Appendix A: What's New?

TransAction Technical Report

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1 Introduction

Transportation is in the midst of a series of quiet but profound revolutions. Travelers now have choices that go beyond the classic dichotomy of private cars versus bus and rail transit. Many of these changes take advantage of new technology, with some of the most dramatic changes yet to come including self-driving vehicles. New transportation services are now available, including many stimulated by private entrepreneurs. These changes also respond to market forces including increased preferences by some for urban living and a world where mobile communications provide near real-time access to information for business and individuals. The specific impact of these changes on demand for traditional modes, including private cars, transit, walking, biking, taxis, and telecommuting is unknown but will have important implications for how we plan, fund, and operate regional transportation.

The world has gone wireless and the use of smartphones will continue to grow. Smartphones/tablets/pads provide numerous opportunities for near real-time communication regarding transportation options including the ability to pay for transportation. While newspaper reports have focused on urban Millennials, increasing numbers of people are less dependent on private automobiles and many seem to have adopted an "anywhere-everywhere work style." These changes affect more than work trips, with changes in how we shop (fully 25 percent of non-automobile purchases are now done online) and how we socialize (often via social media rather than traveling to a physical place). People may also be traveling to a physical place to socialize or work remotely.

These changes differ from a simple extension of past trends. Indeed, a series of non-linear changes generate increased uncertainty regarding forecasts. At the same time, new public policies are being tried – for example California's sweeping changes aimed at reducing greenhouse gases. Growing regional traffic congestion (the recent 2015 Texas Transportation Institute's Urban Mobility Scorecard shows the Washington metro area as the most congested in the nation) imposes new costs and stimulates changes in business and residential location and modal choice.

A series of books, most with provocative titles, are part of a growing literature focused on the impacts of technology and new attitudes regarding mobility on future transportation choices:

- Beyond Traffic, USDOT
- Street Smart: The Rise of Cities and the Fall of Cars, Sam Schwartz
- The End of Traffic and the Future of Transport, David Levinson and Kevin Krizek
- The End of Driving, Bern Grush and John Niles
- Start-Up City, Gabe Klein

While specific comments and recommendations vary, these books all highlight that we face a very different transportation future than in the past. Most emphasize the growth of new forms of mobility that offer practical options to the private car. Some also highlight the potential for autonomous vehicles to support the growth in car sharing and to add capacity to the roadway network.

This memo contains two sections: 1) a description of major changes that could affect the future transportation outlook for Northern Virginia and 2) a review of the implications for these changes on travel behavior, system performance, and future investments. The description section includes a summary of what is happening, what firms and/or institutions are involved, and what implications this set of changes could have for the TransAction plan. The list of changes being considered includes:

- New data and travel information
- New values and attitudes of the traveling public
- New pressures on decision making
- New mobility – near term
- New mobility – long term
- New institutions

These changes have a series of implications for TransAction. The analysis section describes several implications of these changes, and how TransAction can incorporate them into the technical modeling and broader planning processes. Specific applications range from performance measures (new and better data make improved performance measures possible) to near-term investment opportunities (for example, integrated corridor management offers a cost-effective way to improve transport operations). Given uncertainty regarding the pace and breadth of new technologies and new mobility services, TransAction will benefit from several scenarios that cover the range of possibilities. We will then need to track change over the next few years and identify which scenarios appear most likely. Each scenario will be linked with different packages of attractive investments.

2 Description: New Dimensions and Major Changes

This section describes changes that will influence future transportation demand and services in Northern Virginia. These changes are not independent of each other. For example, the burst of new forms of mobility is motivated in part by new attitudes among the traveling public, the availability of new forms of communication, and new organizations in the transport business. One example of this interaction is the active investment by Uber in developing autonomous vehicles and similar interest by Google in shared car services. These interactions will be an important part of alternative future scenarios.

Any review of new technologies and new services should be addressed with humility. There is no guarantee that any new technology will meet its original claims, its original schedule, or its original costs. The Segway electric scooter provides a good transportation example. Rather than providing a revolutionary form of transportation as claimed when they were first introduced, Segways now serve a few useful, but limited and somewhat quirky applications. Google Glasses are another example of a technology that has so far failed to meet the expectations of its promoters. Similarly, a host of start-up firms now provide new forms of mobility. Experience tells us that many of these will likely fail. In sum, it makes sense to track these changes, but it is prudent to avoid basing investment plans on a specific technology and to avoid picking winners and losers among specific technologies and businesses. Setting up a system of trigger points can help identify early signs of success, failure, or delayed deployment of a new technology or service. These trigger points could be linked with implications for different types of policies and investments.

2.1 New Data and Travel Information

The new data and new forms of communication systems have two broad implications: support for travel decisions by individuals and support for transportation planning by public agencies and private companies.

2.1.1 Data for Travelers

Smart phones are in widespread use – 84 percent of US residents between the ages of 18 and 29 have a smart phone and 64 percent of the overall US population.[1] Smart phones come equipped with GPS, making location-based applications such as transportation routing and service options practical. On average, people spend 5.6 hours a day working with digital media, with more than half this time spent using smart phones. The smart phone use alone approaches 3 hours a day and represents a ten-fold increase over 2008.

