening highways in the region. In order to achieve this, Scenario D assumes that one lane on each freeway in the region will be dedicated for use by Type 2 or 3 AVs.

It is also assumed as part of Scenario D that time spent traveling in an AV is viewed by passengers as more pleasant than time spent driving a vehicle. This has impacts on the number of people willing to drive and the distances of those driving trips. Section 3.5.12 includes more details on assumptions related to changing travel demand.

3.5.7 Parking

Under Scenario D, parking needs in the urban areas inside and surrounding the District will decrease as residents in these areas come to rely increasingly on shared fleets of AVs. Vehicle ownership will decrease over time, as these shared mobility options make it possible for people to get around cheaply and conveniently without owning a car. As such, the need for parking is expected to decrease in urban areas. Shared vehicles will still require parking, but those parking facilities will be fewer and smaller. Scenario D assumes that existing off-street parking will be transitioned for use as AV storage, maintenance, and fueling. This will limit the amount of ZOVMT occurring as empty vehicles relocate themselves.

On-street parking needs will also be significantly diminished by the new mobility paradigm, with fewer people needing to park a personal vehicle nearby. As vehicle ownership decreases, Scenario D assumes that on-street parking will also be converted to other uses, including well-designed pick-up/drop-off points that will help make automated ridesourcing and AV shuttle services safe, convenient, and easy for users District-wide. Other uses, such as widened sidewalks, green space, and/or dedicated lanes for specific modes could also be implemented depending on the policies implemented by the District.

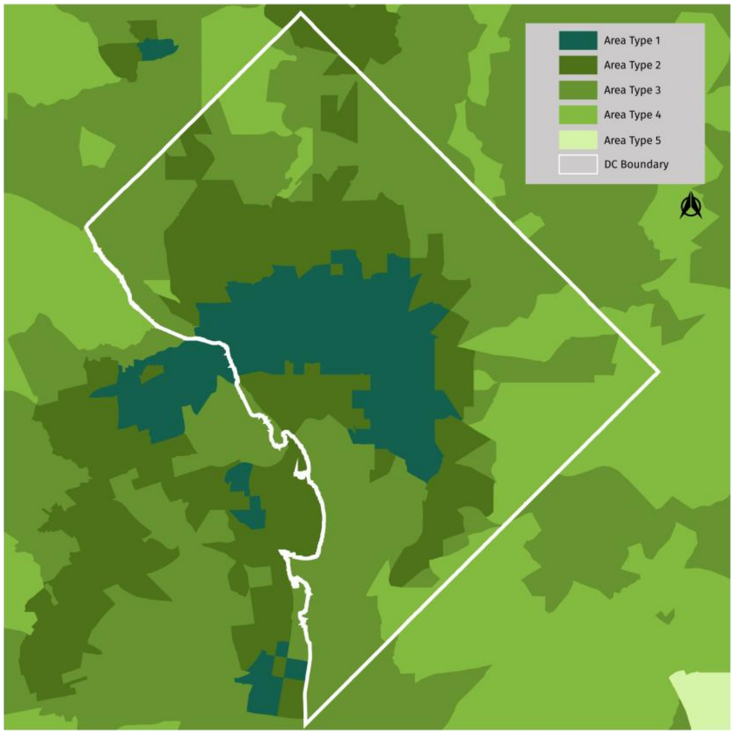
3.5.8 Future of Transit

Scenario D assumes that public transit continues to operate in high demand corridors, and Metrorail service continues to operate as planned throughout the region. High-demand bus corridors will continue to be served by high-capacity bus service, mostly likely to be operated by a public entity; the major difference to these trunk services will be that the buses will incorporate automated technologies, allowing for more frequent service to be provided at the same cost.

To complement these high-capacity services, AV shuttles (publicly or privately owned and operated) will be used to provide local circulation within neighborhoods, and to improve access from neighborhoods to the trunk transit lines, bridging the first-mile/last-mile gap. Where shuttle buses aren't necessary automated ridesourcing will also provide these connections.

3.5.9 Ridesourcing

As previously outlined, Type 3 AVs are introduced in 2025, but with a high purchase cost that makes them best suited for use in shared fleets or automated ridesourcing services where these assets can be used more efficiently. Automated ridesourcing services are introduced in downtown DC, and the mapping and processing technologies advance quickly, allowing for expansion into suburban areas until the whole region is served by 2036. Detailed expansion assumptions are outlined in Figure 3-39. Expansion of automated ridesourcing service areas is likely to spread outwards, as individual areas are mapped for inclusion in AV software. During actual implementation, policy should ensure that the service area covers all eight wards in a fair and equitable way.



Area Type	Expansion Timeline
Area Type 1 Downtown	beginning in 2025
Area Type 2 Urban	beginning in 2027
Area Type 3 Mixed Use Suburban	beginning in 2030
Area Type 4 Suburban	beginning in 2032
Area Type 5 Rural	beginning in 2036

Figure 3-39: DC Automated Ridesourcing Service Expansion – Scenario D

3.5.10 Road Capacity

Roadway carrying capacity is assumed to see an increase in Scenario D with the introduction of both Type 2 and Type 3 AVs, and connected vehicle technology. The biggest increases in capacity will occur on freeways, as concentrations of CV and AV technology allow vehicles to travel faster in congested conditions and smooth traffic through bottlenecks. A 25 percent increase in the potential carrying capacity of a freeway lane is assumed at 100% market penetration (Type 2 AV or higher), although the relationship between capacity and market penetration is not linear[2]. At very low levels of AV market penetration, capacity is actually likely to decrease, as AVs are likely to maintain wider separations from vehicles that they cannot communicate with than human drivers would (Arnaout *et al.*, 2011). Dedicated AV lanes are assumed to always have 100 percent market penetration.

[2] Industry estimates of the capacity increases achievable with AV and CV vary widely, and in early days were as high as 5x capacity increases (USDOT, 2017). More recent literature has pulled back from these estimates somewhat, so that a 50% increase in capacity represents a middle-of-the-road assumption.

In addition to these increases, CV and AV technologies are assumed to help alleviate congestion caused by crashes and other incidents, thus increasing the effective carrying capacity of all roadways in the region. One-quarter of congestion is caused by crashes; Table 3-15 highlights the assumptions around how many of these crashes are assumed to be removed in Scenario D, and the associated increase in carrying capacity by facility type.

Table 3-15: Effective Capacity Increases Associated with Crash Reduction – Scenario D

Facility Type	Crashes Eliminated	Effective Capacity Increase
Freeways	80%	20%
Arterials	80%	20%

The effective carrying capacities of different roadway types are shown in Figure 3-40 as a percentage of current roadway capacities.

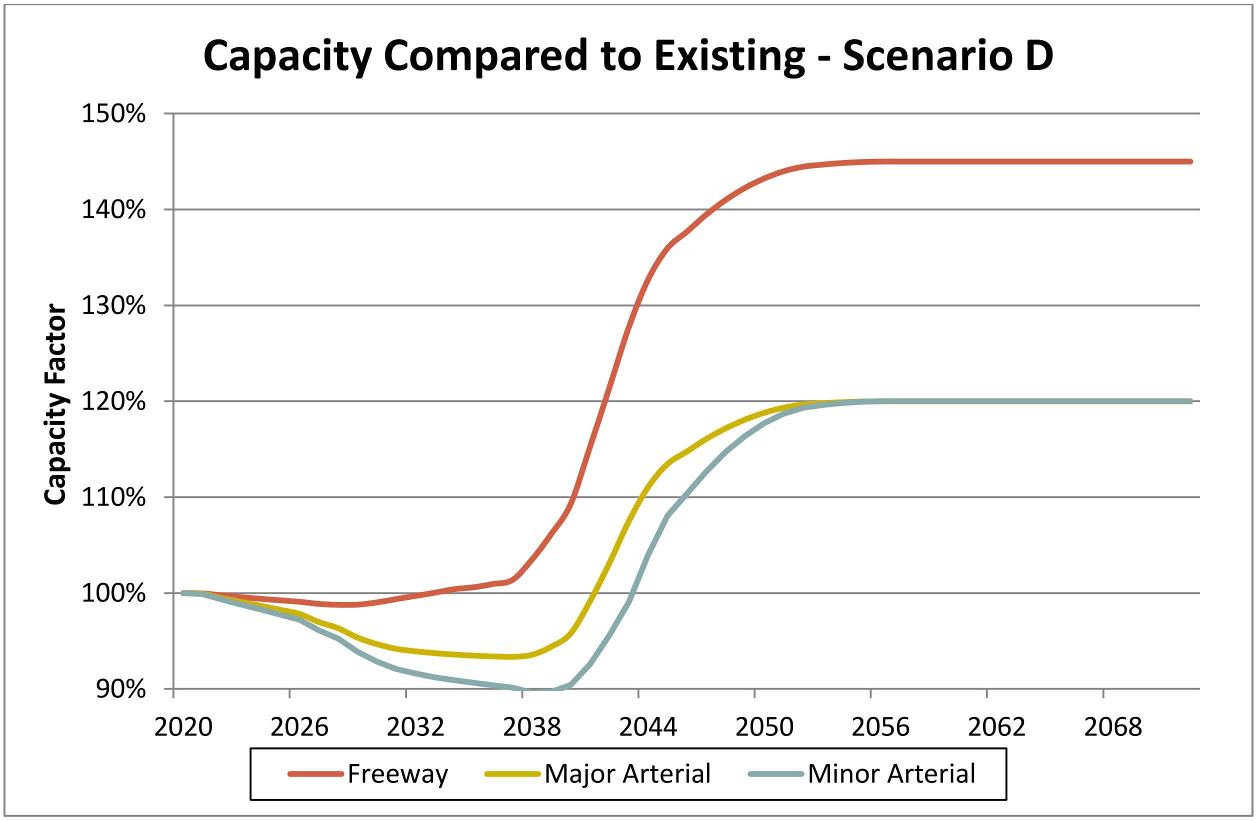


Figure 3-40: Effective Carrying Capacity as compared with current Capacity – Scenario D

3.5.11 Vehicle Ownership

In Scenario D, AVs will be available both for purchase and for use via shared vehicle fleets. These vehicles will be introduced at a cost premium that will make them unattainable for most people for several years. However, as costs decrease over time, some households, especially those in the suburbs will continue to purchase cars, albeit fewer vehicles per household than today. Decreases in vehicle ownership will only take place once prices have fallen significantly and automated ridesourcing services have expanded sufficiently to provide good alternatives for suburban trips.

Vehicle ownership in urban areas will decrease more significantly as other options become competitive, convenient, and fast alternatives to car ownership. These reductions in vehicle ownership would therefore occur in areas in which automated ridesourcing have been introduced, and are likely to occur slowly as the automated ridesourcing service areas expand. The assumptions account for the concept that a car owner in downtown is unlikely to give up their vehicle until they feel comfortable that they can rely on other services to maintain their freedom and flexibility to travel when and where they want. Therefore, fewer people are willing to give up their vehicles when automated ridesourcing only serve the downtown area than once they have expanded to the suburbs as well.

Research into carsharing provides the basis for the assumptions about vehicle ownership (Fagnant, *et al.*, 2015) which shows that in different Area Types, each shared vehicle can replace a different number of household-owned vehicles. The replacement rates are shown in Figure 3-41 below.

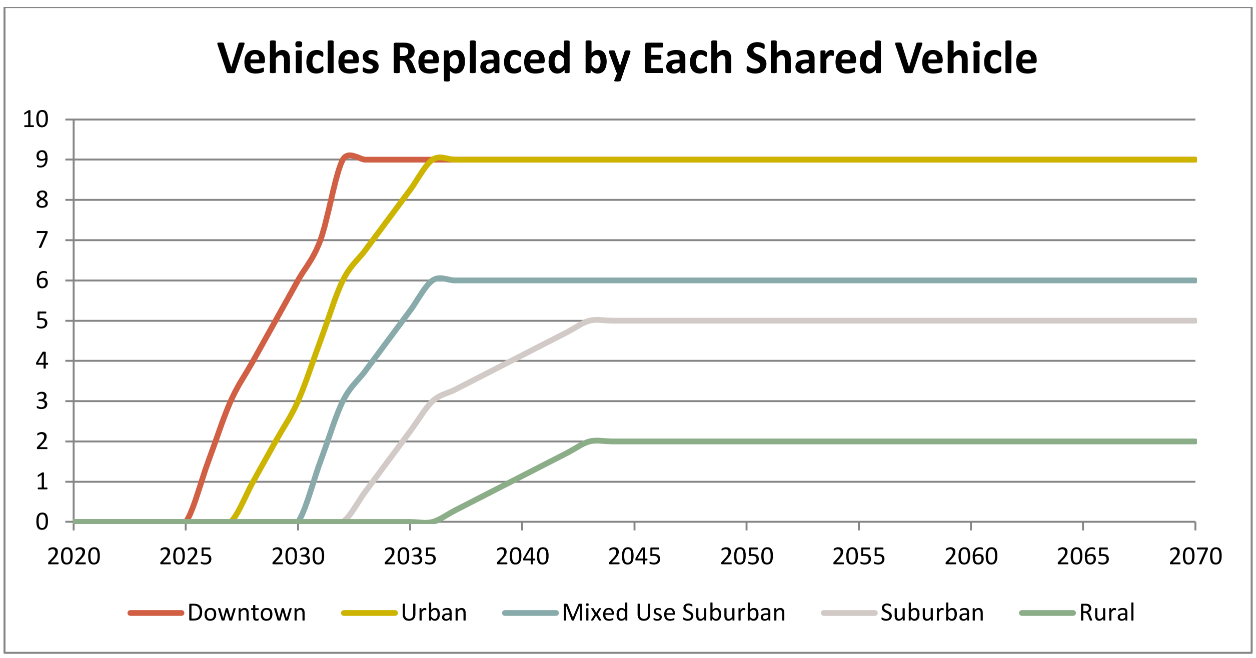


Figure 3-41: Vehicle Replacement Rate by Area Type – Scenario D

3.5.12 Travel Demand

Travel demand and travel patterns under the assumptions of Scenario D are expected to change in several ways. These changes will impact the number of trips people take (Henderson *et al.*, 2016), the length of those trips, and/or the mode of travel used (Fagnant & Kockelman, 2015; Carriea *et al.*, 2016). In addition to changes to personal travel patterns, the assumptions also consider the addition of ZOV travel behavior (Maciejewski *et al.*, 2017; Fagnant & Kockleman, 2014). The changes are outlined in the Table 3-16; the impacts of these changes on performance metrics such as VMT, transit ridership, and congestion are quantified in Section 4.0. These changes and impacts will vary geographically based on the service options available in each Area Type.

Table 3-16: Travel Demand Assumptions – Scenario D

Assumed Changes	Behavior
Automated ridesourcing is cheaper to use than privately-owned vehicles with no ownership costs	Significant number of travelers are able to shift from transit to automated ridesourcing services for particularly long transit trips
Automated ridesourcing provides mobility for people who couldn't drive previously	Disabled residents are able to increase the number of trips made Elderly residents increase the number of trips made Youth are able to travel independently of their parents
Empty vehicles relocation	Automated ridesourcing services will have empty relocations to pick up passengers, but generally short in order to optimize costs

3.5.13 Land Use

The assumptions included in Scenario D focus on the effects of AV usage and their impacts under regional congestion pricing. AVs provide a range of new mobility options under these assumptions, while congestion pricing encourages people to use other modes when available, share rides, and/or travel outside of peak travel times. This in turn entices people to live in either the densest urban areas where alternatives to driving are easy, affordable, and convenient, or to live far from the District in an attempt to avoid congestion and the associated fees.

The MWCOG Cooperative Land Use forecasts for the region result in an imbalance between residents and employment; MWCOG estimates that the excess jobs are filled by 100,000 households outside of the region who commute into the region every day. Scenario D assumes that these households are able to be accommodated within the region due to a wide range of changes included in the Scenario. Zoning requirements and regulations would need to be revisited to make these Land Use assumptions possible in reality, and Scenario D assumes that these changes take place in order to allow more housing in these areas. Specifically, 100,000 households are added to the region between 2030 and 2045 as shown in Table 3-17.

Table 3-17: Change in Households compared to MWCOG 2045 Land Use Forecasts – Scenario D

	Change in Households Compared to MWCOG Forecasts	
Jurisdiction	#	%

Jurisdiction	Change in Households Compared to MWCOG Forecasts	
	#	%
DC	42,855	10.4%
Montgomery County	9,011	2.0%
Prince George's County	4,711	1.3%
Arlington	2,838	2.0%
Alexandria	2,769	2.6%
Fairfax County	10,303	2.0%
Falls Church	250	1.9%
All other jurisdictions	27,254	1.9%
Grand Total	**100,000**	**2.9%**

Figure 3-42 shows geographically where these changes in household growth were implemented throughout the region, which includes additional households compared to the MWCOG forecasts.

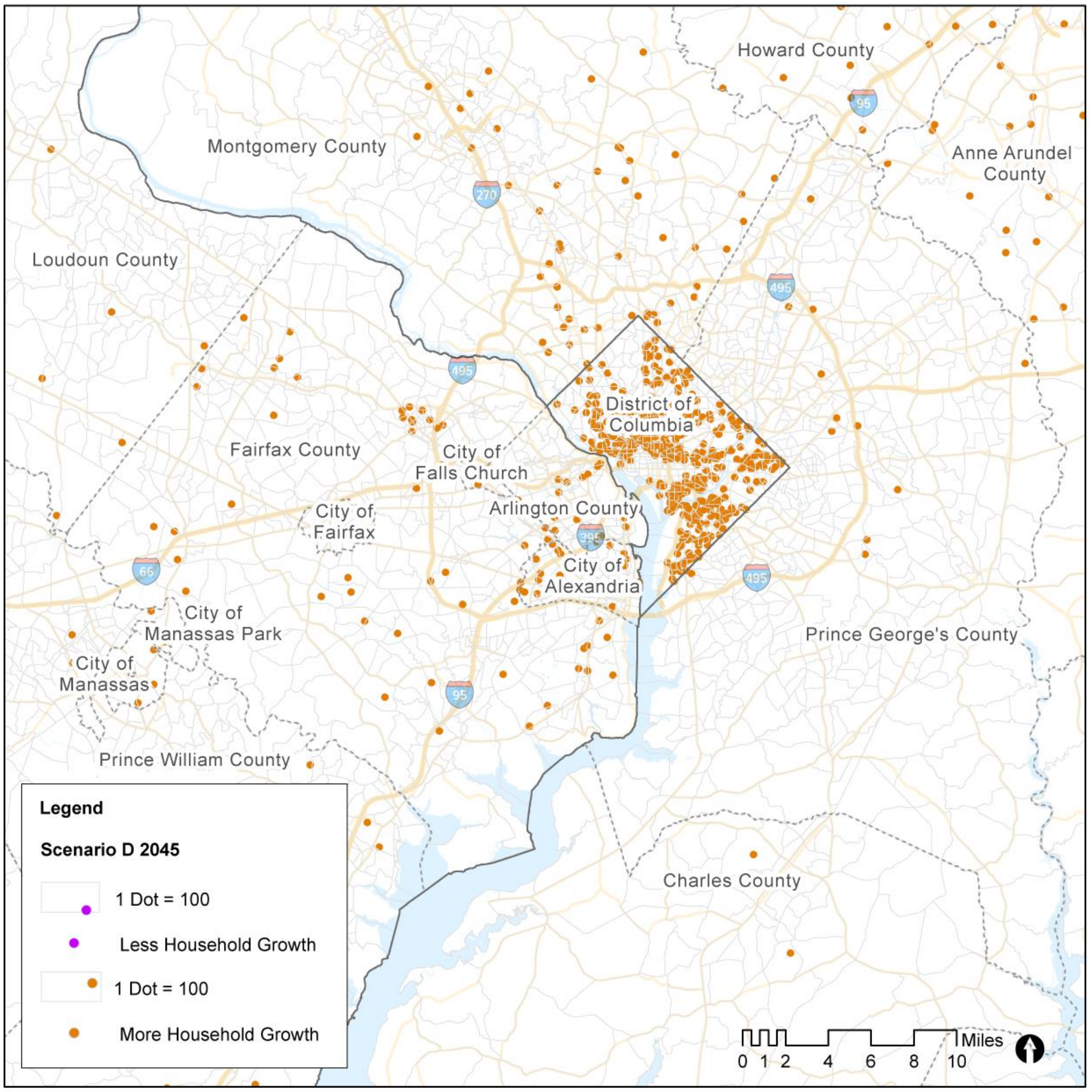


Figure 3-42: Household Growth Change – Scenario D

No changes to the distribution of jobs in the region were made as part of Scenario D, and the resulting land use totals are shown in Table 3-18.

Table 3-18: Scenario D 2045 Land Use Assumptions by Jurisdiction

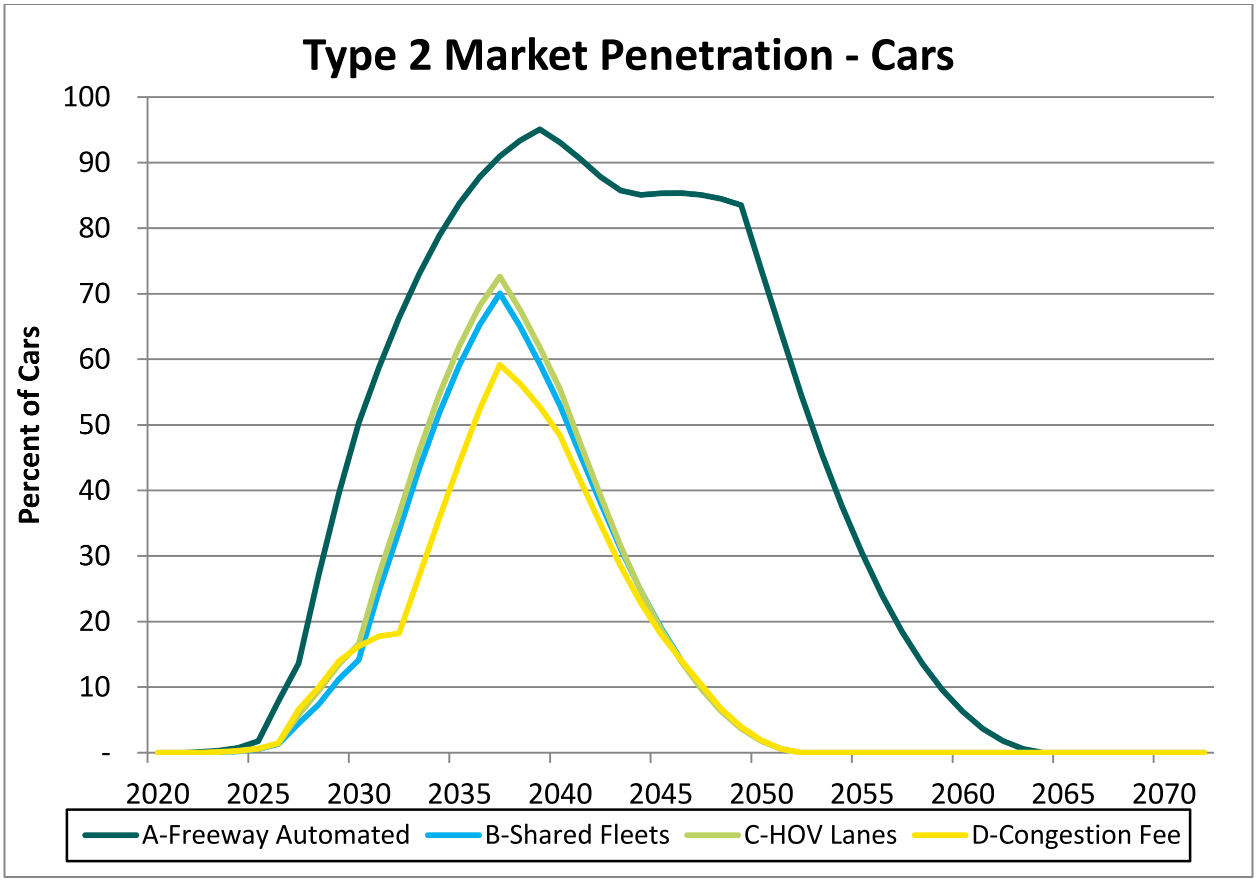
Jurisdiction	Households	Population	Retail Jobs	Office Jobs	Total Jobs
DC	454,727	1,085,366	114,794	834,122	1,045,390
Montgomery	470,927	1,247,014	109,826	407,725	678,753
Prince George's	381,498	1,007,574	96,170	91,024	402,145
Arlington	144,681	307,238	39,899	182,776	269,064
Alexandria	109,851	213,782	25,472	105,730	155,095
Fairfax County	538,396	1,444,017	123,417	654,016	889,863
Fairfax City	13,720	35,802	7,114	13,964	23,429
Falls Church	8,420	18,071	6,353	6,666	18,600
Loudoun	170,160	511,783	59,825	115,571	291,165
Other MD	432,636	1,134,176	134,807	302,745	688,052
Other VA	862,567	2,364,592	296,357	319,595	992,447
Total	**3,587,583**	**9,369,415**	**1,014,034**	**3,033,934**	**5,454,003**

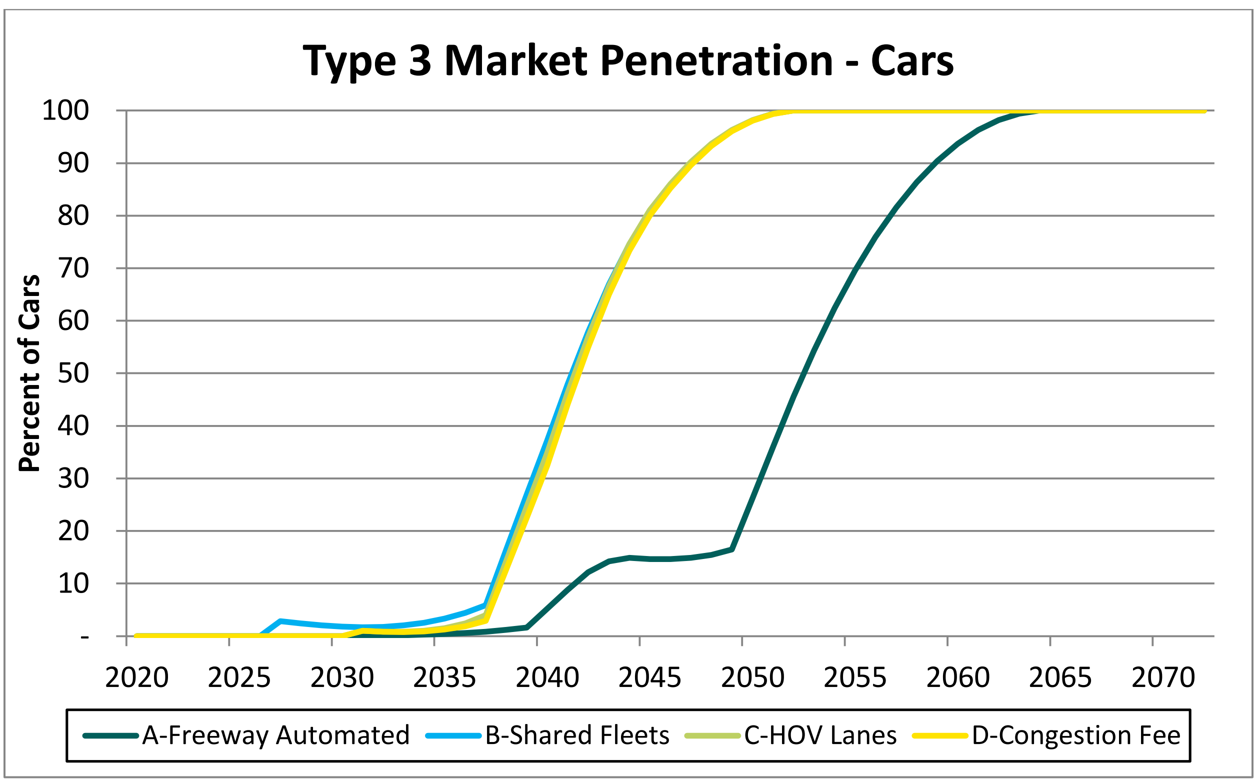
3.6 Scenario Comparisons

The following graphs highlight the differences between the assumptions for each of the four AV Scenarios for three categories.

3.6.1 Technology Adoption

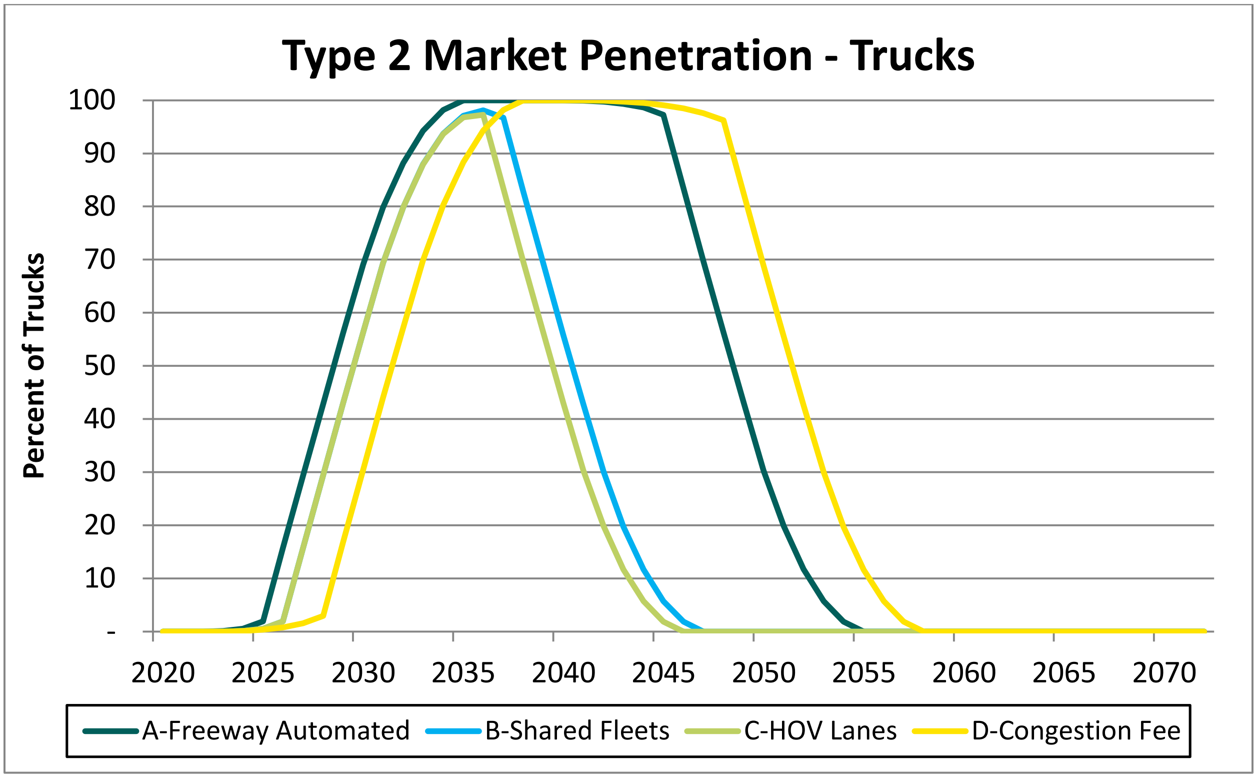
The following graphs compare the AV adoption rates for Type 2 and Type 3 car, identified as light-duty passenger or delivery vehicles.

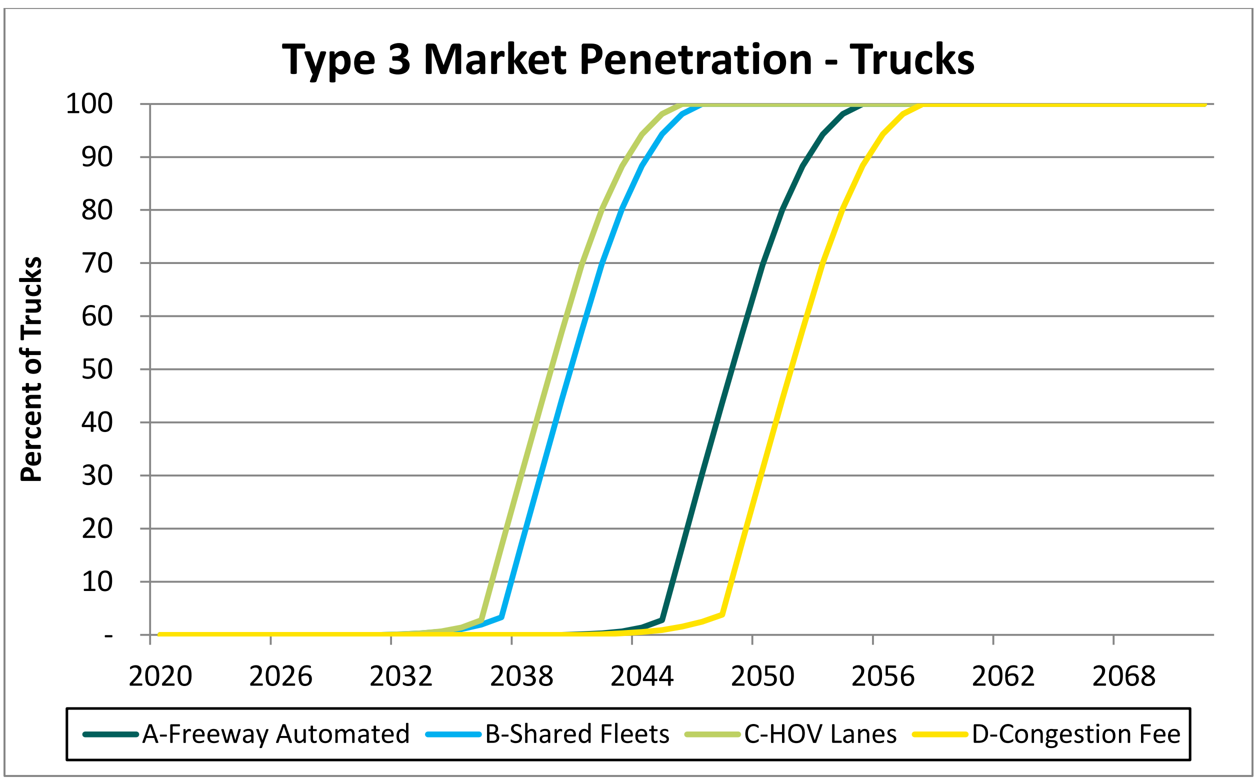

Type 2 Market Penetration - Cars
Percent of Cars
100
90
80
70
60
50
40
30
20
10
-
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
A-Freeway Automated
B-Shared Fleets
C-HOV Lanes
D-Congestion Fee


Type 3 Market Penetration - Cars
Percent of Cars
100
90
80
70
60
50
40
30
20
10
-
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
A-Freeway Automated
B-Shared Fleets
C-HOV Lanes
D-Congestion Fee

3.6.2 Freight

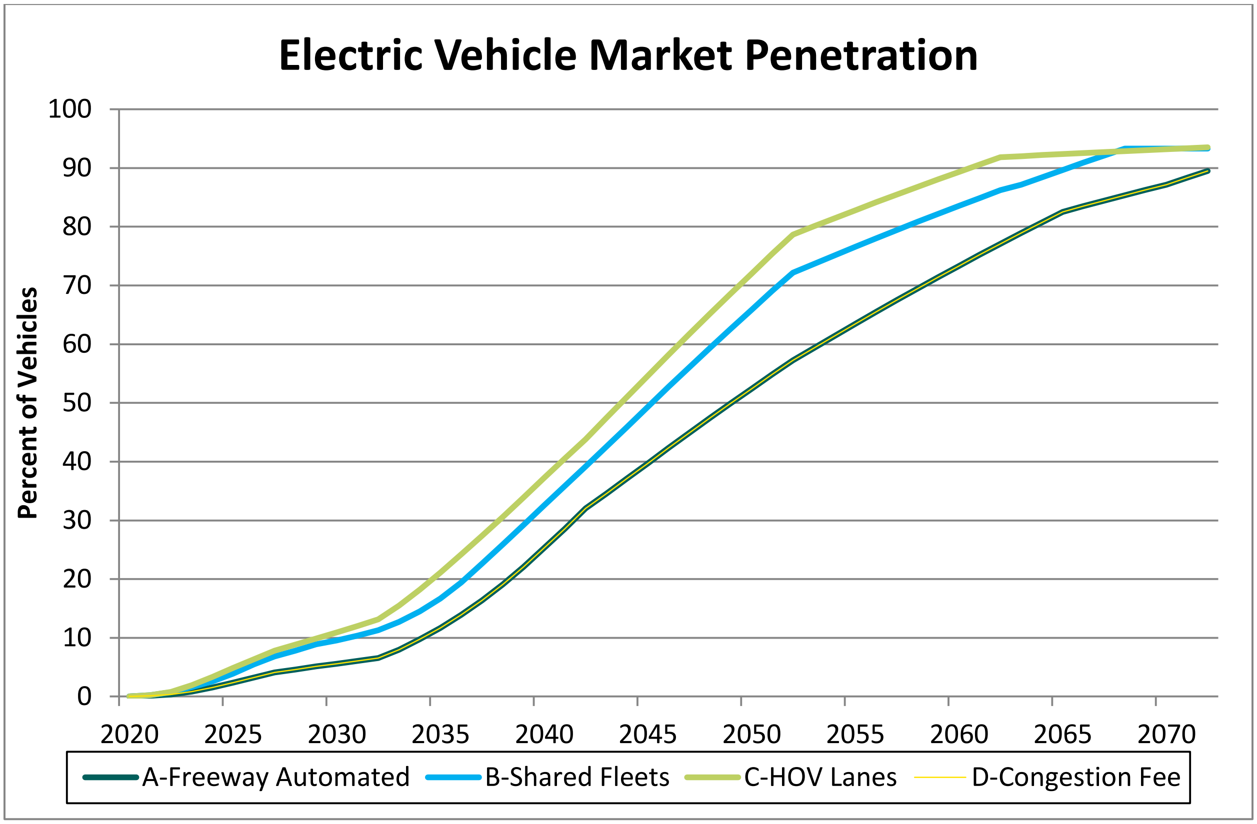
The market penetration rates assumed for heavy trucks are shown in the graphs below.





3.6.3 Electrification

Scenario C has the most aggressive electrification assumptions. Scenarios A and D have identical assumptions in this category.



4.0 SCENARIO RESULTS

The impacts of AVs in each of the scenarios described in Section 0 were analyzed across a number of performance metrics that highlight the many different ways that AVs could impact the District. These performance metrics have been grouped into five broad categories for discussion:

1. Transportation Performance Impacts
2. Transportation System Impacts
3. Environmental Impacts
4. Safety Impacts
5. Economic and Financial Impacts

The sections below highlight the key results for these performance metrics for the District; additional details at the Planning Area level can be found in Appendix A.

It is important to remember that while the four scenarios studied reflect a range of reasonably possible potential futures, they do not reflect all possible futures. They were selected to illustrate reasonable scenarios that could evolve if current District and federal policies are maintained. It is also important to note that even if the findings indicate the magnitude of a given metric is similar across all four scenarios, it does not mean that this outcome is certain in all potential futures with AVs. Public policy decisions will likely influence whether the variables in question would remain within the range studied here or deviate significantly.

In the following sections, performance metrics are shown for each of the four AV Scenarios and for MWCOG forecasts for the region. The MWCOG forecasts are developed through 2045 using the MWCOG/TPB regional travel demand forecasting model and the Round 9.1 Cooperative Land Use Forecasts. These forecasts do not include any direct assumptions about AVs, CVs, or other emerging transportation technologies, as outlined in Appendix C. MWCOG does not currently forecast past 2045. For the purposes of comparison, results after 2045 are estimated assuming that growth in the region continues at the same average rate as from between 2020 through 2045.

4.1 TRANSPORTATION PERFORMANCE METRICS

The performance of the District's transportation system is quantified in two sets of metrics in this section. Miles of Travel, both for people and for vehicles, is a metric used to quantify the amount of travel occurring on DC's transportation network, including all types of vehicles and non-motorized travel. Vehicle Miles of Travel (VMT) is usually closely associated with congestion levels. However, due to the potential for AVs and other technologies to mitigate congestion while increasing the amount of vehicle travel, these metrics are presented separately in this section.

4.1.1 Miles of Travel

The metrics in this category quantify the amount of travel occurring on the District's transportation network and include all modes of travel unless otherwise noted. These metrics are important to understanding how much travel is occurring, and increases can represent improved mobility and/or to increases in people's desire to travel to and in Washington, DC. Increases in miles of travel can also reflect increases in the distance people are willing to travel. Increases in travel in the District can often be good for the economy, as more travel in DC may represent more spending on goods and services in DC. However, there may be downsides to increased travel, especially when those increases are caused by changes such as people commuting longer distances each day. Other externalities caused by increasing travel, such as vehicle emissions and congestion, are discussed separately.

Total Vehicle Miles Traveled (VMT)

The total Vehicle Miles of Travel (VMT) in the District on an average weekday is shown over time in Figure 4-1. This represents travel occurring within the District's borders, no matter where the traveler lives. All of the scenarios show an increase in VMT in the long term over the existing conditions, including the MWCOG regional forecasts. Some of this increase is due to population growth in DC and the surrounding region, and as noted in Section 3, Scenarios B, C and D include 100,000 more households in the region than the MWCOG forecasts and Scenario A. Several of the AV Scenarios show a decrease in VMT in the short-term (before 2030) as compared to the MWCOG forecast, as ridesourcing and ridesharing actually dampen demand for vehicle travel somewhat.

Scenario D shows the most pronounced decrease in VMT beginning in 2025 with the assumed implementation of congestion fees. These fees encourage people to share rides or shift to transit, significantly decreasing VMT. While VMT does rebound and continue to grow as the regional population grows, Scenario D has the lowest VMT of any of the AV Scenarios tested. Scenario B results in the highest VMT, as people rely on shared AV fleets for almost all of their mobility needs, often replacing travel in larger transit vehicles with travel in smaller ridesourcing vehicles. More VMT is therefore required to serve the same number of trips. The growth in VMT in Scenario A is somewhat delayed compared to the other AV Scenarios due to the delayed introduction of full automation in this scenario, and the lower overall regional and DC population.

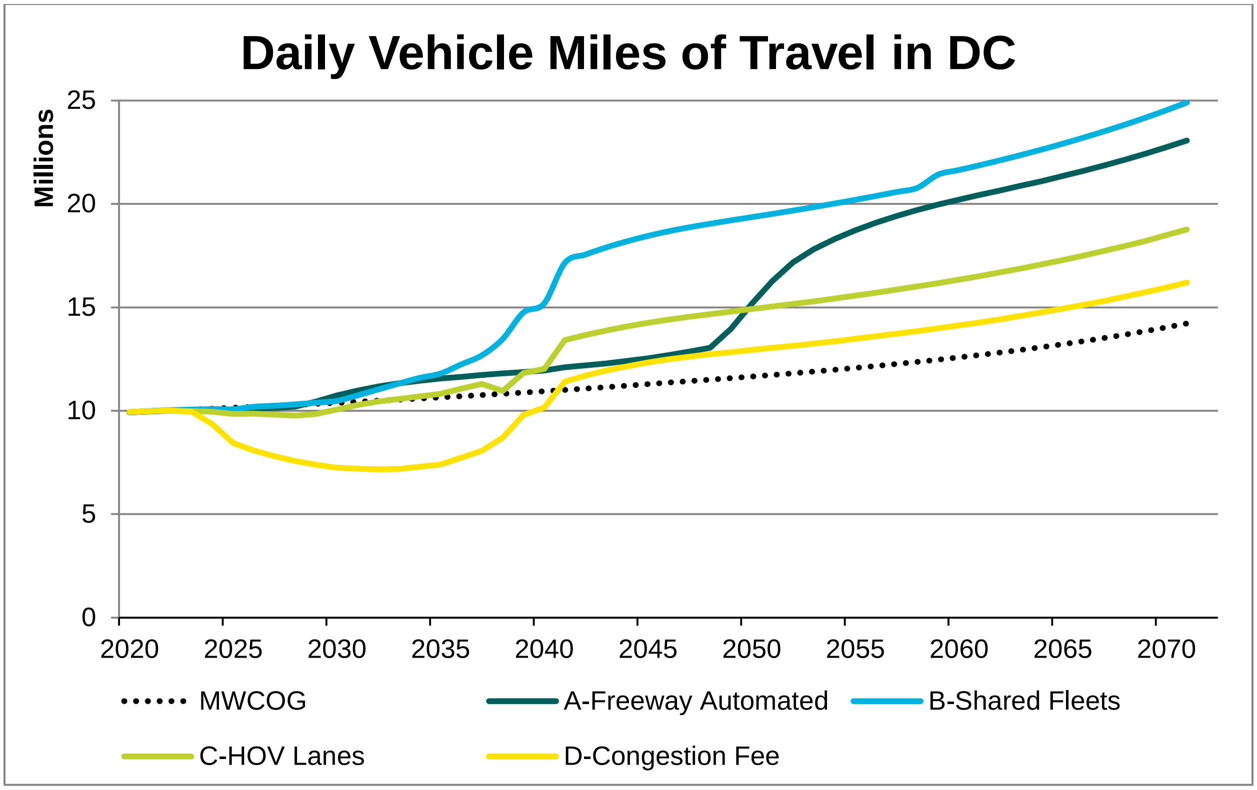


Figure 4-1: VMT in DC

Details about VMT growth in each of the District's Planning Areas can be found in Appendix A. As a snapshot, Table 4-1 highlights the growth in VMT by Planning Area comparing 2045 to existing conditions. The largest increases in VMT occur in Lower Anacostia Waterfront & Near Southwest, where the largest amount of growth is forecast to occur. Scenario C shows the largest increases in VMT occur in the Planning Areas east of the Anacostia, led more by through traffic. These Planning Areas currently have the highest levels of low income and minority populations in the District and could face a larger increase in VMT than other parts of the District if other actions are not taken. These increases would be caused both by new vehicle travel generated by planned growth in these areas (particularly true in Lower Anacostia Waterfront & Near Southwest) and growth in travel through these areas by other residents of the region.

