AUTOMATED VEHICLES: A GUIDE FOR PLANNERS AND POLICYMAKERS

by
Charlie Coles
20620 Reid Lane Saratoga, California 95070
408.803.0865

Institute of Transportation Engineers
Western District
May 2016

ABSTRACT

Automated vehicles are those which are capable of sensing their environments in order to perform at least some aspects of the safety-critical control (like steering, throttling, or braking) without direct human input. As a guide for planners and policymakers, the objective of this paper is to develop a strong foundation for anticipating the potential impacts resulting from advancements in vehicle automation. To establish the foundation, this paper uses a robust qualitative methodology, coupling a review of literature on the potential advantages and disadvantages of vehicle automation and lessons from past innovations in transportation, with recent trends of the Millennial Generation, carsharing services, and a series of interviews with thought-leaders in automation, planning, policymaking, transportation, and aviation. Five significant findings emerged from this paper: (1) the impacts of vehicle automation differ depending on one's visions of what automation means, how it is implemented, what the automation does, and where it operates; (2) current limitations of vehicle automation to perform all aspects of the dynamic driving task in all driving conditions make it difficult to move from level-4 to level-5 automation; (3) level-5 automation is required to have any effect on carsharing, mobility, and quality of life; (4) assuming effective planning and policymaking techniques, housing preferences, urban growth, and increases in total VMT will likely not be significantly impacted by vehicle automation; (5) human drivers may never be allowed to disengage their attention from a partially-automated vehicle, specifically in applications where drivers are expected to reengage their attention in safety-critical situations. From the perspective of understanding the bigger picture, this paper recommends guiding principles for planners and policymakers.

Keywords: Automated, Vehicles, Transportation, Planning, Policymaking, Millennials, Carsharing, Interviews, Aviation

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INTRODUCTION

Automated vehicles, also termed autonomous, driverless, self-driving and robotic vehicles, are those which are capable of sensing their environments in order to perform at least some aspects of the safety-critical control (like steering, throttle, or braking) without direct human input. Examples of automated technologies range from completely self-driving vehicles, where no human driver is required, to basic functions, such as cruise control. The Society of Automotive Engineers' (SAE) International On-Road Automated Vehicle Standards Committee (2014) has established definitions of the different levels of vehicle automation that are used throughout this paper, and are summarized here:

- **No Automation (Level 0):** The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
- **Driver Assistance (Level 1):** The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.
- **Partial Automation (Level 2):** The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.
- **Conditional Automation (Level 3):** The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
- **High Automation (Level 4):** The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
- **Full Automation (Level 5):** The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

The automobile was perhaps the most influential invention in transportation of the 20th century and even today, the personal automobile is used by most as their primary mode of transportation (Meyer, 2016). As of 2015, there are presently over 800 million cars on the road worldwide, and more than 75% of Americans commute alone by car (U.S. Census, 2009-2013). The average family organizes car-related expenses as their second highest expense below rent, mortgage, or home expenses (U.S. DOT, 2015). Americans typically spend an average of 100 hours a year in traffic (Cowen, 2011), with around 33,000 people killed annually in the nearly 5.7 million highway traffic accidents in the United State alone. Traffic congestion accounts for 3.7 billion wasted hours and 2.3 billion wasted gallons of fuel. Additionally, cars utilize less than 4% of their lifetime wasting precious natural resources and space when not in use because of our nation's strong emphasis on personal car ownership (Thrun, 2010). Despite the significance automobiles have on daily life, there has been a considerable lack of automotive innovation in the past decade; however, this lack in innovation will soon change as fleets of automated vehicles are deployed into society.

Planning and policymaking is a future oriented activity that is concerned with the use of land, protection of the environment and public welfare, and is capable of confronting inconceivable problems (Patton et al., 2015); however, these professions currently face their own problem by being left without a reasonable range of outcomes regarding higher levels of vehicle automation (Davidson et al., 2015). In addition, there are many potential applications and differing timelines of how and where automated vehicles will be released that present numerous unknowns and assumptions contributing to the complexity of this problem. Without a fundamental understanding of how, where, and when higher levels of vehicle automation will be implemented, planners and policymakers will have a difficult time anticipating changes and, as a result, making decisions and providing recommendations for the future.