A large and growing number of firms provide a range of transportation services, most geared to smart phones as well as traditional internet access. Some of these firms provide services nationwide while others focus on local or regional travel. **Figure 2-1** shows more than 200 local and national travel applications and gives a flavor for the scale of new resources available. Examples vary widely, covering firms that focus on specific modes (traffic navigation – Waze, TomTom, Garmin, Google, Inrix, HERE, etc.) while others provide cross-modal information, with a heavy emphasis on non-auto travel (Ride Scout, for example, among many others). These services aim to provide near real-time information on travel times and costs for options such as transit, bike, walking etc. Most do not yet incorporate auto travel and non-auto travel. Some (Ride Scout for example) integrate payment options into the sources.

Near-term gains in congestion are possible when travelers have near real-time[2] information on congestion (TomTom claims 15 percent improvement in congestion for users of their auto navigation system). Some firms offer predictions regarding future traffic. But will there be long-term issues if everyone has the same excellent information? TomTom also says these gains begin to disappear when market penetration of navigation systems approaches 40 to 50 percent, although overall travel times are still better than without these systems.

Transit providers are improving real-time data, both from GPS-equipped buses and information regarding travel times from electronic tickets. Similar data on car sharing and bike sharing adds useful details.

2.1.2 Data for Planners

Much of the data that makes personal transportation services practical also provides value to transportation planners and policy makers. These data combine new sources of raw data and efforts to integrate these into useful formats.

GPS-equipped cars and smart phones are a vital source of data on speeds, locations, and routes for travelers and the vehicles that they use. These data are termed probe data and under some circumstance can also be provided by locating cell phones. With the recent rapid growth in smart phone use, the

[1] Kleiner Perkins Caufield Byers, *Internet Trends* May 27 2015.
[2] There is always some delay in collecting traffic information, integrating it into an analytic tool, and then communicating it to the traveler. Delays are not long (1-5 minutes or so) but not true real time.

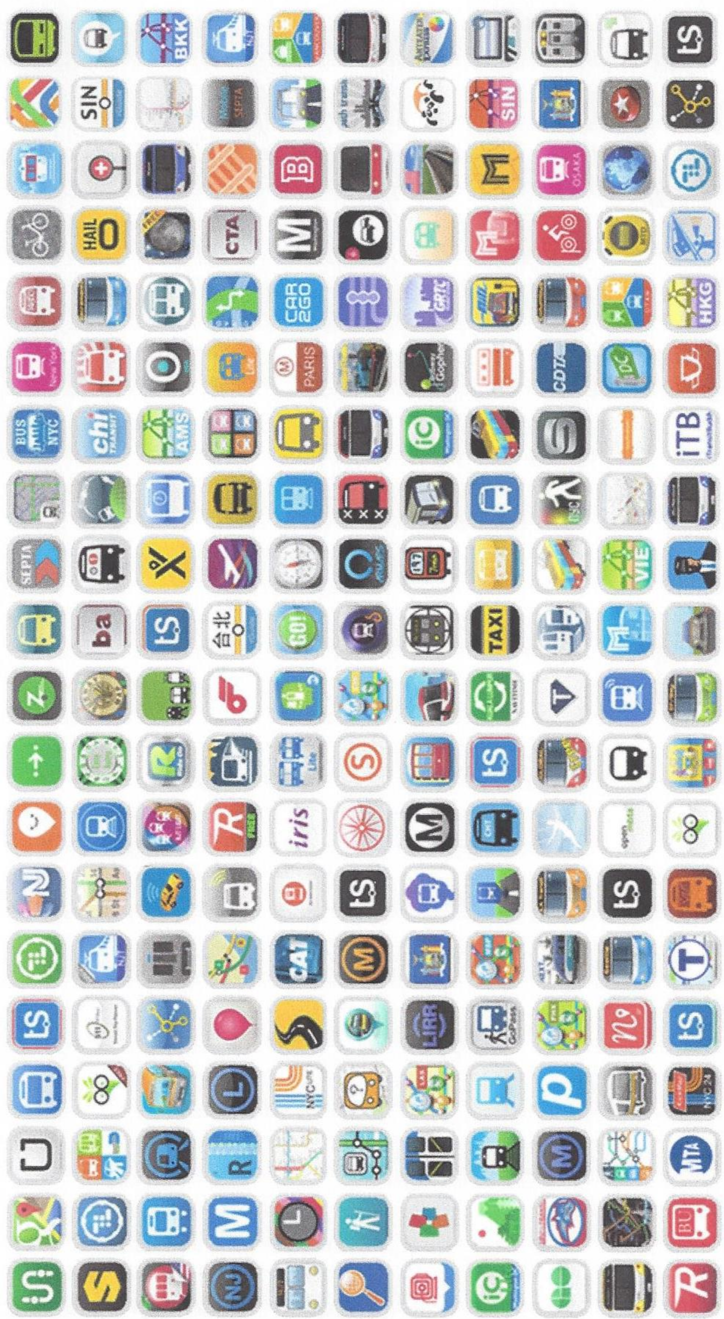
quality and quantity of traffic data now cover many more roads (including most arterials) with more detail on travel times throughout the day.