It should be noted that the Planning Areas vary considerably in size, and therefore the total VMT is not directly comparable across Planning Areas. A map of the Planning Areas can be found in Appendix A.

Table 4-1: Existing VMT and Growth by Planning Area

Planning Area	2019 Existing Conditions VMT	Growth Over Existing Conditions			
		A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Central Washington	2,001,000	29%	96%	39%	29%
Near Northwest	853,000	33%	104%	38%	31%
Rock Creek West	1,331,000	16%	63%	32%	8%
Rock Creek East	871,000	17%	69%	40%	14%
Mid-City	527,000	25%	87%	38%	24%
Upper Northeast	1,157,000	25%	82%	48%	23%
Far Northeast and Southeast	1,125,000	23%	74%	50%	18%
Capitol Hill	575,000	31%	96%	47%	29%
Lower Anacostia Waterfront & Near Southwest	633,000	39%	108%	52%	40%
Far Southeast & Southwest	851,000	28%	77%	53%	26%
DC Total	**9,925,000**	**26%**	**84%**	**43%**	**23%**

VMT per Capita

To help account for some of these differences in regional population, Figure 4-2 shows the VMT per DC resident in each of the Scenarios. This is not necessarily the amount of VMT generated by each District resident, as a significant amount of vehicle travel may be generated by people who live outside DC traveling within its boundaries. The differences between this metric and the total VMT shown in the previous figure are significant. While total VMT in the long-term is highest under Scenario B, when normalized to account for changes in population, Scenario A actually has the highest VMT per capita over much of the future, as longer-distance commutes and long-distance empty vehicle relocations combine with lower population levels than the other scenarios. Scenarios B, C and D all show decreases in per capita VMT from their peaks, once high levels of AV market penetration are reached after 2045.

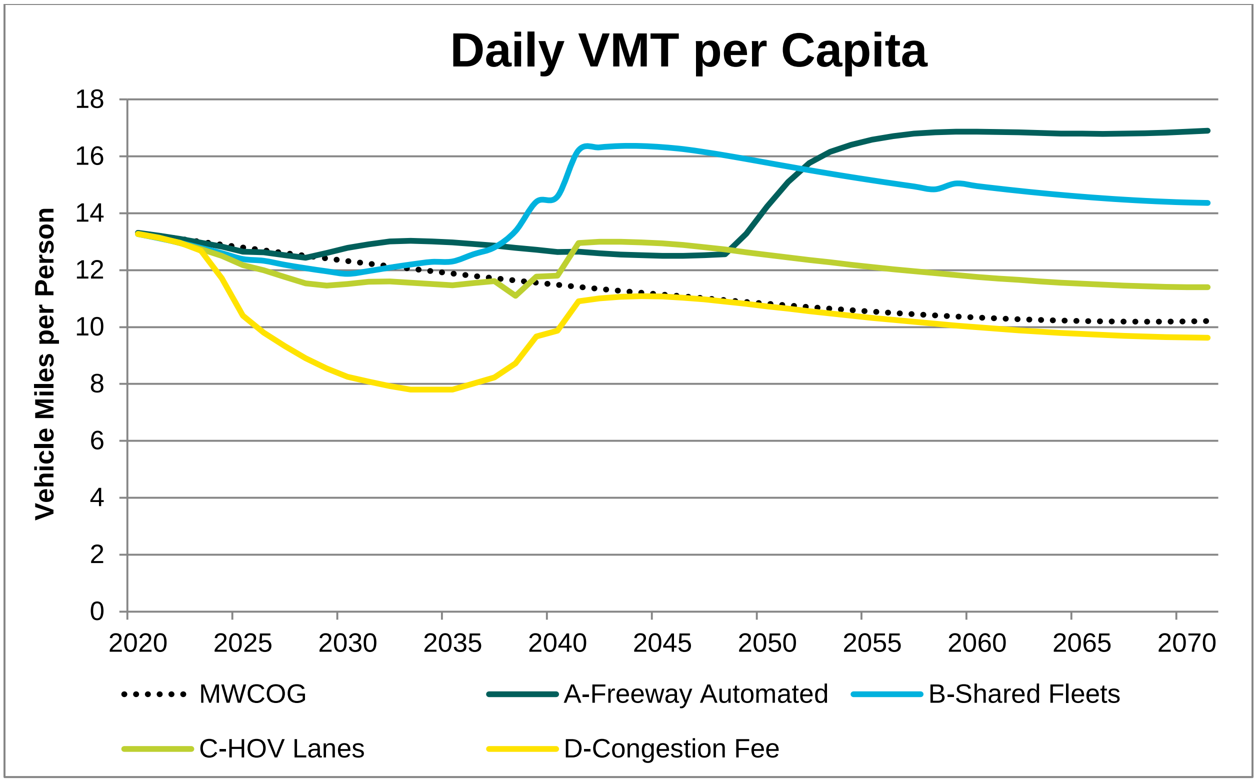


Figure 4-2: DC VMT per Capita

Person Miles Traveled (PMT)

Person Miles Traveled (PMT) is a measure of mobility which includes travel by all modes by calculating the miles traveled by all people. That means that 20 people traveling one mile in a bus would not be counted as a single VMT, but as 20 PMT. Figure 4-3 shows how PMT in DC is forecast to change over time based on the AV Scenarios. All four AV Scenarios show higher levels of PMT than the MWCOG forecasts after 2040, and the estimates of its growth after 2045. This indicates more travel, activity, and mobility in the District. This would likely prove beneficial for the District's economy, as more activity generally equates to increased spending. PMT grows faster in all scenarios than VMT, indicating that vehicle travel is occurring more efficiently in DC, with more people in each vehicle.

Scenario B includes the highest levels of PMT in the District; Scenario A shows high PMT in the long-term as well, especially when considering that the regional and District populations are lower in Scenario A than in Scenario B. In Scenario D, the regional congestion fee appears to have some impact on personal mobility in the District by discouraging travel to limit congestion. Not all of the decrease in PMT necessarily represents lost economic activity, since Scenario D does include stronger assumptions about telework, which would decrease commute travel without impacting employment levels.

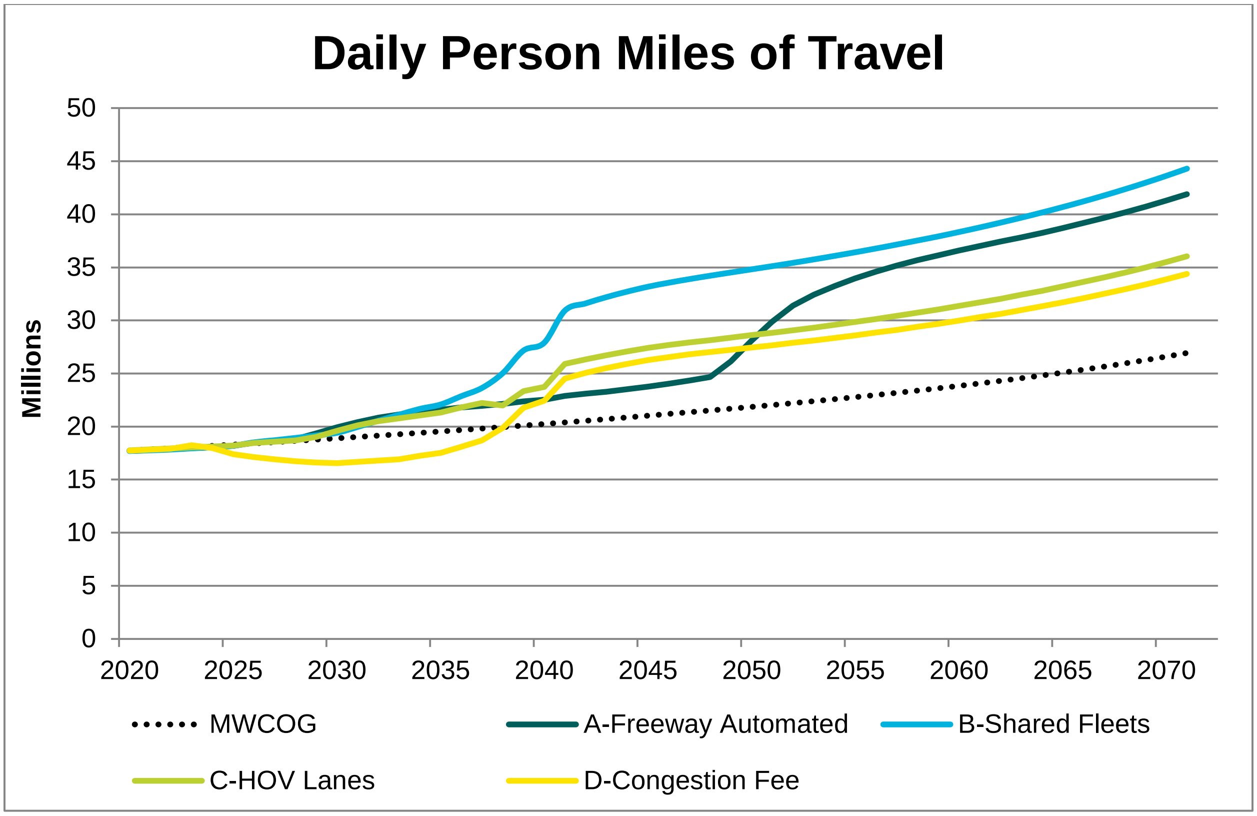


Figure 4-3: PMT in DC

Vehicle Miles Travel on Freeways

Freeways make up a relatively small portion of VMT in the District, currently accounting for just over 10.5 percent, as freeways also make up a small portion of total road-miles in the District. None of the scenarios cause a major change in this metric, although there is a general trend towards a higher portion of VMT on freeways. The congestion fee in Scenario D causes a short-term decrease in VMT on freeways, but this trend reverses in the longer term as congestion pricing limits the total amount of traffic on the District's roads. Scenario B results in the lowest proportion of VMT occurring on freeways. These results are only shown for roadways in the District in Figure 4-4; the results are different when considering the region as a whole, particularly for Scenario A which sees a larger percent of VMT on freeways in the region.

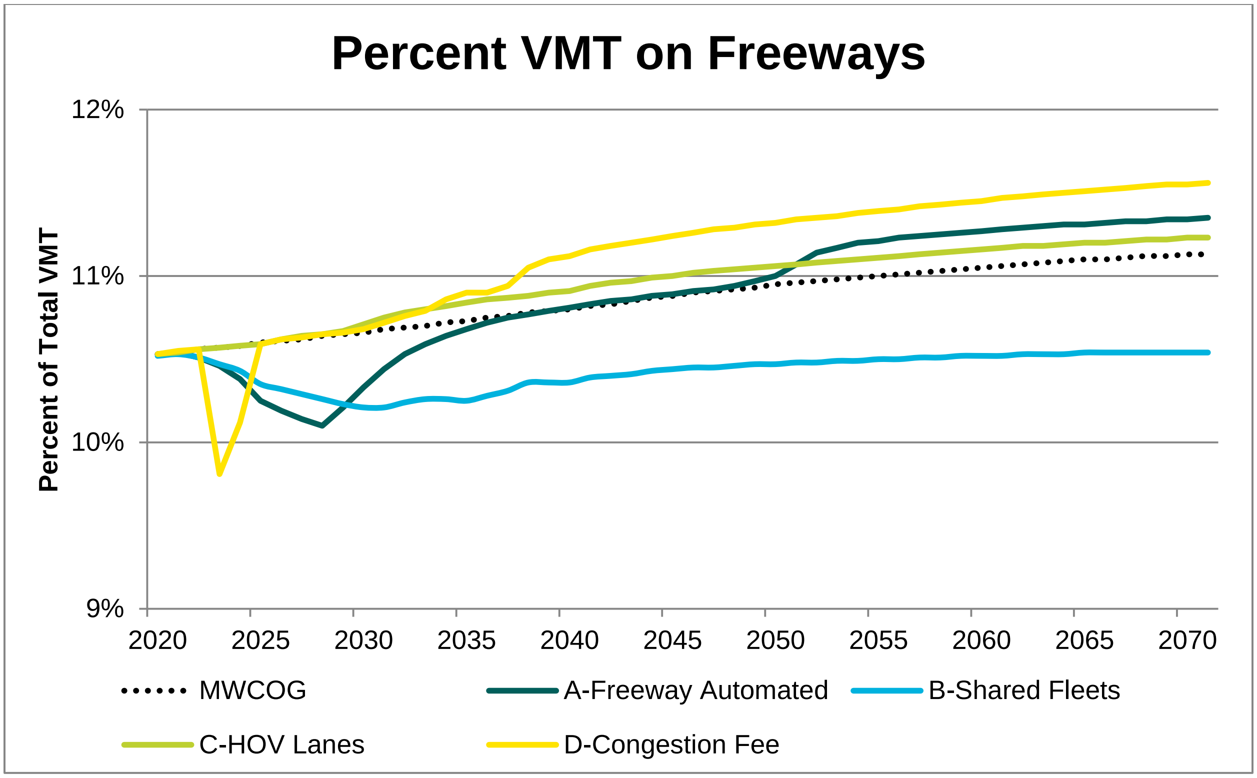


Figure 4-4: Percentage VMT on freeways

VMT by Household-Owned Vehicles

While the total VMT in the District is estimated to grow in the long term, only some of that VMT is expected to occur in vehicles that are owned by households (as opposed to shared vehicles). All four AV Scenarios show a decrease in VMT for household owned vehicles in the medium-term (through at least 2037), a trend which echoes the increase in VMT from ridesourcing vehicles that can already be observed, even if it is not represented in the MWCOG regional forecasts. In the long term, the total VMT driven by household-owned vehicles does increase, but at a lower rate than total VMT. Ultimately, only around 60 percent of VMT will be driven by household owned vehicles in Scenarios A, C, and D. Less than 50 percent of VMT in the District will be driven by household owned vehicles in Scenario B, where far more people rely on shared vehicle fleets. The variation between the AV Scenarios shown in Figure 4-5 are primarily due to variation in the overall VMT total in the District, as previously shown in Figure 4-1.

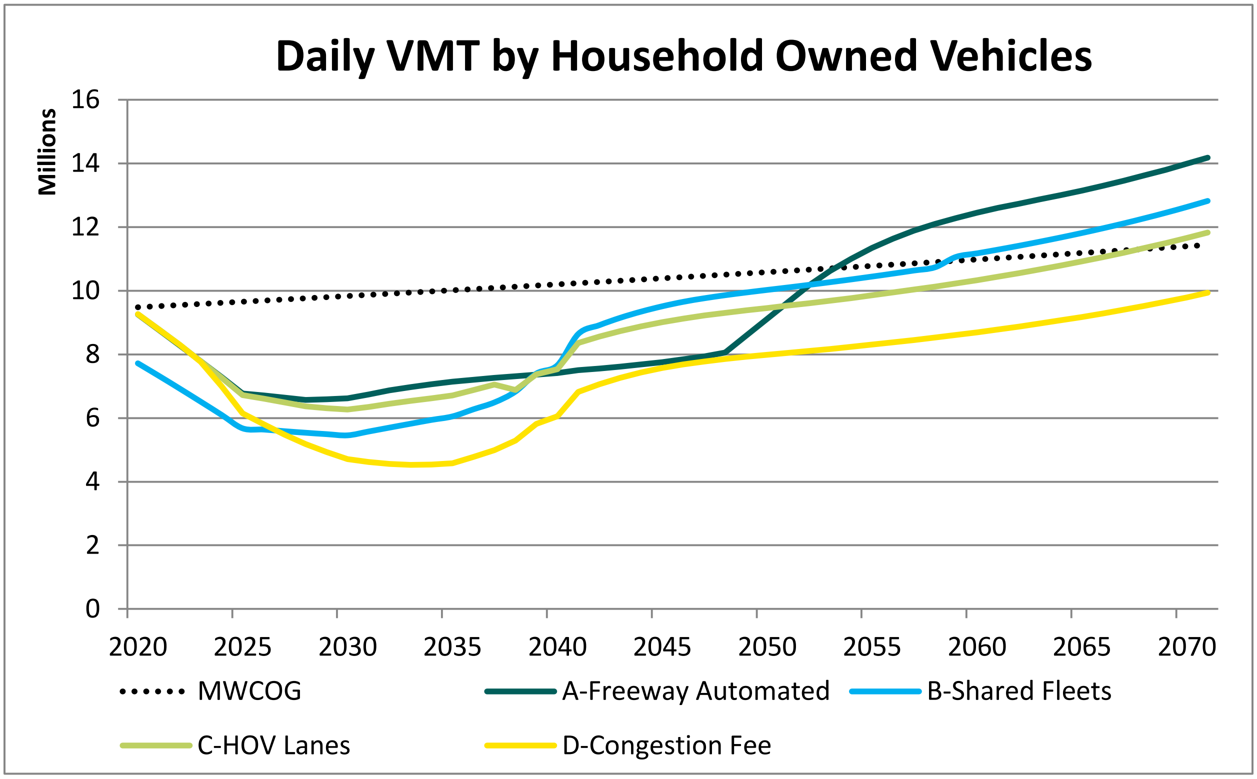


Figure 4-5: VMT by Household-owned vehicles

VMT in the Peak Periods

Currently, 45 percent of daily VMT occurs during the peak periods. Peak period VMT is a more likely indicator of congestion than total VMT. As shown in Figure 4-6, VMT is growing faster in the off-peak periods than during the peak. This growth in off-peak period VMT is attributed to a number of factors including a rise in delivery traffic, empty vehicle relocations, and travelers switching to vehicles from transit. The most off-peak period VMT growth occurs in Scenario B and C. However, because total VMT grows in the future, the total peak period VMT actually increases, as shown in Figure 4-7. Total VMT in Scenario B is by far the highest of the four AV Scenarios. Even though the majority of this increase occurs during the off-peak, VMT in the peak also increases significantly, resulting in the highest peak period VMT in Scenario B. The congestion fees in Scenario D, which are implemented wherever and whenever severe congestion occurs, have impacts on VMT during both the peak and off-peak periods, resulting in the lowest peak period VMT along with the lowest total daily VMT.

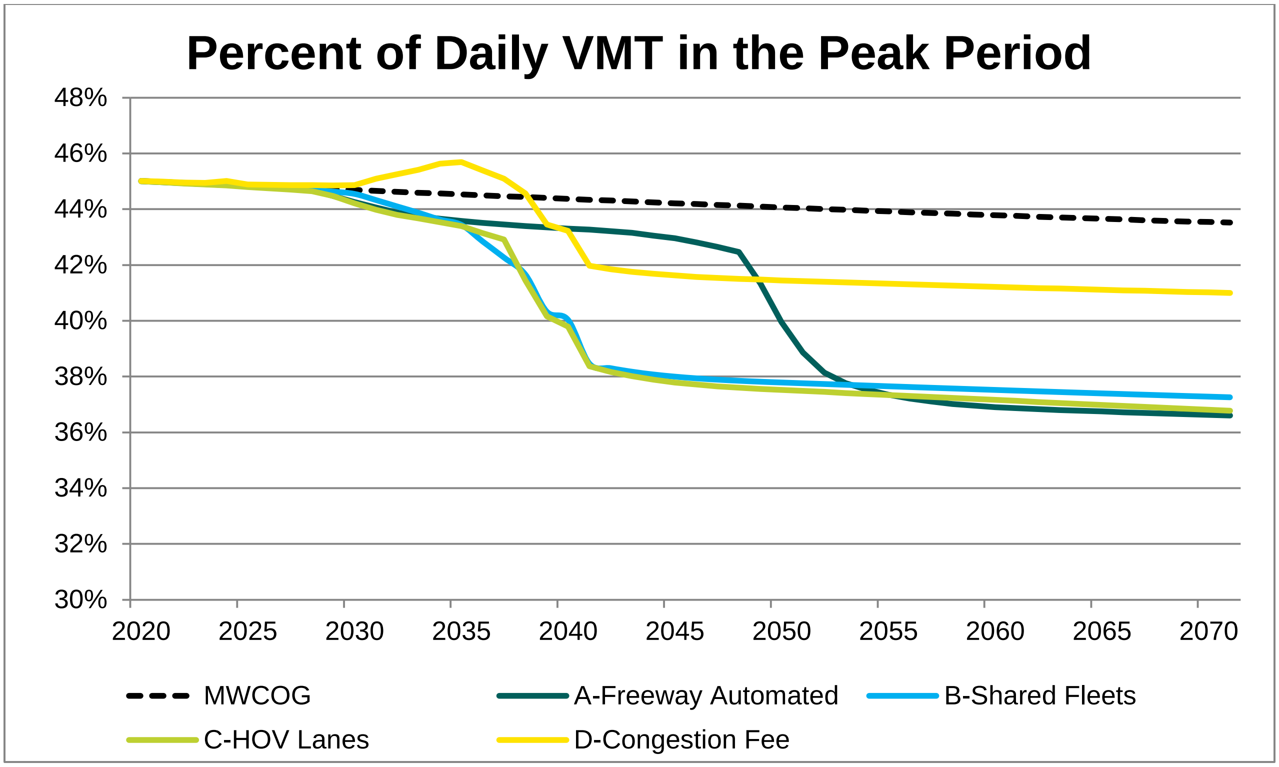


Figure 4-6: Percentage of Daily VMT occurring in the Peak Period

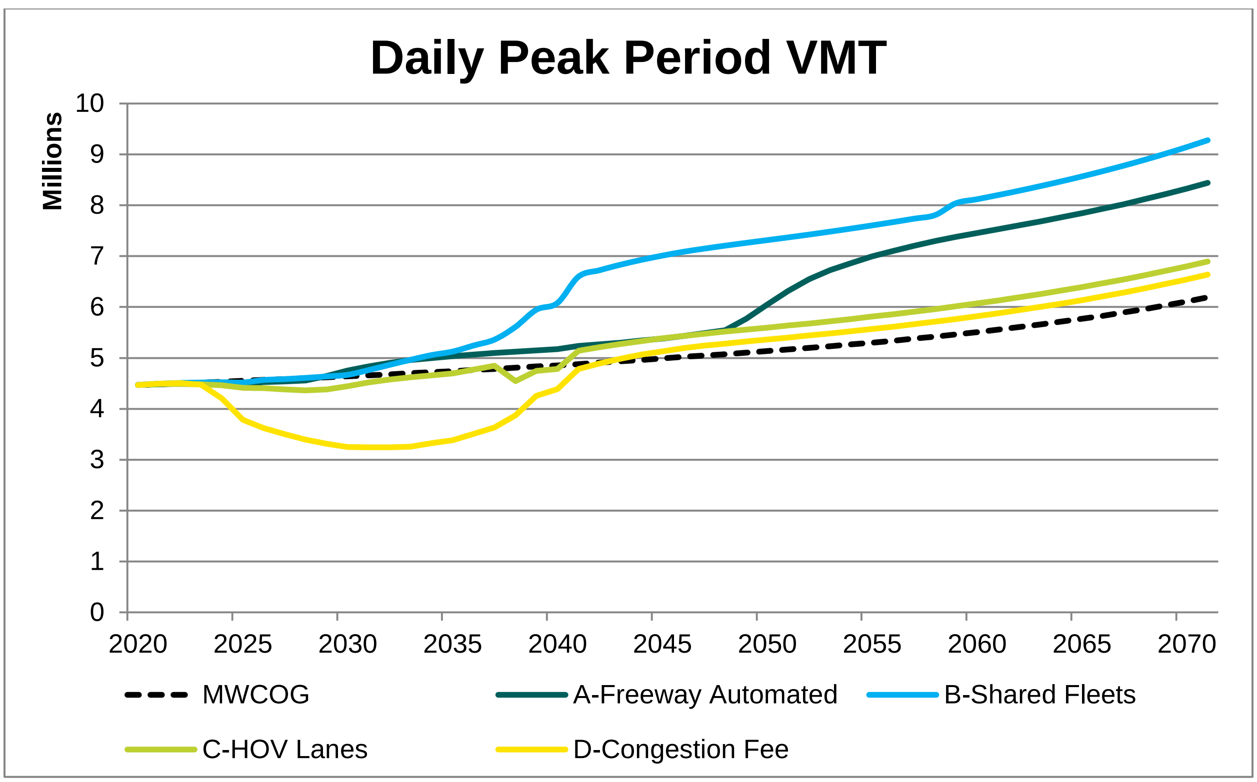


Figure 4-7: Peak Period VMT

Freight VMT

Figure 4-8 shows the VMT of heavy trucks in the District. As shown, all the AV Scenarios result in a long-term increase in freight traffic as population and economic activity in the region grows and AVs make trucks increasingly competitive for shipping and deliveries. Scenario D does result in a decrease in freight VMT through 2040, as congestion fees stem increases to freight demand.

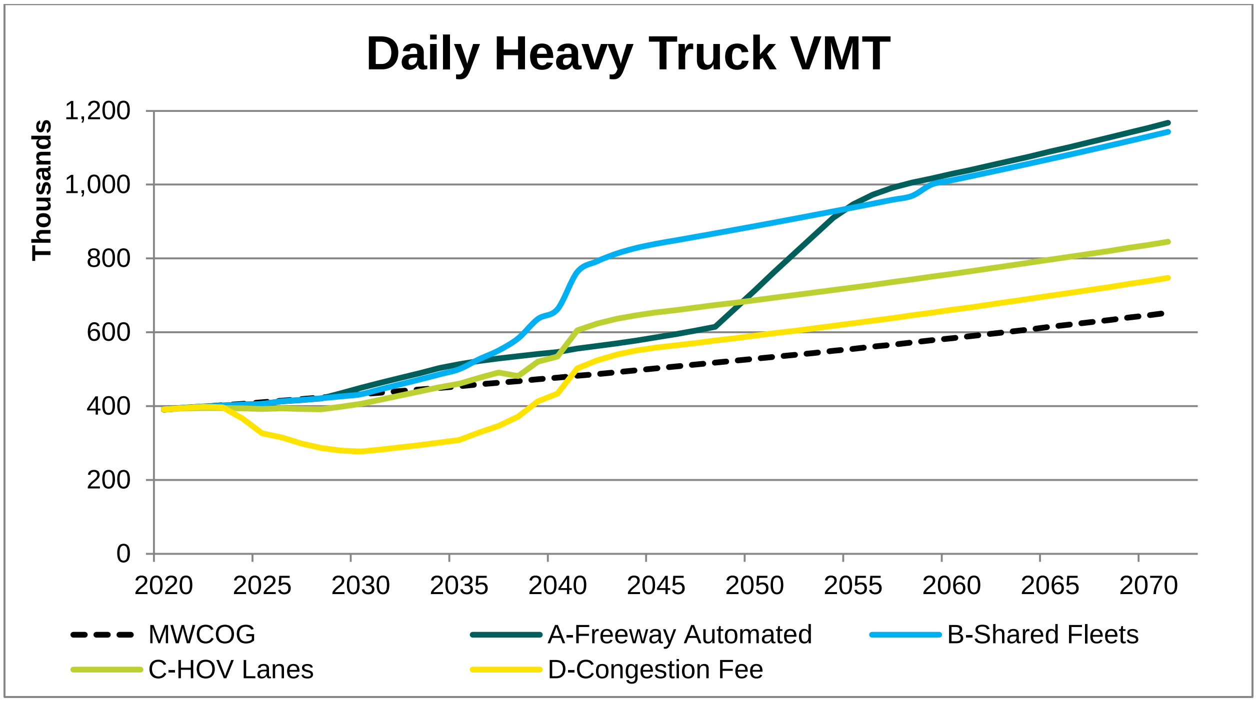


Figure 4-8: Freight VMT

4.1.2 Congestion

Congestion is one of the major impacts of vehicle miles traveled, because the more vehicles that use our roads, the more congested they become. For that reason, forecasts and planning studies often focus solely on VMT as a proxy for measuring congestion. Congestion does not grow linearly with increases in VMT, particularly on streets that are already busy; and an increase in VMT will result in a more than proportional increase in congestion. The AV Scenarios envisioned involve a number of changes that mean that VMT and congestion will no longer track together in the same way in the future. Changes to how many vehicles a lane is able to carry would mean higher traffic throughput and less delay without changes to the number of lanes. Additionally, the behavior of empty AVs would be different than that of people and is more likely to occur in off-peak periods and/or off-peak directions as discussed in Section 4.1.1. This increase in off-peak period vehicle travel is likely to be less congested than a similar increase in peak period vehicle travel.

For these reasons, congestion is measured directly in this section and is one of the key performance metrics for each of the AV scenarios. Congestion is quantified using Person Hours of Delay (PHD) or the amount of time people spend traveling above free-flow time. (For example, if it would take 10 mins to make a trip in uncongested conditions and 25 minutes in traffic, the delay is 15 minutes.) As a metric, PHD inherently places value only on the delay experienced by people and does not consider the impact of congestion on empty vehicles.

Total Person Hours of Delay (PHD)

PHD in the District is measured as the delay experienced by people traveling on all modes on roadways within the District. As indicated Figure 4-9, PHD is anticipated to increase as AV technologies become more ubiquitous over time and the region grows in population and VMT. Scenario A and B show the highest congestion levels in the long-term, related to the large VMT increases forecast in those scenarios. Scenario D does the most to limit the growth of congestion in the District, as the congestion fee policy actively works to remove large amounts of delay by shifting travelers to other modes, time periods, or eliminating trips altogether.

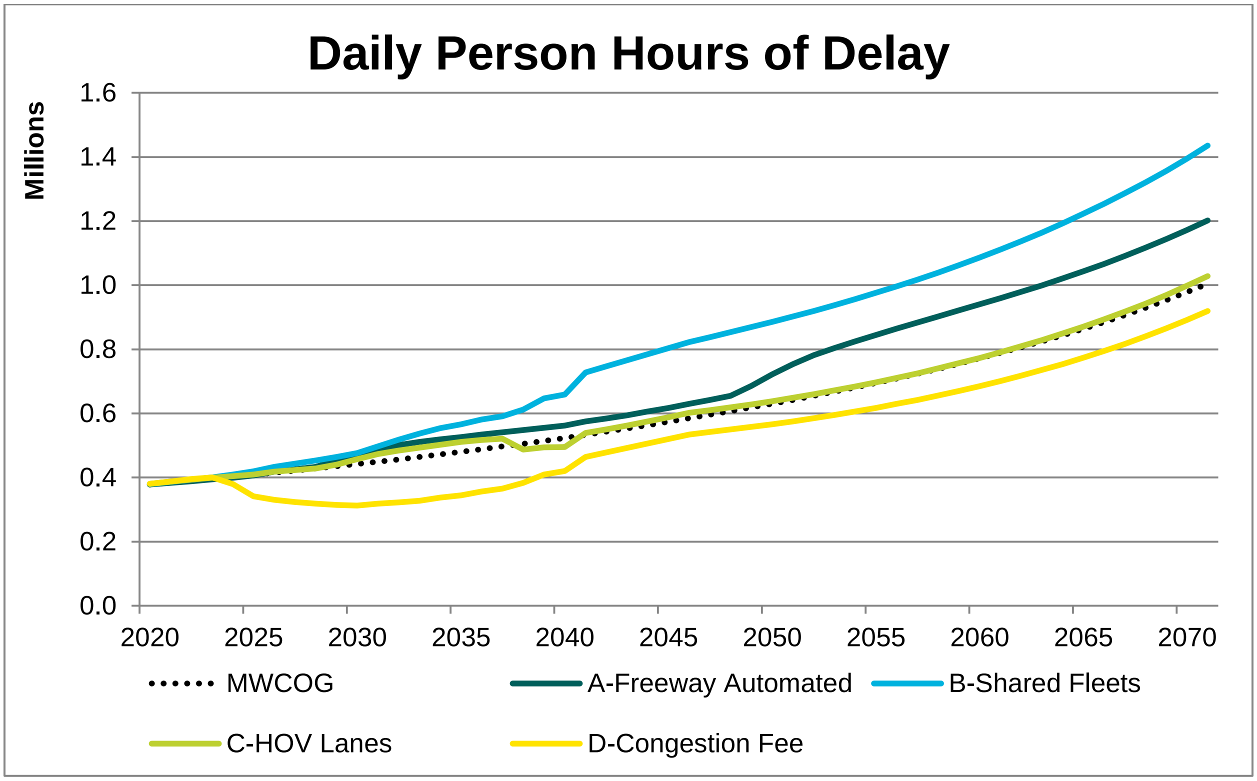


Figure 4-9: Person Hours of Delay

While congestion and VMT are closely related, there is a non-linear relationship between these two metrics. For example, MWCOG forecasts a 14 percent increase in VMT by 2045, with a 52 percent increase in congestion. This indicates that congestion grows almost four times faster than VMT. In all four AV Scenarios, PHD grows more quickly than VMT, as shown in Table 4-2. However, the ratio between PHD growth and VMT growth is smaller in all four AV Scenarios than in the MWCOG forecasts. This illustrates that any increase in VMT adds proportionally less congestion under the AV assumptions due to the assumed increases in roadway carrying capacity and the fact that VMT is being added during off-peak periods and/or off-peak directions where there is less congestion. This is especially true for Scenarios B and C, which include the lowest portion of peak-period VMT (shown earlier in Figure 4-7) and are therefore able to accommodate the increased VMT with relatively low increases in congestion.

Table 4-2: Comparison of Growth in VMT and congestion in 2045

	VMT Growth	PHD Growth	Growth Ratio PHD/VMT
Scenario A: Freeway Automated	26%	63%	2.41
Scenario B: Shared Fleets	86%	112%	1.30
Scenario C: HOV Lanes	43%	55%	1.26
Scenario D: Congestion Fee	24%	37%	1.53
MWCOG	14%	52%	3.76

Table 4-3 presents the change in PHD by Planning Area comparing 2045 to existing conditions. In all of the AV Scenarios, the greatest increase in congestion occurs in the Lower Anacostia Waterfront & Near Southeast Planning Area, which also has the highest increase in population and VMT, along with high growth in employment. The congestion fees in Scenario D actually decrease congestion compared to existing levels in Rock Creek East and Far Northeast & Southeast. Several Planning Areas (highlighted in orange) show less increase in congestion than what would be expected under the MWCOG forecasts, particularly when the interventions in Scenarios C and D are implemented.

Table 4-3: Person Hours of Delay Percent Growth by Planning Area in 2045

Planning Area	Existing	Percent Growth - Existing Conditions to 2045				
		MWCOG	Scenario A	Scenario B	Scenario C	Scenario D
Central Washington	43,800	51%	58%	144%	72%	51%
Near Northwest	25,100	84%	104%	143%	58%	87%
Rock Creek West	45,300	46%	55%	91%	15%	5%
Rock Creek East	51,900	2%	12%	45%	6%	-6%
Mid-City	33,800	30%	57%	95%	40%	41%
Upper Northeast	37,600	78%	85%	176%	94%	83%
Far Northeast & Southeast	44,200	74%	59%	78%	65%	-1%
Capitol Hill	32,200	48%	57%	80%	44%	7%
Lower Anacostia Waterfront & Near Southwest	36,200	76%	119%	177%	99%	90%
Far Southeast & Southwest	27,900	57%	59%	133%	97%	63%
DC Total	**377,900**	**52%**	**63%**	**112%**	**56%**	**37%**

Note: Cells highlighted in orange show less growth in PHD than predicted by the MWCOG forecasts, despite increases in population and VMT.

Person Hours of Delay per Capita

Because each of the scenarios includes different population assumptions, PHD per capita is shown in Figure 4-10. These results show the amount of PHD in the District normalized by DC's population, and includes delay experienced by all travelers using DC's roads, not necessarily the average delay experienced by each resident of the District. (Trip-based measures that illustrate the amount of delay experienced on trips starting in DC can be found in section 4.2.3.) This essentially shows that more people can be accommodated in the region with the same or lower levels of congestion.

As with total PHD, Scenarios A and B result in the highest levels of per capita delay. However, PHD per capita in Scenario A begins to exceed Scenario B by 2054, due to the lower population levels in Scenario A. While congestion will be worse in Scenario B, it is at least in part due to the additional residents that would be living in and around DC. These additional households would bring other economic benefits to the region. On a per capita basis, Scenario D will actually decrease PHD compared to the MWCOG forecasts, with congestion not reaching existing levels until after 2065. Scenario C also manages to achieve only minimal growth in PHD, by encouraging use of high capacity modes.

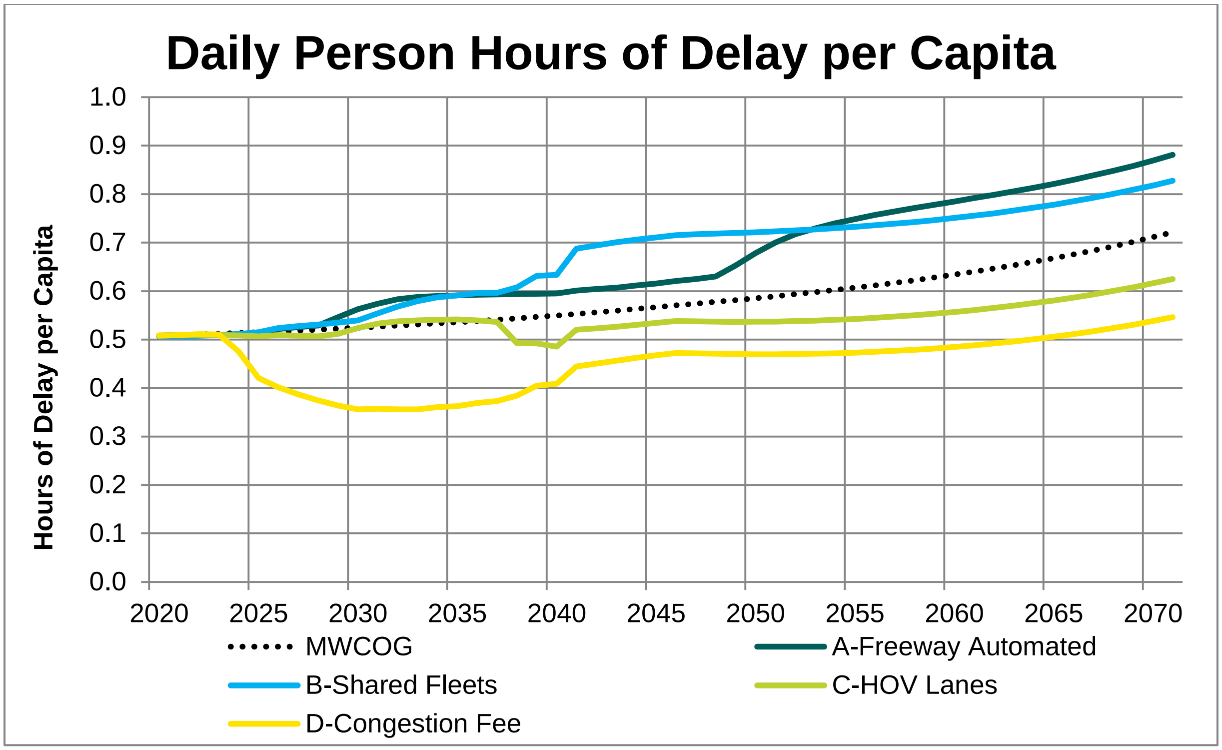


Figure 4-10: Person Hours of Delay per Capita

Congestion in the Peak Periods

Currently, 45 percent of the District's VMT and almost 80 percent of its congestion occur during the peak periods. In all of the AV Scenarios, a larger proportion of daily congestion will occur during the off-peak periods, as shown in Figure 4-11. Three of the scenarios show a significant decrease in the portion of congestion occurring during the peak periods in the long term. Scenario D however, decreases only slightly as the congestion fees equally affect all congestion regardless of time of day. Scenarios B and C experience significant spreading of congestion to the off-peak periods after 2040. The impacts in Scenario A are realized more slowly than the other scenarios, as AV technologies penetrate the market more slowly. The effects are also strongest in Scenario A, as the changes to travel patterns and land use result in longer relocations of empty vehicles, adding congestion during previously uncongested time periods.

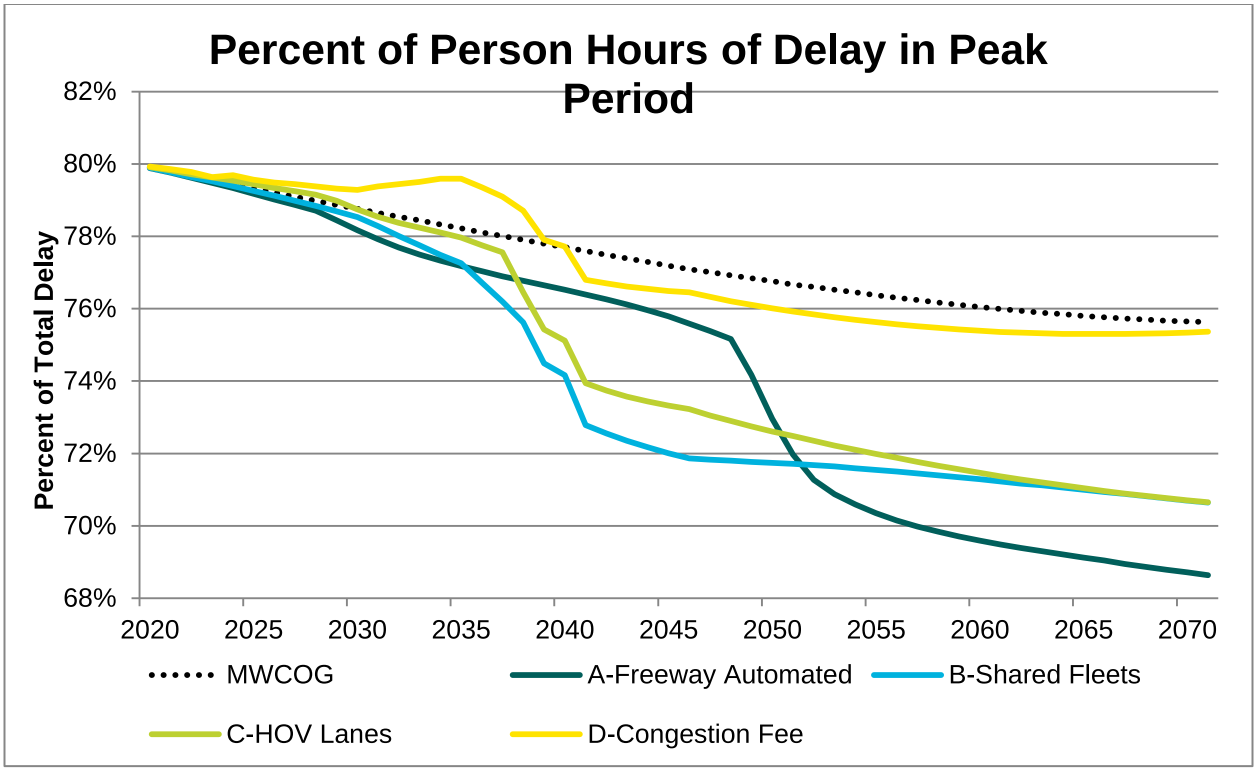


Figure 4-11: Percent of Person Hours of Delay in Peak Period

Delay on Freeways

While just over ten percent of VMT in the District currently occurs on freeways, these facilities only account for approximately 5.5 percent of daily congestion. Figure 4-12 illustrates the percentage of person hours of delay which occurs on freeways. Scenario A shows a significant decrease with the introduction of dedicated AV lanes which improve capacity and decrease delay on freeways. Scenario B also shows a slight decrease as more travel and more congestion shift towards surface streets due to changes in land use and travel patterns.