This paper intends to contribute meaningful information back to the transportation planning and policymaking professions through its pursuit of data gathered from interviews with experts of vehicle automation, urban and transportation planning, policymaking, and aviation. The interview questions are aimed toward learning more about vehicle automation, discovering new lessons which may be underrepresented from experts in relevant industries, and uncovering other analogous examples from past innovations in transportation. In addition, the varying sources of information from literature and findings from the interviews are compared and validated against each other in order to strengthen the arguments made in this paper. Based on the findings, this paper recommends guiding principles for planners and policymakers. By understanding the key lessons discussed in this paper, planners and policymakers receive clarity they can use to critically evaluate and better predict the anticipated effects of automated vehicles.

FINDINGS

This paper interviewed key individuals with specialized knowledge on vehicle automation, urban and transportation planning and related fields, as a way to identify and gather data. The interviews where unstructured in order allow for questions to be asked based on the responses from earlier questions (Patton et al., 2015). The experts interviewed for this paper were: Dr. Robert L. Bertini, Dr. William Riggs, Dr. Steven Shladover, Kevin Dopart and Kenneth M. Leonard. Five significant findings emerged from the interviews:

- The impacts of vehicle automation differ depending on one's visions of what automation means, how it is implemented, what the automation does, and where it operates.
- Current limitations of vehicle automation to perform all aspects of the dynamic driving task in all driving conditions make it difficult to move from level-4 to level-5 automation.
- Level-5 automation is required to have any effect on carsharing, mobility, and quality of life.
- Assuming effective planning and policymaking techniques, housing preferences, urban growth, and increases in total VMT will likely not be significantly impacted by vehicle automation.
- Human drivers may never be allowed to disengage their attention from a partially-automated vehicle, specifically in applications where drivers are expected to reengage their attention in safety-critical situations.

The following sub-sections explain the key findings from the interviews organized into three overall themes: level-5 vehicle automation, measuring the success of automated vehicles, and lessons from aviation.

Level-5 Vehicle Automation

One of the first questions asked to every interviewee was, have you ever been skeptical of level-5, fully-automated, vehicles? While *skeptical* may have not been the correct descriptor, all respondents were willing to acknowledge that level-5 automation will eventually be attainable; however, they each expressed different expectations and raised a variety of questions for society to consider when developing fully-automated vehicles. In the interview, Bertini stated he's a healthy skeptic and tries to look at all sides of an issue. Bertini believes that just because we have the technology, we still have to be careful, cautious, sensible, and open about unintended consequences, and not become the victims of the technology. Bertini believes we should "not let technology drive us, [rather] let's still be focused on creating places where we want to [live] as people."

According to Coles (2016), the impacts of vehicle automated cannot be accurately predicted at this time; research suggests that automated vehicles could improve accessibility, affordability, and comfort of travel, incentivizing more automobile usage; however, vehicle automation might also facilitate carsharing which could reduce the total number of vehicles on the roadway. During the interview, Shladover provided one of the more significant findings for better understanding and anticipating the effects of how vehicle automation will impact society. Simply put, he explained that the impacts resulting from the deployment of automated vehicles differ depending on your visions of what automation might mean, how it might be implemented, what you assume the automation does, and where it operates. Shladover mentioned that you can come up with radically different answers to predicting the impacts of automated vehicles based on your vision. There are potentially many applications of automated technology for society to choose from; the interesting puzzle then becomes how and where automated vehicles will be deployed, and how they will influence change. Professionals in planning and policymaking should then start by clearly defining and understanding the capabilities and limitations of vehicle automation in order to better predict how society and regulators will allow automated vehicles to be implemented.

During the interview, Leonard explained that the technology is not mature enough for widespread deployment in the form of what most people think of when they think of an automated vehicle:

> *"[People] think of the most advanced level of automation where you open an app on your cell phone, walk out to your driveway, hop into the back of the car and it takes you to wherever you want, and you're the only person in the car… That's the vision. I don't think the technology is mature enough for that to be a primary mode of transportation right now for a lot of people..."*

Dr. Shladover agreed that "the leap to go from level-4 to level-5 is hugely challenging." Based on the definitions of vehicle automation, level-5 automation would need to be achieved before the type of system being described by Leonard is possible. Shladover supported this position by explaining:

> *"The fundamental technology to verify and validate complicated software does not exist. There's a whole new technology that needs to be developed and matured to get to the point that somebody would have the basis of being able to say yes, indeed this system has been engineered to the level that it can indeed operate for over 3 million hours without a serious flaw."*