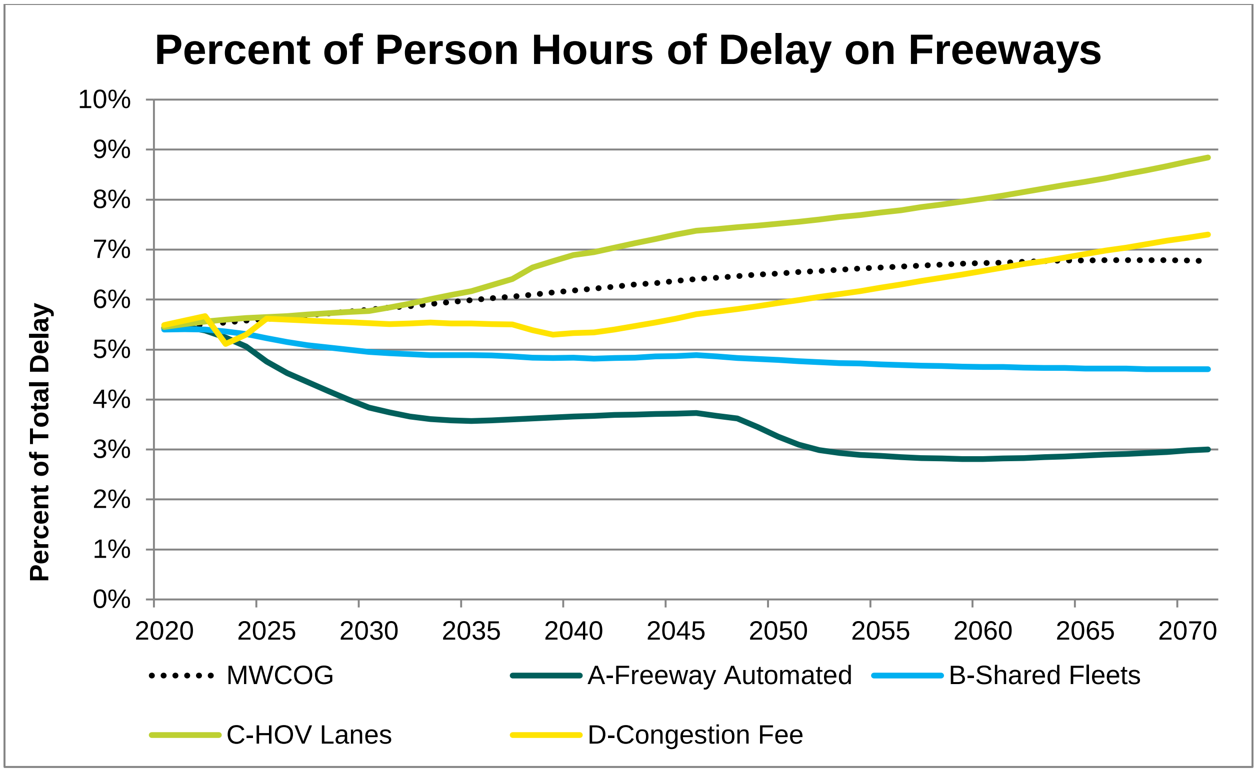


Figure 4-12: Percent of Person Hours of Delay on Freeways

4.2 Transportation System Impacts

This section measures how AVs and other emerging technologies could impact the transportation system. The system impacts are evaluated by three main metric categories: vehicle utilization, vehicle fleet, and trips. Respectively, these metrics address how vehicles are used under each of the AV Scenarios including transit ridership, impacts to the size and composition of the District's vehicle fleet, and impacts to individual trip characteristics, such as trip length and time.

Special consideration must be considered in these metrics for the definition of "transit" in the future. As discussed in Section 0, transit in the future may come to mean many different things, and each of the AV Scenarios analyzed as part of this study may consider a different vision for transit in the future. Transit could include not only the more traditional publicly-operated fixed route service, but also incorporate the evolving business models that include large-scale shared ride options and microtransit, among others. The definition of "transit" in the future is an important conversation that will continue to evolve as technologies and business models are adopted in DC and the surrounding region.

4.2.1 Vehicle Utilization

Average Vehicle Occupancy

The Average Vehicle Occupancy, or the average number of people per vehicle, is shown in Figure 4-13. This metric includes all vehicles, including transit vehicles, passenger cars, and trucks. As shown, all AV Scenarios result in higher vehicle occupancy than under current conditions. Scenarios A, B, and C result in an overall increase to an average vehicle occupancy of over 1.5 by 2055. Scenario D results in the highest average vehicle occupancy over 1.6, a 27 percent increase over existing occupancy levels. Based on these results, the congestion fees in Scenario D prove to be strong enticement encouraging people to share rides. Auto occupancy in Scenario A also increases, as Type 2 freeway automation has very little impact on occupancy in the District, where the majority of the roads are not freeways.

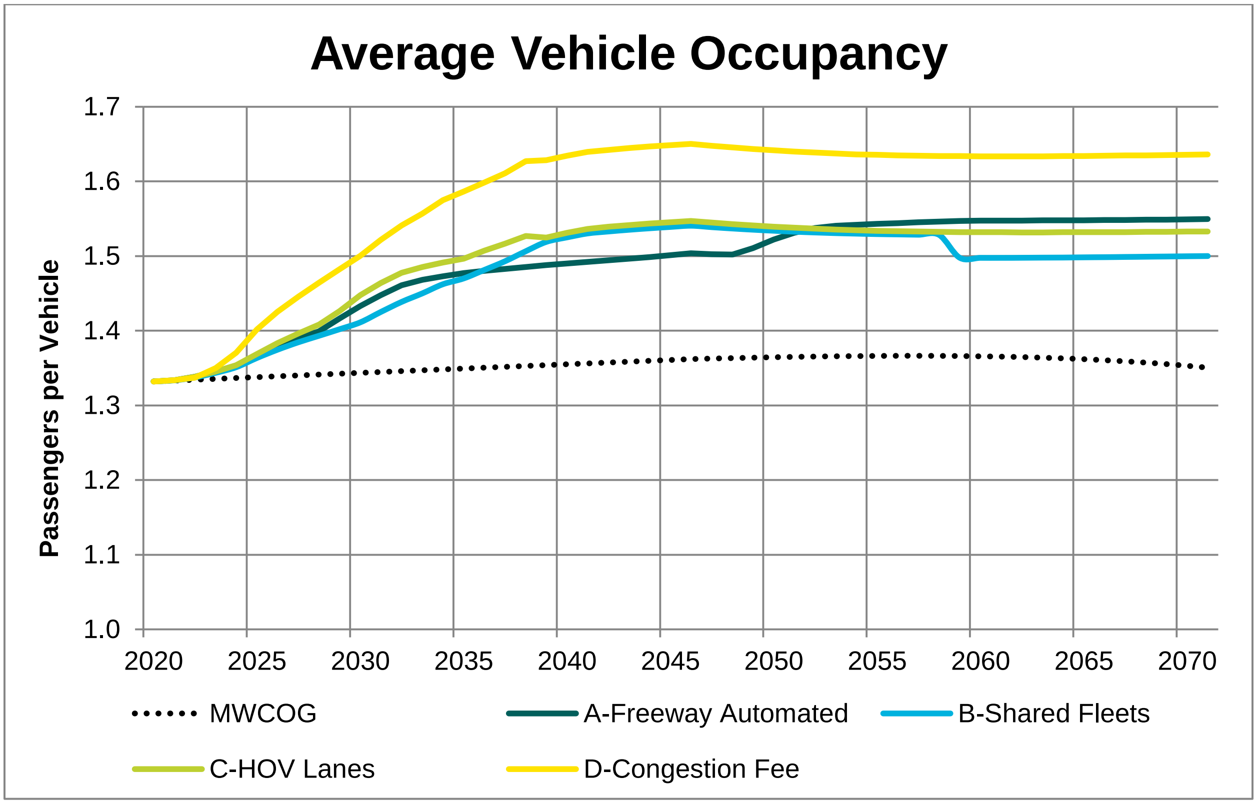


Figure 4-13: Average Vehicle Occupancy

Vehicle Miles Traveled per Vehicle

As shown in Figure 4-14, vehicles not only carry more people in the AV Scenarios, but each vehicle is also driven more under these conditions. Completing more trips with fewer vehicles is a more efficient use of resources. This will in turn allow the District to devote less space to vehicle storage, which is discussed in more detail in Section 4.2.2. Scenario B has the highest vehicle efficiency, due to its heavy reliance on shared vehicle fleets. The decrease in vehicle efficiency seen in the short term of Scenario D is caused primarily by the overall decrease in VMT precipitated by Congestion Pricing; under Scenario D, all vehicles are used less.

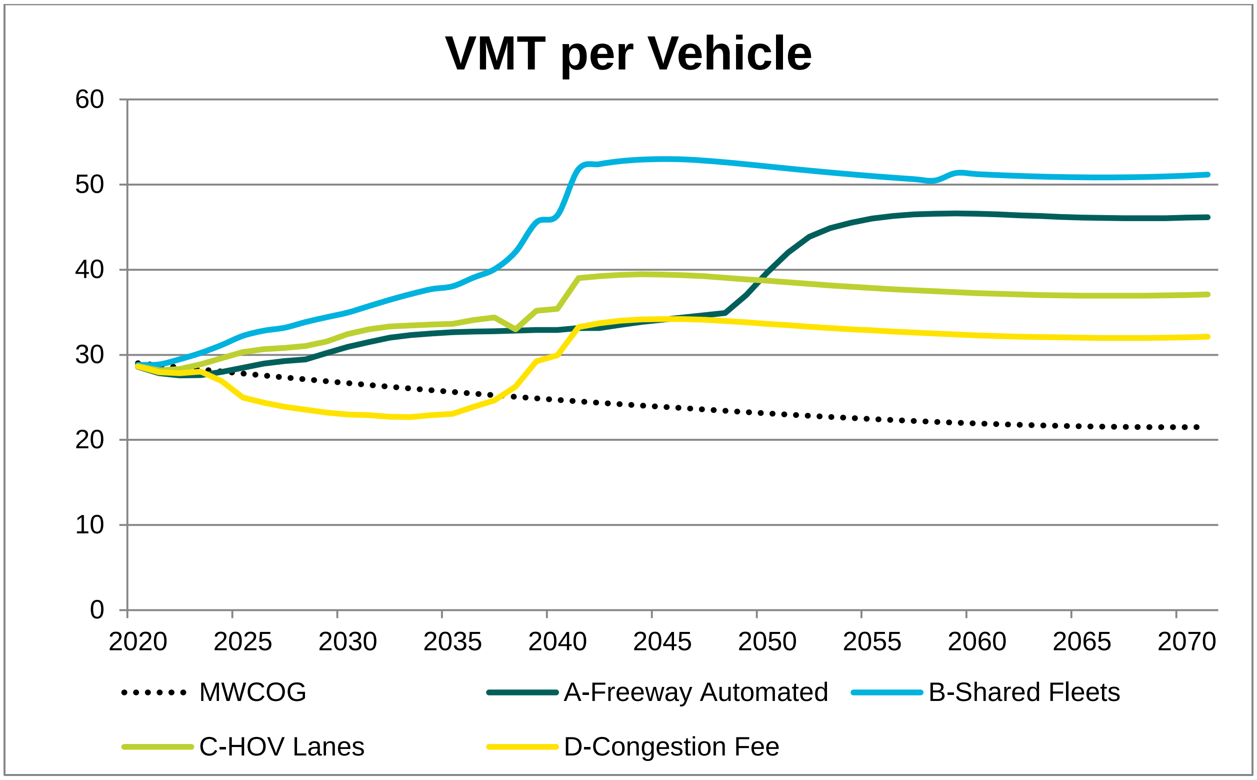


Figure 4-14: Average Vehicle Usage (Total VMT/Total Vehicles)

Transit Ridership

Transit ridership has been decreasing in the DC region over the last five years, a trend caused by a number of factors. While a causal relationship between the decrease in transit ridership and the introduction and proliferation of ridesourcing services cannot be proven, the timing indicates a link. Studies in other cities have shown that a significant portion of users of ridesourcing services would have otherwise used transit to complete their trips. While these impacts are not included in the MWCOG forecasting model, almost all market forecasts indicate that these trends are likely to continue to grow into the future.

At the same time, new business models are redefining what the future definition of "transit" might be, including shared-ride ridesourcing options, publicly or privately owned microtransit, and traditional publicly operated fixed route systems. The AV Scenarios each include different assumptions about what the future of transit will look like in the District, including some mix of each of these types, as detailed in Section 0. Figure 4-15 shows the estimated transit ridership under each of these Scenarios. It is important to note that these estimates do not only consider the more traditional definition of publicly-operated fixed-route bus and rail transit, but also incorporate the evolving business models that include large-scale shared-ride options including ridesourcing and microtransit. This analysis does not identify what type of service travelers are using, only that riders are using some subset of this wider definition of "transit."

Scenarios A, B, and C show transit ridership essentially stagnating in the immediate future, and growing only slowly in long-term, despite significant population growth in the District and the surrounding region. Scenario D results in a marked increase in transit ridership immediately following the introduction of congestion pricing. This follows the experience of other worldwide cities that have implemented congestion pricing. Scenario C, with its focus on priority for HOVs, results in the second highest transit ridership, but additional incentives may be necessary in order to encourage more people to take advantage of these facilities.

It is important to note that the specific numerical results for this performance metric are highly dependent on the relative improvements in cost, time, and comfort that AVs and other new mobility options are able to provide travelers. While assumptions have been made for each AV Scenario about the available mobility options, business models, and consumer prices, these remain uncertain market-based estimates. Significant changes in these characteristics could impact what is considered to be "transit" in the future, and therefore the results of this performance metric.

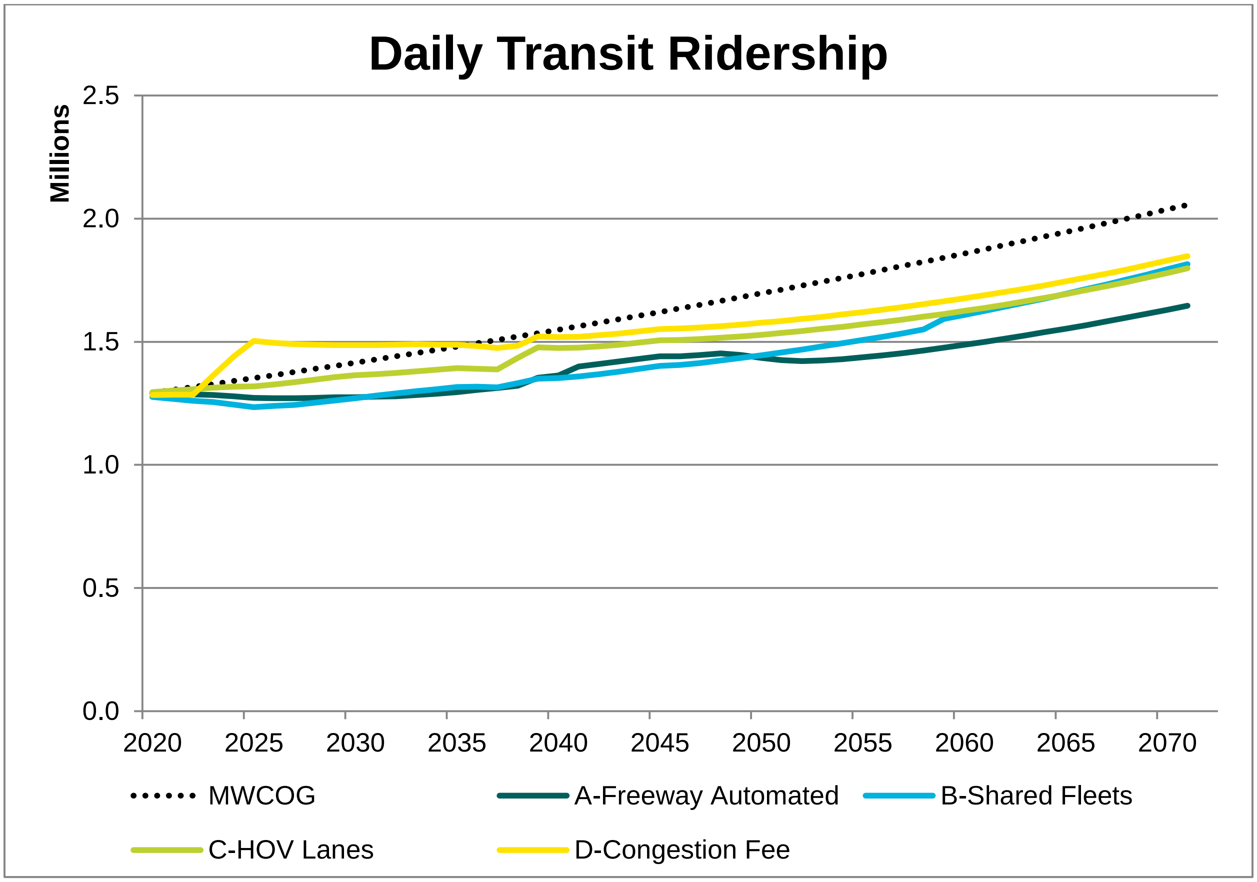


Figure 4-15: Transit Ridership

Almost two thirds of daily transit ridership in the District occurs during the peak periods, as shown in Figure 4-16. As shown, the AV Scenarios decrease both transit ridership, and the portion of ridership occurring during the peak period. This means that transit ridership is decreasing during the peak faster than it is decreasing during the off-peak. This may imply that off-peak transit riders are more likely to be transit-dependent riders who cannot afford or do not want to switch modes, even with the introduction of AVs as a new mobility option.

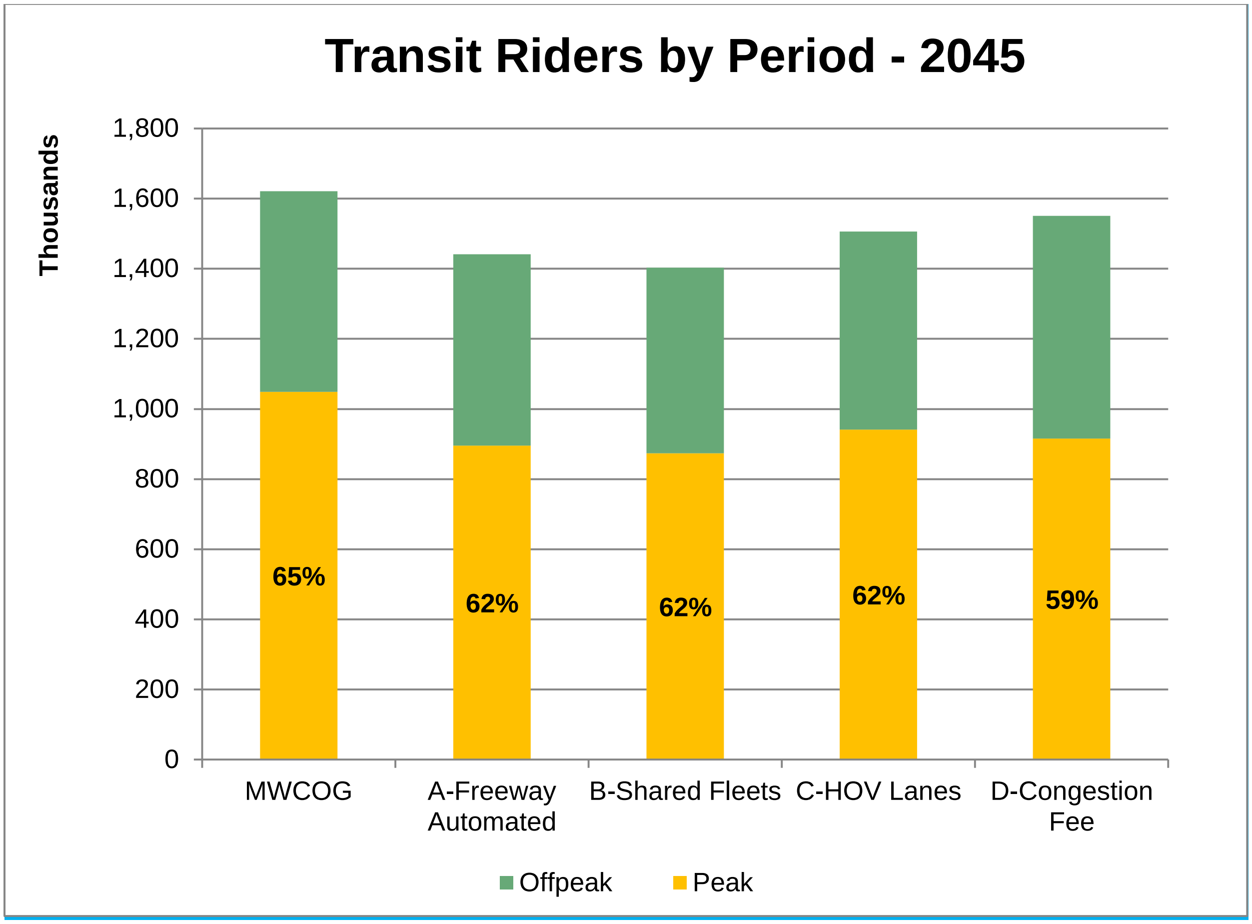


Figure 4-16: Transit Ridership by Time Period

Scenario labels are the percent of transit ridership that occurs during the peak periods.

Table 4-4 summarizes the transit ridership in 2045 by Planning Area, representing all transit boardings occurring in an area, including those made by residents of other parts of the District or the region. The Lower Anacostia Waterfront & Near Southwest Planning Area has the highest increase in transit ridership in all four of the AV Scenarios. This is due to the relatively large amount of growth planned for the area. Decreases in transit ridership are forecast for the Planning Areas in the residential portions of Northwest DC (Rock Creek West, Near Northwest, Mid-City, and Rock Creek East) in all AV Scenarios. These tend to be higher-income areas where residents are more likely to be able to afford to use new forms of automated mobility. Policies may be helpful in ensuring that choice riders continue to use transit in the District, and that the benefits of automated mobility are available to travelers of all income levels.

Table 4-4: 2045 Transit Ridership by Planning Area

Planning Area	Existing	Scenario A Change	Scenario B Change	Scenario C Change	Scenario D Change
Central Washington	352,600	15%	13%	21%	31%
Near Northwest	74,700	-24%	-31%	-21%	-19%
Rock Creek West	59,200	-25%	-30%	-25%	-21%
Rock Creek East	35,800	-17%	-25%	-17%	-19%
Mid-City	37,600	-21%	-32%	-20%	-21%
Upper Northeast	63,900	27%	22%	30%	33%
Far Northeast & Southeast	35,400	23%	25%	27%	35%
Capitol Hill	53,000	13%	9%	23%	25%
Lower Anacostia Waterfront & Near Southwest	32,400	35%	31%	35%	46%
Far Southeast & Southwest	25,500	17%	14%	36%	19%
District Total	**770,100**	**7%**	**3%**	**12%**	**17%**

4.2.2 Vehicle Fleet

Total number of Vehicles

All four AV Scenarios result in a smaller vehicle fleet than would be possible without AVs, as shown in Figure 4-17. This includes household owned vehicles, trucks and shared vehicles. By 2045, the vehicle fleet could be at least 20 percent smaller than would be necessary without AVs while maintaining current mobility levels. Scenario B has the largest decrease in vehicle fleet size, with a decrease of 26 percent, or more than 120,000 thousand fewer vehicles. These vehicles would be shed by households that currently own vehicles choosing to own fewer or no vehicles, and relying partly or completely on shared vehicles and other forms of publicly available transportation. Scenario A shows a slower decrease in vehicle fleet size due to the slower introduction and adoption of fully automated Type 3 AVs assumed in this scenario.

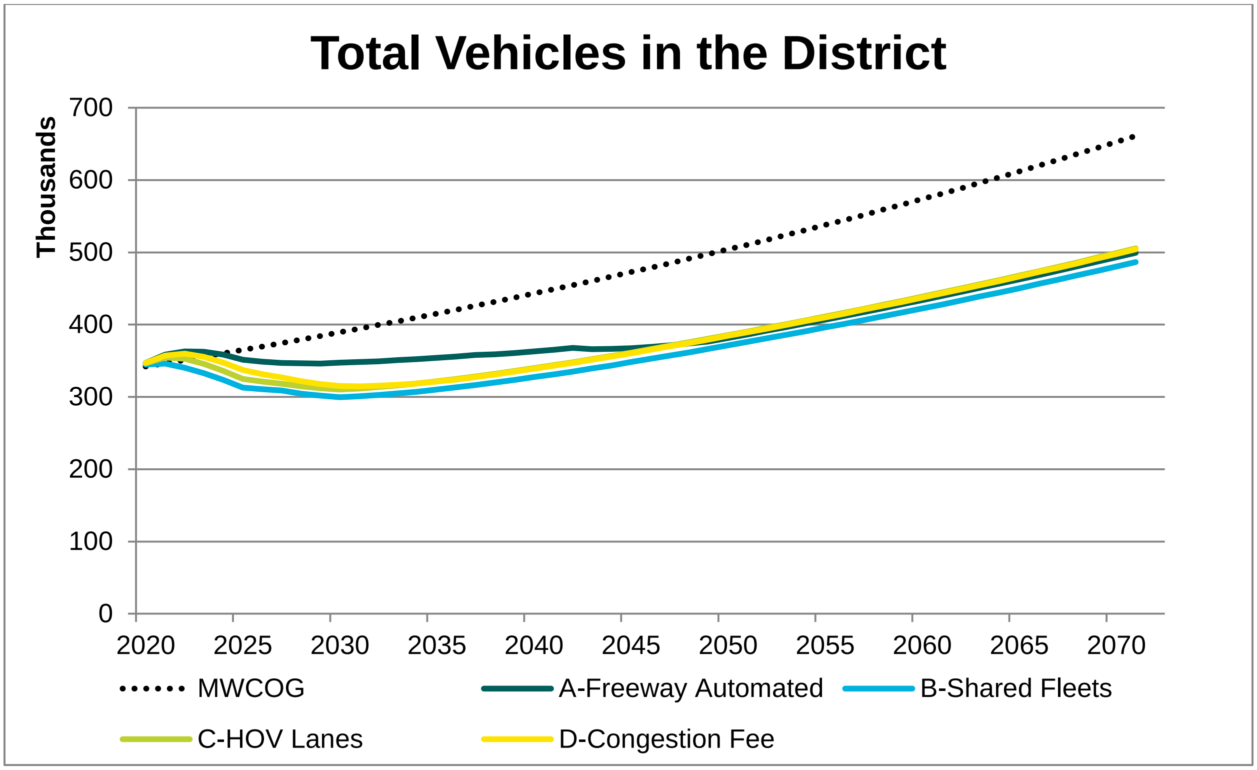


Figure 4-17: Total Vehicles in DC

Table 4-5 summarizes the total vehicles by Planning Area in 2045, including household owned and shared vehicles, and trucks. These numbers include both privately owned vehicles and the shared vehicle fleets that would be needed to serve the District's mobility needs. In all four AV scenarios, AV technologies will reduce the total number of household vehicles needed in all Planning Areas. Shared vehicle fleets will grow in size, but at a much slower rate. While the fleet vehicles are shown in the individual Planning Areas where they are likely needed to serve local mobility needs, there is no requirement that they actually be stored in these locations. Shared vehicle storage could potentially occur anywhere in the District or outside of it. Additional consideration for the location of vehicle storage areas and their potential impacts on communities should be considered. For the purpose of this analysis only, shared fleet vehicles were assigned to the individual Planning Areas based on the existing distribution of household-owned vehicles. The largest decreases in vehicle fleet size occur in Near Northwest and Lower Anacostia Waterfront & Near Southwest.

Table 4-5: 2045 Total Vehicles by Planning Area

Planning Area	MWCOG	Scenario A	Scenario B	Scenario C	Scenario D
Central Washington	21,400	16,800	16,500	16,500	16,500
Near Northwest	40,700	28,400	27,600	27,800	27,800
Rock Creek West	71,700	54,700	52,100	55,700	55,500
Rock Creek East	45,700	35,000	33,800	35,600	35,400
Mid-City	56,800	41,000	39,600	42,200	42,200
Upper Northeast	46,500	36,400	34,800	36,000	35,800
Far Northeast & Southeast	82,000	71,900	64,700	65,400	65,200
Capitol Hill	30,300	22,000	21,200	22,300	22,200
Lower Anacostia Waterfront & Near Southwest	22,100	15,900	15,400	16,200	16,200
Far Southeast & Southwest	54,900	45,400	41,900	43,400	43,300
DC Total	**472,100**	**367,400**	**347,700**	**361,200**	**360,300**

Vehicles per Household

Figure 4-18 highlights the average number of vehicles per household in DC, since the four AV Scenarios each include a different number of households and residents. This is not necessarily representative of the number of vehicles owned by each household, since it includes shared vehicles as well.

All four AV scenarios see an increase in vehicle fleet size over approximately the next five years, as population in the District continues to grow without high levels of AV penetration. By 2045, vehicle fleet size in Scenarios B, C, and D will average between 0.73 – 0.78 vehicles per household, a decrease of 26-30 percent compared to current conditions. Only small decreases will occur after that point. Despite having a similar number of vehicles in the long-term, Scenario A has the highest number of vehicles per household, since it has the lowest household total and the most households which continue to own their own cars. By 2045, there will still be 0.88 vehicles per household in the District under Scenario A.

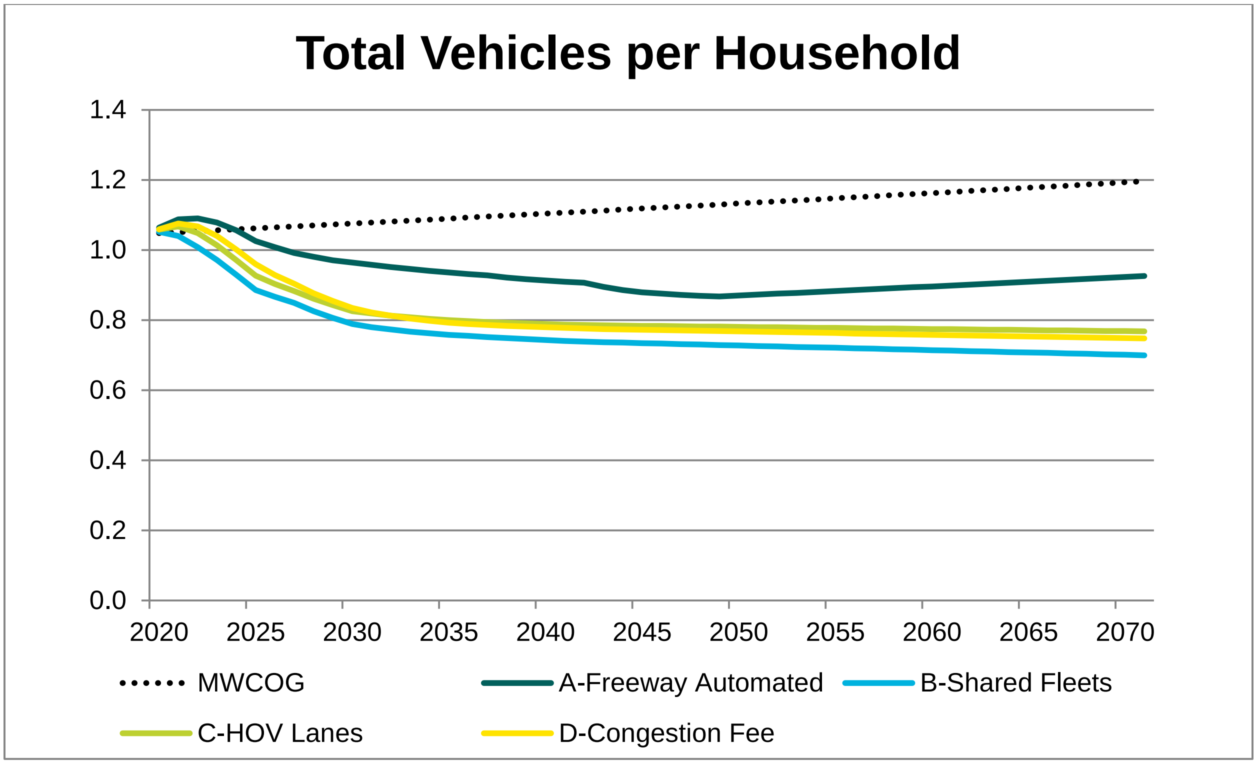


Figure 4-18: Total Vehicles per Household

Household Vehicle Ownership

Table 4-6 highlights changes in household vehicle ownership caused by AVs. This metric includes only the vehicles that are owned by households, not shared fleet vehicles. The District currently averages just over one vehicle owned per household. There is however significant variation in that auto ownership throughout the District. Vehicle ownership is far above average in the Far Northeast & Southeast and the Far Southeast & Southwest. Vehicle ownership is lowest in Central Washington and Near Northwest.

By 2045, household vehicle ownership is forecast to decrease throughout the District, although the areas with the highest ownership will remain unchanged. Central Washington and Lower Anacostia Waterfront & Far Southwest will have the lowest vehicle ownership under all of the AV Scenarios. However, in all AV Scenarios, low vehicle ownership rates is not the same as low access to vehicles, as all of these reductions are expected to be made by households choosing to rely on the services provided by shared vehicles and other mobility options.

Table 4-6: Household Vehicle Ownership Rates by Planning Area - 2045

Planning Area	Existing	Scenario A	Scenario B	Scenario C	Scenario D
Central Washington	0.6	0.3	0.3	0.3	0.3
Near Northwest	0.6	0.4	0.4	0.4	0.4
Rock Creek West	1.1	0.9	0.8	0.9	0.9
Rock Creek East	1.0	0.8	0.7	0.7	0.7
Mid-City	0.8	0.6	0.6	0.6	0.6
Upper Northeast	1.0	0.6	0.5	0.5	0.5
Far Northeast & Southeast	1.6	1.3	1.2	1.2	1.2
Capitol Hill	0.8	0.6	0.5	0.5	0.5
Lower Anacostia Waterfront & Near Southwest	0.7	0.3	0.3	0.3	0.3
Far Southeast & Southwest	1.4	1.1	0.9	0.9	0.9
DC Total	**1.0**	**0.7**	**0.6**	**0.6**	**0.6**

Shared AVs will be used much more efficiently than household owned vehicles, completing many trips for a multitude of users. Research into carsharing has shown that each shared vehicle can replace up to 13 household owned vehicles in an urban area like DC. This will mean that the significant majority of the District's vehicle fleet will continue to be owned by households, even as more and more people chose to rely on shared fleets. Household-owned vehicles will still comprise more than 80 percent of the District's vehicle fleet in the future under the four scenarios studied, even though they will account for only 60 percent of the VMT.

4.2.3 Trip Measures

This section focuses more closely on the travel experience of travelers in the District by measuring how their trips will be impacted by the introduction of AVs. Several trip characteristics are analyzed for trips starting in DC. This does include all trips originating in DC, including DC residents, employees, and visitors and is our most accurate way of tracking how the changes in transportation technologies will impact individual trips.

Average Trip Length

Figure 4-19 shows the average trip length in miles, for all daily trips starting in the District. On average, the average daily trip is currently just over 9.7 miles in length. Commute trips tend to be significantly longer than other types of trips, like shopping or social trips. Scenario A tracks very closely with the MWCOG forecasts for average trip length, only starting to diverge once AVs have reached a high level of market penetration in 2044. Trip lengths increase into the future as land use changes and the presence of dedicated AV lanes encourage longer freeway-based trips. Scenarios B, C, and D see the addition of more residents in urban areas, resulting in shorter trips as people are able to live closer to where they work. These scenarios also eliminate the need for many extremely long-distance commutes from outside the region to DC. The scenarios with more population in DC result in a lower average trip length in the long-term. The 'bump' in the trendlines for these three scenarios starts to occur as additional households, above the MWCOG forecast, are added to the region beginning in 2035.

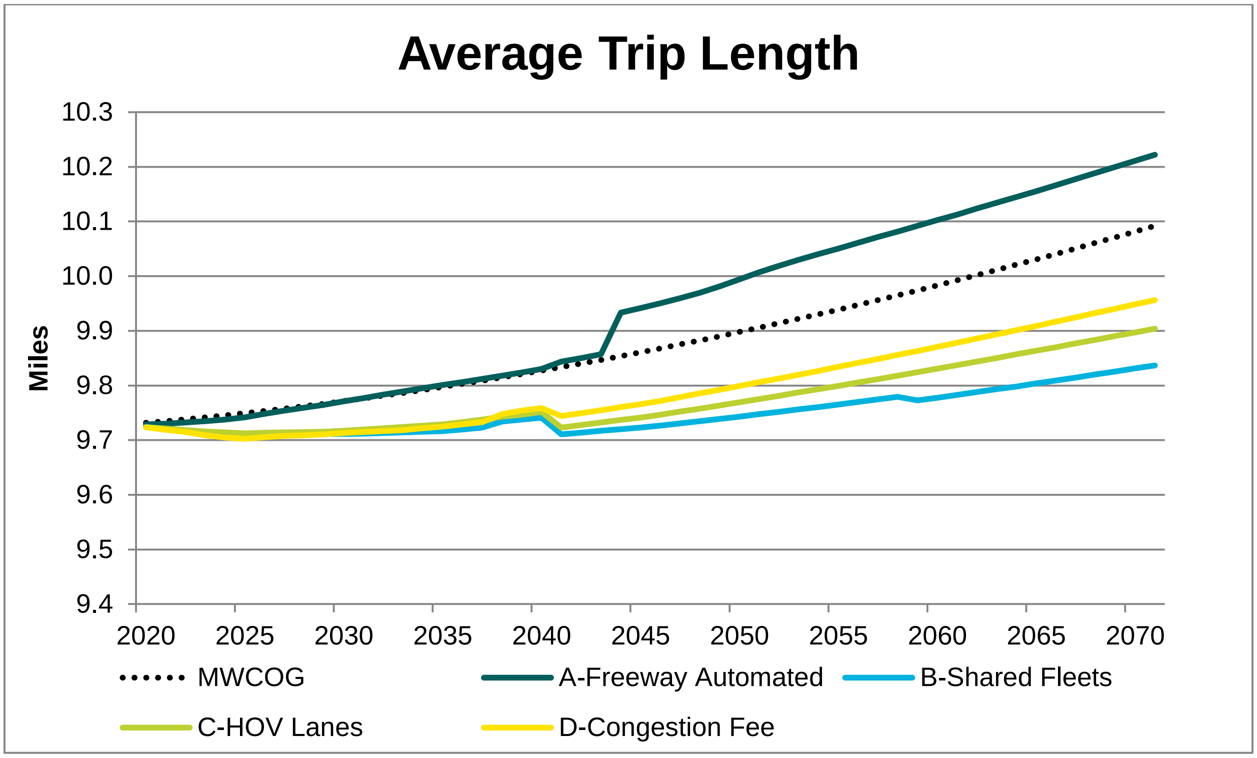


Figure 4-19: Average Trip Length (miles)

As shown in Table 4-7, trips starting in Central Washington and Lower Anacostia Waterfront & Near Southwest will have the longest average length in 2045. Rock Creek West and Upper Northeast will have the shortest trip length. The AV Scenarios do not have major impacts on average trip length in any of the Planning Areas, although Mid-City is projected to see a small increase (less than five percent) in all four AV Scenarios. The change in average trip length is never greater than 0.3 miles.

Table 4-7: Average Trip Length (Miles) by Planning Area - 2045

Planning Area	MWCOG	Scenario A	Scenario B	Scenario C	Scenario D
Central Washington	11.3	11.3	11.0	11.1	11.2
Near Northwest	9.8	9.9	9.7	9.7	9.7
Rock Creek West	8.5	8.7	8.4	8.4	8.4
Rock Creek East	8.7	8.9	8.7	8.7	8.7
Mid-City	8.6	8.9	8.9	8.8	8.8
Upper Northeast	8.5	8.7	8.6	8.6	8.6
Far Northeast & Southeast	9.2	9.4	9.1	9.1	9.1
Capitol Hill	9.0	9.3	9.2	9.1	9.1
Lower Anacostia Waterfront & Near Southwest	11.3	11.3	11.3	11.3	11.2
Far Southeast & Southwest	9.7	9.9	9.6	9.6	9.6
DC Total	**9.9**	**9.9**	**9.7**	**9.7**	**9.8**

Average Trip Time

Trip time is related to two major factors: trip length and travel speed. Travel speed is directly determined by the roadway conditions or the level of congestion. Currently, the average trip starting in DC takes 28 minutes, including trips on all modes (Figure 4-20). By 2045, the average trip would be expected to take 31 minutes due to land use changes that alter where people are going and increases in roadway congestion. Average travel times follow a similar pattern to the congestion metric presented in Section 4.1.2. Scenarios A and B have the highest levels of congestion, and also result in the longest average trip lengths in the long term. Prior to 2045, dedicated AV lanes provide congestion relief on many freeways, decreasing travel times for many travelers. However, induced demand from AVs and a more dispersed land use pattern eventually results in longer travel times. Scenarios C and D include both shorter trip distances and lower levels of congestion, resulting in lower travel times, averaging 29 and 25 minutes in 2045, respectively.

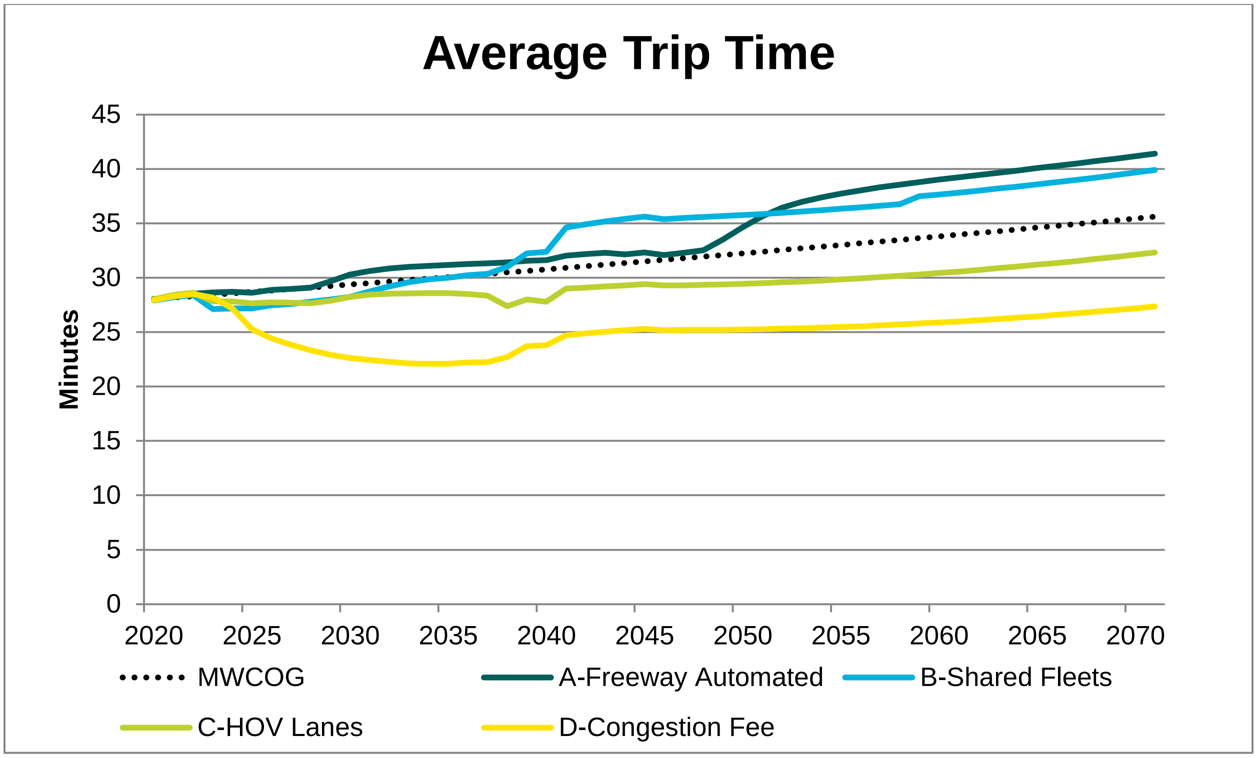


Figure 4-20: Average Trip Time

In 2045, trips that start in Central Washington will have the longest average travel time, at over 37 minutes, while trips that start in Rock Creek West will have the shortest average travel time, less than 26 minutes (Table 4-8). Rock Creek West and the Far Northeast & Southeast are expected to experience longer average trip times in Scenarios A, B, and C in 2045. Meanwhile, trip times in Rock Creek East improve in three of the AV Scenarios, and perform well even in Scenario B where average travel times increase for all Planning Areas. The Far Southeast & Southwest is predicted to experience significant improvements in trip time under Scenarios A and D helping improve quality of life in an area with high concentrations of low-income and minority residents.

Scenario A results in longer average trip times in most Planning Areas, although the Far Southeast & Southwest, Rock Creek East, and Central Washington will see somewhat shorter trips. More detail on average travel times for the larger region are provided in the appendix, but it should be noted that travel time improvements in the suburbs are much higher in Scenario A than they are in the District. All Planning Areas will see longer average travel times in 2045 under Scenario B, due to the increased congestion levels. In Scenario C, dedicated HOV lanes are able to provide shorter travel times for most of the District, with the exceptions of the Far Northeast & Southeast and Rock Creek West. Scenario D results in shorter travel times for all areas of the District (and the region overall). While driving may be more expensive under the congestion fees in Scenario D, travel will be faster for everyone. Congestion pricing may be a viable policy option for limiting the impacts of congestion so long as equitable transportation options and/or fee subsidies are available for low-income travelers.

Table 4-8: Average Trip Time (Minutes) by Planning Area - 2045

Planning Area	MWCOG	Scenario A	Scenario B	Scenario C	Scenario D
Central Washington	37.3	36.4	40.1	32.8	30.8
Near Northwest	32.1	32.5	36.5	26.1	24.5
Rock Creek West	25.6	30.7	34.1	27.3	22.5
Rock Creek East	28.0	26.7	29.0	23.3	19.0
Mid-City	28.7	29.1	32.7	23.9	21.4
Upper Northeast	27.5	31.5	33.8	27.5	23.1
Far Northeast & Southeast	27.1	32.0	37.0	29.2	24.9
Capitol Hill	30.6	31.8	35.3	27.5	25.5
Lower Anacostia Waterfront & Near Southwest	35.1	38.6	46.3	33.2	30.3
Far Southeast & Southwest	27.8	23.5	30.0	26.7	19.4
DC Total	**31.5**	**32.3**	**35.6**	**29.4**	**25.3**

4.3 Environmental Impacts

The environmental analysis in this study is focused on tailpipe greenhouse gas emissions from driving of non-electric vehicles, which is one of the most direct impacts related to changes in travel patterns. Additional environmental analysis could prove beneficial, including analyzing the source point of pollutants and any environmental impacts of land use changes. Tailpipe emissions are one of the major impacts of increasing vehicle travel that planners seek to minimize. In the past, this was accomplished by encouraging people to drive less. In a future in which electric vehicles are prevalent, the amount of VMT is likely to be less directly correlated to emissions levels; however, the source of the electricity used to power EVs may itself contribute to greenhouse gas emissions.

It should be noted that all of these results represent a substantial improvement over the assumptions that must be used by MWCOG in its air quality analysis work. The purpose of the Air Quality Conformity Analysis requires that very conservative assumptions be used; the vehicle fleet is therefore assumed to include the same number of electric vehicles in the future as it does today – less than one half of one percent.

It is similarly important to recognize that the introduction of autonomous vehicles does not inherently ensure that AVs will be electric; electrification is a separate process significantly influenced by separate technologies and public policy. While the introduction of AVs will lead to fleet turnover and (especially in some scenarios) an increase in shared fleets which are more likely to be electrified, this is not guaranteed to happen.

VMT by Engine Type

The four AV Scenarios studied assume that electrification reaches 85-95 percent of the vehicle fleet by 2070, as detailed in Section 0. Figure 4-21 illustrates the growth in electric VMT that occurs in the District if these vehicles are adopted as assumed in the AV Scenarios. Scenario B has the highest amount of electric VMT, in part because it has the highest total VMT coupled with strong electrification due to the fact that so much of the VMT is shared vehicles, which are assumed to all be electric by 2030.

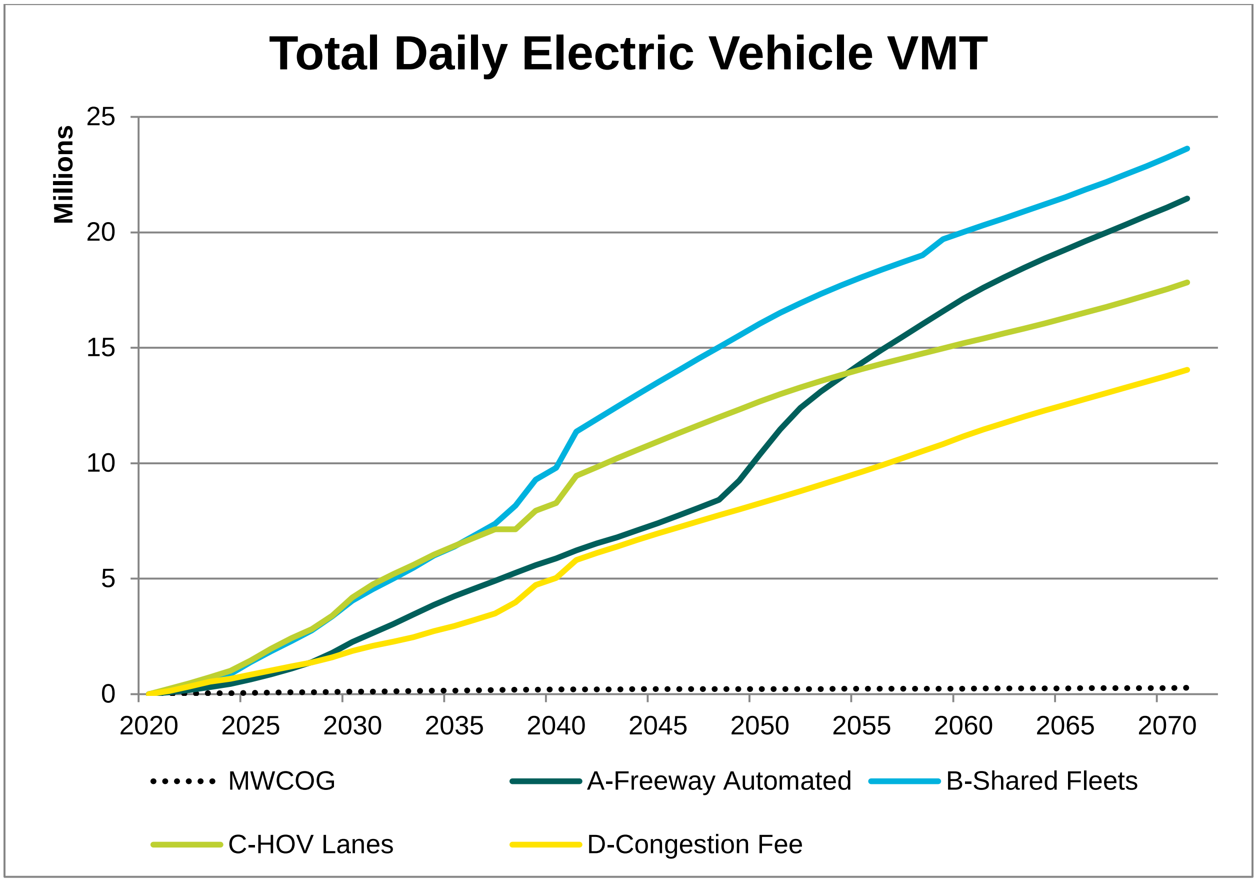


Figure 4-21: Electric Vehicle VMT

Non-electric vehicle VMT is most directly related to tailpipe GHG emissions, and decreases over time across all AV Scenarios. By 2045, non-electric VMT and therefore annual vehicle emissions decrease by at least 40 percent as shown in Figure 4-22.

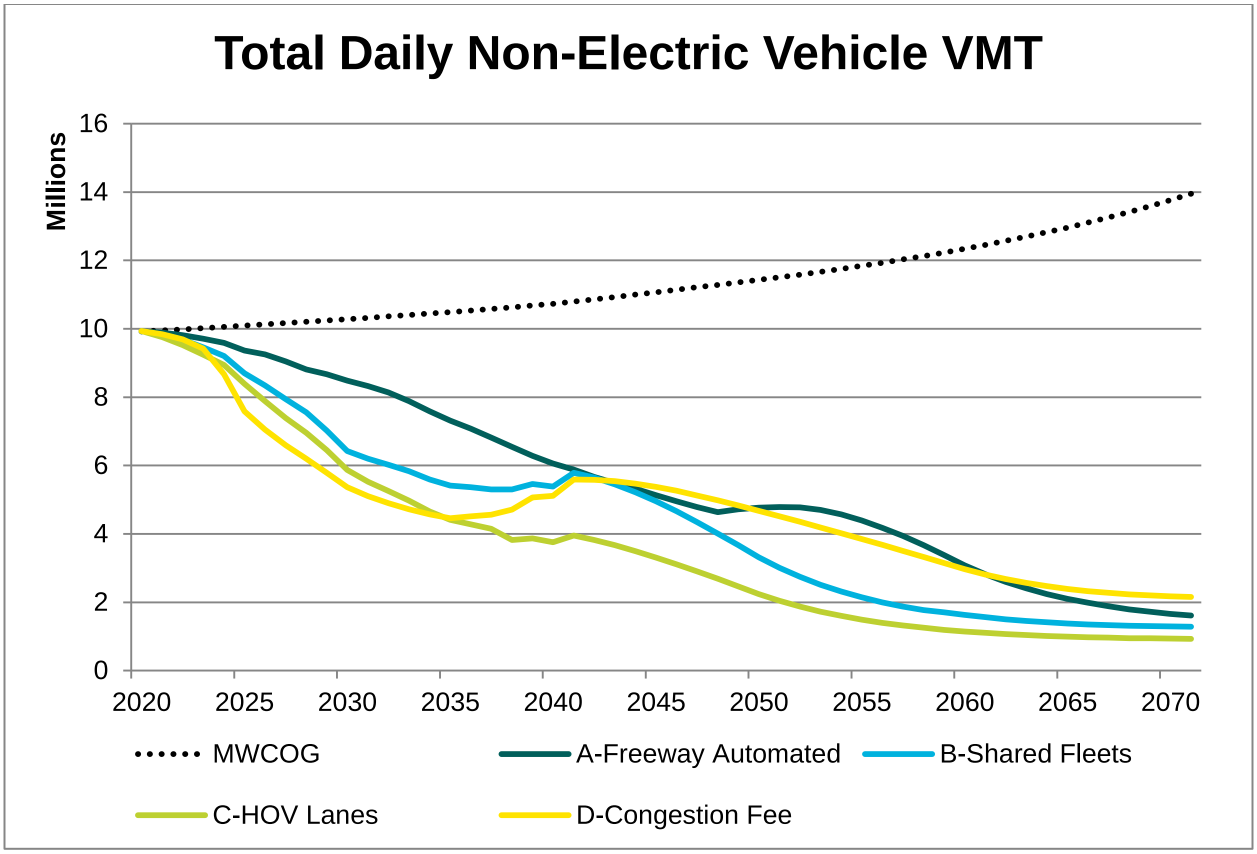


Figure 4-22: Non-electric Vehicle VMT

Tailpipe GHG Emissions

Detailed air quality analysis would be necessary in order to accurately estimate the emissions outputs of each of these AV Scenarios. The number of 'cold starts', average travel speeds, and total VMT all contribute to these results. This study includes a simpler analysis which assumes that the average rate of GHG emissions per non-electric vehicle mile traveled will remain the same into the future, at 0.88 million metric tons of $C0_2$ ($MMTCO_2e$) per mile[3]. Greenhouse gas tailpipe emissions are directly related to the non-EV VMT, hence Figure 4-23 is displaying the same pattern as Figure 4-22.

[3] *Calculated from data included in the Transportation Planning Board (TPB) 2016 Financially Constrained Long-Range Plan for the National Capital Region.*

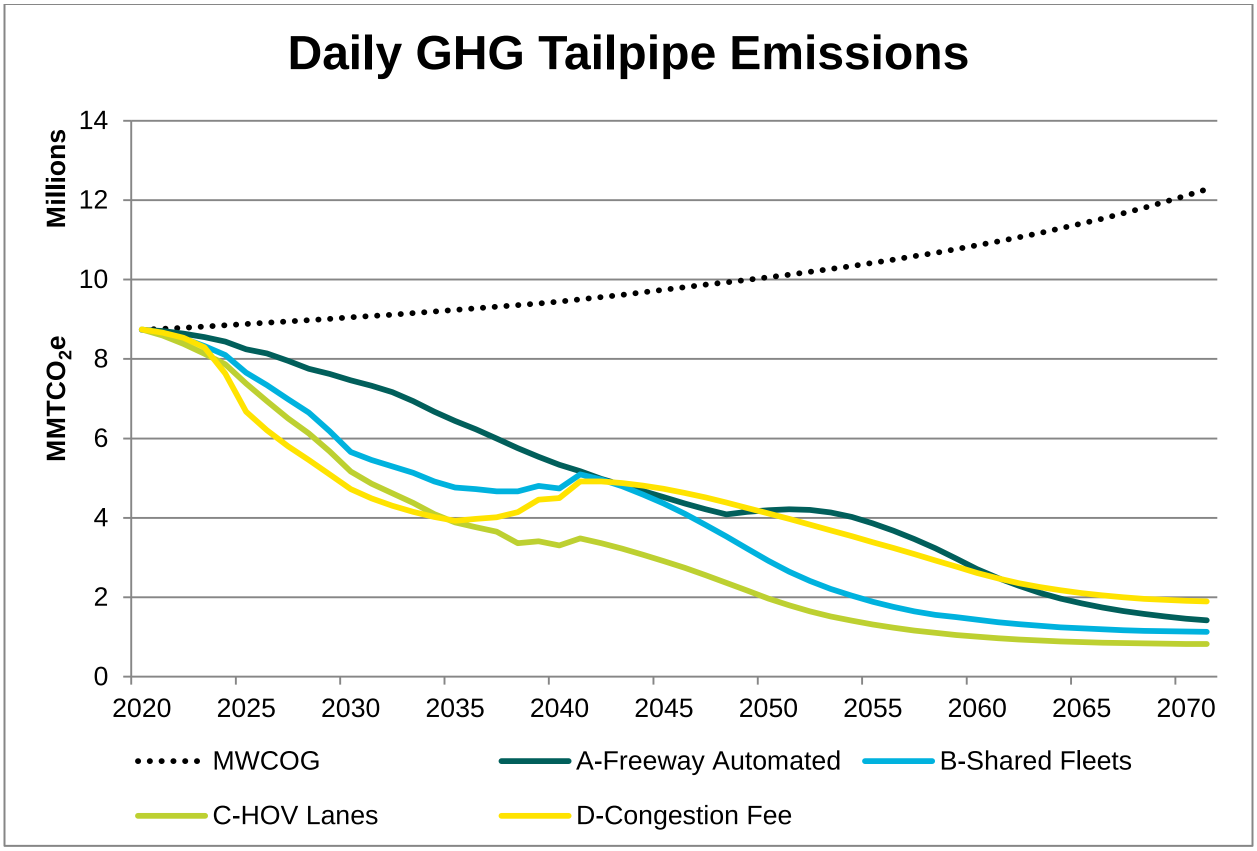


Figure 4-23: Green House Gas Tailpipe Emissions by Year

The emissions produced in 2020 in each Planning Area are summarized in Table 4-9, along with the percent change forecast by 2045. Decreased emissions are projected in all parts of DC, with the largest decreases occurring in Rock Creek West and Rock Creek East.

Although still representing decreases of over 40 percent, the smallest decreases occur in Lower Anacostia Waterfront & Near Southwest and the Far Southeast & Southwest areas, which are projected to experience some of the highest growth in the District. In order to avoid exacerbating environmental disparities in low-income communities, vehicle electrification will need to be pursued, especially in these areas. Public policy will need to support these efforts, especially as some of these neighborhoods may not be the most profitable markets for private sector technology developers.

Table 4-9: Emissions by Planning Area - 2045

Planning Area	Existing	Change from Existing Conditions			
		Scenario A	Scenario B	Scenario C	Scenario D
Central Washington	1,761,200	-49%	-51%	-70%	-46%
Near Northwest	750,600	-48%	-49%	-70%	-45%
Rock Creek West	1,171,400	-52%	-56%	-70%	-53%
Rock Creek East	766,500	-50%	-52%	-65%	-49%
Mid-City	463,900	-49%	-49%	-67%	-46%
Upper Northeast	1,018,300	-46%	-48%	-63%	-45%
Far Northeast & Southeast	990,200	-46%	-49%	-62%	-46%
Capitol Hill	505,700	-47%	-49%	-67%	-44%
Lower Anacostia Waterfront & Near Southwest	557,400	-45%	-47%	-67%	-41%
Far Southeast & Southwest	749,200	-46%	-50%	-63%	-44%
DC Total	**8,734,400**	**-48%**	**-50%**	**-67%**	**-46%**

Emissions in a single day are not really what matters in the case of the environment; the total amount of GHG emissions is the important metric. Figure 4-24 highlights the cumulative effect of emissions in each of the scenarios over time. As shown, of the AV Scenarios, Scenario A results in the highest levels of vehicle emissions in the District, with a total of approximately 87 billion tons of CO_2 emitted between 2020 and 2070. Scenario C ultimately results in the lowest total amount of GHG emissions, approximately 58 billion tons over the same time period. All four AV scenarios represent a decrease in cumulative emissions of at least 49 percent when compared to the MWCOG forecasts without strong electrification assumptions. This highlights the dramatic impact that electrification can have on one of the largest negative externalities of driving.

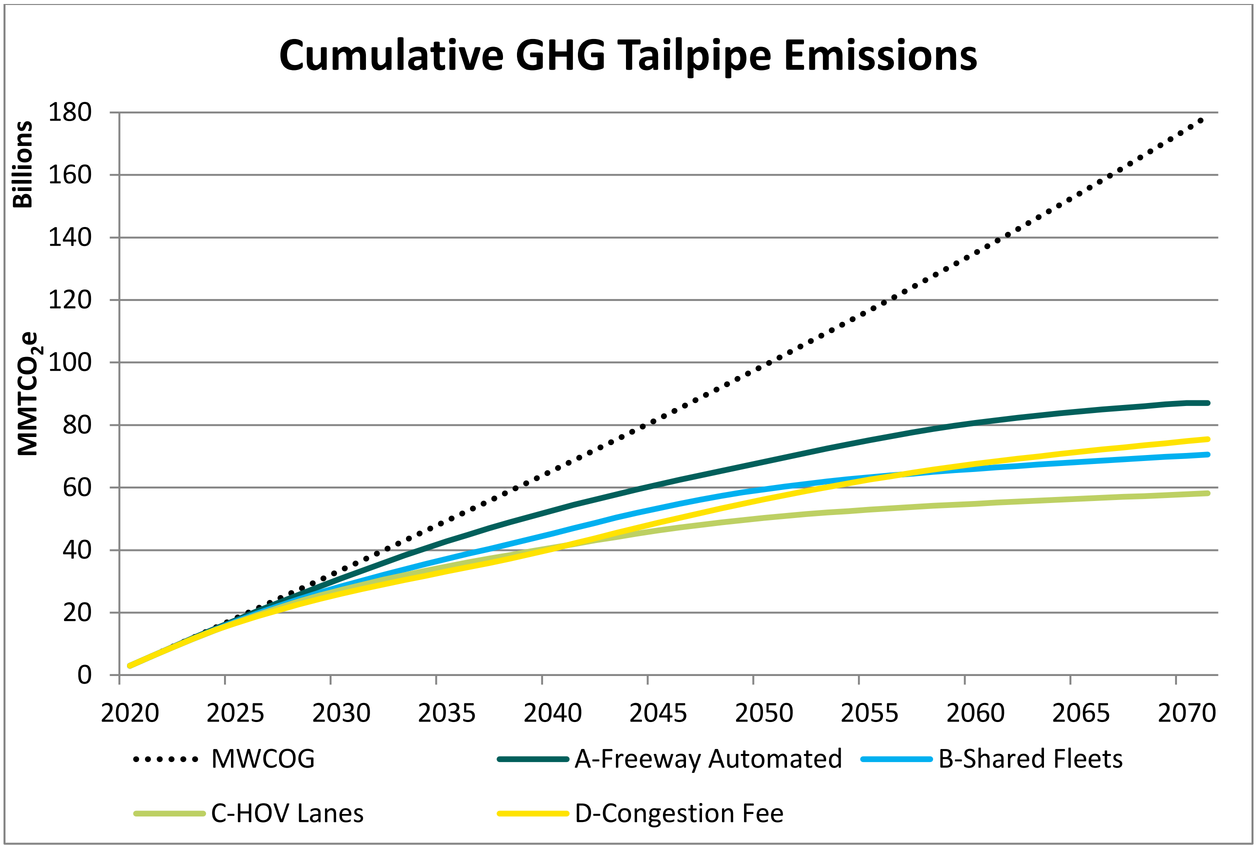


Figure 4-24: Cumulative GHG Emissions by Year

The results shown in Figure 4-24 are highly dependent on the assumptions about electrification rates. Should these assumptions prove incorrect, the AV Scenarios could have significant negative consequences associated with their increased levels of VMT. Figure 4-25 highlights the range of possible GHG Emissions outcomes based on the potential increases in VMT caused by AVs and slower or faster electrification rates. The "low end" of the range uses the lowest scenario-specific VMT estimates (Scenario D) coupled with the more aggressive electrification rates assumed in Scenario C. This results in a range of approximately 50 billion tons of CO_2 emissions over the 50-year time frame. The "high end" of the range includes the highest scenario specific VMT estimate (Scenario B) coupled with the low electrification adoption rates used by MWCOG, resulting in more than five times are much GHG emissions. Vehicle electrification will have a huge impact on emissions in the District and the region; strong policies promoting electrification across the fleet will be necessary in order to avoid the potential for major negative externalities.

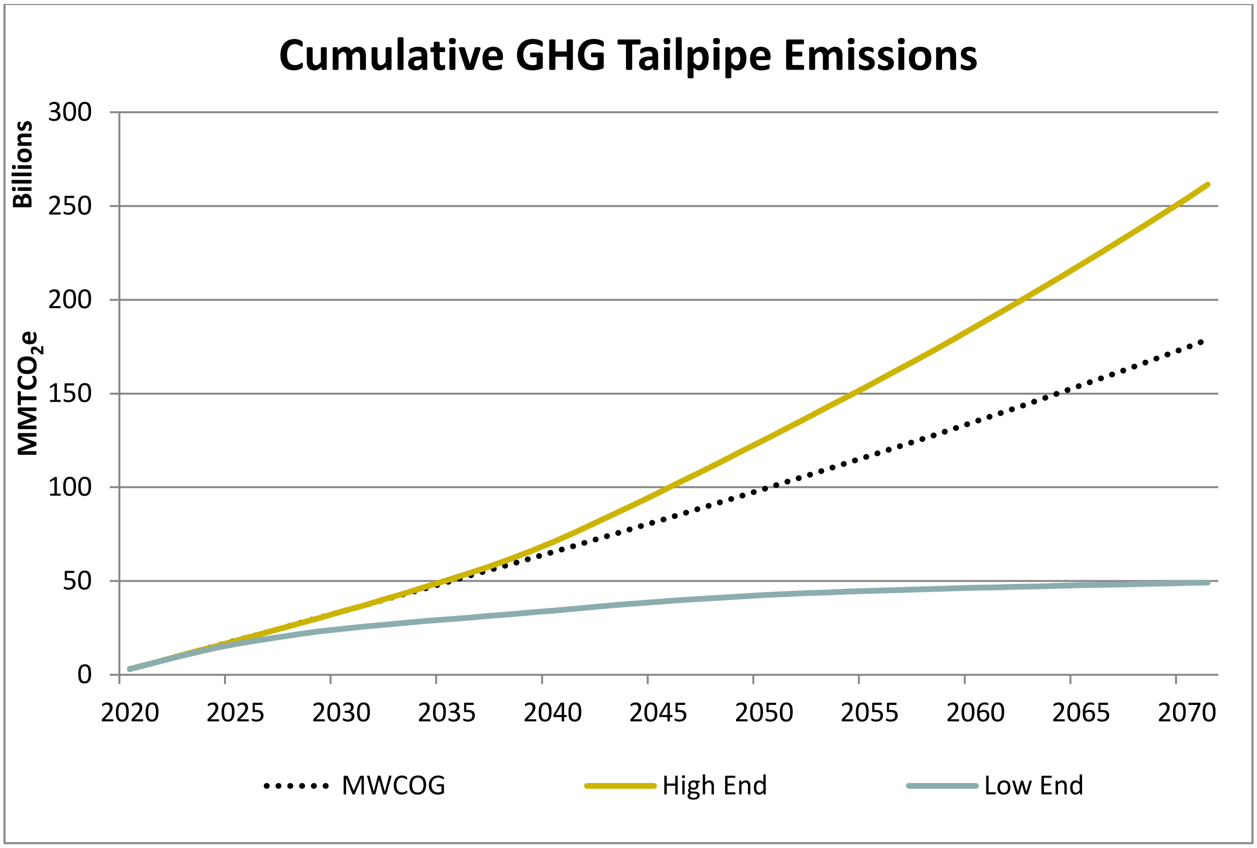


Figure 4-25: Range of Cumulative GHG Emissions Impacts (2020 – 2070)

4.4 SAFETY IMPACTS

This section measures how AVs could impact safety by considering changes to the number of crashes that will occur in the District and their severities. This analysis also considers the economic gains that could be made by avoiding traffic crashes and the many associated costs.

Existing Crashes

Table 4-10 summarizes the existing number of crashes by severity across each Planning Area. Central Washington has the most crashes and Lower Anacostia Waterfront & Near Southwest has the fewest crashes. The majority (more than 85 percent) of crashes in 2018 resulted in property damage only.

Table 4-10: Existing Crashes Summary by Planning Area by Severity Type (2018)

Planning Area	Fatal	Major Injury	Minor Injury	Property Damage Only	Total
Central Washington	6	41	544	4,220	4,811
Near Northwest	2	26	314	2,348	2,689
Rock Creek West	1	17	187	1,255	1,460
Rock Creek East	3	16	320	1,846	2,185
Mid-City	2	29	343	2,173	2,547
Upper Northeast	5	17	424	2,730	3,177
Far Northeast & Southeast	6	38	487	3,311	3,842
Capitol Hill	1	14	192	1,428	1,635
Lower Anacostia Waterfront & Near Southwest	3	6	149	1,064	1,222
Far Southeast & Southwest	6	19	374	2,507	2,907
DC Total	**36**	**224**	**3,334**	**22,881**	**26,475**

Source: DDOT, DC Open Data. Note: Fatal crashes are the average number of fatal crashes between 2015-2018. All other data is for 2018 only.

Crash rates describe the number of crashes of different levels of severity as compared to the traffic volume (FHWA). Traffic volume (VMT) is used to quantify the level potential exposure to traffic; as exposure levels go up, crashes tend to go up as well. Table 4-11 calculates the existing crash rates for the District of Columbia for 2018. While injury and property damage crashes tend to be relatively consistent with exposure levels as shown in the table, traffic fatalities tend to be more random and less stable from year to year. As such, the fatality rates are calculated based on the average of 2015-2018 crash data to get a more accurate average fatality rate.

Table 4-11: Existing Crash Rates in DC by Severity

Crash Severity	Crashes per 100 million VMT	
	Freeway	Arterial
Fatal	0.8	1.1
Major Injury	2.4	7.1
Minor Injury	53.4	103.4
Property Damage Only	344	711.8

Safety Improvements

Based on the review of AV technology, major improvements to safety are expected with the introduction of CV and AV technologies. The expected improvements are outlined in Section 0 and summarized in Table 4-12. Crash rates will transition slowly from existing levels as the technologies are adopted. While all scenarios assume increases in safety, there are other possible futures in which AVs could not achieve these levels of safety improvements. Public policy decisions, especially at the Federal level, may strongly influence these outcomes.

Table 4-12: Crashes Eliminated at 100% CV and AV Adoption

	Freeways	Arterials
Scenario A	60%	40%
Scenario B	60%	40%
Scenario C	40%	60%
Scenario D	80%	80%

Based on these revised crash rates and the scenario-specific VMT estimates presented in Section 3.1, estimates of crashes by severity are calculated for future years. As shown in Table 4-13, if the assumptions made prove to be correct, widespread adoption of CV and AV technology would result in significantly fewer crashes, deaths, and injuries in DC, despite any increases in VMT in all four AV Scenarios. In 2045 Scenario D sees the greatest reduction in all types of crashes, because of both the strong safety assumptions made and the lower level of VMT achieved. AV solutions could help the District achieve its Vision Zero goals.

Table 4-13: DC Total Crashes by Severity Type in 2045

Severity Type	MWCOG	Scenario A	Scenario B	Scenario C	Scenario D
Fatal	42	27	15	12	10
Major	254	168	92	72	61
Minor	3,795	2,500	1,365	1,070	908
Property	26,038	17,200	9,405	7,331	6,244
Total	**30,128**	**19,895**	**10,877**	**8,485**	**7,223**

Table 4-14 summarizes the total number of crashes in each Planning Area in 2045. All show a significant decrease in the number of crashes compared to existing conditions.

Table 4-14: DC Total Crashes by Planning Area – 2045

Planning Area	MWCOG	Scenario A	Scenario B	Scenario C	Scenario D
Central Washington	5,380	3,690	2,037	1,445	1,330
Near Northwest	2,967	2,109	1,177	808	757
Rock Creek West	1,594	1,041	610	500	398
Rock Creek East	2,421	1,519	801	668	540
Mid-City	2,818	1,887	1,026	764	677
Upper Northeast	3,695	2,376	1,271	1,031	849
Far Northeast & Southeast	4,453	2,819	1,520	1,326	1,030
Capitol Hill	1,912	1,262	690	524	453
Lower Anacostia Waterfront & Near Southwest	1,473	1,002	549	404	370
Far Southeast & Southwest	3,415	2,190	1,196	1,013	821
DC Total	**26,475**	**19,895**	**10,877**	**8,485**	**7,223**

Economic Cost of Crashes

Crashes are costly to the individuals involved, and to the economy as a whole. The National Highway Traffic Safety Administration (NHTSA) has identified a range of categories where costs are incurred by traffic crashes including medical, emergency response, market and household productivity, insurance administration, legal costs, added congestion, and any property damage. These costs also include any physical impacts to quality of life as measured by Quality-adjusted life-years (QALY), which account for more than 80% of total crash costs in any cost with an injury or fatality. Based on this analysis, the average cost per crash, by severity is shown in Table 4-15.

Table 4-15: Average Crash Costs by Severity

Crash Severity	Total Average Economic Costs
Property Damage Only	$4,332
Minor Injury	$164,710
Major Injury	$3,364,935
Fatal	$10,259,329

Based on these costs and the Scenario-specific crash estimates, Figure 4-26 highlights the total economic costs associated with crashes in each year. As shown, the dramatic decrease in the number and severity of crashes has the potential to provide billions of dollars of economic benefit in DC. This analysis has not been completed for the region as part of this study, but impacts should be similarly large for other jurisdictions.

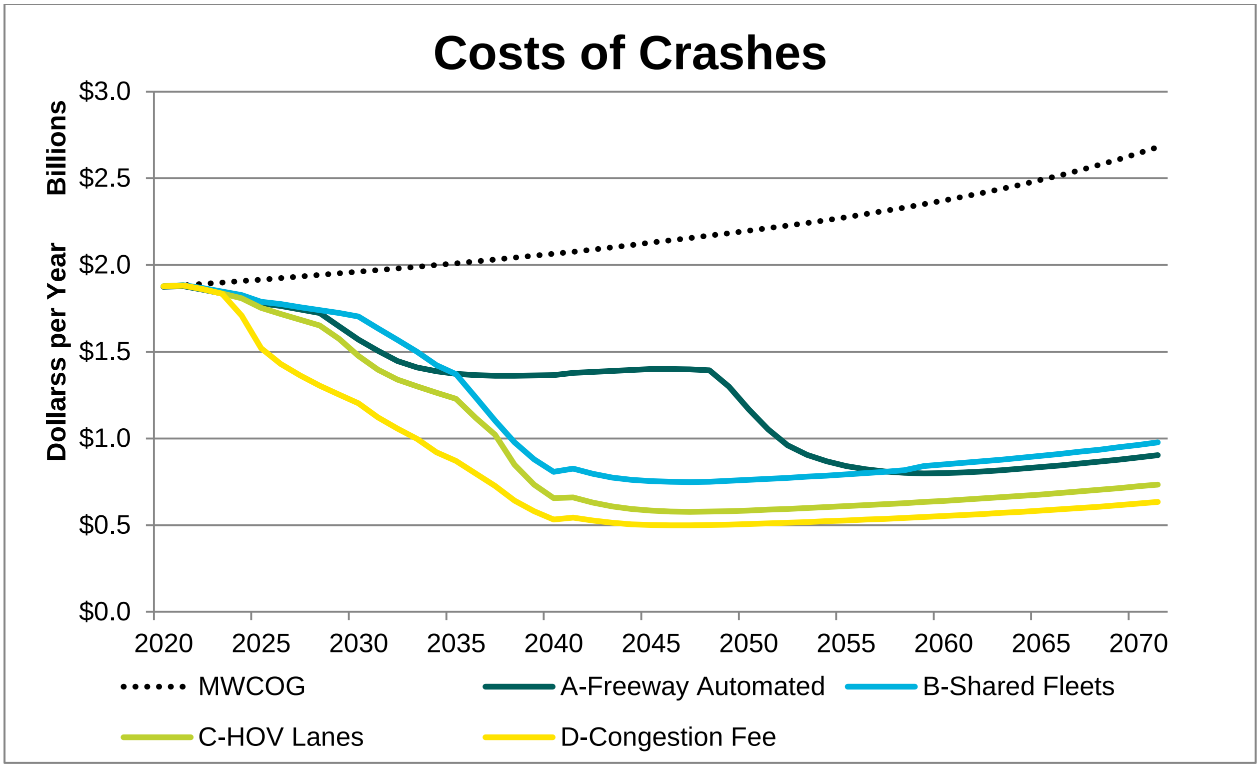


Figure 4-26: Total Economic Cost of Crashes

In total as shown in Table 4-16, connected and automated vehicles could have between $45 and $71 billion in economic benefit to the District between 2020 and 2070, solely accounting for their ability to improve roadway safety.

Table 4-16: Total Economic Cost and Savings Associated with Crashes (2020-2070)

	Total Cost of Crashes	Economic Savings
MWCOG	$ 113.3B	--
Scenario A	$ 65.0B	$ 48.3B
Scenario B	$ 58.0B	$ 55.3B
Scenario C	$ 49.7B	$ 63.6B
Scenario D	$ 42.4B	$ 70.9B

4.5 Economic and Financial Impacts

The introduction of AVs and other associated technologies have the potential to impact the economy of DC and the surrounding region in a number of ways. These impacts will vary based on how the technologies are implemented and evolve, with each scenario having a different level of impact. The faster travel times discussed in Section 4.2.3 will mean travelers in DC will spend less time traveling and will have more time to spend productively or at leisure. Additionally, and perhaps more importantly will be the fact that workers in DC will be able to focus on other tasks such as work while commuting, potentially increasing the productivity of employees around the region. The potential economic impacts of this improved productivity have not been studied in detail as part of this analysis but should be considered for future study. Similarly, changes in the transportation system can have major impacts on the real estate market, increasing demand for some locations while making others less attractive. A more detailed analysis would be needed to attempt to quantify those impacts.

Three categories of economic performance are addressed to some degree in this section. The impact of congestion on regional economic growth is discussed qualitatively. Any impacts these scenarios may have impacts on the District's finances are quantified based on the range of revenue sources that may change as these technologies become more prevalent. As an offset, some costs currently borne by the DC government may decrease in scale over time. Employment impacts in the District are also discussed.

Economic Growth

Decreasing congestion also has the ability to impact DC's and the region's overall economic growth in the future, and several of the AV Scenarios would result in less congestion than otherwise forecast to occur. Borne out by anecdotal evidence, research has shown that congestion can slow regional economic growth (as measured by the growth in regional employment), by making areas less attractive for companies. Research has shown that up to a certain threshold level, congestion is actually good for economic growth, as it represents vibrant activity levels where companies and their employees want to be located (Sweet, 2013). Past that threshold, congestion actually acts as a deterrent to regional economic growth, as shown in Figure 4-27. For the Washington, DC metropolitan region, that threshold value was shown to be at around 36 annual hours of delay per auto commuter. Anything above this value would slow economic growth in the region.

Unfortunately, the Washington metropolitan region already suffers from some of the worst congestion in the country, and in 2015 average delay had already increased well past this threshold to 82 annual hours of delay per auto commuter (TTI, 2015). By 2045, this level of delay is forecast to increase by 27 percent to over 104 hours of delay per auto commuter annually without the introduction of new technologies. Based on this analysis, that level of congestion could potentially make the addition of jobs in the region very unattractive and unlikely.

As discussed in Section 4.1.2, several of the AV Scenarios have the potential to decrease congestion regionally, or at least the average congestion experienced on a per capita basis. As such, implementing some of the solutions in these scenarios could help spur regional economic growth and achieve the region's economic goals. For the purposes of this study, the MWCOG regional employment totals were used in all four AV Scenarios, although they were distributed differently between the jurisdictions. Without effective congestion relief, it is possible that the region will not be able to achieve these forecasted levels of job growth, as unpleasant traffic and unaffordable housing costs discourage companies from locating here.

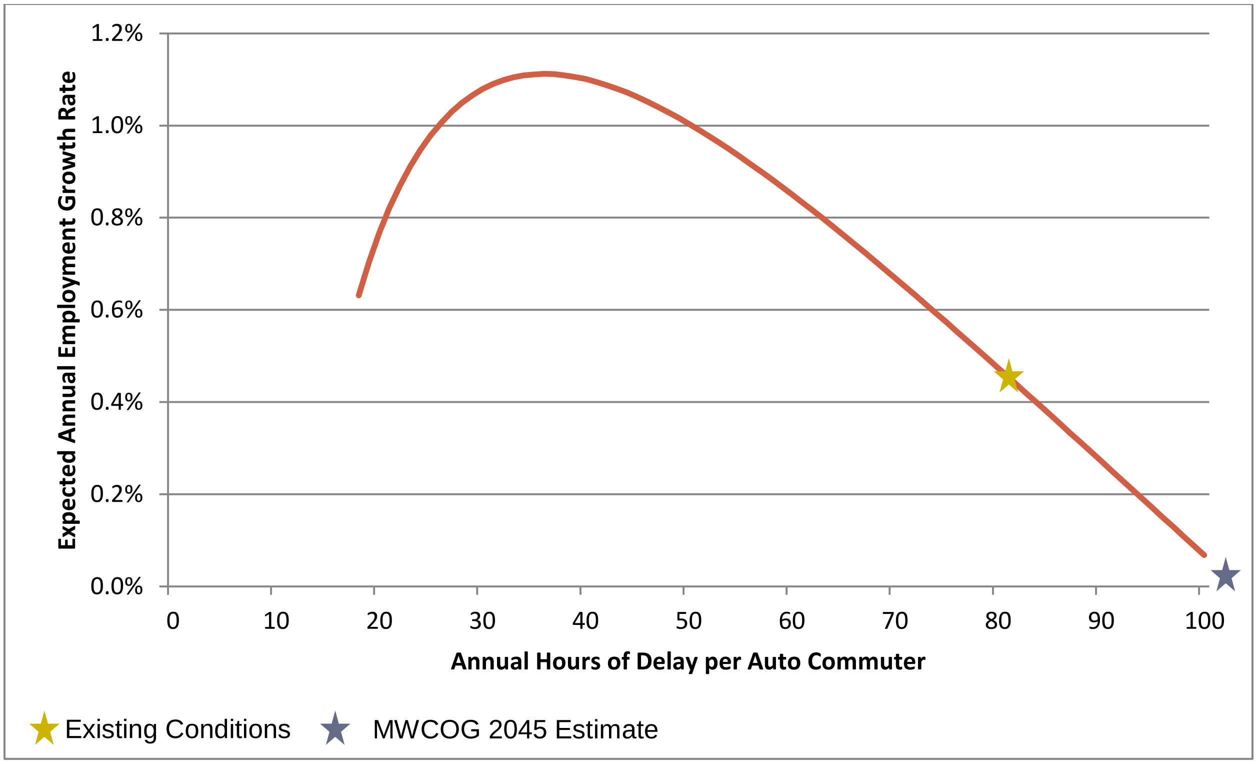


Figure 4-27: Congestion's Impact on Regional Economic Growth

Revenue and Cost Impacts

There are a number of existing revenue sources that could be impacted by AVs in various ways. As AVs cannot speed, run red lights, or park illegally, the fees associated with these bad behaviors will decrease as AV technology is adopted into the vehicle fleet. Driver's Licensing fees may also diminish if licenses are no longer required to ride in an AV. Gas tax revenues are at risk as vehicles electrify. Parking revenues from parking meters will no longer be available when AVs and shared vehicles make parking at or near your destination irrelevant. As the number of vehicles decreases in the District's fleet, so too will the amount of revenue earned from vehicle registrations. Figure 4-28 highlights the existing revenue sources that may be lost, which combined account for over $340 million in annual revenues for the District.

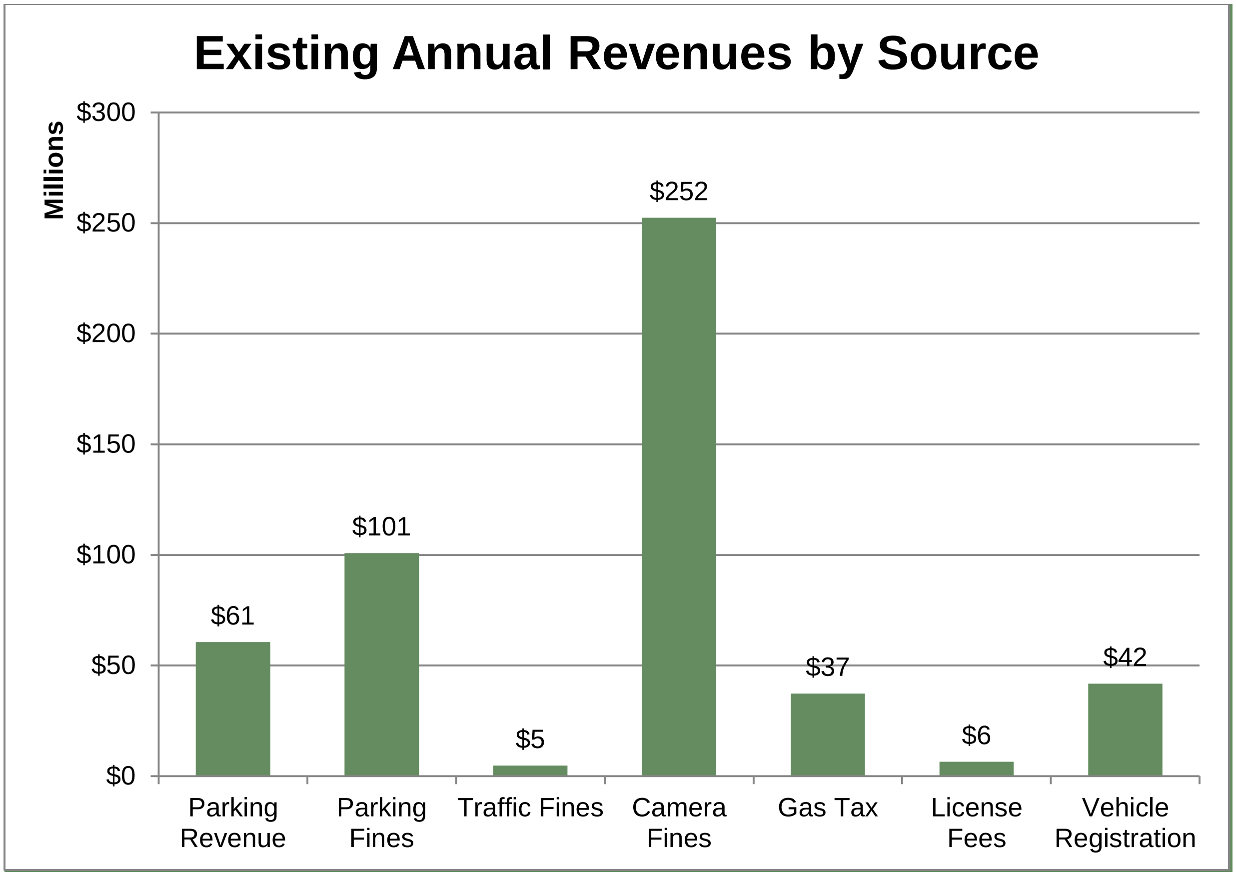


Figure 4-28: Existing Revenues by Source

Note: This chart only includes revenue sources that are likely to be impacted by AVs.