Within the realizations discussed are hints that level-5 automation may take many years before it becomes available. Shladover discussed the importance of level-5 automation and how it is required to have any effect on the feasibility of carsharing services. Research suggests fully-automated vehicles have the potential to reduce costs for individual users and households by eliminating the need of paid drivers for taxis and commercial transport, and accommodating carsharing services (Silberg et al., 2012). Carsharing services would likely receive an economic benefit from level-5 automation due to the technological ability to automatically recirculate vehicles at potentially much lower costs (Dutzik et al., 2013; Flämig et al., 2015; Anderson et al., 2014). Furthermore, Millennials were shown to likely accept this form of travel due to their perceived comfort levels with leveraging technology and preferences with modes of transportation that eliminates the requirement of private vehicle ownership (U.S. DOT, 2015). This combination of a supported share-based transportation industry with a general acceptability from a majority segment of society would appear to point to all things positive for higher levels of vehicle automation; however, Shladover and Leonard explained that there are limitations that currently exist in vehicle automation making it challenging for the technology to move from level-4 to level-5 automation. As a result, the vision of a share-based, fully-automated vehicle system, where humans are never required to operate the vehicle, may not be possible for many years.

Measuring the Success of Automated Vehicles

Interview participants were asked how the success of automated vehicles should be measured. Interviewee responses discussed many different measures of success, including thoughts on safety and public health, quality of life, mobility, efficiency, congestion, time of commute or total trip time, energy and the environment, social equality, livability, and total cost of transportation for the user. During the interview, Shladover expressed a compelling response that success must be studied as a multi-dimensional assessment, explaining that "transportation systems that are intended to maximize success along one dimension will probably not do so well along other dimensions." Looking at the industry from multiple dimensions will allow transportation professionals and policymakers to better understand the effects of vehicle automation.

Safety and public health are overwhelming concerns focused on vehicle automation as confirmed by all interviewees. Dopart noted that we have the data available to measure changes in roadway safety and as vehicle automation increases, the 5 million crashes, 2.5 million injuries and fatality numbers per year should all decline. Similarly, Leonard agrees that if the introduction of vehicle automation results in something other than an improvement in safety, "then automated vehicles have not been implemented and deployed appropriately, or there's a problem with having a mixed fleet environment and we're having a transition problem where driver operated vehicles and self-driving vehicles are having difficulty mixing." In fact, Leonard continued by stating that if we designed a system that maintains the status quo of safety, then we're missing a tremendous opportunity that technology provides and has provided historically in the past.

Safety is observed to be a major threshold that must be met before vehicle automation is allowed on public roadway. Shladover (2009) puts the safety metric into perspective by showing how designing a system that guarantees improvements in safety is technically challenging:

> *"If we go into the U.S. traffic safety statistics and look at the frequency of fatal crashes and injury crashes, we discover that they are amazingly rare… When you look at that in terms of the exposure, the fatalities occur on average once in 3.3 million hours of driving. The injury crashes once in about 65,000 hours of driving. So if you think of that in terms of mean time between failures, the designer of that system has to design a system that's going to operate for these tremendous amounts of hours without a fault that's serious enough to cause a significant crash."*

According to Coles (2016), when automated vehicles are first introduced, they will be too expensive for wide adoption without sufficient demand and economies of scale. This has been observed in past innovations in transportation, like the omnibus, commuter trains and electric streetcars, when they were first introduced into society. As these transportation innovations became available, they were generally only used by people who could afford to pay the high costs of travel. Over time, the technology became cheaper to produce and more affordable. As a result, automated vehicles may not be affordable to the masses at first, which present some equity issues when considering there are individuals who would likely benefit from this technology, like persons with disabilities, the elderly, and younger generations.

Riggs, Bertini, and Leonard agreed that a measure of success should also be social equity. Riggs believed that fully-automated vehicles could assist in helping to bridge societal wage and societal job gaps, and generational cycles of poverty by bringing about new opportunities for people in lower and middle classes. Riggs stated, "I think there may be a cross-section of people that could potentially benefit from the increased job accessibility, and increased accessibility in general that a world of [automated] vehicles might provide." Leonard discussed how a measure of success for self-driving vehicles is the potential to help disabled veterans, survivors of accidents, or people with mobility challenges get to work or out to a function that they can't get to otherwise." Bertini agreed and encouraged the profession to think in terms of accessibility, or how accessible is a particular use or location, and if "we [are] providing equitable levels of accessibility for all our citizens." Likewise, Bertini noted measurements of success should also include total costs and the proportions of household income spent on transportation. He says that "if cost and time goes down that's probably a good thing" for society.

The opportunity for vehicle automation to improve quality of life and mobility was mentioned in some form by all interviewees. Shladover stated that automation levels would have to reach levels-4 or -5 in order to maximize quality of life and mobility. At the highest levels of vehicle automation, people are able to use their travel time as leisure time or as work time by allowing the driver to disengage their attention from driving and apply their attention heavily on some other activity (Cyganski et al., 2015; Dizikes, 2010). Leonard discussed there are a whole host of things that get opened up in the mobility space, like automated van pools and mobility options improving for people who lost their ability to drive or never had it before. Additionally, Leonard discussed that since you don't have to drive your vehicle, you could stagger out of your house at 4 a.m., lie down in your driver's bed, press a button that says go to work, and spend the next 3 to 4 hours driving to work. Shladover and Bertini agree that's certainly a choice that some people make today.

The potential for automated vehicle technology to facilitate and encourage longer commutes may boost automobile dominance, increase VMT, and possibly cause increases in urban growth (Guerra, 2014; Fagnant et al., 2014; Cheon, 2003; Bierstedt et al., 2014; Dutzik et al., 2013; Hendrickson et al., 2014). During the interviews, questions focused on the idea of whether a significant amount of people would choose to live 3 to 4 hours away from work if vehicle automation allows them to sleep, among other things, while they are transported to their workplace. Answers reflected a general consensus that automation will likely not influence increases in total VMT and urban growth, or sprawl, within society for a variety of reasons; however, automation may contribute towards more automobile dominance. Bertini discussed that it's difficult to know what sort of value or feeling people would have about spending so much time in a vehicle:

> *"Some people gravitate more towards those types of long driving experiences, but it removes the human component… The idea of home is still something that people seem to value… In terms of quality of life, I think to a lot of people that means spending time and interacting with people."*

Dopart offered an alternative perspective when he discussed how on the one hand, the suburban or ex-urban areas could end up being sprawled out, especially in areas where there is lower infrastructure and housing costs. In the urban areas, carsharing and new forms of Uber or Lyft style of services, could lower the cost of urban transportation and even reduce the need to own a vehicle, which has been the trend in the Millennial Generation (U.S. DOT, 2015). The potential for vehicle automation to reduce travel costs could induce more VMT (Somers et al., 2015). Dopart and Bertini added it comes down to simple economics of transportation:

> *"…If you could own or subscribe to a stake in a vehicle that doesn't require a person to be paid, like a taxi, Uber, lyft model, then conceivably the cost could go down quite a bit (Bertini)."*

In addition, Coles (2016) proposes level-5 automated vehicles may result in shifted housing choice preferences among more-affluent households when the technology is first released. However, today's world features communication channels allowing opportunities for people, like policymakers, planners and the general public, to anticipate and mitigate negative behaviors. Furthermore, it is unlikely that the introduction of automated vehicles would enhance issues with congestion, urban growth and total VMT, especially considering all that society knows about these challenges today. In an interview, Riggs noted that just because you have the opportunity to choose a longer commute with the introduction of automated vehicle technology, a persons' housing choice may overshadow the distance factors:

> *"It relates less to the vehicle and more to what the buyer preferences are for housing. When you think about your palette of available choices for housing, [automated vehicles] have the potential to open that choice set up… It may*

allow some people to live further away from where they work; however, the ultimate goal is it actually opens up potentially more ease of travel opportunity for people who live more distantly irrespective of how much they make."

From the perspective of understanding the bigger picture, automated systems that remove the act of driving will most likely not result in shifted housing preferences by the more-affluent, however, it's still a concern that should be monitored and mitigated using techniques in effective planning and policymaking.

Lessons from Aviation

Shladover, Leonard, and Dopart believe there are analogous lessons in aviation and air traffic control that apply to the adoption of automated vehicle technology. Shladover explained that much like the automobile, in air traffic control systems, you've got vehicles that are privately developed, owned, and operated that need to work together with the infrastructure that is publicly owned and operated. Aviation is a combination of human operation and various degrees of automation; however, Shladover clarified that today's aviation is not an automated system because there are highly skilled operators watching over the system all the time, and taking over if anything goes wrong; that is essentially an autopilot feature, or level-2 automation.