As AVs, EVs, and shared mobility make up increasing portions of travel in the District, Figure 4-29 highlights how these revenues will be impacted over time. Scenarios B and C show significant decreases in these revenue streams relatively quickly, while Scenario A shows similar decreases but later in time due to the delay in AV adoption. Scenario D incorporates similar losses from these revenue sources, but is accompanied by a significant increase in revenues from the Congestion Fee. While the precise price required to achieve the desired congestion mitigation results was not determined as part of this analysis, even a very low charge of 10 cents per mile has the potential to offset any revenue losses through at least 2035. (A ten cent per mile congestion fee is of course unlikely to have the desired impacts on congestion, but is shown here as a very conservative revenue example.) A higher fee would result in higher revenues. Further analysis would be necessary to determine the correct price, and the revenues associated with it.

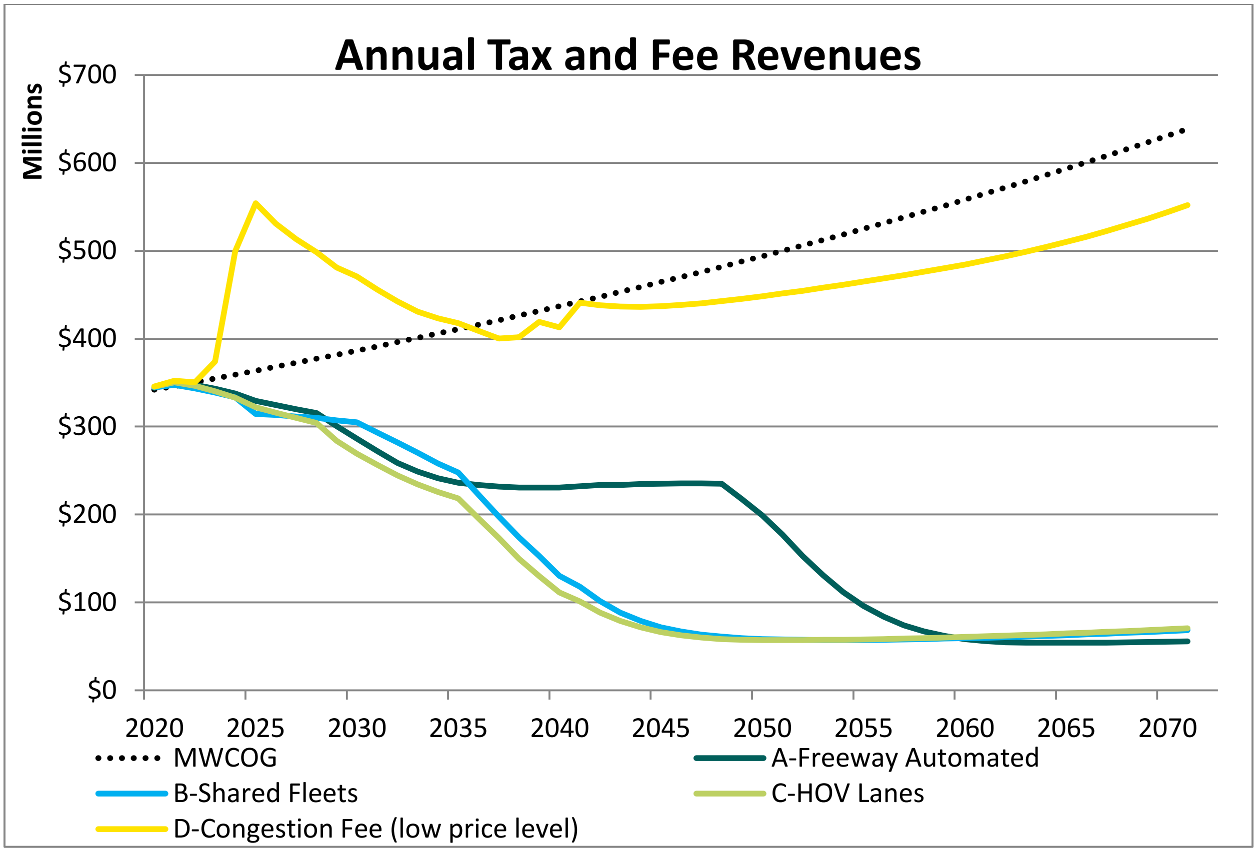


Figure 4-29: Tax and Fee Revenue, including Congestion Pricing

Note: This chart only includes revenue sources that are likely to be impacted by AVs.

In addition to lost revenues, there are significant costs that could be reduced as well. For example:

- Some portion of the almost $200M spent in the District on emergency medical services in 2018 is related to crash response;
- More than $25 million is spent on Parking Management Enforcement each year;
- Almost $8M is spent by the DMV's Driver Services Program, which is responsible for testing and licensing;
- The Vehicle Services Program at the DMV also costs $8M annually, some of which could be spent on activities besides vehicle registration activities; and
- Labor represents approximately half of Metrobus' operating costs. Fully automating buses that are capable of driving on urban and suburban streets without human intervention could dramatically the amount it costs to operate transit service – or allow for more service at a lower cost. The District current spends over $240 million each year on bus operations:
    - Metrobus: over $200M annually to subsidize Metrobus operations
    - Circulator: over $40M annually to operate
- Bus operating costs are driven by traffic speed, and WMATA has estimated that the one mile per hour slowdown caused by traffic in the last decade costs the region $30 million

in operating costs annually. Any reduction in congestion or dedication of bus lanes could significantly decrease operational costs.

Jobs at Risk

Similar to other industry sectors, automation in transportation will have an impact on employment in a number of different types of jobs. Unfortunately, the jobs that are most likely threatened by automation are highly concentrated among lower-paid, lower-skilled and less-educated workers (Executive Office of the President, 2016). Demand for some of these jobs will decrease and their footprint in DC and the region will shrink. Drivers of all types, parking attendant and enforcement jobs, gas station employees, or even personal injury lawyers may be impacted. The majority of these jobs are activities that may be replaced directly with some type of automation, particularly drivers. Other jobs will be affected by a drop in demand for their services, as could be the case if crashes dramatically decrease providing less work for insurance administrators and personal injury lawyers.

On the other hand, new technologies have historically almost always resulted in an increase in total jobs. Based on the employment impacts of the Internet, another major disruptor, AVs could create 2.4 jobs for every job lost to automation (McKinsey, 2017). The new jobs are more likely to be related to the development, maintenance, and implementation of AVs and other emerging technologies. These jobs are likely to be more technical in nature, with a focus on engineering and data security and analysis which may be growing due to other changes and evolutions in the labor market. Additionally, with less land devoted to parking vehicles, it is possible that more land will be dedicated as green space, resulting in some rise in demand for landscaping services.

Figure 4-30 highlights some of the job categories that qualify as “growing” and “shrinking” for the purposes of this analysis. These categories were identified based on a detailed review of Standard Occupational Classifications (SOC). The new “growing” jobs are unlikely to be in the same field or rely on the same skillsets as the “shrinking” job categories. Many of the people currently employed in these shrinking fields will need to change careers, which will likely require additional training.

Shrinking Job Types	Growing Job Types
• Taxi Drivers and Chauffeurs • Parking Lot Attendants • Delivery Drivers • Bus Drivers • Truck Drivers • Parking Enforcement Workers • Personal Injury Attorneys • Insurance Administration	• Programmers • Engineers (software and electrical) • Computer Systems (architects, administrators, etc.) • Mechanical Technicians • Information and Data Security • Customer Service • Landscaping

Figure 4-30: Examples of Shrinking and Growing Job Types Impacted by AVs

The jobs that are likely to disappear entirely were identified separately from the jobs that are just likely to see a decrease in demand. The majority of people in the shrinking job categories will need to transition into new jobs, however not all will do so. Workers over the age of 55 are unlikely to successfully start a new career and are not assumed to do so in this analysis (Federal Reserve Bank of St. Louis, 2015). Eighty percent of those younger than 55 are expected to transition to another job, while the remaining 20 percent might have more difficulty and may suffer from long-term unemployment.

Based on these assumptions and the existing and forecasted jobs in the region, the number of jobs at risk and the number of jobs added in DC can be estimated. Figure 4-31 shows the net change in jobs forecast in the District due to AVs. Over time, the result is predicted to be a net gain of more than 35,000 jobs in the District, an increase of approximately four percent. This growth will be slower in Scenario A than in the other AV Scenarios due to the slower adoption of AV technology. While many of the "growing" jobs will be growing in the overall labor market as well; this analysis addresses only the job changes related to the introduction of AVs, although it is very difficult to forecast future occupations (The Economist, 2016.)

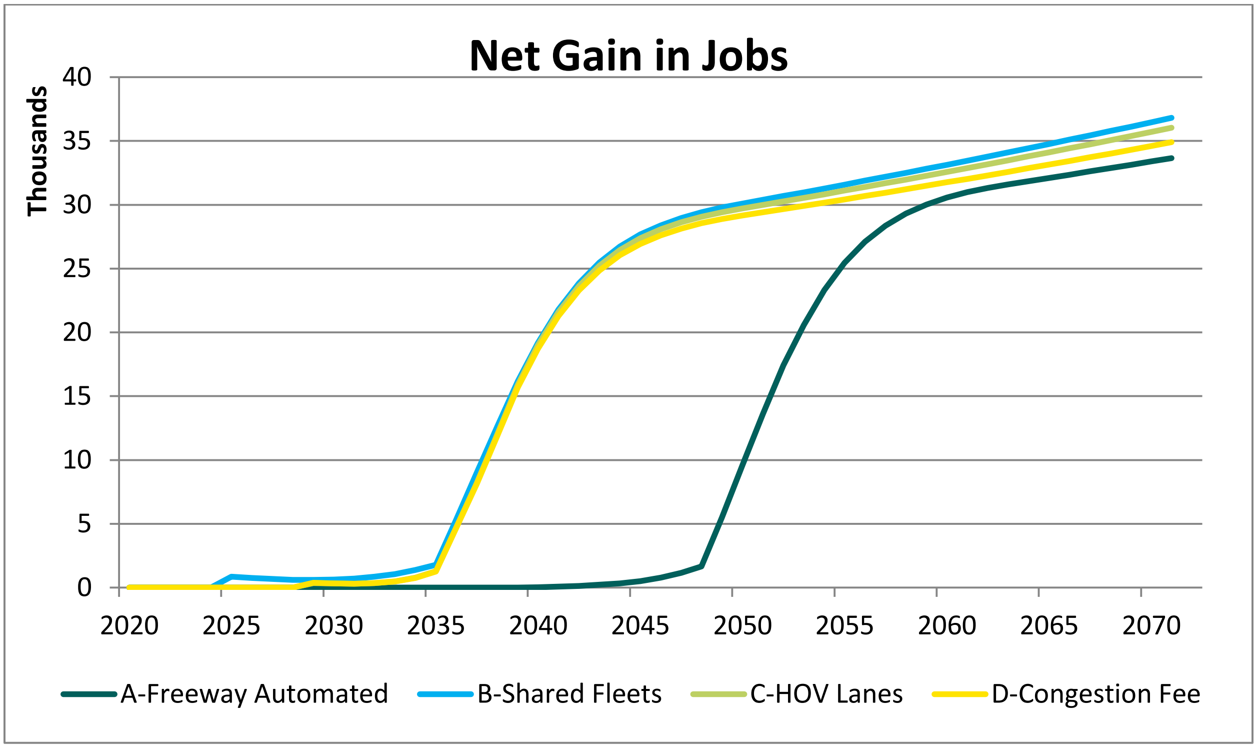


Figure 4-31: Net Gain in Jobs Caused by AVs

Source: Mobilitics Analysis

As mentioned, the growing jobs are more likely to be high-skill jobs than the shrinking jobs. Figure 4-32 illustrates that issue for 2045 by way of example. In 2045, Scenario A will still see lower levels of disruption in the job market than the other AV Scenarios, due to slower adoption of AVs. Without significant investment in training programs, it is unlikely that lower-skilled workers will be able to acquire these new higher-skill jobs.

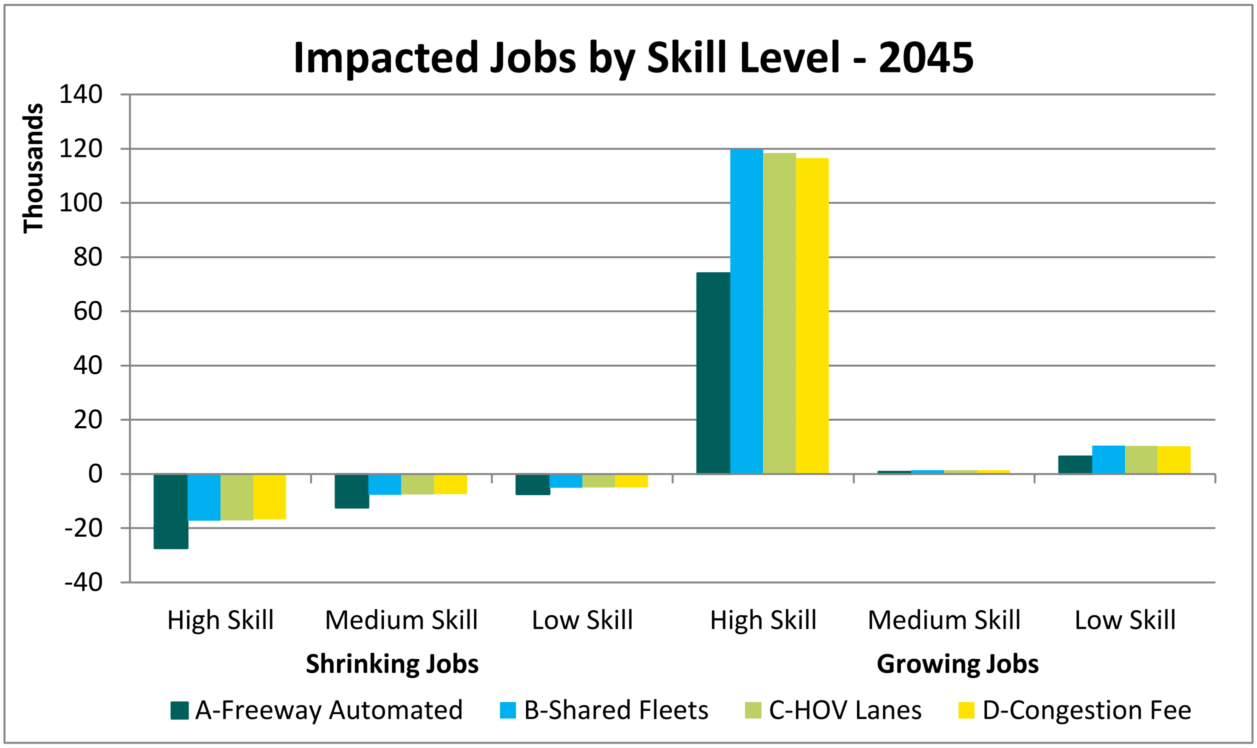


Figure 4-32: Impacted Jobs by Sill Level - 2045

Source: Mobilitics Analysis

As shown in Figure 4-33, these higher-skill jobs are also likely to be higher paying jobs, thus resulting in more income for DC residents and a stronger economy for the District and the region, as compared to a future without AVs.

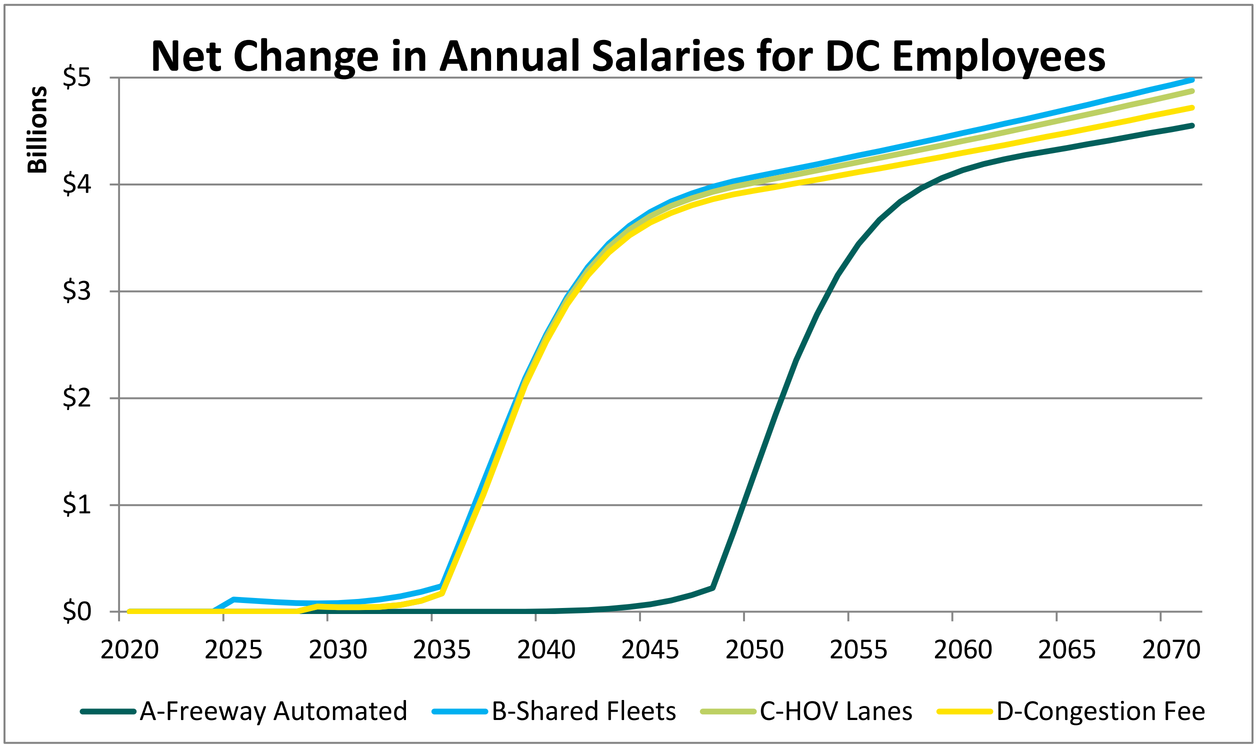


Figure 4-33: Net Change in Salaries of Job Impacts by AVs
Source: Mobilitics Analysis

Between 2020 and 2070, Scenarios B, C, and D would add more than $140 billion to the regional economy, while Scenario A would add more than $80 billion (Figure 4-34).

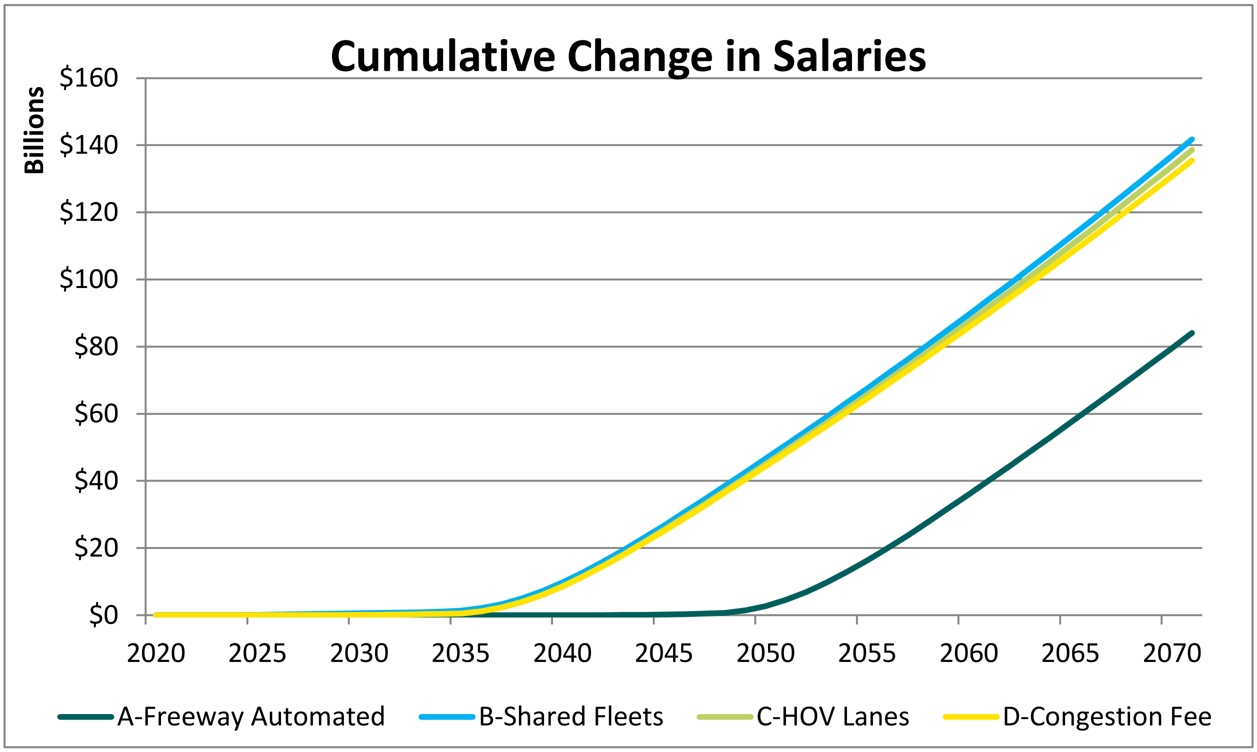


Figure 4-34: Cumulative Growth in Salaries (2020-2070)

Source: Mobilitics Analysis

4.6 Conclusions

AVs and other emerging transportation technologies have the potential to help address some of the District's major transportation problems. But the technology alone will not solve every issue – and may in fact exacerbate some challenges, like increasing VMT and spreading of congestion outside of the peak periods. Without strong guidance from planners and policy makers, the District could see few of the benefits and many of the problems. This study provides the guideposts to help ensure that does not happen.

All of the scenarios indicate that VMT is likely to rise with the widespread adoption of AVs. VMT is not a problem on its own. DC must focus on limiting growth in the externalities that arise from VMT – namely congestion, emissions, and crashes. By focusing on the problem instead of the proxy, DC can sustain high levels of mobility and economic activity while limiting the negative impacts. This study highlights several options that DC can enact to limit the negative externalities associated with additional vehicle traffic:

- **Congestion**: The major direct impact of additional travel in cars can be addressed with policies that encourage travel choices that are better for everyone. Dedicated HOV lanes can incentivize people to share rides in order to make their trip faster. Congestion pricing can make people think seriously about the total cost of their trip and make the appropriate financial decision for their situation. Any of these options will require strong policy action.

- **Emissions**: Tailpipe GHG emissions continue to grow with VMT so long as internal combustion engines remain the norm. The solution is being developed in parallel with AVs: electric vehicles. EVs remain a small portion of the region's vehicle fleet (less than half of one percent) but have almost unlimited potential to limit the environmental impacts of vehicle use. If people use them. DC must focus on strong policies that will encourage the proliferation of EVs – and the sooner it happens the better.
- **Crashes**: More exposure to vehicle traffic typically results in more crashes, more injuries, and more fatalities. The combination of CV and AV technologies has the potential to dramatically decrease the number of crashes in DC, saving lives, time, and billions of dollars every year. Part of the solution is policies that push for technology applications related to safety improvements, no matter how incremental.

Strong policies will result in the most dramatic improvements and will be easier to enact now before new travel behaviors get 'locked in' and new constituencies form. Most of these policies should be coordinated with the surrounding region as well, since decisions in one jurisdiction will impact travel behavior region-wide.

While this is primarily a transportation study, land use decisions have an important role in any discussion of transportation impacts. This study shows that the District can and should accommodate more residents, using AVs and other mobility options to provide access to neighborhoods that have typically been accessible predominately by car. Not only can this solution help address transportation issues in DC, it can help solve the region's housing affordability crisis as well.

Moving into an AV future, the District must remain strong in its priorities and commit to values about the use of road space. Pressures will mount to encourage AV implementation by making the roads "less complex" for the vehicles. These less complex roads could be achieved by separating pedestrians and bicyclists from other traffic to make urban streets more like expressways, a pressure District must stand resolute against. None of the scenarios tested in this study contemplated such a change, and it would exacerbate the potential downsides highlighted by the results.

This study points to the fact that the time is ripe for a conversation about the future of transit in DC and the surrounding region. Public transit as we have known it over the last 40 years may not be the way forward – or more likely is not the only way forward. How the District chooses to accommodate new forms of transit will be an important decision for the future of the city, the Circulator, and WMATA. Where privately owned transit offers a market solution, is it welcomed, or discouraged? If transit agencies are no longer the only providers of mass mobility, how will they transition to their new role? These questions require serious discussion, as they have no easy answers.

Finally, it is important to note that any policies advancing or shaping AVs must prioritize equity, ensuring that services are available to and affordable for all, particularly for populations which have historically been and/or continue to be disadvantaged by transportation policy decisions. This reason alone highlights the need for strong guidance from DC government in planning and implementing the transportation systems of the future.

4.6.1 Key Findings

Below are some of the key findings from the scenario analysis performed in this study. More details, including charts and graphs of the detailed performance metrics can be found in the appropriate parts of Section 4.0.

Vehicle travel will increase more than previously expected. All four of the AV Scenarios result in additional vehicle miles traveled. This includes people using cars who were previously using other modes, but also includes empty vehicles that are able to relocate themselves.

Congestion will likely rise significantly, but public policy can change that. Strong interventions that encourage shared rides and other modes could mitigate some of this growing congestion, but not all. Although overall congestion on the network could increase, especially outside of the peak periods, interventions like dedicated HOV lanes and/or congestion pricing could actually decrease the average trip times for *people.*

With increasing VMT, ***vehicle emissions will grow exponentially unless strong action is taken to encourage vehicle electrification.*** With strong early adoption of electric vehicles, more than 190 billion tons of greenhouse gas emissions could be avoided in the District alone. Far more could be avoided in the larger region.

The number of vehicles needed to provide mobility could decrease by more than 20 percent. In the long term, this could mean more than 120,000 fewer vehicles that need to park in DC. That means fewer parking garages, lower housing costs, and the ability to redesign parking spaces for other uses like parks.

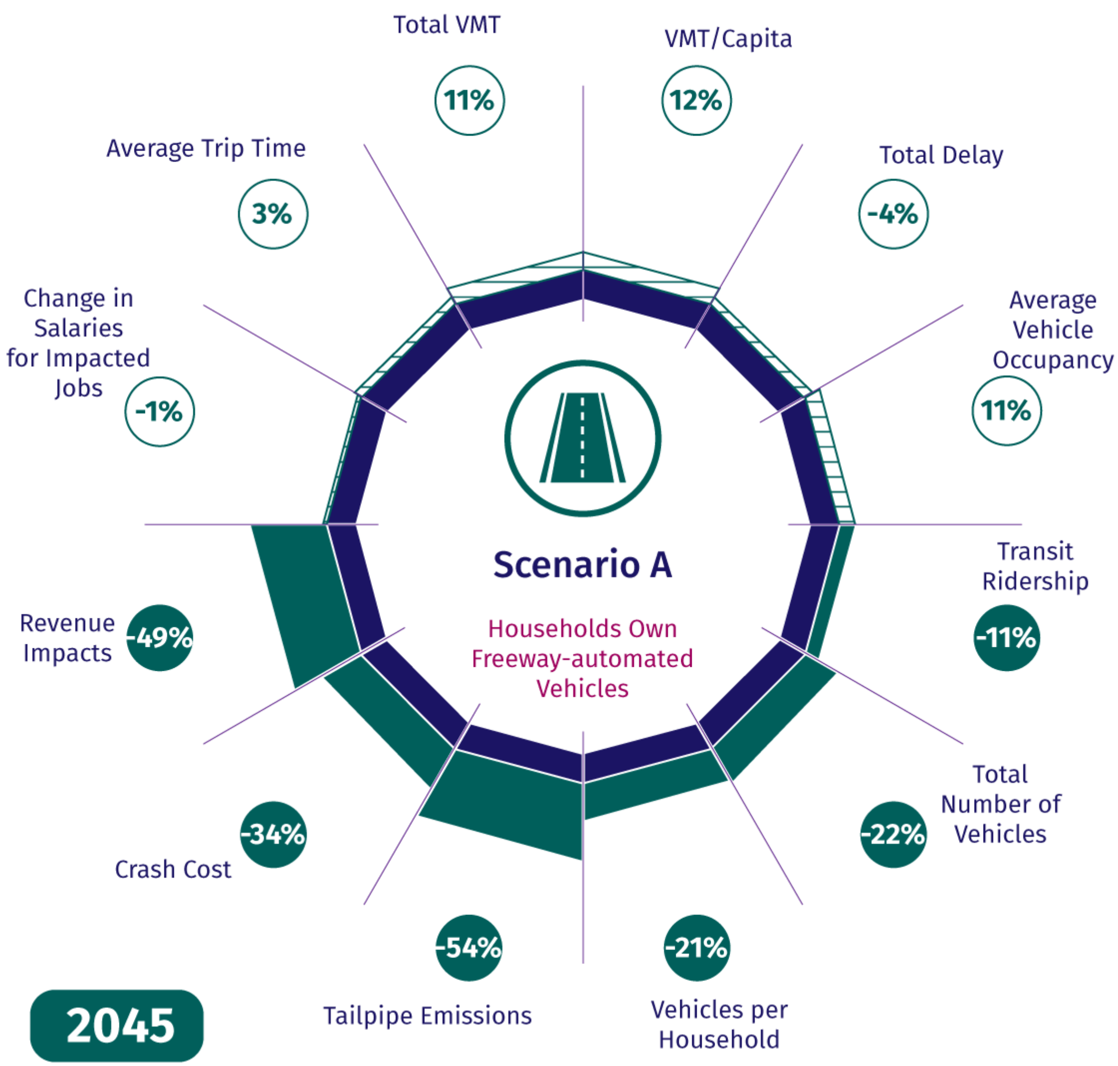
More than $340M in revenues may be at risk as AVs (most likely) will not be able to speed or park illegally meaning they will not receive tickets. New revenue sources, particularly from congestion pricing, could mitigate these revenue sources, and potentially help pay for other transportation projects and programs. Some costs may also be eliminated, such as parking enforcement and testing new drivers for licenses.

AV and CV technologies can save lives every year, and pump billions of dollars back into the DC economy. By helping to eliminate crashes and limit their severity, the money currently spent on insurance, emergency response, lost productivity, legal proceedings, property damage and injuries and fatalities could be put to better use. These technologies could help DC achieve its Vision Zero goals, saving more than 30 lives each year. This requires that vehicle manufacturers and technology companies ensure their products really are safer than human drivers, and avoid any trends toward more aggressive modes or products which do not prioritize the safety of all roadway users.

AVs can enable more people to live in walkable urban areas. DC and the larger region face a housing affordability crisis, as housing in transit-rich urban areas rises in cost and pushes people to the suburbs, or even out of the region entirely. The transportation system as currently planned cannot accommodate everyone who wants to live here, and MWCOG forecasts that by 2045 there will be 100,000 households that work in the region which have to live outside of it. But AVs and the new mobility options they enable will make it possible to accommodate more residents in the District and the region with less congestion. Easy and affordable mobility could be ubiquitous across the District. AVs could open new neighborhoods to mixed use development and encourage higher densities in areas further from Metrorail stations without requiring more cars. With land reclaimed from parked cars, the District will have more space for the things its residents want: green space, affordable housing, and economic opportunities. But this type of growth and change must be implemented intentionally, with policies and interventions that encourage more efficient use of the transportation network such as dedicated HOV lanes or congestion pricing.

The figures on the following pages highlight the key results of each of the four AV Scenarios tested in this study, comparing the MWCOG forecasts with the AV Scenario forecasts for 2045. The diagrams compare each scenario with the MWCOG forecasts as a percent change. For example, in 2045 Scenario A shows 12 percent higher VMT per capita than in the MWCOG forecasts. Some key findings about each scenario are also included.

Scenario A: Household own Freeway-Automated Vehicles

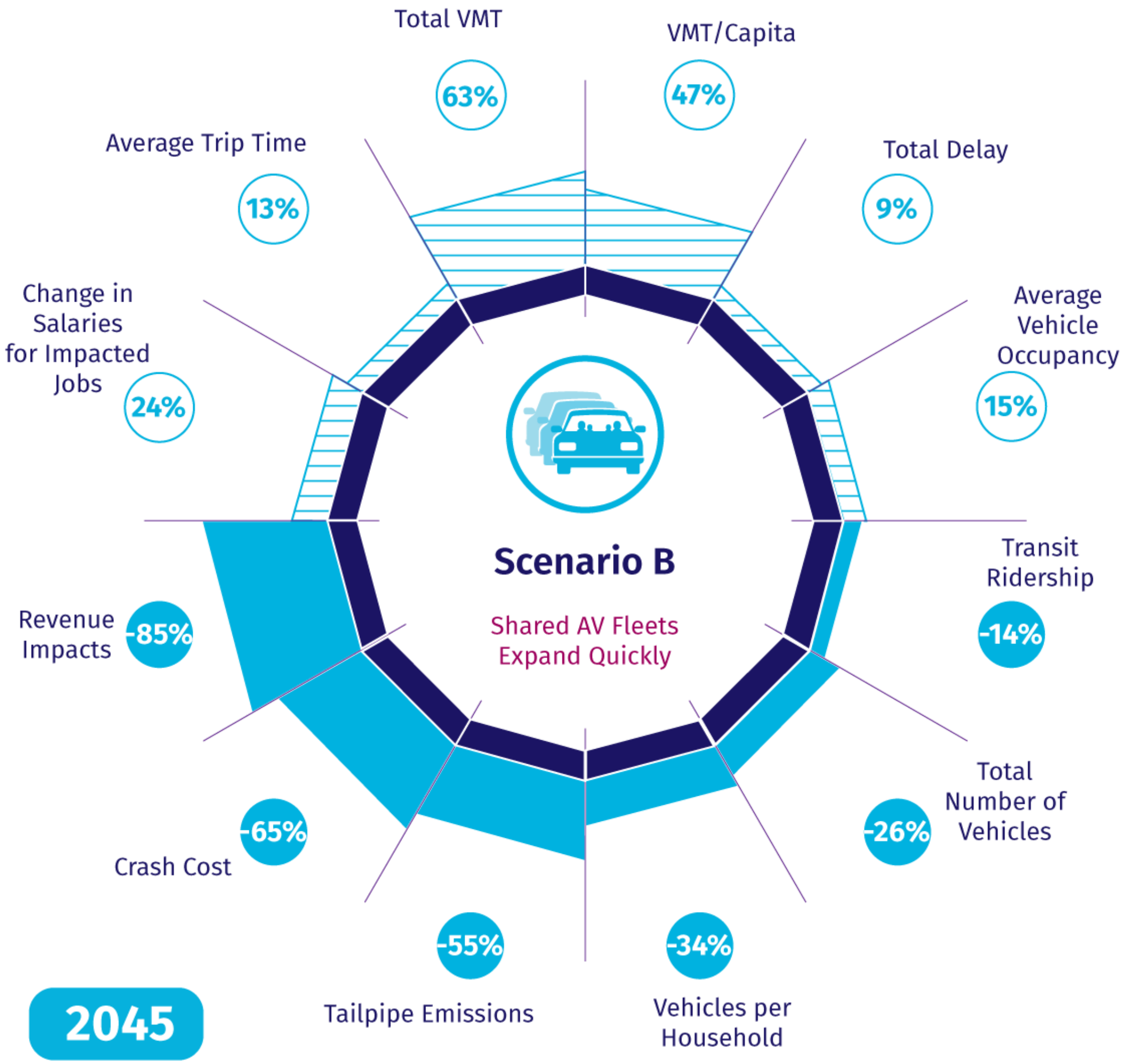


Key Findings

- High levels of VMT
- Larger fleet size as people continue to buy cars
- High congestion levels and slower trip times
- Lowest transit ridership
- Highest GHG emissions of AV Scenarios
- Job loss will be slower due to delayed uptake of fully automated vehicles.
- More significant impacts in surrounding jurisdictions

A gradual development path for AVs with relatively low consumer costs is more likely to result in continued auto-ownership and auto-oriented land use. The delay in full AV capability significantly delays impacts and allows current travel patterns to entrench further. If the assumed increase in freeway capacity is not able to be achieved, then this future could result in much greater negative impacts on travel time, congestion, and equity.

Scenario B: Shared Fleets Expand Quickly

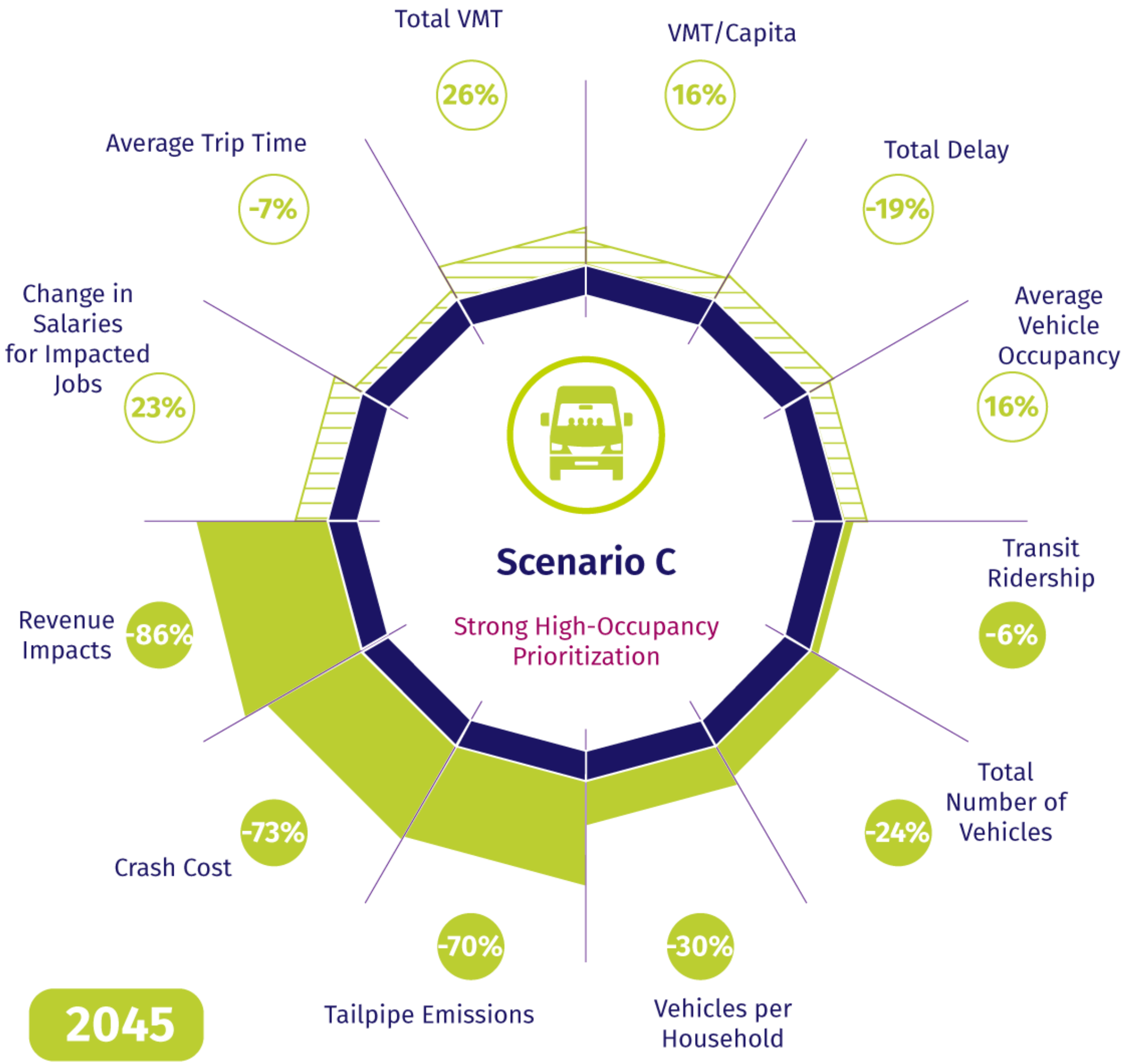


Key Findings:

- Highest levels of VMT and congestion of all scenarios
- Lowest number of vehicles needed to serve mobility needs
- Slower trips for everyone during the peak and off-peak

Unchecked, shared AVs could result in many more trips in small cars than under current conditions, impacting congestion, transit ridership, and emissions. Methods for modulating growth in VMT while maintaining mobility and accessibility must be considered. Electrification of the vehicle fleet is essential in deployment of shared vehicles in order to avoid significant increases in emissions.

Scenario C: Strong High-Occupancy Prioritization

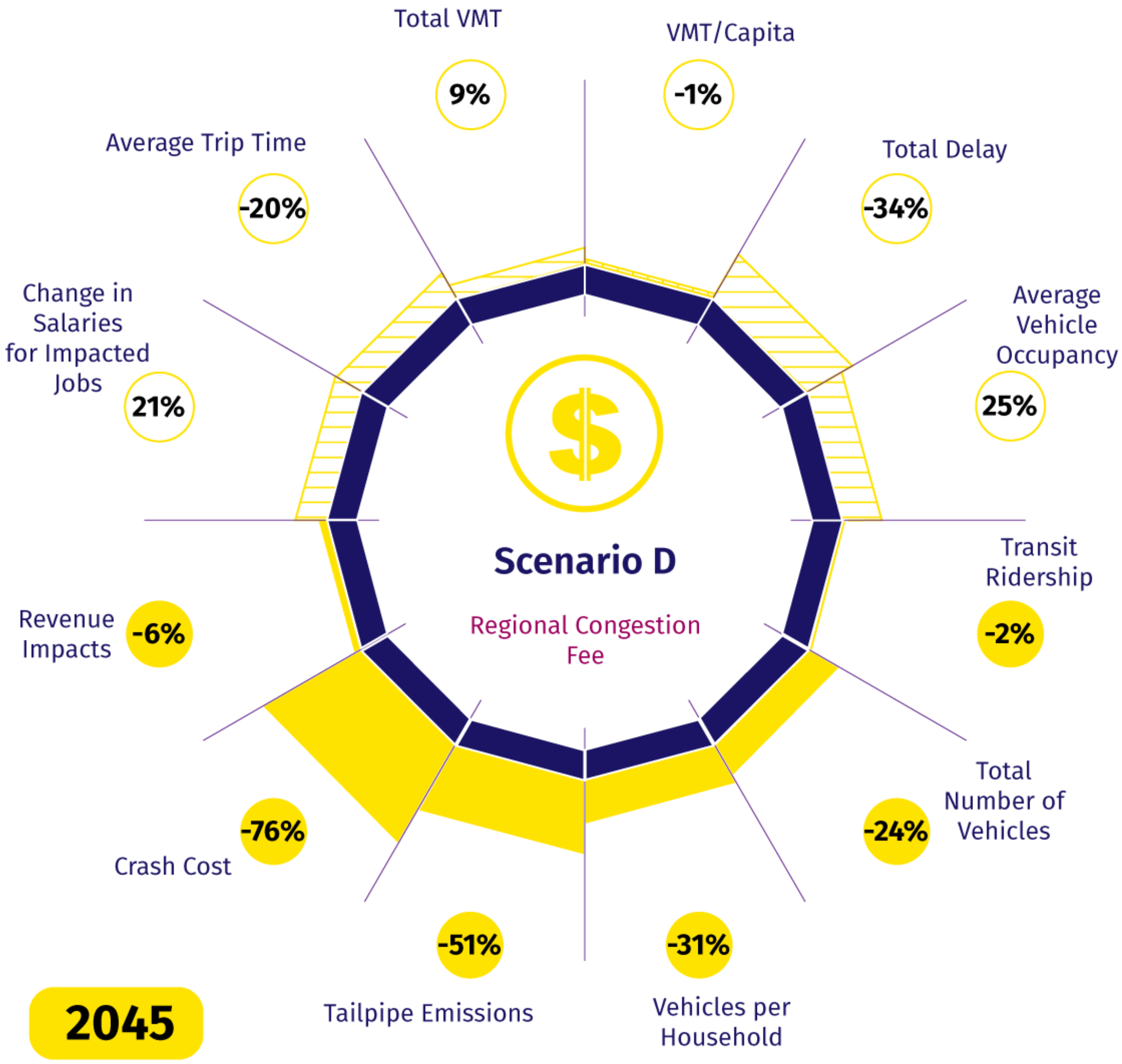


Key Findings:

- Lower growth in VMT
- Lower growth in congestion, in line with current regional forecasts despite including an additional 100,000 residents
- Relatively high transit ridership, with a broader definition of transit
- Faster travel times
- Lowest GHG emissions of any scenario tested
- Decrease in the number and severity of crashes
- Revenues may be at risk faster than in other scenarios

HOV Lanes have the potential to encourage the use of shared-ride modes, but their effectiveness will depend on pricing on the service levels offered. Providing frequent reliable service all day long in these lanes will be essential, along with identifying the best operating methods for serving the whole District whether by private or public service providers. The future definition of “transit” must be clearly identified.