Research identified the two major aircraft manufactures have developed different philosophies regarding the authority of automation: hard automation and soft automation (Young et al., 2007). Airbus uses a 'hard protection' system which acts in the form of automated interventions to prevent the pilot for inadvertently exceeding safety limits. Hard automation has ultimate authority and can override the human operator's input. On the other hand, Boeing uses a 'soft protection' system as a tool to aid pilots, allowing pilots full authority to override the automated system. The automatic gearbox, anti-lock brake systems, traction control, and electronic stability programs are examples of hard automation in automobiles. In comparison, adaptive cruise control could be classified as soft automation, since it is fully acceptable by the driver and any manual control will override the system. According to Young et al. (2007), lack of coordination has emerged as the central issue in both hard and soft automation philosophies. As a result of issues observed in aviation, the allocation of function in automated design will require coordination and cooperation between the human driver and automation technology in automobiles (see Young at al., 2007, for a summary). There is a wealth of knowledge that exists in the aviation and automotive research domains that examine issues associated with the interaction between humans and complex systems. Due to the limitations of this paper, these issues are discussed entirely; however, the complexity of human and automated vehicle technology interactions suggests a slower adoption of other level-2 automation applications and supports that level-3 automated features, where drivers are expected to re-engage control in safety critical situations, may never be permitted.

Dopart explained how automobiles on the road are in a much more complex operating environment compared to what we see in aviation. “The air is pretty simple so your crash avoidance problem is much simpler,” Dopart said, “you have three dimensions to move in, and you can detect things in minutes or 10s of seconds.” On roadways you’re dealing with a couple of seconds to react, often a fraction of a second; this is a much more complex environment. Similarly, Shladover compared the complexity of the aviation system with the complexity of a system with level-5 automated vehicles and “came up with about a factor of 10 orders of magnitude greater difficulty for the road vehicle automation compared to aircraft autopilot.”

During the interviews, Leonard and Dopart solidified the problem of relying on people to reengage in systems with partial automation, particularly level-3 automation. Dopart explained that the problem is you cannot depend on people to re-engage in the operation of a vehicle during emergency situations. He confirms that research has identified the average time to get someone back engaged where they could safely operate a vehicle was 7 seconds. There’s also a concern that people are going to make bad decisions and use the technology, whether intentionally or unintentionally, in an irresponsible manner. Leonard explained that “somebody might take a level-2 technology and act as if it’s a level-4 technology… One of the things I worry about is making sure we are aware of the limitations of the technology as they get exposed to it.” Dopart continued by clarifying how there are things people do well and computers do well. One thing people don’t do well, that’s been observed in aviation, is remaining engaged by monitoring the system when you have an airplane that’s mostly on autopilot. What’s even worse is when pilots’ skills deteriorate because they're flying less often. Dopart explained how the FAA basically told the airlines they're going to have to make the pilots fly more often. Dopart reassured:

> *"[This] is going to be a question in any automated mode… It's my opinion that the highway level-3 operations, where you could be watching a video for 10 minutes legally, but then be expected to grab the wheel in 5 seconds, [should never] be allowable."*

Dopart raised another analogous example from aviation, suggesting that someday policymakers may be considering areas where older-style vehicles and technology are not permitted. Dopart explained, "In aviation, you cannot operate an old airplane in national airspace… you have to have newer navigation and radio equipment." Just as there are a lot of places where older planes without the latest technology can operate, there may be places in the future where antique vehicles can and cannot operate. Dopart suggested that these places will probably not be where people use vehicles the most.

Overall, there is evidence from the potential benefits of vehicle automation and lessons from aviation that suggests we may never allow partially automated (level-3) systems in private automobiles (Blanco et al., 2015). In this context, a partially automated system is where drivers are given the option to completely disengage their attention, handing all safety critical controls over to the automated system until instructed to re-engage. Airplanes have highly skilled operators, who watch over the system and its environment at all times, and take over if anything goes wrong. As Shladover explained, this is an example of an autopilot system, not an automated system. Vehicles often travel within a matter of seconds from each other meaning it will take some time before level-5 automated vehicles are able to operate at high speeds without human drivers. Discovery of these parallel lessons from aviation that could be applied to more accurately predicting the short- and long-term outcomes of vehicle automation suggests future research should analyze the implementation of automation the aviation industry in more detail.

GUIDING PRINCIPLES FOR PLANNERS AND POLICYMAKERS

There is a big need for an education and outreach initiative to bring up people's awareness of vehicle automation. Planners and policymakers should start by remaining informed on the progression of the technology in order to accurately educate themselves. Newsletters and journals from respected authors and thought-leaders are recommended in order to receive accurate and comprehensive information. In addition, planners and policymakers should work together to encourage the public and other professionals to become more proactive in vehicle automation, rather than passive recipients of technological change. It is important that technological change is not an evolution that comes from the top-down, but that communities remain focused on designing in the places where people want to live. In order to achieve this objective, one must start by being at the table, being specific about what is important, and considering what needs to change.