Scenario D: Regional Congestion Fee



Key Findings:

- Lowest VMT growth
- Lowest congestion levels, due to implementation of congestion fee
- Highest average vehicle occupancy, as congestion pricing encourages shifts to higher occupancy modes
- Highest transit ridership
- Largest improvement in safety
- Potential to replace lost revenue with congestion fees

A strong policy of congestion pricing has the most potential to limit the growth of negative transportation externalities, such as congestion and emissions. However, additional study is necessary to identify the optimal policy option and pricing level. Consideration for low-income travelers in the whole region will need to be made to ensure that their mobility is not impaired by a congestion fee.

5.0 RECOMMENDATIONS AND NEXT STEPS

The results of the DC AV Study indicate that there is more work to be done to prepare for the introduction and widespread adoption of automated vehicles and other emerging transportation technologies. The detailed analysis of four potential AV futures has revealed some important insights and ways that the District can achieve desirable and equitable outcomes, regardless of how the technology itself evolves. This section highlights a series of recommendations for additional actions that can be undertaken in the near future that will continue the work of preparing for AVs in a way that benefits the whole community. These recommendations have been developed with the AV Study Working Group in support of the District's larger policy goals.

5.1 POLICY RECOMMENDATIONS

Recommendation #1: Pricing Strategies

Perform a detailed analysis of alternative transportation pricing strategies and how they might be implemented.

Autonomous vehicles have the potential to increase automobile travel demand, which has already been increasing in recent years due to population and job growth, ride-hailing, gas prices, and other factors. Multiple previous DC and regional planning efforts have recommended studying pricing strategies, including the Comprehensive Plan, Sustainable DC, and MoveDC as well as the regional Transportation Planning Board. Pricing of roadways, curbside assets, or cordon areas could be an important tool used to decrease vehicle emissions, ease congestion, and generate revenue.

Multiple pricing strategy analyses have been conducted in the United States, ranging from New York to Los Angeles, and several international examples have been deployed. This recommendation encourages funding for analysis and community engagement around transportation pricing strategies in the District, including analysis of how different pricing strategies would be compatible with the introduction and adoption of automated vehicles. This study should be conducted in collaboration with the full metropolitan region if possible.

The study should define goals and objectives (for example replacing lost revenues, achieving equity outcomes, or mitigating increased travel demand), develop performance measures, and conduct a performance evaluation of several alternative pricing strategies. The study should also include an outreach and information gathering component involving communication with stakeholders and potentially affected communities.

For purposes of this analysis, equity should be analyzed broadly across characteristics to include demographics, residents/non-residents, geographic areas, and income levels. Implementation needs and strategies for different pricing strategies will also be assessed.

Target Implementation Year: 2020, to begin in October of 2019
Legislative Categories Addressed: 1, 2, 3, 4, and 6

Recommendation #2: Electrification

Investigate, develop, and pursue policies and programs to incentivize electrification of the vehicle fleet.

Tailpipe greenhouse gas (GHG) emissions are one of the major negative externalities of vehicles travel, and they often tend to disproportionally impact low-income communities. The study's Scenario Analysis indicates that the introduction and widespread adoption of AVs is likely to increase the amount of VMT on the District's roads. In order to reap the benefits of improved mobility, the District will need to work to limit the negative consequences by eliminating as many GHG emissions as possible. Electrification of the vehicle fleet is the best way to accomplish this.

The District should investigate and pursue policies and programs that encourage electrification of the whole vehicle fleet, including privately-owned vehicles, ridesourcing vehicles, and delivery vehicles and trucks. Options may include construction of charging infrastructure, purchase subsidies, emissions fees, preferred parking locations, and others.

The District will need to work with its regional partners the neighboring jurisdictions to achieve the level of electrification necessary to avoid major environmental impacts within DC.

Target Implementation Year: 2022
Legislative Categories Addressed: 3, 4

Recommendation #3: Job Re-Training

Develop and implement programs for workforce retraining focused on jobs that are the most likely to be impacted by AVs.

Job training programs will be necessary to ensure that DC's workforce is ready for the new employment marketplace. The District should develop programs focused on specific types of jobs that are the most likely to be replaced or reduced with the introduction of automation, particularly including jobs where driving is the primary activity. Programs should identify target job types, training and educational needs, potential private sector partners, and strategies for enrolling students. Within District government, any jobs that fall into these categories should be identified and transition planning and re-training started early.

Target Implementation Year: 2023
Legislative Categories Addressed: 1

Recommendation #4: Zoning and Land Use Changes

Analyze planning and zoning requirements related to options to accommodate additional residents in DC. Evaluate any land use regulations that should be revised in light of AV adoption.

The transportation system as currently planned cannot accommodate everyone who wants to live in DC and the region, and MWCOG forecasts that by 2045 there will be 100,000 households that work in the region which have to live outside of it. AVs and the new mobility options they enable will make it possible to accommodate more residents in the District and the region with less congestion and less space devoted to storing vehicles.

The District should study opportunities to add housing, including affordable housing, citywide and particularly in areas which have seen little growth in recent years. MWCOG, in collaboration with regional governments, should similarly analyze opportunities to meet the housing and affordable housing need in activity centers region-wide. The costs of parking contribute to the high costs of housing in DC; underground parking spaces can cost $60,000 per space to construct. Surface parking takes up valuable space that could be better used to serve other needs. The District revised minimum parking requirements earlier this decade but the requirements that were instituted should be re-evaluated in light of AV adoption, so that parking is not constructed unnecessarily.

A comprehensive review of existing land use and zoning codes and land use policies will be necessary to identify other types of land use that may need to change in an AV future. This could include parking requirements as previously mentioned but should also consider non-residential land uses that may be impacted by emerging technologies including gas stations, curb-side space, existing parking garages, auto repair facilities, and others.

Recommendation #5: Shared-Ride Incentives

Develop and implement programs and policies that encourage the use of high-occupancy vehicles for all types of trips to achieve goals in MoveDC and SustainableDC.

Ride-sharing, whether in shared vehicles, private cars, or buses will be important in limiting the impacts of increasing VMT in the District. Public and private entities have used a number of techniques to encourage the use of high occupancy vehicles, such as transit subsidies or preferred parking locations. The District should investigate and pursue additional strategies that could encourage use of all types of shared modes including expanding transit benefit programs, dedicated lanes for high-occupancy vehicles, discounts or subsidies for shared ridesourcing rides, or apps that incentivize ride sharing. Lessons learned nationally and in the region can guide the development of these programs and incentives, such as MWCOG's recent pilot with an app that incentivizes sustainable transportation choices.

Target Implementation Year: 2022
Legislative Categories Addressed: 3,4,5,6,7

5.2 Research Recommendations

Recommendation #6: Economic Analysis

Conduct a broad economic analysis of the impacts of automation and other emerging technologies on the District's economy.

A broader economic study should be conducted that considers the complete economic impacts of AVs and other emerging technologies on the District. Non-transportation technologies could be included in this analysis as well, to the extent that they will impact land use patterns and other behaviors. This analysis should include impacts on DC's major revenue streams including sales tax and property tax. Any analysis of property tax impacts will need to consider how the real estate market could be impacted by different policies, including increasing or decreasing demand for different types of real estate in different parts of DC. The potential for AVs to alleviate or exacerbate housing affordability should be considered.

Target Implementation Year: 2021
Legislative Categories Addressed: 1, 2

Recommendation #7: Infrastructure Needs

Conduct a needs-based analysis to identify specific infrastructure investments needed to adapt to AV deployment.

AV technologies are intrinsically correlated to a vehicle's surrounding environment such as roadways, lane striping, signage, parking spaces, and curbsides. Infrastructure is crucial for piloting AV projects and expanding AV fleets. This recommendation proposes development of a needs-based infrastructure improvement and/or maintenance strategy to adapt to and monitor AV deployment and identify complementary infrastructure throughout the District. Infrastructure types to be evaluated include roadways, right-of-way, signage, parking (surface, structured, and on-street), and curbsides. The analysis will address the quantities and types of infrastructure needed, as well as the potential to adaptively reuse infrastructure over time. The analysis will also examine other emerging technologies such as CV and EV technologies' impact on infrastructure related to AV use.

In addition to traditional infrastructure, the introduction and large-scale adoption of connected and automated vehicles will require new data infrastructure. This analysis will identify the hardware, software, and other data needs in the District.

A phased analysis approach is recommended, with an initial assessment in 2021 to provide guidance to a more detailed analysis in within the following three years.

Target Implementation Year: 2021, 2024
Legislative Categories Addressed: 3

Recommendation #8: Policy and Regulatory Needs

Review and analysis of policy and regulation needed to adapt to AV and other technology and services.

Existing policies and regulations will shape AV technology deployments while AVs will create the need for new policy and regulatory frameworks. As technologies continue to advance, the regulatory and policy framework will need to be updated to better guide implementation and development. This recommendation will conduct a comprehensive review of existing land use, zoning, and data laws, policies, and regulations as they relate to AVs, including laws, zoning codes, data sharing and ownership policies, land use policies, contractual obligations and others. The study will provide recommended updates and/or additions to ensure coordination between technological advancements and public policy.

Target Implementation Year: 2021
Legislative Categories Addressed: 3, 5, and 8

Recommendation #9: Model Development

Support the updating and/or development of tools and planning processes that incorporate emerging mobility trends for the purposes of making informed investment decisions locally and regionally.

This analysis has shown that the current travel demand forecasting model is not accurately able to represent emerging transportation trends. Many transportation decisions in the region today are made based on the results of this model, even though major modes of transportation are not included, including the existing ridesourcing services. MWCOG/TPB is in the process of updating their model to a new version that will improve many of these characteristics, but the update process is scheduled to take more than three years. The District and the region need to support and encourage this model update process, and any options for speeding up the process should be exercised.

Additional consideration should be given to the overall planning and investment processes, and how they can best use existing tools to incorporate future technologies. MWCOG's charge has always been to be conservative with their modeling for air quality conformity purposes. If the MWCOG model is going to continue to be used to make transportation planning and investment decisions, methodologies need to be developed that account for the uncertainty and disruption associated with many future technologies.

Target Implementation Year: 2020
Legislative Categories Addressed: 3,4,7

5.3 Operational and Organizational Recommendations

Recommendation #10: DDOT Staffing

Increase organizational capacity at DDOT with staff positions dedicated to emerging technologies.

The rapid evolution of CV, AV, micromobility, and other emerging transportation technologies has widespread implications for travel patterns, systems, and agency operations. This recommendation supports the creation of two dedicated emerging technology staff members at DDOT in FY 2021, and two additional positions in 2022. These staff positions will support the implementation, regulation, public engagement and information, funding, and oversight needs related to emerging transportation technology in the District, in addition to important coordination roles within the region and with neighboring jurisdictions.

Target Implementation Year: 2021, 2022
Legislative Categories Addressed: 1

Recommendation #11: Pilot Projects

Support pilot projects with other organizations or private entities including AV and CV technologies. Develop and implement an equity analysis methodology for pilots and future programs.

AV pilot projects in the District are key to eventual large-scale adoption. If deployed conscientiously, AV pilots have the potential to increase mobility options for disadvantaged communities, as well as provide connections to existing transit stations. For example, AVs can help bridge first/last mile gaps and enhance disadvantaged communities' accessibility to existing public transit services. This recommendation will support up to two pilot projects, such as the SWBID AV Shuttle, as well as a second pilot in AV or CV. Support for the pilot projects should include a rigorous technology selection process to ensure that the best technology providers are selected.

Ongoing monitoring and evaluation of the pilots are also necessary to ensure that lessons learned are appropriately incorporated into future implementation projects, and to help grow the available data related to potential impacts and benefits, resource allocation, public safety, data generation and ownership, and partnership success of AVs in dense, urban environments. Data from the pilot projects will be shared appropriately for use in the District including occupancy rates, ridership and demand levels, and other best practices and lessons learned. The pilots will be evaluated for their equity performance, and equity issues that new AV deployments could help to address will be identified. This analysis will develop a methodology that can be used in the future analysis of any proposed AV pilots or programs.

Target Implementation Year: 2020
Legislative Categories Addressed: 1, 4, 5, 6, 7, and 8

Recommendation #12: Regional Coordination

Play an active role in coordinating regional plans and policies for AVs and other emerging transportation technologies.

The impacts of AVs will not stop at the District boundaries and must be considered at a regional scale. All of the scenarios analyzed as part of this study require that the District and the surrounding jurisdictions work together to implement policies, pricing structures, and other decisions together. This will not only make things easier for residents and other travelers but will help the region's transportation network perform optimally. Working together is the best way to achieve common goals. Future policy studies and analysis should be conducted with that coordination in mind.

A regional coordinating committee focused on the implementation of AVs and other emerging transportation technology should be created to facilitate and encourage coordination and cooperation. This committee may be most appropriately housed at MWCOG, but other options should be considered.

Target Implementation Year: 2021
Legislative Categories Addressed: 1,2,3,4,5,6,7,8

Recommendation #13: Connectivity for Safety

Investigate and implement connected vehicle technologies with a focus on applications that improve safety in urban environments.

The safety benefits of AVs become even more pronounced when coupled with Connected Vehicle (CV) technology. These communications technologies are being developed and tested for a range of applications, although many of the initial larger-scale applications have been on freeways. CV technology can help the District achieve its Vision Zero goals, saving lives and making roads safer for all users. Before AVs, CV technology can help people be better drivers. With the adoption of AVs, CV technology will amplify their safety benefits.

The District should investigate available CV applications that would improve safety on urban streets. Large-scale investment in technology systems may require some longer-term evaluation, as industry tests different protocol systems and technologies to determine the best technologies. Some applications could be implemented now, or in the near future and the District could serve as a test bed for pilot tests of urban CV applications, giving DC a voice in guiding their creation and development.

Target Implementation Year: 2021
Legislative Categories Addressed: 3,4,5,6

5.4 DATA RECOMMENDATIONS

Data will continue to play a growing role in the planning, operations, and management of transportation systems as AVs and CVs grow their presence in the District. Ensuring that DC has access to the data it needs to manage its transportation system efficiently is the key goal of this recommendation. This data could come from multiple sources and be used for multiple purposes but will be essential in limiting the impacts of AVs and other new mobility options and ensuring equity for DC residents. Some important data and their uses are outlined below; this list of data requirements will likely evolve as new business models are introduced. Once AVs, CVs, automated ridesourcing and other new mobility options are operating on the ground, it will be considerably harder to enact data sharing requirements. To make it easier to enact any required legislation or regulation, the requirements should be implemented as early as possible.

Policy Enforcement

The results of this study show that some form of policy intervention will be necessary in order to limit the impacts of AVs in the District, and to combat the congestion problems already faced by the region. These policy interventions could be related to pricing, dedication of roadway or curbside space, or others. There are many possible variations within these broad categories such as a congestion fee (as tested in this study), a cordon charge, emissions-based fees, dedicated AV lanes, dedication HOV lanes, and/or curb access fees.

Implementation of any of these policies will require data from vehicles to accurately charge roadway users and/or enforce dedicated lanes. The data necessary to do this would most likely have to come from the vehicles themselves, as self-reporting and manual enforcement are not viable from the perspective of cost and efficiency. Data requirements will vary by policy, but could include:

- Vehicle type (e.g. passenger car, bus, large truck, delivery van, etc.)
- Engine type (internal combustion, battery electric, hybrid)
- Time and occupancy of entry (in the case of a cordon charge)
- Miles of travel on each roadway in the District by:
  - Time of day
  - Vehicle occupancy, including zero-occupancy travel (ZOV)
- Parking location and duration
- Curb access locations and time spent at the curb, by time of day

For the purposes of enforcing dedication roadway space, the data would need to be provided by each vehicle in real-time, likely to roadside units, to confirm that the vehicle is permitted in the designated lane. However, this data could be anonymized, and may not need to be stored by the District, limiting public concerns about privacy.

For pricing policies, the data would need to be provided for each user, household, or corporate entity so that charges can be allocated appropriately. This would require that the data is kept and stored by the District (or other appropriate pricing authority) for revenue collection and enforcement. To allay privacy concerns, only the minimum amount of information necessary in order to accurately enforce a pricing policy should be stored and should be scrubbed of personal information before being used in planning or analysis purposes.

Planning and Performance Management

Some of the same types of data will be useful in planning and operating DC's transportation network. These items can be used in planning transit services, implementing bike and/or bus lanes, identifying pick-up/drop-off points, and identifying transportation needs. In addition to the data listed above, additional data items could include:

Data point	Uses
Travel time by time of day on each roadway in the District	Used to understand congestion and identify potential solutions
Anonymized start and end-points for all trips, particularly in shared vehicles (this data is already required for TNCs operating in DC)	Used to identify travel patterns of DC residents and commuters
Average wait time for on-demand services by location	Used to assess equity
Average wait time for ADA-accessible on-demand services	Used to ensure access for ADA populations
Curb access locations by time of day	Used to identify locations for pick-up/drop-off points

All data would need to be anonymized and aggregated to maintain the privacy of travelers. Data should be aggregated to an appropriate geographic level as needed to perform these planning and performance management functions.

Safety Data

Ensuring the safety of AVs for all roadway users is one of the main responsibilities of the District of Columbia. To do this job effectively and efficiently, AV manufacturers and owners will need to report details of any safety incidents, near incidents, or other concerns to the District. These could include:

- Details of any vehicle crashes, including detailed information recorded by any on-board "black box" recorders.
- Reports of shut-offs of automated driving systems, where an AV is unable to continue the driving task. The circumstances of these events and the causes will need to be shared to identify any improvements needed to either District infrastructure or manufacturer hardware or software to avoid the issue in the future.
- Security incidents, particularly on shared AVs should always be reported to the proper authorities. Security incidents can be aggregated by provider, but will include any reports of crimes or harassment on-board unmanned vehicles.
- Data security breaches that expose District residents must be reported to the District.

In addition to these types of performance and usage data, DC may want to ensure that it knows the operational capabilities of all the AVs on the road, both in use as share vehicles and privately owned. Currently, different advanced driver assist systems (ADAS) have very different levels of capabilities and operating design domains. Understanding these functionalities will be key in ensuring the safety of DC's residents and emergency response personnel. The District will want to track which vehicles are capable of safely interacting with pedestrians, or traffic lights, or can only travel below a certain speed. Software capabilities will also likely be of interest. For example, the District may want to know from manufacturers if an AV owner or user is able to override speed limit controls on DC streets. This type of data should be requested and provided by the vehicle manufacturers in order to be allowed to operate in DC.

Advanced Traffic Management

In the future, the District may want to consider implementing advanced traffic management solutions. For example, dynamic curb usage programs could be implemented that allow users to reserve curb space in advance for pick-ups, deliveries, or drop-offs. Cooperative traffic management, in which traffic operations are changed dynamically to optimize traffic flow throughout the District. These types of solutions could be possible in the medium to long-term with full market penetration of CV and AV technology. But these types of applications would require additional real-time data, such as desired destination, vehicle occupancy, or the ability to identify vehicles that may want to be prioritized. Data privacy concerns would be even more pronounced in this paradigm, and anonymization must be assured to all users.

Data Sharing

Because the data specified above will likely have multiple uses for different District and regional entities, it is essential that DC agencies be able to share these datasets easily. This may require updates to a range of internal IT systems at various District agencies, such as OP, DDOT, DMV, MPD, and others. Data sharing agreements between the District and the surrounding jurisdictions will also be necessary because so much travel in DC crosses jurisdictional boundaries. Travel patterns, safety and security incidents, parking and curb usage among others will help DC and the region plan and operate better.

Federal preemption

The District should closely monitor any federal legislation which preempts local or state authority regarding CV and AV technology. Some provisions of the AV START Act, considered by Congress in 2018 but not passed by the Senate, might have preempted local authority over CV and AV technology including the possibility of preventing some of the Policy Enforcement or Planning and Performance Management opportunities detailed above. Local governments should monitor any future legislation and ensure that their ability to collect data directly from CV and AV vehicles or operators continues to allow the flexibility needed to enact and enforce local policies.

LEGISLATIVE CATEGORIES:

Below are listed the categories references under the recommendations.

1. The effect on the District's economy, including economic development and employment;
2. The impact on the District government's revenue, including motor vehicle excise taxes, motor vehicle registration fees, motor vehicle fuel taxes, residential parking permit fees, parking meter revenue, fines and fees relating to moving infractions or parking, standing, stopping, and pedestrian infraction, commercial parking taxes, insurance taxes;
3. The impact on the District's infrastructure, traffic control systems, road use, congestion, curbside management, and public space;
4. The impact on the District's environment and public health;
5. The impact on public safety in the District, including the safety of other road users such as pedestrians and bicyclists;
6. The impact on the District's disability community;
7. The impact on the various transportation modes in the District, including mass transit, shared-use vehicles, and public and private vehicles-for-hire; and
8. The need for and use of autonomous vehicle data, including data from autonomous vehicle manufacturers and public and private vehicle-for-hire companies.

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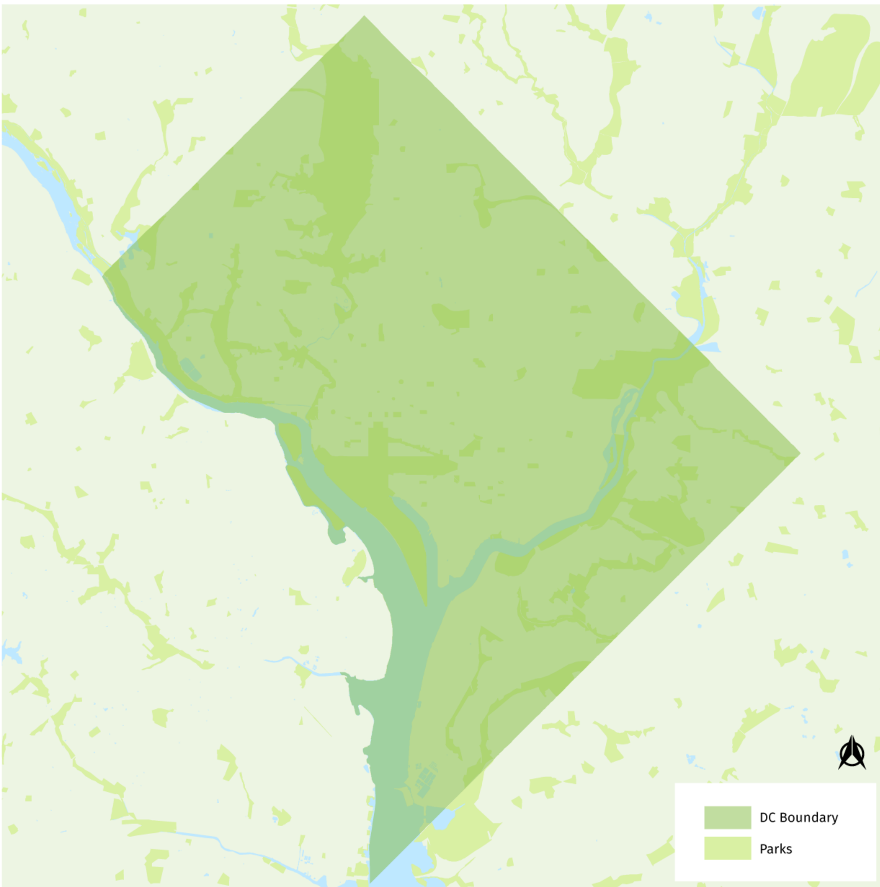
7.0 APPENDIX A: PLANNING AREA OVERVIEWS

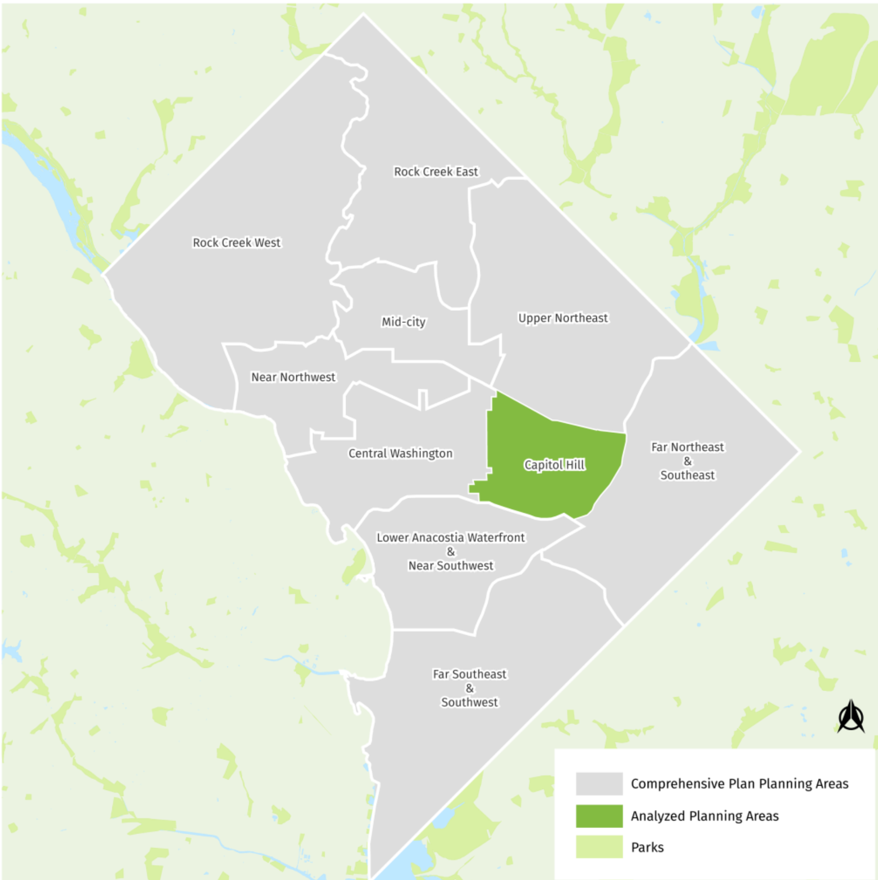
7.1 DISTRICT OF COLUMBIA



Population	672,400
Households	278,100
Jobs	357,700
% Low Income*	1.43%
% Minority	59.33%
% Zero-Car Households	35.75%
Roadway Lane-Miles	1,600
Area (sq. mi.)	67.4

Low income households earn less than $25,000 per year (ASPE, 2019).

7.2 CAPITOL HILL



Population	60,100
Households	25,500
Jobs	25,000
% Low Income*	0.9%
% Minority	37.5%
% Zero-Car Households	22.9%
Roadway Lane-Miles	123
Area (sq. mi.)	3.1

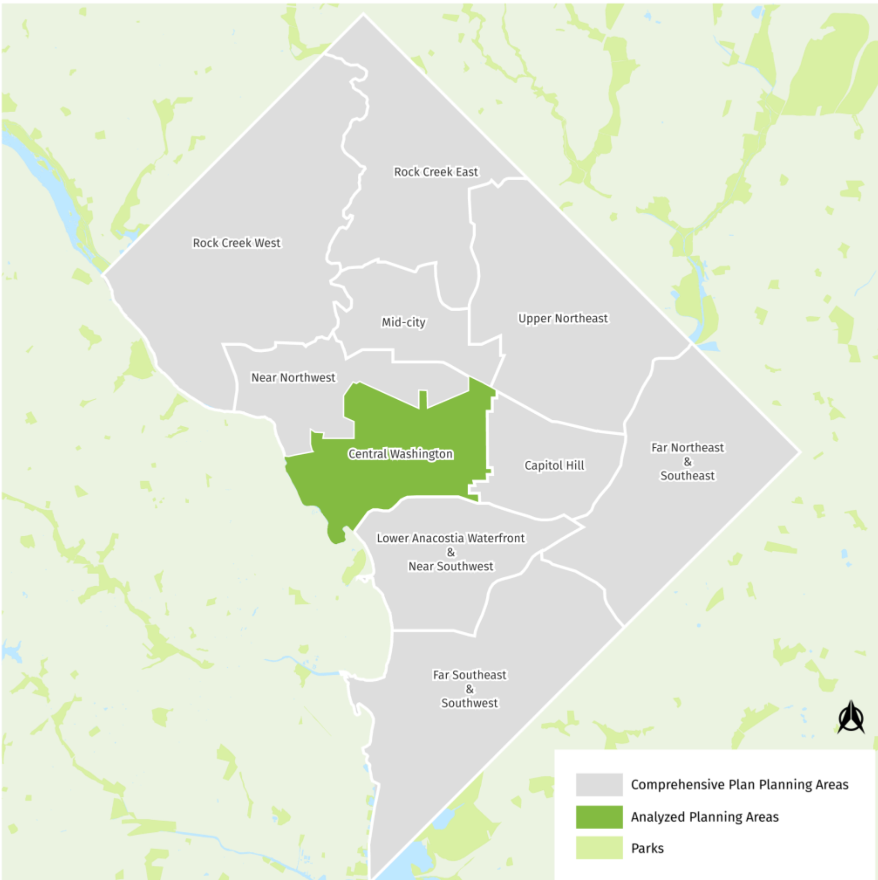
Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	81,400	35%	81,000	35%	93,600	56%	87,800	46%	88,700	47%
Households	31,200	22%	31,000	22%	36,100	42%	33,800	33%	34,200	34%
Jobs	37,100	48%	35,700	42%	38,300	53%	38,200	53%	37,100	48%

Capitol Hill

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	672,600	752,200	1,135,500	851,200	749,500
VMT Per Capita	8.1	9.0	12.1	9.4	8.2
PHD Per Capita	0.6	0.6	0.6	0.5	0.4
Average Vehicle Occupancy	1.3	1.5	1.5	1.6	1.7
Transit Ridership	63,400	59,700	57,700	65,400	66,300
Total Number of Vehicles	30,300	22,00	21,200	22,300	22,200
Average Vehicles Per HH	0.9	0.7	0.6	0.6	0.6
Emissions ($MMTCO_2e$)	580,600	266,300	260,000	168,500	281,300
Cost of Crashes ($M)	$117.3	$77.2	$41.6	$31.3	$27.3
Average Trip Time (Mins)	30.6	31.8	35.3	27.5	25.5

7.3 Central Washington



Population	29,600
Households	16,600
Jobs	463,900
% Low Income*	1.0%
% Minority	35.9%
% Zero-Car Households	49.6%
Roadway Lane-Miles	299
Area (sq. mi.)	6.8

Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	49,000	66%	48,600	64%	54,700	85%	51,700	75%	52,100	76%
Households	26,400	59%	26,100	57%	29,700	79%	28,000	69%	28,300	70%
Jobs	546,300	18%	539,200	16%	557,300	20%	551,000	19%	546,300	18%

Central Washington

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	2,241,400	2,596,600	3,952,800	2,791,700	2,610,500
VMT Per Capita	45	52	72	52	48
PHD Per Capita	1.3	1.4	2.0	1.4	1.2
Average Vehicle Occupancy	1.3	1.5	1.5	1.6	1.7
Transit Ridership	421,700	404,400	398,800	426,500	462,000
Total Number of Vehicles	21,400	16,800	16,500	16,500	16,500
Average Vehicles Per HH	0.8	0.6	0.6	0.6	0.6
Emissions (MMTCO2e)	1,934,600	896,500	868,600	534,900	959,300
Cost of Crashes ($M)	$363,277,800	$248,234,300	$134,738,300	$94,870,400	$88,147,200
Average Trip Time (Mins)	37.3	36.4	40.1	32.8	30.8

7.4 Lower Anacostia Waterfront & Near Southwest

Population	34,700
Households	20,200
Jobs	56,800
% Low Income*	2.7%
% Minority	78.7%
% Zero-Car Households	42.8%
Roadway Lane-Miles	83
Area (sq. mi.)	3.0

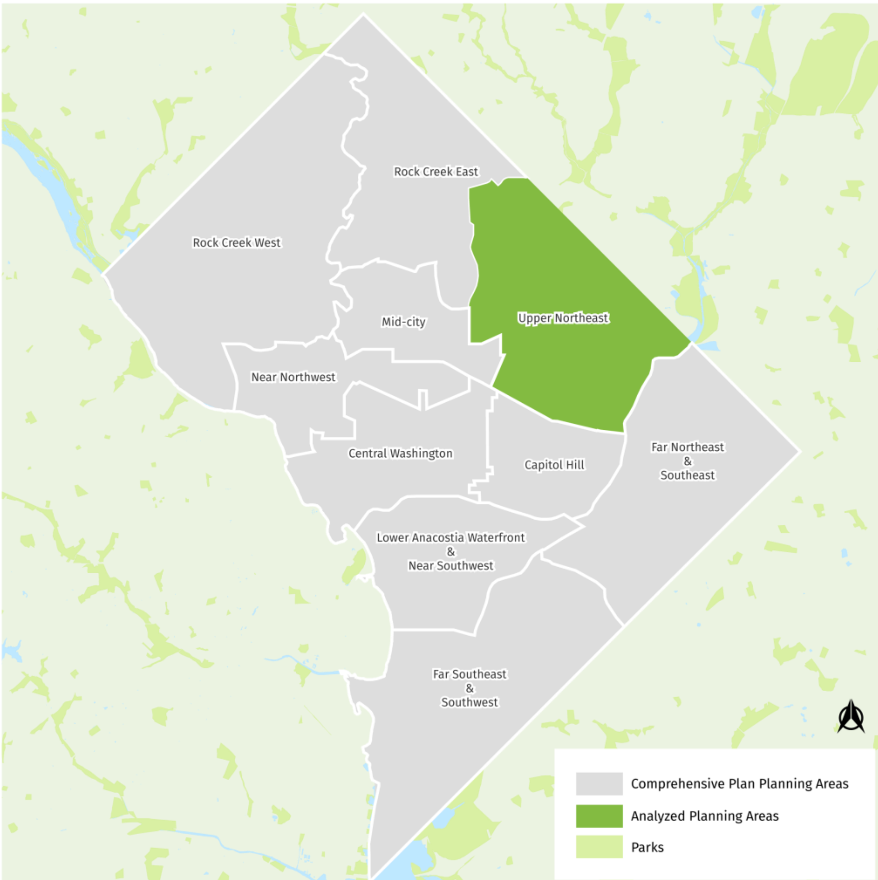
Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	68,600	98%	66,900	93%	85,000	145%	76,300	120%	77,400	123%
Households	38,800	92%	37,800	87%	48,100	138%	43,100	113%	43,700	116%
Jobs	97,300	71%	93,400	64%	103,200	82%	101,400	78%	97,300	71%

Lower Anacostia Waterfront & Near Southwest

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	762,800	879,800	1,330,700	966,100	894,800
VMT Per Capita	10.8	12.8	15.9	12.3	11.1
PHD Per Capita	0.9	1.2	1.2	0.9	0.9
Average Vehicle Occupancy	1.3	1.5	1.6	1.6	1.7
Transit Ridership	45,400	43,700	42,300	43,700	47,200
Total Number of Vehicles	22,100	15,900	15,400	16,200	16,200
Average Vehicles Per HH	0.6	0.4	0.3	0.4	0.4
Emissions (MMTCO2e)	658,400	305,100	293,800	184,100	329,700
Cost of Crashes ($M)	$103.4	$70.1	$37.8	$27.6	$25.5
Average Trip Time (Mins)	35.1	38.6	46.3	33.2	30.3

7.5 Upper Northeast



Population	73,200
Households	30,300
Jobs	31,400
% Low Income*	1.9%
% Minority	80.2%
% Zero-Car Households	31.9%
Roadway Lane-Miles	213
Area (sq. mi.)	8.7

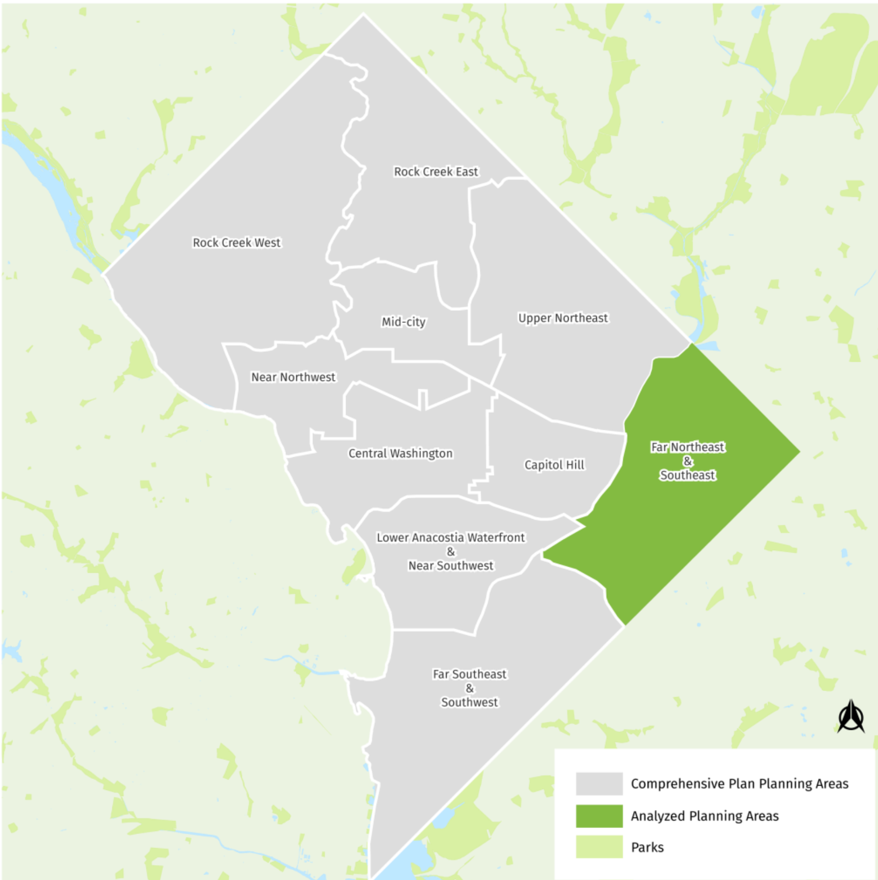
Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	113,00	54%	111,100	52%	128,500	76%	121,700	66%	122,900	68%
Households	50,700	68%	49,700	64%	58,400	93%	55,000	82%	55,600	84%
Jobs	49,500	58%	48,100	53%	50,400	61%	50,000	59%	49,500	58%

Upper Northeast

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	1,336,300	1,456,000	2,126,600	1,722,500	1,430,900
VMT Per Capita	11.53	12.74	16.51	13.74	11.26
PHD Per Capita	0.6	0.6	0.8	0.6	0.5
Average Vehicle Occupancy	1.3	1.4	1.5	1.5	1.6
Transit Ridership	82,700	81,000	77,900	83,100	84,800
Total Number of Vehicles	46,500	36,400	34,800	36,000	35,800
Average Vehicles Per HH	0.9	0.7	0.6	0.6	0.6
Emissions (MMTCO2e)	1,153,700	544,900	530,700	373,300	562,600
Cost of Crashes ($M)	$239.4	$153.5	$80.6	$65.0	$54.0
Average Trip Time (Mins)	27.5	31.6	33.8	27.5	23.1

7.6 FAR NORTHEAST & SOUTHEAST



Population	80,500
Households	33,700
Jobs	8,600
% Low Income*	2.7%
% Minority	97.8%
% Zero-Car Households	40.6%
Roadway Lane-Miles	159
Area (sq. mi.)	8.3

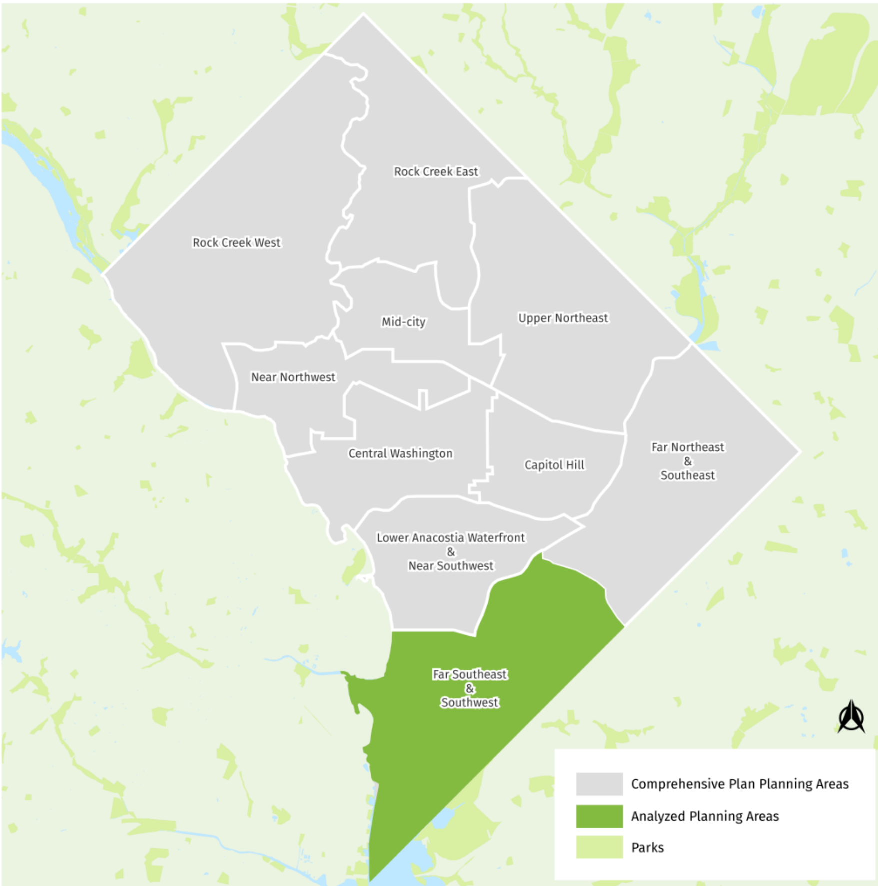
** Low income threshold is set at $25000 per year. Reference https://aspe.hhs.gov/poverty-guidelines*

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	106,900	33%	105,600	31%	126,900	58%	118,700	47%	120,400	50%
Households	43,400	29%	42,800	27%	51,600	53%	48,400	44%	49,100	46%
Jobs	19,400	124%	18,300	112%	20,000	131%	19,800	129%	19,400	124%

Far Northeast & Southeast

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	1,311,800	1,384,700	1,970,700	1,692,700	1,332,900
VMT Per Capita	12.0	12.8	15.6	13.8	10.7
PHD Per Capita	0.7	0.7	0.6	0.6	0.4
Average Vehicle Occupancy	1.3	1.4	1.4	1.5	1.5
Transit Ridership	45,100	43,400	44,200	44,900	47,700
Total Number of Vehicles	82,000	71,900	64,700	65,400	65,200
Average Vehicles Per HH	1.8	1.6	1.3	1.3	1.3
Emissions (MMTCO2e)	1,132,400	530,500	504,700	372,800	534,500
Cost of Crashes ($M)	$351.8	$221.7	$118.4	$102.1	$80.0
Average Trip Time (Mins)	27.1	32.0	37.0	29.2	24.9

7.7 Far Southeast & Southwest



Population	76,300
Households	27,000
Jobs	23,000
% Low Income*	3.6%
% Minority	95.2%
% Zero-Car Households	45.9%
Roadway Lane-Miles	128
Area (sq. mi.)	10.1

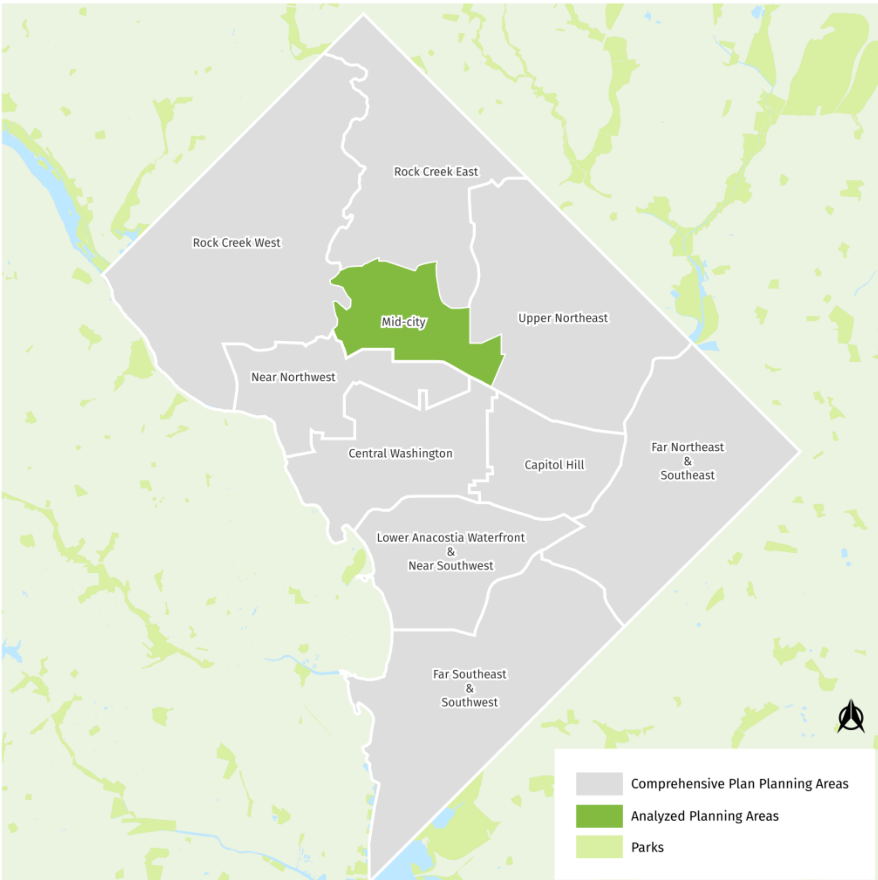
Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	108,400	42%	107,100	40%	134,700	76%	124,400	63%	126,700	66%
Households	34,400	27%	33,900	25%	43,000	59%	39,600	47%	40,400	49%
Jobs	31,200	35%	30,600	33%	33,300	44%	32,900	42%	31,200	35%

FAR SOUTHEAST & SOUTHWEST

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	1,019,300	1,096,700	1,520,800	1,311,000	1,078,900
VMT Per Capita	9.2	10.0	11.5	10.2	8.2
PHD Per Capita	0.4	0.4	0.5	0.4	0.4
Average Vehicle Occupancy	1.3	1.5	1.5	1.5	1.6
Transit Ridership	32,400	29,800	29,200	34,800	30,300
Total Number of Vehicles	54,900	45,400	41,900	43,400	43,300
Average Vehicles Per HH	1.6	1.3	1.0	1.1	1.1
Emissions (MMTCO2e)	879,800	406,000	371,200	273,500	420,700
Cost of Crashes ($M)	$249.6	$159.7	$85.6	$72.0	$58.9
Average Trip Time (Mins)	27.8	23.5	30.0	26.7	19.4

7.8 Mid-City



Population	101,800
Households	44,500
Jobs	31,600
% Low Income*	1.1%
% Minority	53.4%
% Zero-Car Households	42.8%
Roadway Lane-Miles	103
Area (sq. mi.)	3.1

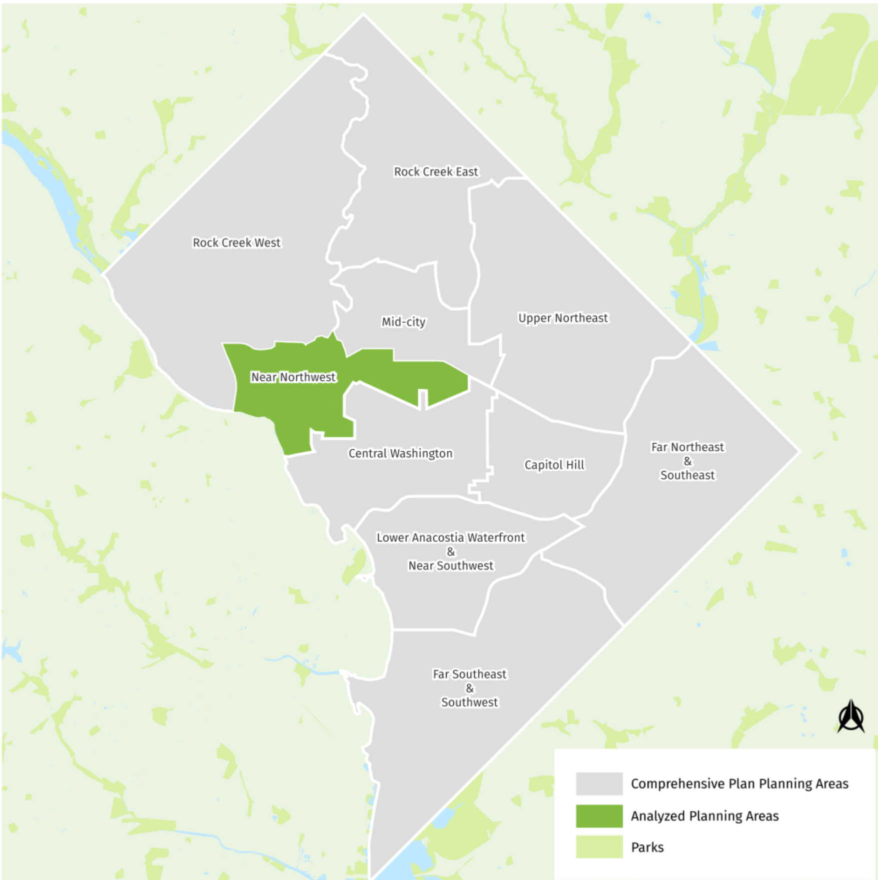
Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	134,200	32%	133,500	31%	149,000	46%	143,900	41%	145,300	43%
Households	52,600	18%	52,300	18%	58,800	32%	56,700	27%	57,300	29%
Jobs	38,000	20%	37,500	19%	38,500	22%	38,200	21%	38,00	20%

MID-CITY

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	583,200	661,700	993,500	732,100	656,700
VMT Per Capita	4.2	4.8	6.6	4.9	4.4
PHD Per Capita	0.3	0.4	0.4	0.3	0.3
Average Vehicle Occupancy	1.3	1.5	1.5	1.6	1.7
Transit Ridership	41,500	29,800	25,700	29,900	29,500
Total Number of Vehicles	56,800	41,000	39,600	42,200	42,200
Average Vehicles Per HH	1.1	0.8	0.7	0.7	0.7
Emissions (MMTCO2e)	503,500	237,700	234,300	150,900	249,600
Cost of Crashes ($M)	$214.2	$143.0	$76.5	$56.5	$50.5
Average Trip Time (Mins)	28.7	29.1	32.7	23.9	21.4

7.9 Near Northwest



Population	89,400
Households	43,300
Jobs	110,900
% Low Income*	0.6%
% Minority	30.4%
% Zero-Car Households	45.7%
Roadway Lane-Miles	162
Area (sq. mi.)	3.9

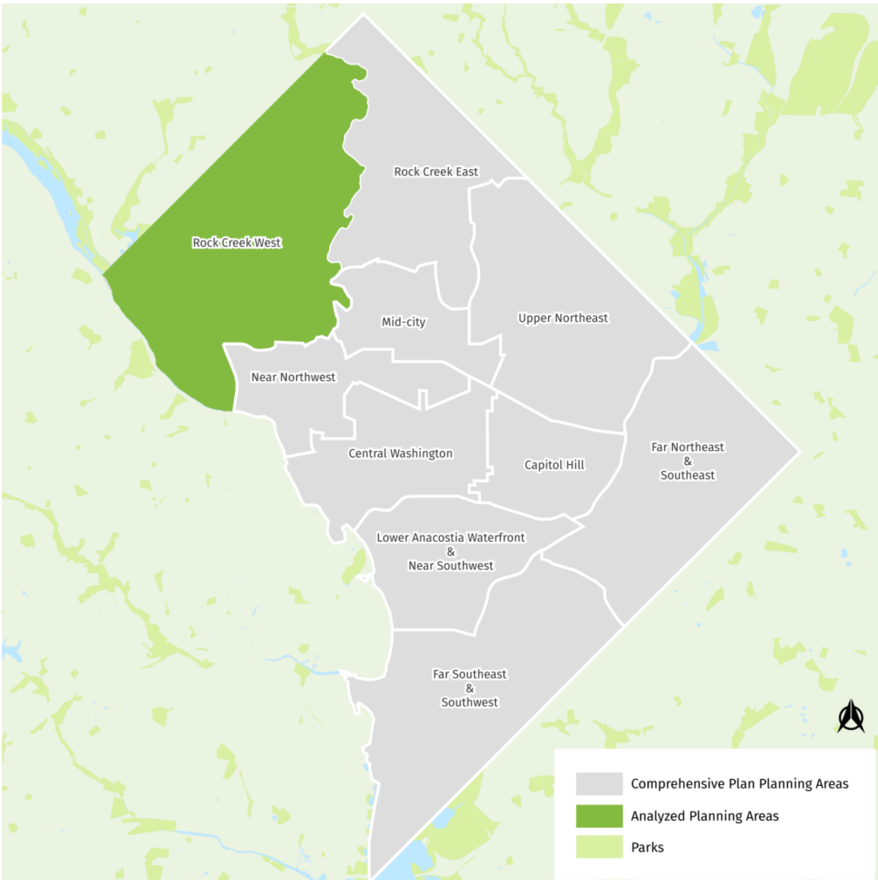
Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	107,700	20%	107,000	20%	122,900	37%	116,800	31%	118,100	32%
Households	48,700	12%	48,400	12%	56,600	31%	53,500	23%	54,200	25%
Jobs	123,900	12%	122,700	11%	128,100	15%	127,500	15%	123,900	12%

NEAR NORTHWEST

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	941,200	1,133,400	1,750,000	1,184,600	1,126,700
VMT Per Capita	8.5	10.3	14.2	9.8	9.2
PHD Per Capita	0.4	0.5	0.5	0.3	0.4
Average Vehicle Occupancy	1.3	1.5	1.5	1.6	1.7
Transit Ridership	1.3	1.5	1.5	1.6	1.7
Total Number of Vehicles	40,700	28,400	27,600	27,800	27,800
Average Vehicles Per HH	0.8	0.6	0.5	0.5	0.5
Emissions (MMTCO2e)	812,300	387,900	380,600	222,600	411,400
Cost of Crashes ($M)	$196.6	$139.3	$76.5	$52.0	$49.2
Average Trip Time (Mins)	32.1	32.5	36.5	26.1	24.5

7.10 ROCK CREEK WEST



Population	95,100
Households	44,300
Jobs	49,200
% Low Income*	0.5%
% Minority	19.6%
% Zero-Car Households	20.2%
Roadway Lane-Miles	223
Area (sq. mi.)	13.0

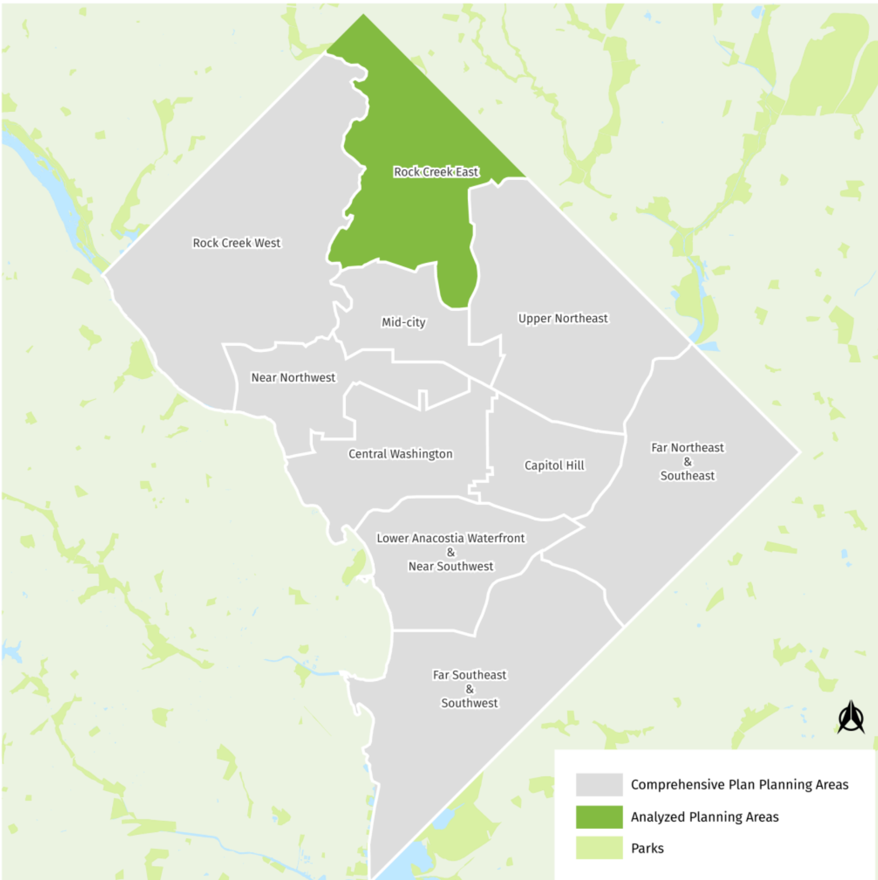
Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	112,200	18%	111,600	17%	128,100	35%	120,000	25%	120,000	26%
Households	48,400	9%	48,100	9%	55,300	25%	51,500	16%	52,000	17%
Jobs	54,800	11%	54,300	10%	56,100	14%	55,100	12%	54,800	11%

Rock Creek West

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	1,453,300	1,545,200	2,183,000	1,768,300	1,444,800
VMT Per Capita	12.6	13.5	17.0	14.4	11.6
PHD Per Capita	0.6	0.6	0.7	0.4	0.4
Average Vehicle Occupancy	1.3	1.5	1.5	1.5	1.6
Transit Ridership	64,600	44,700	41,200	44,400	46,600
Total Number of Vehicles	71,700	54,700	52,100	55,700	55,500
Average Vehicles Per HH	1.4	1.1	0.9	1.1	1.0
Emissions (MMTCO2e)	1,254,200	556,900	511,800	353,800	551,800
Cost of Crashes ($M)	$121.2	$78.9	$45.5	$37.0	$29.7
Average Trip Time (Mins)	25.6	30.7	34.1	27.3	22.5

7.11 Rock Creek East



Population	77.300
Households	29,400
Jobs	36,100
% Low Income*	1.3%
% Minority	77.5%
% Zero-Car Households	23.8%
Roadway Lane-Miles	151
Area (sq. mi.)	7.4

Low income households earn less than $25,000 per year (ASPE, 2019). Highlighted values are higher than the District average.

	MWCOG		A: Freeway Automated		B: Shared Fleets		C: HOVs		D: Congestion Fee	
	Total	Growth	Total	Growth	Total	Growth	Total	Growth	Total	Growth
Population	105,900	37%	104,800	36%	118,100	53%	112,800	46%	113,800	47%
Households	37,300	27%	36,800	25%	41,700	42%	39,800	35%	40,100	36%
Jobs	48,100	33%	46,800	30%	48,800	35%	48,300	34%	48,100	33%

Rock Creek East

	MWCOG	A: Freeway Automated	B: Shared Fleets	C: HOVs	D: Congestion Fee
Total VMT	965,200	1,025,300	1,486,900	1,229,000	1,004,600
VMT Per Capita	8.9	9.5	12.5	10.6	8.5
PHD Per Capita	0.5	0.5	0.6	0.5	0.4
Average Vehicle Occupancy	1.3	1.4	1.5	1.5	1.6
Transit Ridership	43,700	29,600	26,700	29,800	29,000
Total Number of Vehicles	45,700	35,000	33,800	35,600	35,400
Average Vehicles Per HH	1.2	0.9	0.8	0.9	0.9
Emissions (MMTCO2e)	833,300	381,800	369,200	264,600	393,200
Cost of Crashes ($M)	$172.2	$107.8	$55.9	$46.2	$3.7
Average Trip Time (Mins)	28.0	26.7	29.0	23.3	19.0

8.0 APPENDIX B: REGIONAL RESULTS

The performance metrics in the main report in Section 4.0 included results only within the District's borders. The analysis approach included the whole Washington Metropolitan region, with a focus the portion of the region inside the Beltway, which includes DC, Arlington County, the City of Alexandria, the City of Falls Church, and portions of Fairfax, Montgomery, and Prince George's County. This section highlights some of the key performance metrics in this larger area. Not all of the key performance metrics were analyzed for the suburban jurisdictions. Crash rates and revenue sources were only analyzed for the District and are therefore not included in this section. While no quantitative results are included for these metrics, it would be expected that impacts in the suburbs would be on a similar order to magnitude as those within the District. Additional analysis of these metrics by the suburban jurisdictions is encouraged. The performance metrics that were analyzed for the region are listed in Table 8-1.

Table 8-1: Regional Performance Metrics Analyzed

	Performance Metric
1	Total Vehicle Miles Travel
2	VMT per Capita
3	Person Hours of Delay
4	Person Hours of Delay per Capita
5	Average Vehicle Occupancy
6	Transit Ridership
7	Average Trip Time
8	Total Number of Vehicles
9	Average Vehicles per Household
10	Emissions
11	Cost of Crashes

Figure 8-1 illustrates the area included in this regional analysis as all areas inside I-495, including all of DC, Arlington County, Alexandria and Falls Church, in addition to portions of Fairfax, Montgomery, and Prince George's Counties.

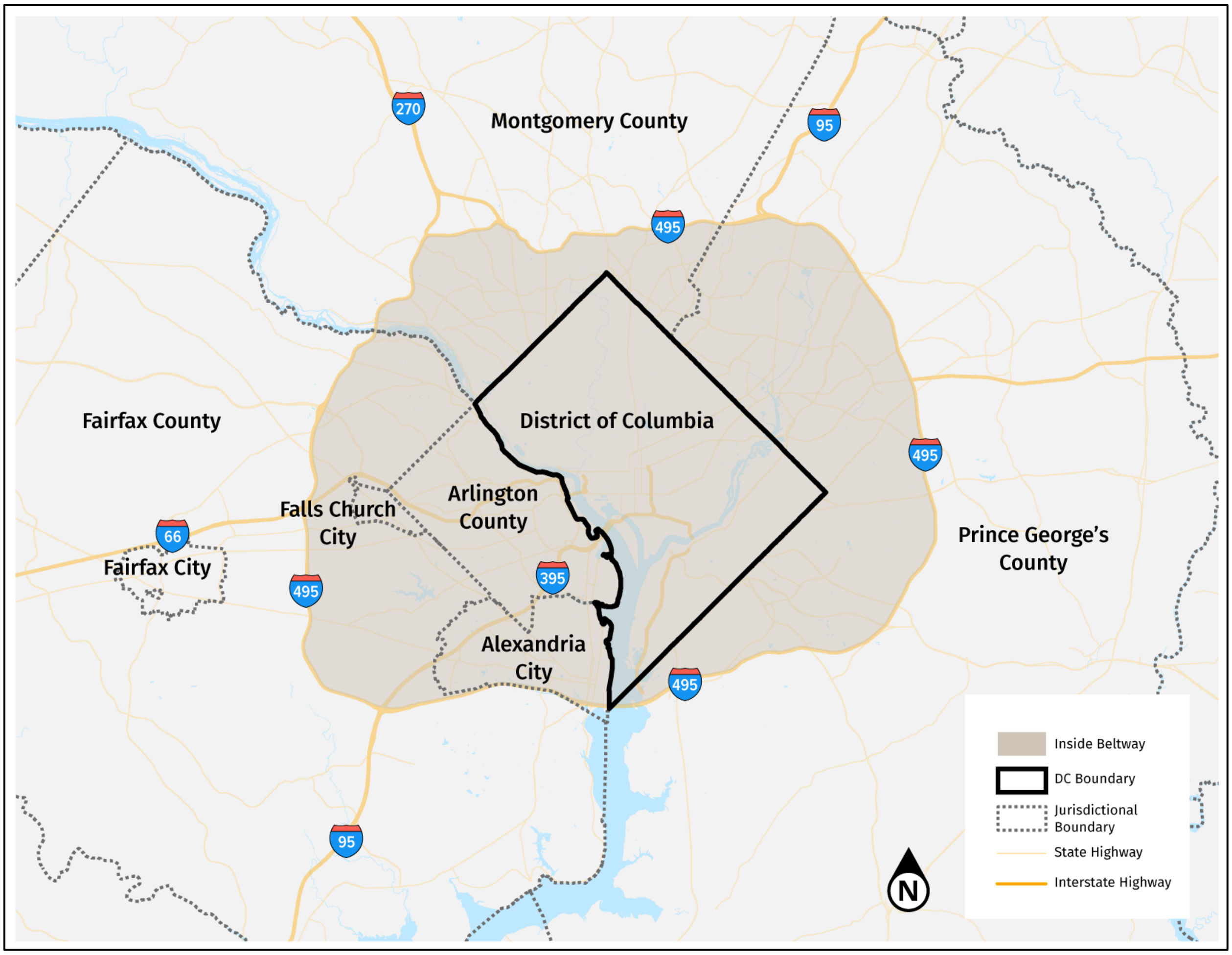


Figure 8-1: Regional Area Summarized as Inside the Beltway

Table 8-2 highlights the regional land use totals for the area analyzed inside the Beltway, including the MWCOG Round 9.1 Cooperative Land Use Forecasts and each of the AV Scenarios. Scenarios B and C include the highest total households in this area, while Scenario B includes the highest employment levels.

Table 8-2: Regional Land Use Totals Inside the Beltway

		MWCOG	Scenario A	Scenario B	Scenario C	Scenario D
Households	DC	411,870	406,930	479,370	449,370	411,870
	MD	263,220	258,760	289,700	286,290	263,220
	VA	388,710	369,220	394,730	428,140	388,710
	Total	1,063,800	1,034,910	1,163,800	1,163,800	1,063,800
Employment	DC	1,045,390	1,026,640	1,073,840	1,062,370	1,045,390
	MD	372,930	390,520	386,940	372,930	372,930
	VA	715,740	737,940	730,170	715,740	715,740
	Total	2,134,060	2,155,100	2,190,950	2,151,040	2,134,060

8.1 Total Vehicle Miles Traveled (VMT)

The regional totals for Vehicle Miles Traveled inside the Beltway are shown in Figure 8-2. The results for all scenarios follow the patterns presented for the VMT inside the District.

Scenarios B and C share a similar growth pattern but Scenario B results in much higher VMT levels after 2035. As with the results in the District, the Congestion Fee included in Scenario D results in a pronounced regional decrease after implementation in 2023. Regional VMT does start to grow again after 2033 as the regional population continues to grow, eventually resulting in higher VMT levels than today. Scenario A results in significant growth in VMT regionally, but this growth is delayed due to the slower introduction and adoption of fully automated Type 3 vehicles. By 2045 all four AV Scenarios will result in more VMT in the region than is currently predicted by the MWCOG forecasts.

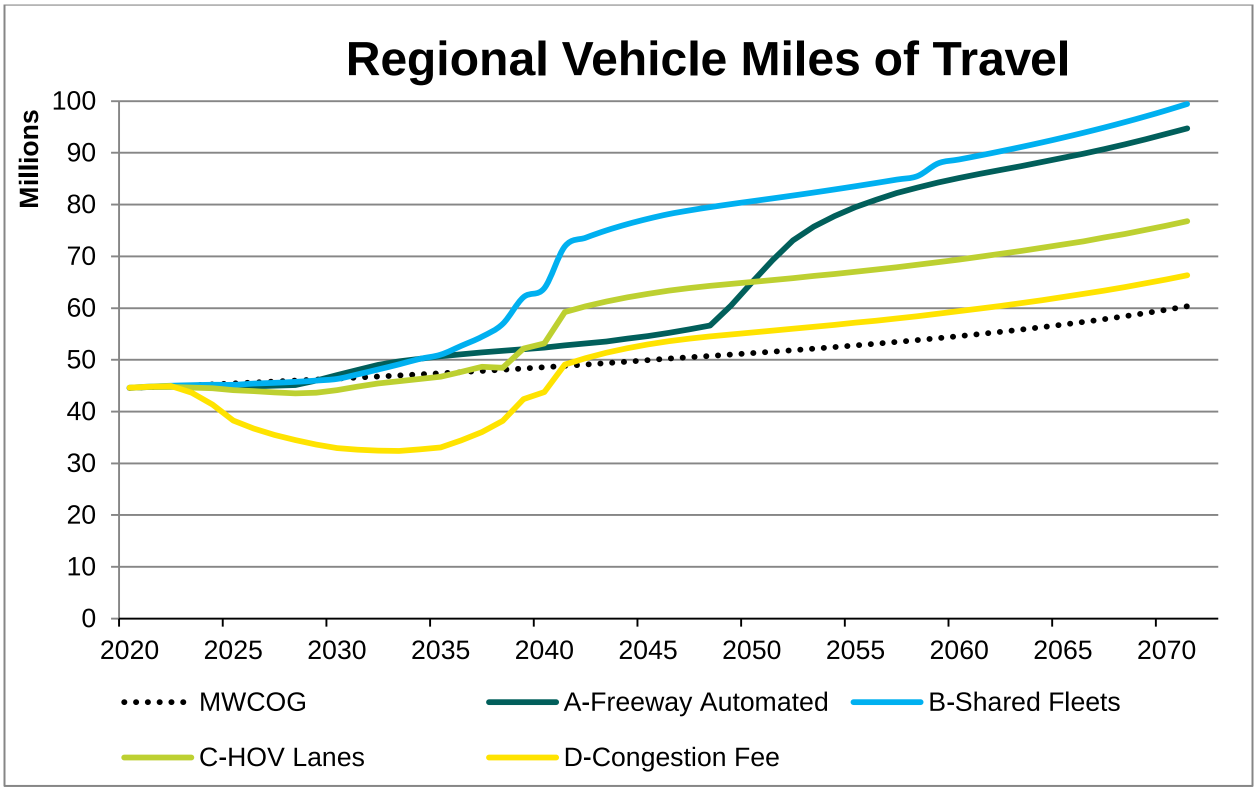


Figure 8-2: Regional VMT - Inside the Beltway

8.2 VMT per Capita

Because the region has different population totals inside the Beltway in each of the scenarios, Figure 8-3 eliminates any impacts of population differences by calculating the VMT per capita. It is important to note that this is not the VMT generated per resident in the region, but the amount of VMT occurring inside the Beltway divided by the number of residents inside the

Beltway. VMT on the areas roads that is generated by residents of the outer suburbs are included in this metric.

All Scenarios actually show a trend of decreasing VMT per capita in the immediate future through 2025, but this trend is the most pronounced in Scenarios C and D. After this initial decrease, Scenarios A, B, and C all show an increase in VMT per capita, as empty vehicle movements become more ubiquitous. Because Scenario A has the lowest regional population coupled with high levels of VMT, Scenario A also has the highest VMT per capita in the long-term. Scenario D manages to stem increases in VMT per capita the most, with long-term results similar to the MWCOG forecasts.

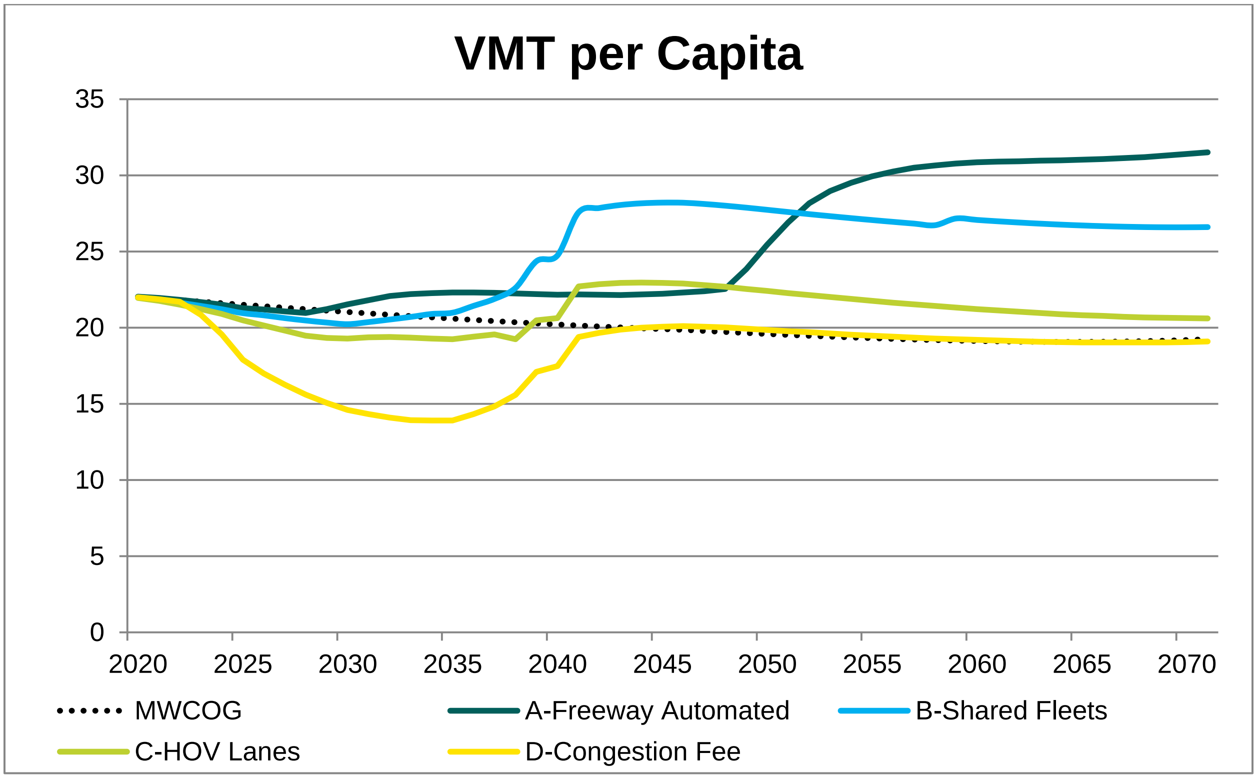


Figure 8-3: VMT per Capita - Inside the Beltway

8.3 Congestion – Person Hours of Delay

Person Hours of Delay (PHD) is the key metric used to define congestion in this study, and it quantifies how much time people spend delayed in traffic above free-flow travel times. Figure 8-4 shows how PHD in the region is predicted to change over time, and there are some important different from the DC only totals. This is because a much higher percentage of regional traffic occurs on freeways than in the District (~40% regionally compared to 10.5% in the District). Regionally, Scenario A results in much lower levels of delay than Scenario B, just slightly higher than MWCOG forecasts. Scenario A includes dedicated AV lanes on freeways that result in higher freeway capacities. The result is less congestion in the region. The other major difference in results is that Scenario C is able to eliminate more congestion on a regional level, resulting in PHD forecasts that are lower than the MWCOG forecasts. Scenario D also results in a more significant decrease in congestion regionally than in DC alone.

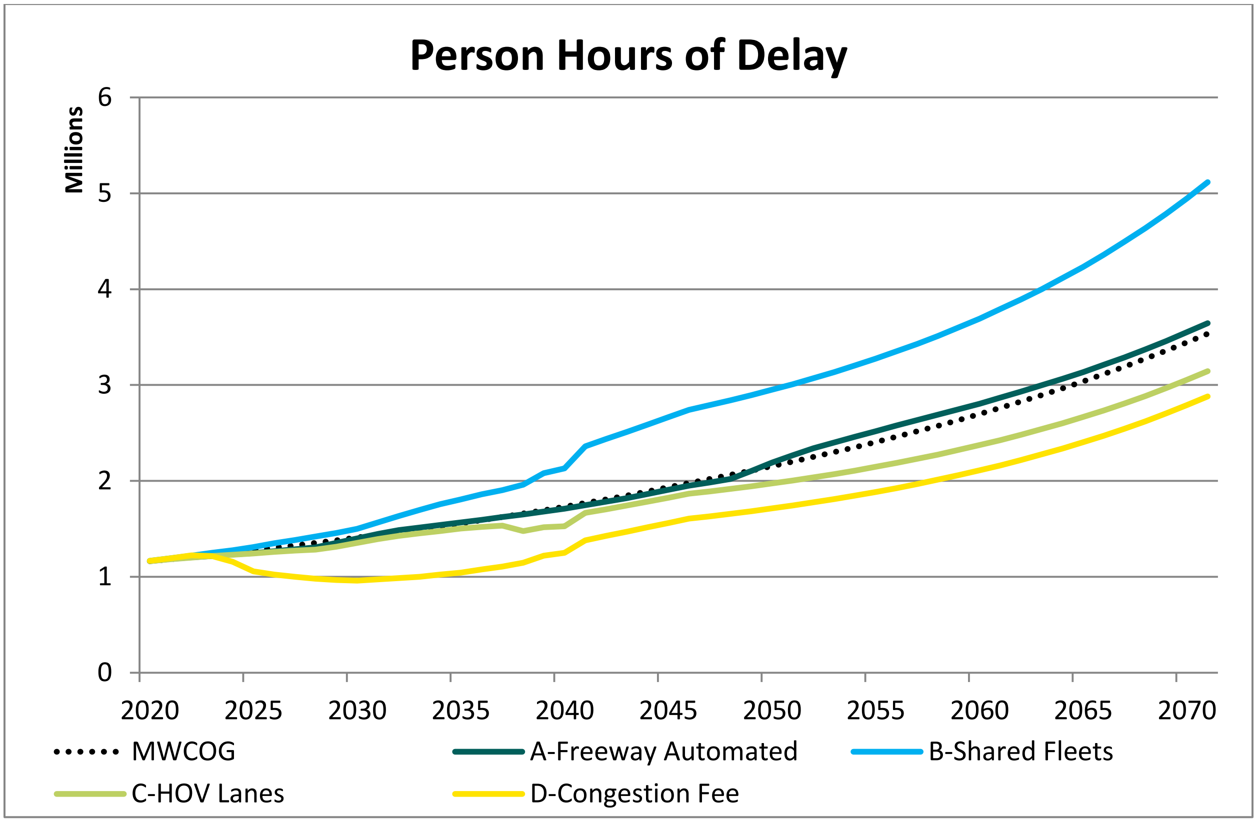


Figure 8-4: Vehicle Hours of Delay - Inside the Beltway

8.4 Person Hours of Delay per Capita

On average, the regional transportation network experiences more congestion per capita than inside the District alone (30 minutes per person in the District compared with 36 minutes in the region). As illustrated in Figure 8-5, Scenario B results in the highest regional PHD per capita among all scenarios in the short and long-term. This is different from the DC-only patterns, in which Scenario A has the highest long-term levels of congestion because of the lower levels of congestion on the region's freeway network in Scenario A. In the long-term, Scenarios C and D may have almost identical congestion levels, but Scenario D's congestion fee has a greater impact at eliminating congestion between its implementation and 2070.

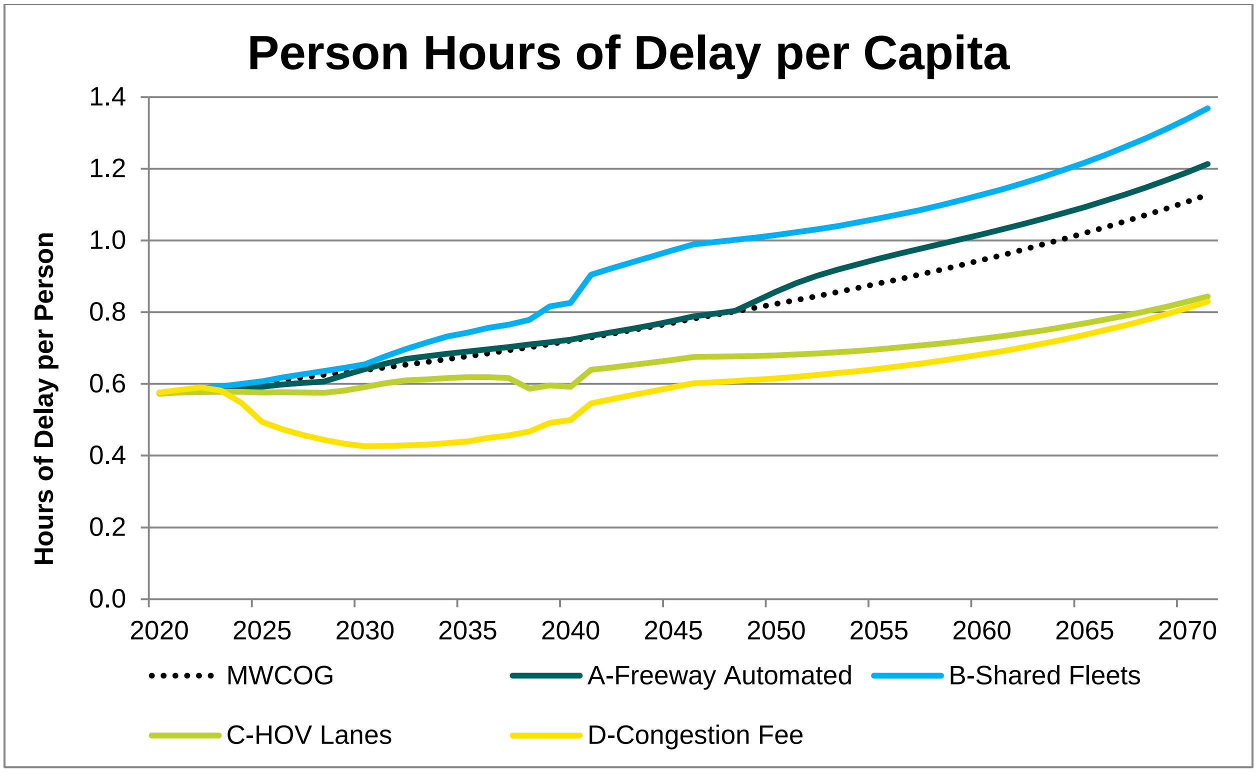


Figure 8-5: Person Hours of Delay per Capita - Inside the Beltway

8.5 Average Vehicle Occupancy

Average Vehicle Occupancy in this region follows similar patterns as inside the District, as shown in Figure 8-6. Scenario D would have the highest average vehicle occupancy throughout the immediate and long-term future, as congestion fees make many people switch to higher occupancy modes. Vehicle Occupancy for the other three AV Scenarios will reach a maximum of just over 1.5 passengers per vehicle, which is still a significant improvement over the MWCOG forecasts of around 1.35 passengers per vehicle.

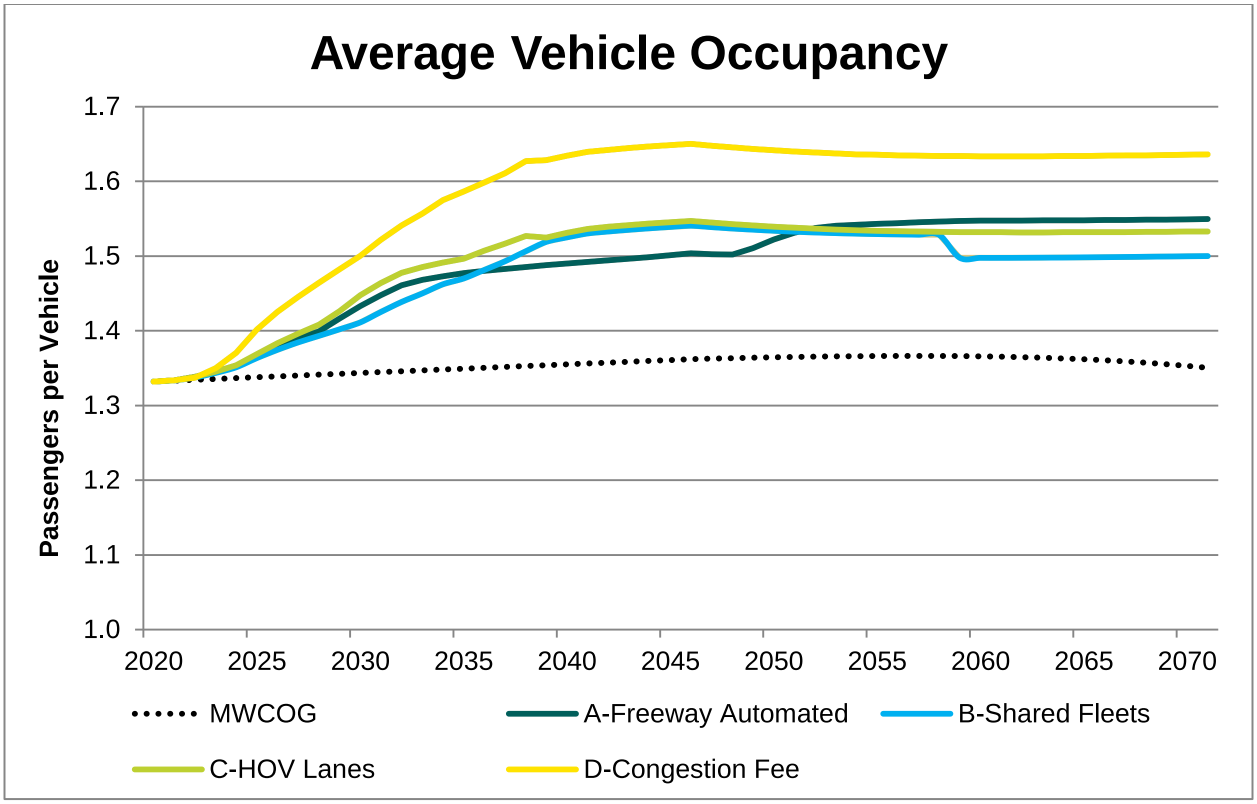


Figure 8-6: Average Vehicle Occupancy – Inside the Beltway

8.6 Transit Ridership

Figure 8-7 shows the estimated transit ridership over time for each scenario. Over time all of the AV Scenarios show a very slow 'natural' increase in transit ridership as population in the region continues to grow. Scenario D results in the highest levels of transit ridership, caused in part by an immediate jump in transit ridership with the introduction of the congestion fee. Scenario C also experiences a relatively higher level of transit ridership as high occupancy modes and business models are encouraged by the dedicated HOV lanes throughout the region. As mentioned, the results below include a somewhat broadened definition of transit that incorporates a flexible range of publicly and privately-operated services such as traditional fixed-route transit service, microtransit, and large-scale ride-sharing options.

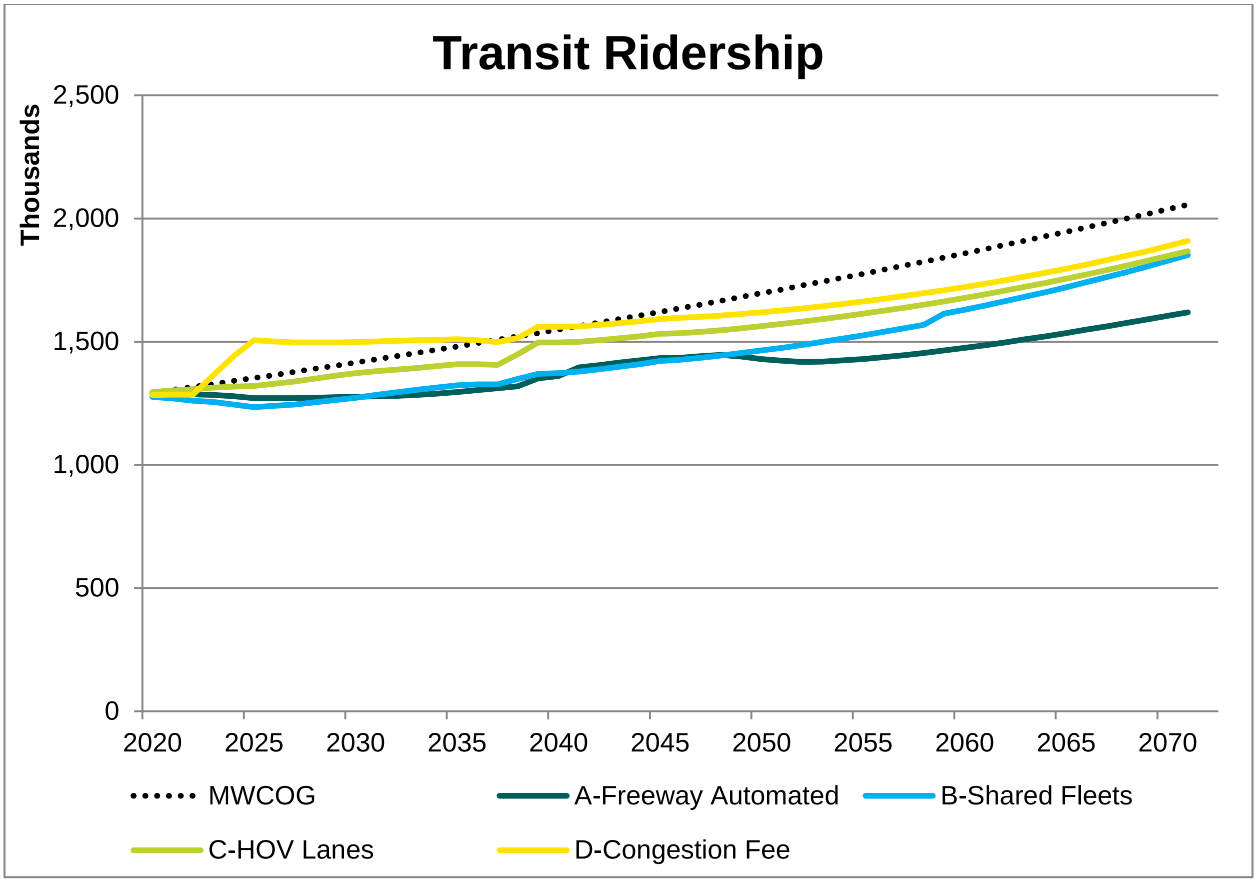


Figure 8-7: Transit Ridership – Inside the Beltway

It is important to note that the specific numerical results for this performance metric are highly dependent on the relative cost and time savings that AVs and other new mobility options are able to provide travelers. While assumptions have been made for each AV Scenario about the available mobility options, business models, and consumer prices, these remain uncertain market-based estimates. Significant changes in these characteristics could impact what is considered to be "transit" in the future, and therefore the results of this performance metric.