Governments at all levels have a constitutional obligation to help people in the pursuit of life, liberty, and happiness, and have a responsibility to address those negative consequences by regulating products and the use of those products. As federal regulations on automated vehicle technology are established, government agencies should assess how implementations of automated technology will influence change over their respective jurisdictions. It is recommended that the first step in assessing these impacts should be to start a dialog in order to offer a channel of communication for the public and key stakeholders to quickly mitigate issues as they arise. Every level of government should create a task force that is responsible for organizing these discussions, educating the public and stakeholders on advancements in the vehicle automation industry, as well as vehicle connectivity, and providing updates on policy reforms from higher levels of government. The objective of the task force program should be to enable safe, efficient, and equitable integration of automation into the transportation system. Task forces will ultimately inform policy development. Policies established at the regional and local levels are recommended to remain flexible in order to easily adapt as new information becomes available. These policies should address potential unanticipated issues with vehicle automation while not limiting potential applications and implementation strategies that are conceived as the technology evolves.

While not discussed in this paper, connected vehicle technology (V2V and V2I communications) should be viewed as a primary focus for adoption and eventual deployment of the automated system. Dedicated short range communication (DSRC) systems are identified to be an important enabler of vehicle automation and should be focused on before vehicle automation. State, regional and local agencies shall encourage programs intended to educate staff and the public on V2V and V2I communications as well as how these systems will support applications of vehicle automation in the future. Agencies may begin by support for equipping traffic signals with DSRC systems that can communicate traffic signal phase and timing information to approaching vehicles. Installing other connected vehicle infrastructure provides more detail and accuracy of the geometry and real-time conditions of the system, which is very useful for vehicle automation.

This paper suggests that vehicle automation technology may first become available to more-affluent households who can afford to pay the higher costs of travel. Regional and local agencies should support programs designed to potentially reverse this trend and encourage more equitable distribution of new transportation technologies. It is recommended that policies are developed to support equality in the system by providing economic benefits, and increased mobility and accessibility for individuals with the highest need.

Policymakers are encouraged to continue developing policies which reduce congestion, discourage automobile dominance and excessive parking requirements, and diminish total VMT, as well as improve safety, accessibility, mobility and livability. In addition, policymakers should consider how vehicle automation could help achieve existing policy goals and objectives. For example, a potential near-term application of vehicle automation is first-and-last mile solutions for public transportation. It is recommended that agencies provide opportunities and flexibility in their policy to allow for automated and connected vehicle applications that enable first-and-last mile solutions. In addition, policy should provide opportunities to leverage new innovative applications that are invented to support non-automobile travel and share-based transportation services.

CONCLUSIONS

The objective of this paper was to develop a strong foundation for anticipating the potential impacts resulting from advancements in vehicle automation to be used a guide for planners and policymakers. Five significant findings emerged from this paper: (1) the impacts of vehicle automation differ depending on one’s visions of what automation means, how it is implemented, what the automation does, and where it operates; (2) current limitations of vehicle automation to perform all aspects of the dynamic driving task in all driving conditions make it difficult to move from level-4 to level-5 automation; (3) level-5 automation is required to have any effect on carsharing, mobility, and quality of life; (4) assuming effective planning and policymaking techniques, housing preferences, urban growth, and increases in total VMT will likely not be significantly impacted by vehicle automation; (5) human drivers may never be allowed to disengage their attention from a partially-automated vehicle, specifically in applications where drivers are expected to reengage their attention in safety-critical situations. A series of recommendations for planners and policymakers was developed based on these significant findings.

Planners and policymakers should challenge themselves, as well as other community members, to think outside of the box when envisioning new strategies for implementing automated vehicles into the transportation system. One thing is clear, the next five to ten years will be extremely important in determining how vehicle automation will impact how people choose to move. Recent developments in automated vehicle technology position us on the brink of another revolution in transportation. Let's work together to encourage the public and other professionals to become more proactive and involved in vehicle automation, rather than passive recipients of technological change, so that society may benefit from applications of vehicle automation which maximize the advantages and minimize the disadvantages of this new technology. By enabling a safe, efficient, and equitable integration, automated vehicles may surely be utilized by society to achieve some goals, like improved mobility, accessibility, and safety within the system.

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