8.7 Average Trip Time

Figure 8-8 presents the average trip time in the region. Currently the average trip time inside the Beltway is 23 minutes, significantly shorter than the average trip starting in DC. This is driven by differences in the average trip length and in average travel speeds. Differences in congestion levels in each AV Scenario result in different average trip times, and the Scenario with the greatest regional congestion (Scenario B) also has the longest average trip time. The congestion fee in Scenario D is designed to eliminate the majority of regional congestion, and as a result manages to improve travel times the most. Scenario A performs much better at the regional scale at this metric, due primarily to the fact that there are more freeways regionally, and that is where most of the congestion mitigation occurs in Scenario A. Scenarios A, C, and D manage to keep average trip times at or below existing levels through at least 2040.

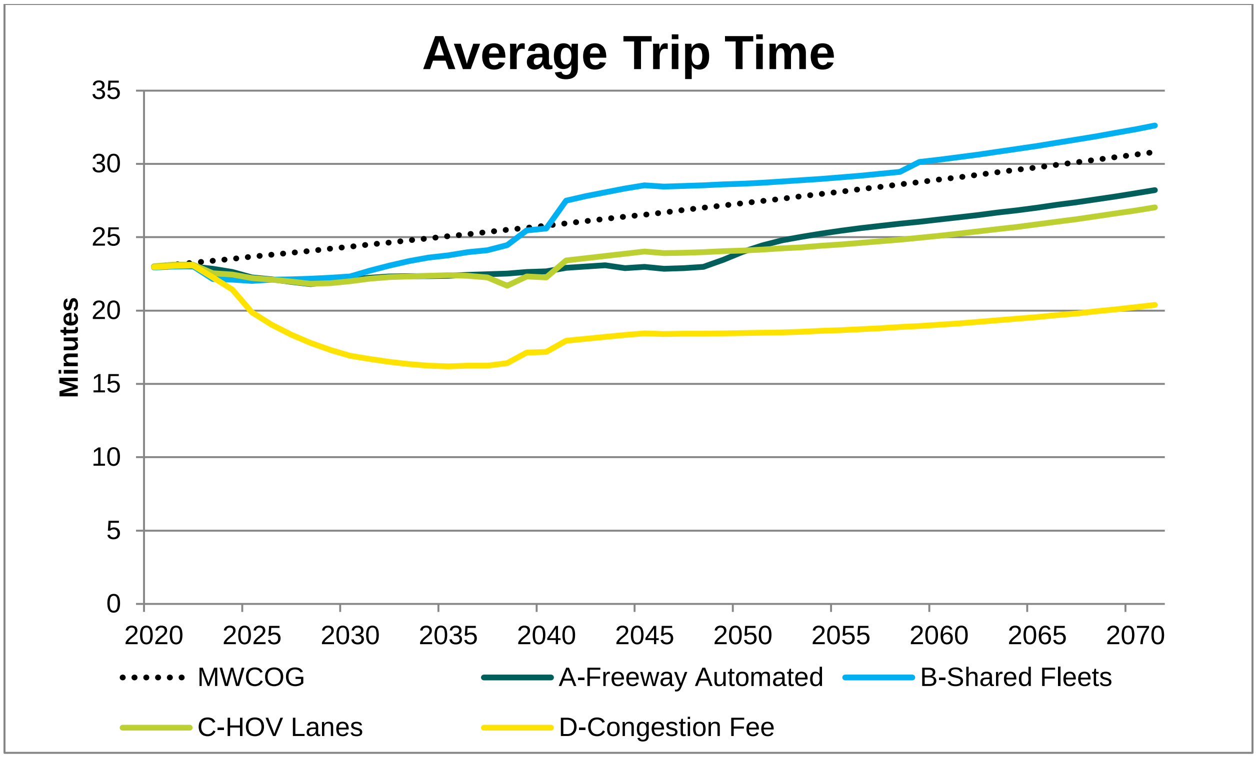


Figure 8-8: Average Trip Time – Inside the Beltway

8.8 Fleet Size

As indicated in Figure 8-9, all four AV Scenarios result in a smaller regional vehicle fleet than would be possible without AVs. This metric includes all types of vehicles, including household-owned passenger vehicles, shared vehicles, trucks, and delivery vehicles. By 2045, the vehicle fleet could be at least 20 percent smaller than would be necessary without AVs while maintaining mobility levels for the region. This resents a decrease greater than 300,000 vehicles, which would also no longer require short-term or long-term parking spaces.

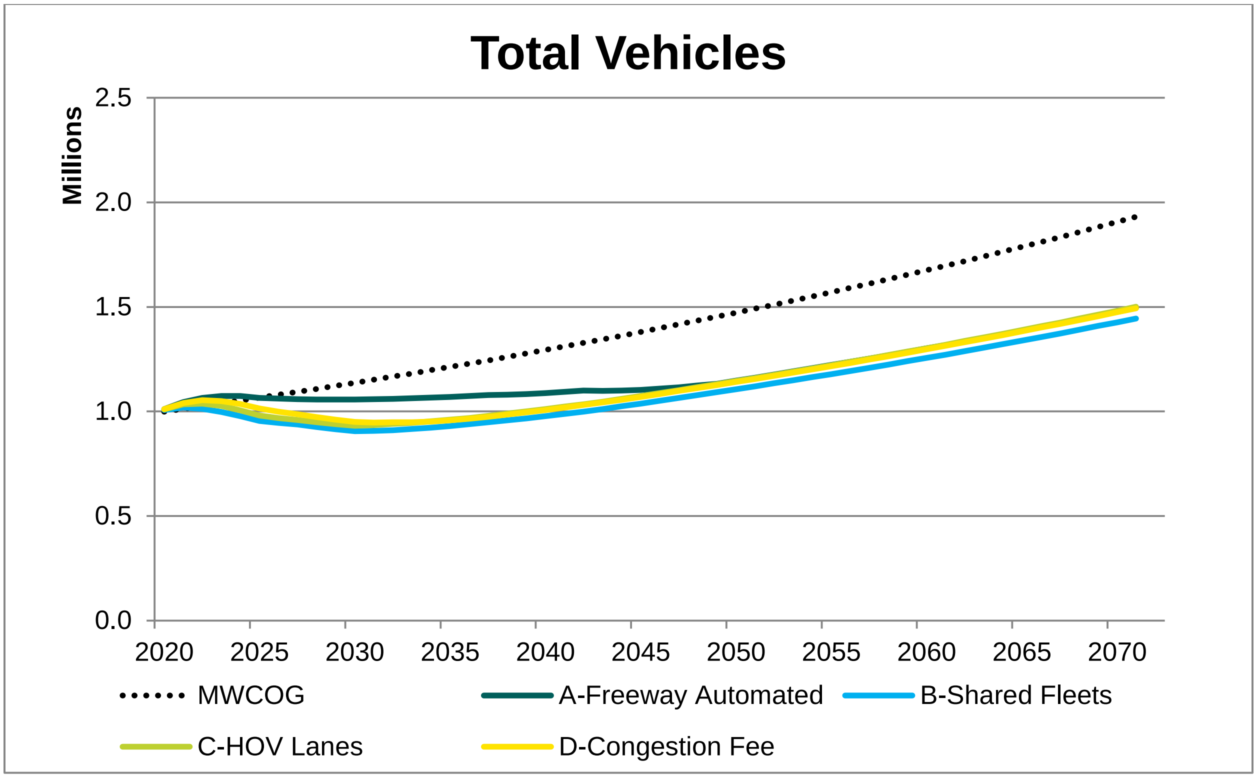


Figure 8-9: Total Vehicles – Inside the Beltway

Considering the varying population levels of each of the scenarios, Figure 8-10 presents the average number of vehicles per household in this region. Regionally, there are more vehicles per household than within the District. Again, including all types of vehicles, there are currently approximately 1.2 vehicles per household in the region. While there is expected to be a slight increase in the very short-term future as automated ridesourcing fleets grow but before people are willing to give up owning their own cars. After 2035 the introduction of high-level AVs will tend to stabilize the number of vehicles per household. In Scenarios B, C, and D there are expected to be between 0.9 and 1.0 vehicles of all types for each household. This should have significant impacts on parking needs for the region. While Scenario A will include the highest number of vehicles, the fleet will still be significantly smaller than MWCOG's forecast.

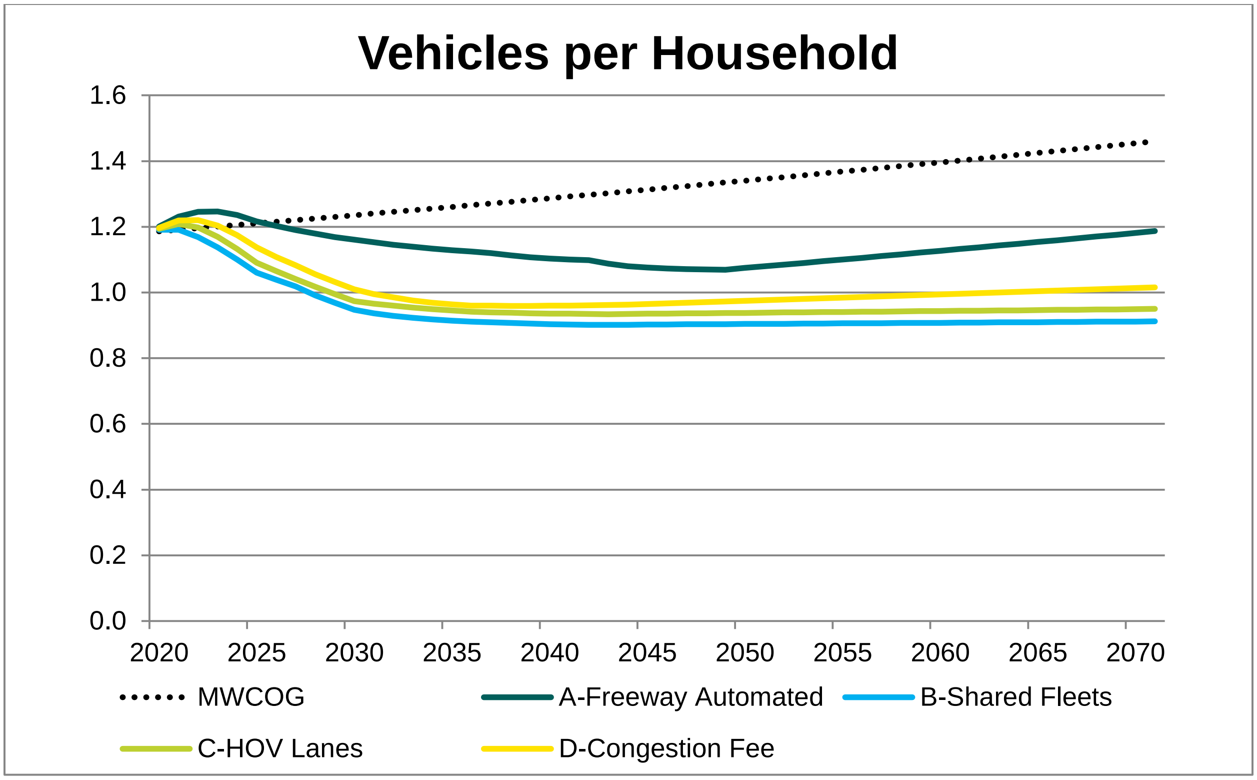


Figure 8-10: Vehicles per Household – Inside the Beltway

8.9 TAILPIPE GHG EMISSIONS

As shown in Figure 8-11, GHG emissions are trending noticeably downward in a pattern very similar to GHG emissions in the District, albeit on a much larger scale. The GHG emissions are related directly to the amount of VMT and the rate of electrification. It should be noted that all of these results represent a substantial improvement over the assumptions that must be used by MWCOG in its air quality analysis work. The purpose of the Air Quality Conformity Analysis requires that very conservative assumptions be used; the vehicle fleet is therefore assumed to include the same number of electric vehicles in the future as it does today – less than one half of one percent. If electrification occurs as projected in these AV Scenarios, by 2045 vehicle emissions could be less than half of what is predicted by MWCOG.

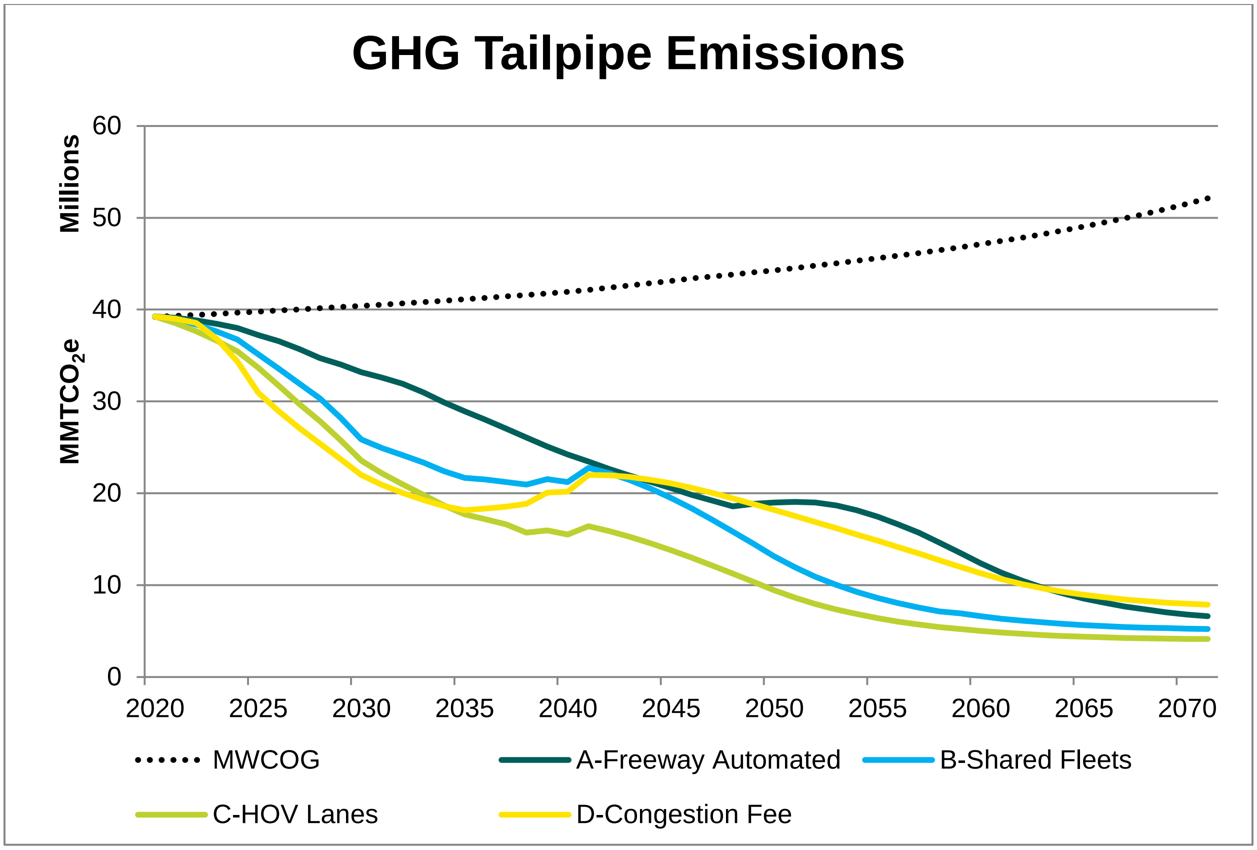


Figure 8-11: Greenhouse Gas Tailpipe Emissions by Year – Inside the Beltway

9.0 APPENDIX C: MWCOG FUTURE ASSUMPTIONS

This section outlines what is included as part of the MWCOG forecast assumptions for 2045, which is used as a baseline for comparison for the AV Scenario results in much of Section 4.0 in this report. The MWCOG forecasts do not explicitly take into account many of the changes in technology and business models that are predicted to redefine the transportation industry in the coming decades. Where these forecasts do make assumptions, they are outlined briefly in this Appendix in the same order as presented for the AV Scenarios in Section 0.

While a scenario that does not include any of these technologies is not considered as a realistic possible future, this scenario is used as a comparison point for what is currently being predicted by the standard forecasting and planning processes in the DC metropolitan region.

The MWCOG model only forecasts through 2045. Because the adoption and proliferation of AVs and other emerging technologies is likely to extend past this date, the AV Scenarios were analyzed in Mobilitics through 2072. For years after 2045, the MWCOG scenario is assumed to continue to growth at the same average rates as for 2020-2045. This is essentially a continuation of the trends already forecast, and may be either conservative or optimistic assumptions, depending on the attribute being considered.

9.1 TECHNOLOGY ADOPTION

The MWCOG scenario makes no assumptions about the introduction or adoption of AV technology in the Washington DC region. Therefore, no AVs are assumed in this Scenario.

9.2 ELECTRIFICATION

The MWCOG forecasts are used to fulfill federal requirements for Air Quality Conformity analysis. As such, these forecasts use very conservative assumptions about the electrification of the vehicle fleet, assuming that the electrification rate will remain the same in the future as it is today. This includes approximately 10,000 fully electric (battery electric and plug-in electric) vehicles in the region today, representing approximately 0.2 percent of the region's light duty vehicle fleet. The region includes an additional 90,000 hybrid-electric vehicles. In total, this accounts for approximately 2.8 percent of the region's light-duty vehicle fleet (MWCOG, 2017).

This is one area in particular where the AV Scenario assumptions are significantly different from the assumptions used in the MWCOG forecasts because MWCOG is required to be conservative in these assumptions. A more complete study of the range of potential electrification assumptions and their impacts on GHG emissions in Section 4.3.

9.3 Connectivity

The MWCOG forecasts include no assumptions about improved vehicle connectivity or its impacts, and thereby includes no assumed roadway capacity improvements or safety enhancements that would come with CV technology.

9.4 Freight

Heavy trucks are forecast to account for approximately 4.5 percent of VMT in 2045 in DC and the area inside the Beltway. This represents growth in truck volumes regionally over existing conditions. Figure 9-1 shows the growth in truck freight over time in DC as assumed in the MWCOG scenario.

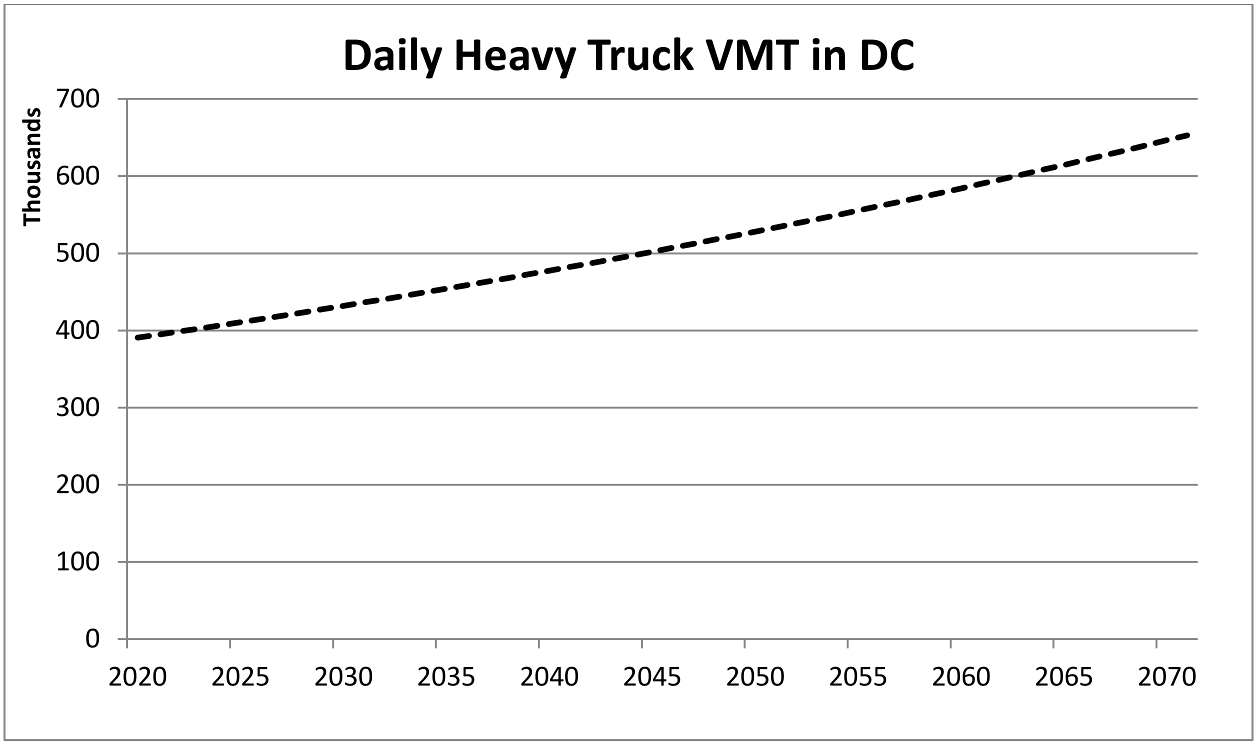


Figure 9-1: MWCOG Scenario – Daily Heavy Truck VMT in DC

9.5 Pricing Strategy

The MWCOG scenario is based on the financially constrained element of Visualize 2045, the most recent Constrained Long Range Plan (CLRP) for the region, which identifies all improvements to the transportation network and when they will be implemented. The CLRP includes only projects that have been planned and programmed by the member jurisdictions. The only pricing strategies included for the region in the CLRP include existing toll roads (e.g. the Dulles Toll Road, Inter-County Connector) and planned and existing HOT lanes in Virginia (e.g. I-66, I-495). No other pricing strategies are included in this scenario.

9.6 Road Usage

The MWCOG scenario is based on the financially constrained element of Visualize 2045, the most recent Constrained Long Range Plan (CLRP) for the region, which identifies all improvements to the transportation network and when they will be implemented. The CLRP includes only projects that have been planned and programmed by the member jurisdictions. Only plans for dedicated lanes that are included in the CLRP have been assumed in the MWCOG Scenario. This includes existing and planned HOV lanes in the region (e.g. I-66, I-270), and dedicated bus lanes on H & I Streets in DC.

9.7 Parking

No major changes to parking policy or availability are assumed as part of the MWCOG Scenario, although parking costs are expected to increase in order to keep pace with inflation. New parking facilities will continue to be built as permitted by existing zoning both in the District and the larger region.

9.8 Future of Transit

The MWCOG Scenario assumes a simpler vision for the future of transit than the AV Scenarios. Transit in this scenario continues to be operated by public agencies, including WMATA and the DC Circulator. All transit services included in the CLRP, including the Silver Line extension to Loudoun County and the Purple Line in Maryland are included. Bus services continue to operate, and the CLRP does not envision a significant expansion of the bus system based on current funding constraints. Microtransit and ridesourcing are not considered to be part of the transit network in this scenario.

9.9 Ride Sourcing

The MWCOG forecasts do not include any assumptions about the growth or proliferation of ridesourcing services such as Uber and Lyft. However, it does include the existing fleet of for-hire taxi vehicles that operate in the District and the region. These vehicles currently represent less than one percent of VMT in DC and are expected to continue to be present in DC throughout the future in the MWCOG Scenario.

9.10 Road Capacity

No assumed changes to the carrying capacity of roadways in the region is assumed in the MWCOG Scenario, unless a widening (or narrowing) of a roadway is included in the CLRP.

9.11 Vehicle Ownership

Because the MWCOG Scenario does not explicitly include a major shift to ridesharing, it also does not include any assumptions about household-owned vehicles being replaced by shared vehicles. The total number of vehicles in the District is forecasted to increase over time as population grows, as shown previously in Figure 4-17. The average number of vehicles per household is also forecast to increase slightly, as shown previously in Figure 4-18.

9.12 Travel Demand

Travel demand is forecast by the MWCOG version 2.3 travel demand forecasting model. No changes to the MWCOG travel demand are included in this scenario.

9.13 Land Use

MWCOG maintains the land use forecasts for the Metropolitan Washington region, which are used in the MWCOG Scenario. The most current version of these forecasts, Round 9.1, was used in this study through 2045. Growth rates were assumed to continue past 2045 for the purposes of more long term analysis. Figure 9-2 shows the population and employment forecasts for DC in the MWCOG Scenario. As shown, based on these assumed growth rates, residents in DC would be forecast to exceed employment starting around 2060.

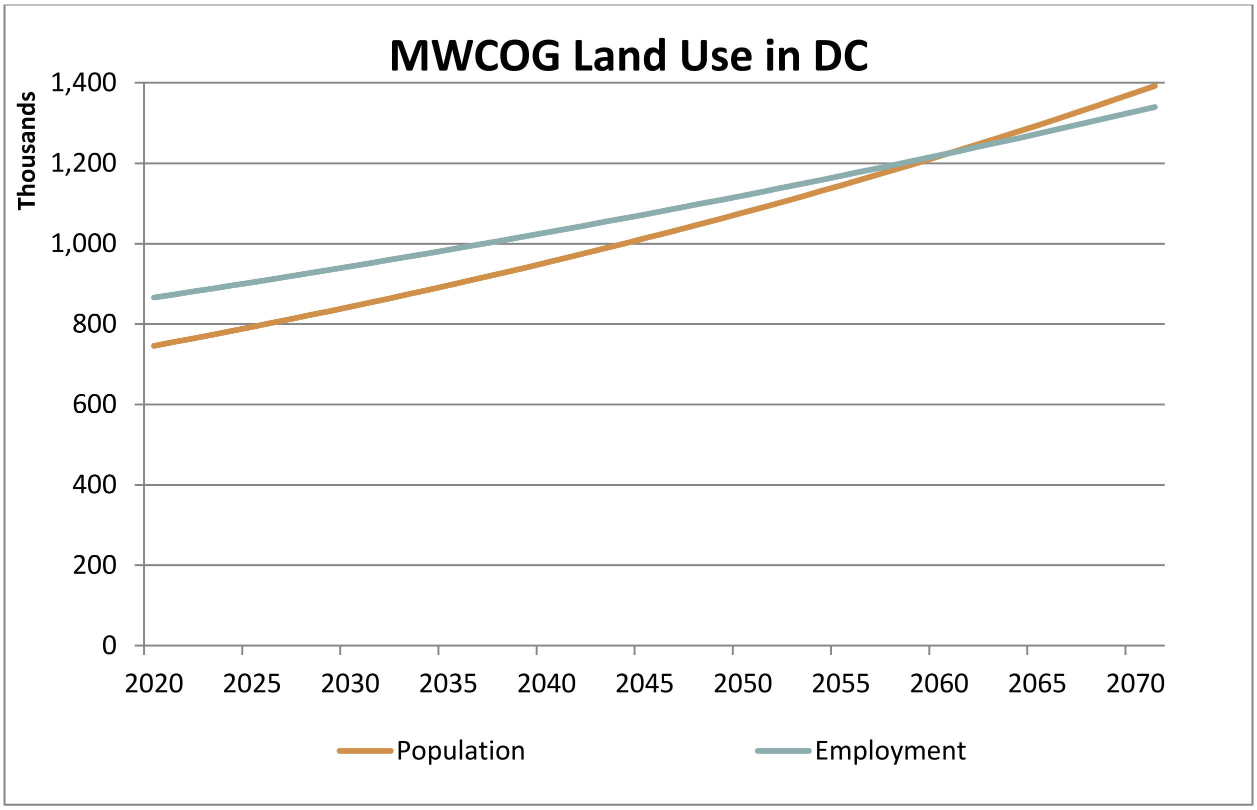


Figure 9-2: MWCOG Land Use in DC

The figures on the following pages illustrate the MWCOG Round 9.1 Cooperative Land Use Forecasts for households and employment in the District and the surrounding region.

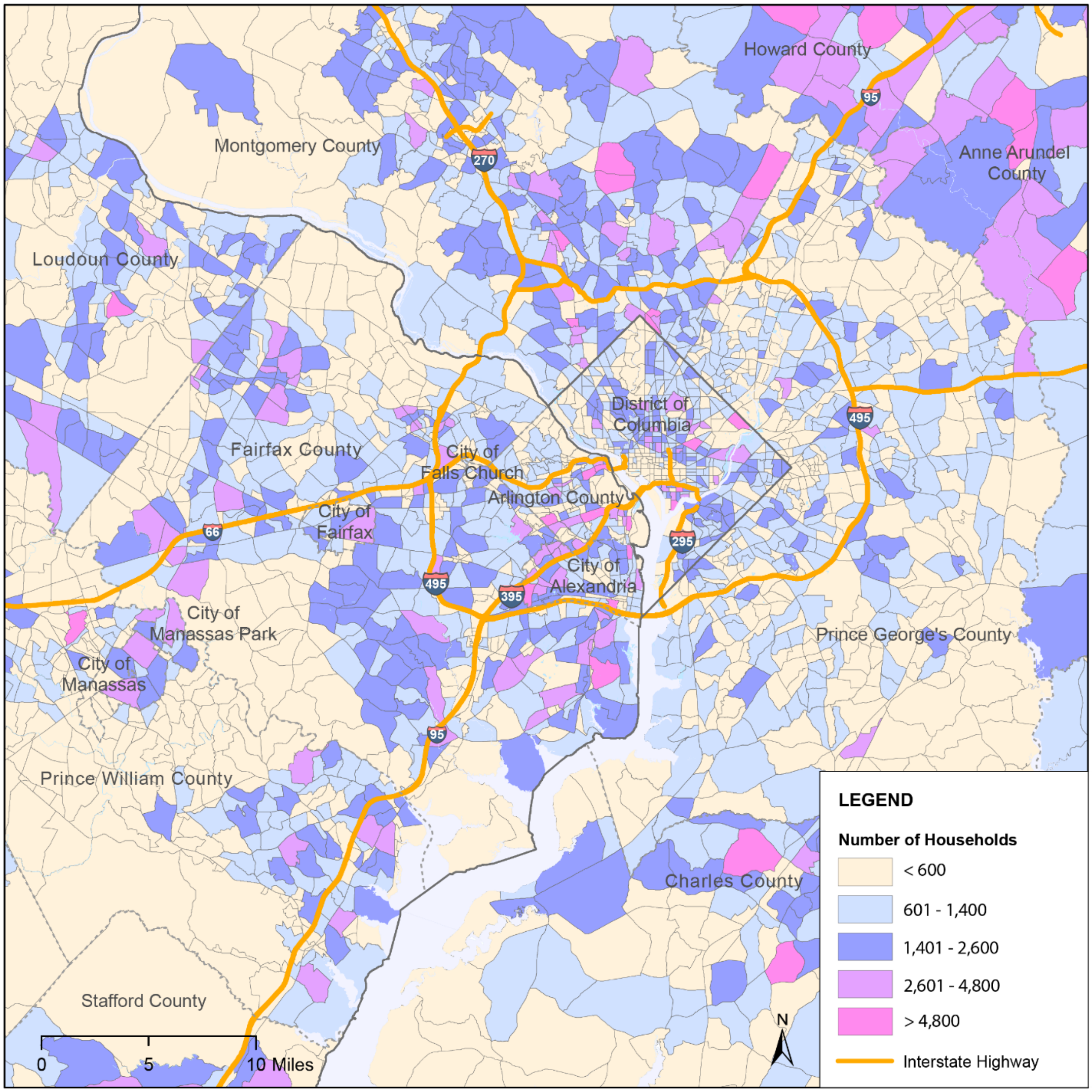


Figure 9-3: 2045 Regional Households

Source: MWCOG Round 9.1 Cooperative Land Use Forecasts

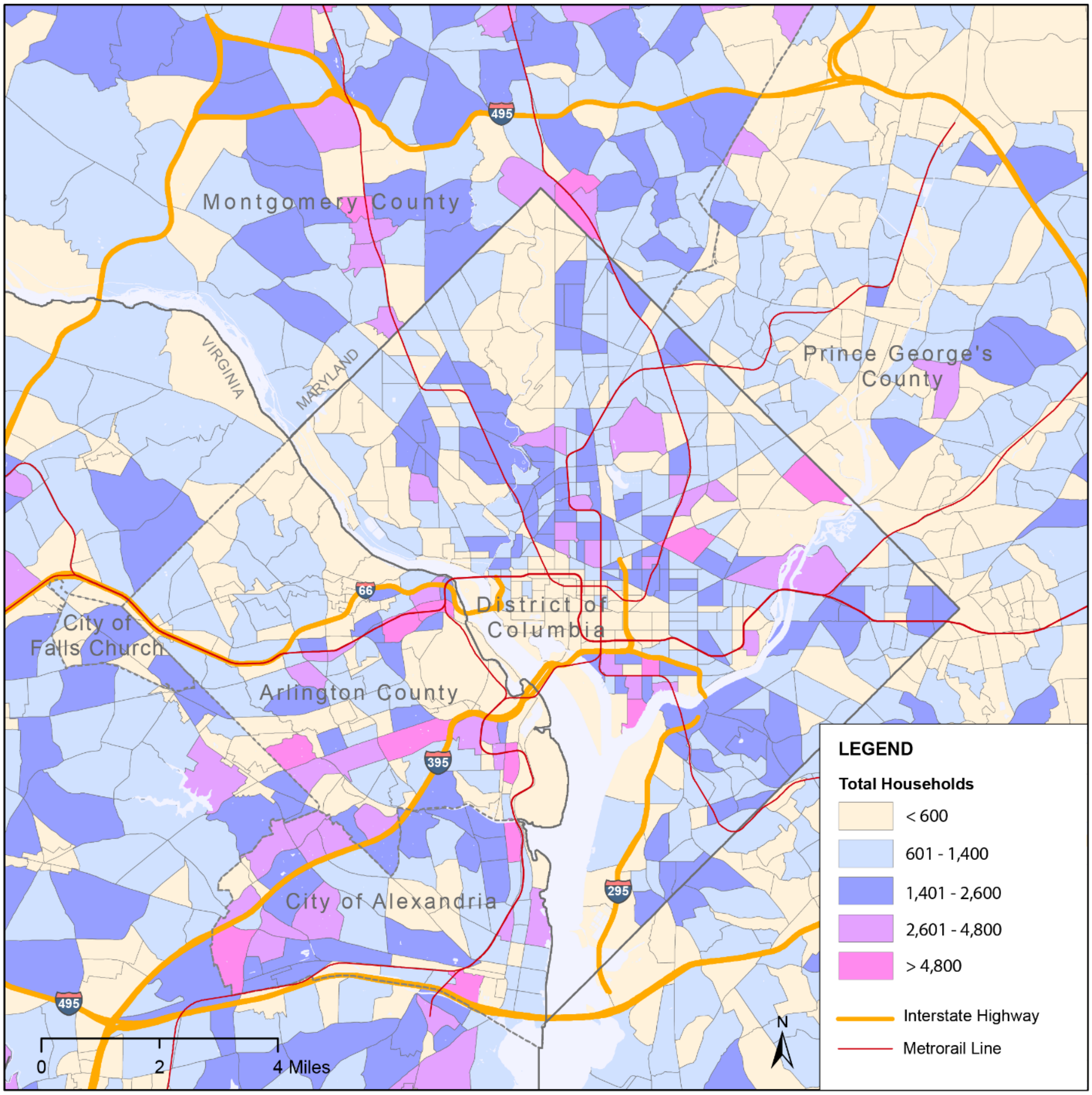


Figure 9-4: 2045 DC Households

Source: MWCOG Round 9.1 Cooperative Land Use Forecasts

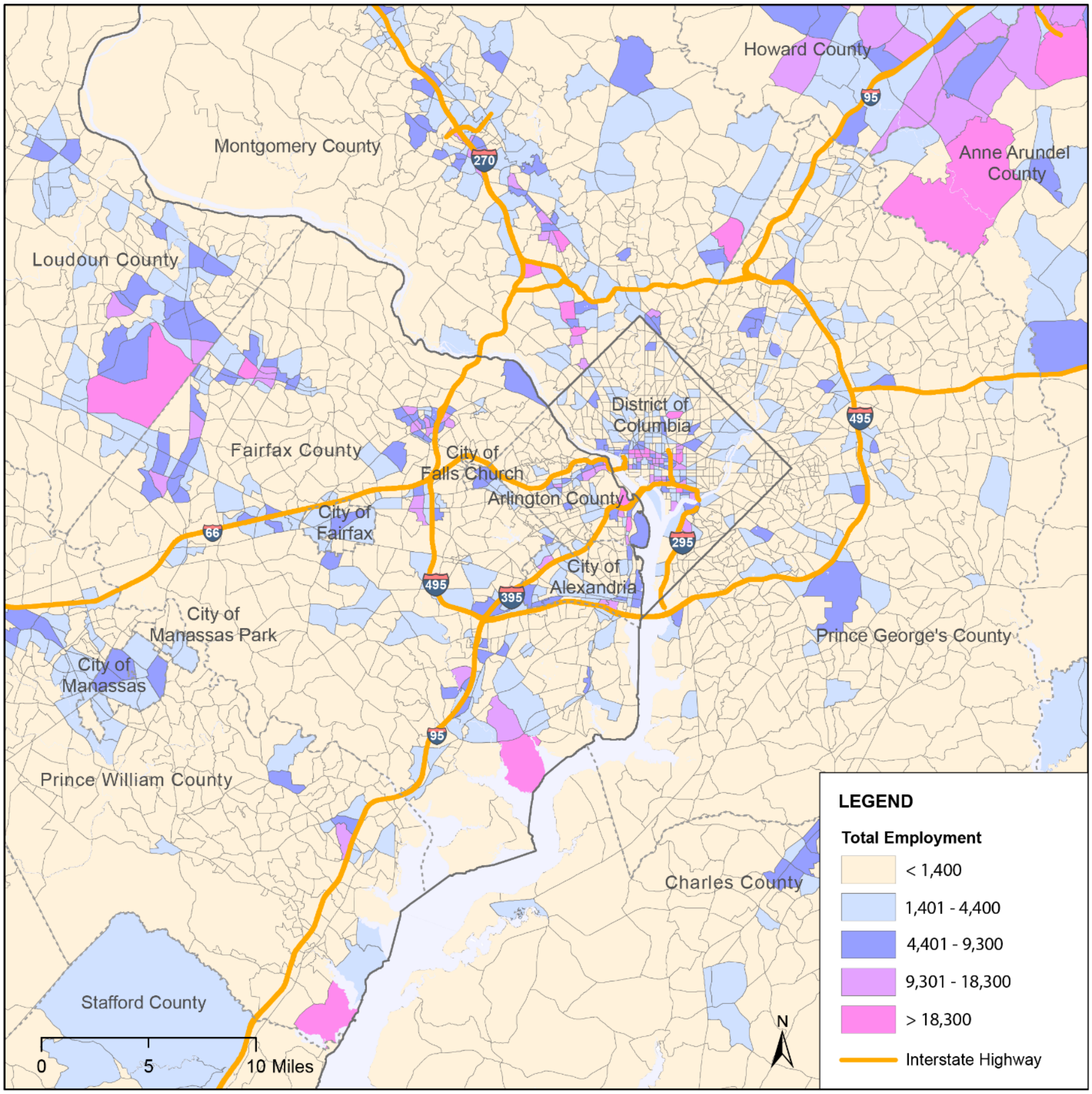


Figure 9-5: 2045 Regional Employment

Source: MWCOG Round 9.1 Cooperative Land Use Forecasts

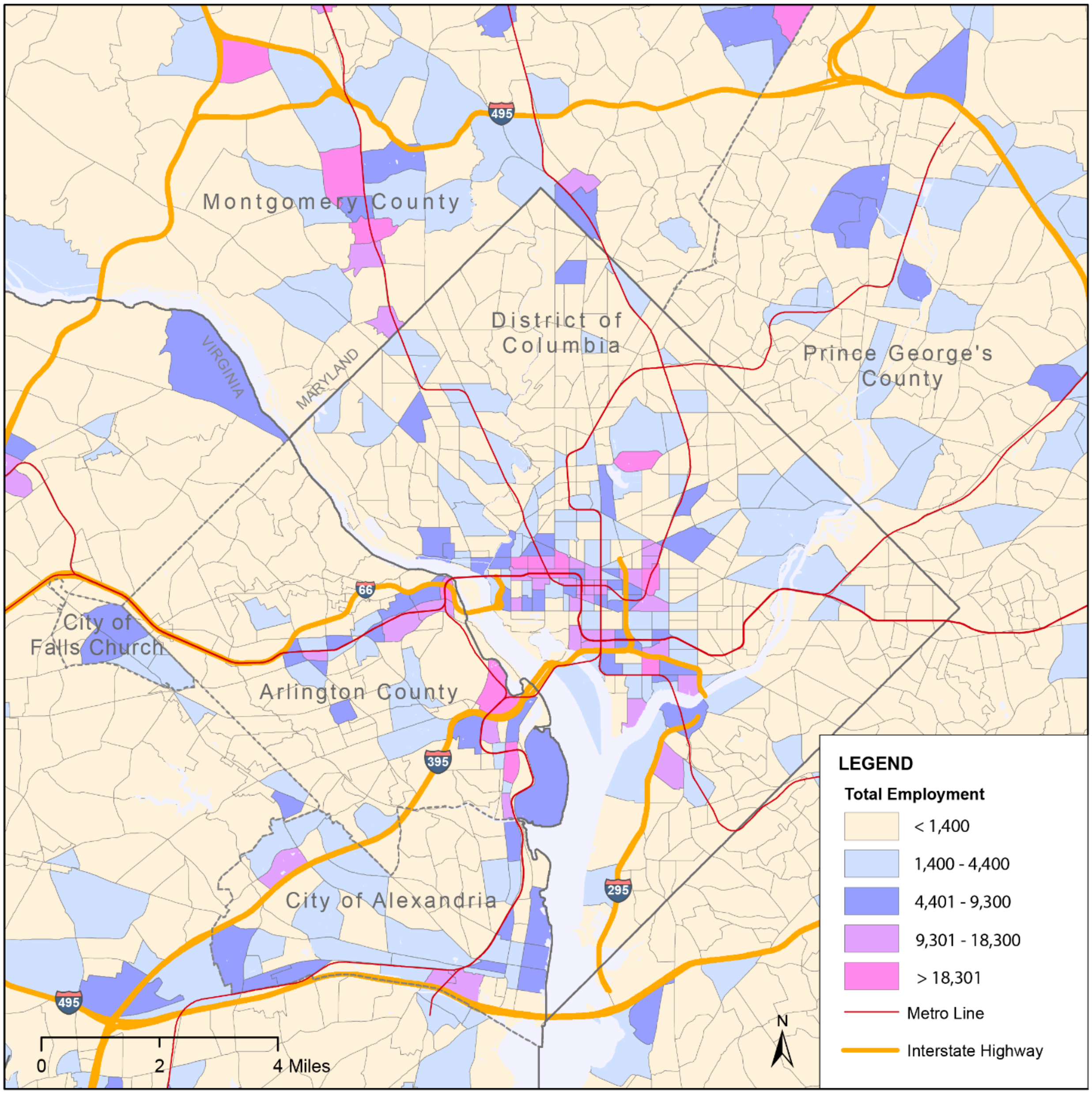


Figure 9-6: 2045 DC Employment

Source: MWCOG Round 9.1 Cooperative Land Use Forecasts