These data can, in turn, support improved performance measures. A good example from the Washington DC region are the measures generated by the Center for Advanced Transportation Technology (CATT Lab) at the University of Maryland. They generate a series of different performance measures including bottlenecks and measures of congestion. Another example includes the measures of accessibility for highways and transit generated by Professor David Levinson at the Transportation Center of the University of Minnesota using probe data and comparable transit information. These access measures offer a broader measure of regional transportation performance regarding key economic measures (access to jobs and labor) and social indicators (access to hospitals).

Some of these sources can provide data on origin-destination patterns and typical routes. These data can raise issues regarding privacy. The volume of origin-destination information is smaller than the typical GPS-based probe data. While fewer firms offer such data and details can be limited, data on origin-destinations can be very useful for planning.

At the same time that new sources of data have begun to appear, some traditional sources have begun to disappear or have become less useful. Budget pressures have forced the US Census to cut back some traditional surveys and the cost of independent regional surveys mean that they are carried out less frequently. The new data adds value (more timely and less expensive) but also does not have the same level of demographic detail as in years past.

Figure 2-1: A Sample of Transportation Apps



(Source: ITS America)

While new and improved sensors appear on a regular basis, some involve repackaging data from existing sources – for example, one firm now can estimate speeds and vehicle mix using existing cameras. Other firms have focused on data integration and related applications. Examples include Urban Engines (with a focus on transit data, including an active contract with WMATA) and StreetLight Data, a firm that integrates vehicle speed data and location (GIS) information. Almost every firm that has access to transportation and location data is actively working to develop applications that can be used by regional planners.

> ***"Ten years from now, when we look back at how this era of big data evolved … we will be stunned at how uninformed we used to be when we made decisions."***
> - Billy Bosworth, DataStax CEO (2015)

2.1.3 Implications for TransAction:

New data and traveler information has two sets of implications for TransAction:

1) New and more comprehensive sets of performance measures are practical. Accessibility measures are a good example of a new measure. Performance measures can be more robust than in the past given the significant increase in the volume of data and the larger geographic distribution of these data.
2) There is better information for individual travel decisions given the array of choices faced by most residents of Northern Virginia. Access to more up to date and more comprehensive information regarding travel options and conditions should result in better transportation choices – better in the sense of more reliable, probably more timely, and more cost-effective (based on individual budgets) decisions about when, where, and how to travel. It will also be more convenient to pay for transit and other travel options. All of this implies a more efficient transportation system in general and perhaps one with easier access to options beyond the single occupancy car.

Of course, more knowledgeable use of the transportation network should have implications for land use and residential and business location in general. To date, however, limited analytic work has been done on how to reflect these changes in planning models and in terms of policy options.

2.2 New Values of the Traveling Public

Individual values and attitudes are always changing, although the pace of recent changes seems to have quickened. While much of the popular press has focused on urban Millennials, many recent trends may affect broader demographic groups.

2.2.1 Demographics and Preferences

Millennials are not just kids right out of college. They now account for about 35 percent of the civilian labor force. Their travel patterns have changed from previous generations: only 46.3 percent have a driver's license by the time they are 19 versus 64.4 percent in 1998.[3] Shopping is now focused on the internet, with fully 25 percent of all purchases (other than automobiles) being made over the internet.[4] More social interaction is carried out via social media, with 54 percent of Millennials reporting that they use social media to interact with friends rather than driving to meet in person.[5]

There are many unanswered questions. To what extent are these changes driven by the recent economic downturn? Since 2000, the population has grown 2.4 times faster than the number of jobs – prior to 2000, jobs outpaced population. How much of this is related to starting families later in life and will shift back to more traditional transportation and location decisions once more Millennials marry and start having children? How much reflects those who seek out urban living or the 50 percent or so of Millennials who live in outer suburbs and rural areas? How widespread is the preference for walkable communities?

As baby boomers age, will they downsize or "age in place"? If they downsize does this increase demand in higher density areas (urban and older suburbs) or do they leave Northern Virginia and move to warmer locations (that also may have lower taxes)?

2.2.2 Travel Trends

Since the end of World War II, automobile VMT has grown steadily, with few downturns. This trend changed recently with a drop in total VMT during the recession (2007-2011) but has since returned to growth and recently set a record high in total VMT. More interesting has been the longer term drop in VMT per capita from 2005 till 2014. National VMT per capita is now comparable to the level from 1997. These trends in auto use have not been offset by increases in other modes. Transit use has grown in recent years, but the absolute increase in the number of transit trips is much smaller than the absolute decline in auto travel. In sum, there appears to have been a decline in overall individual mobility.

Both total and per capita VMT trends are currently trending upward, and national and regional traffic congestion has increased again now that the economy has begun to do better. But the trends described above regarding increased use of social media, internet purchases, freelance employment, and reduced tendency to obtain drivers licenses mean that the future rate of growth in automobile travel is likely to be slower than in past decades.

Telecommuting continues to grow and on some surveys appears as the fastest growing "mode" of urban work trips. This trend will likely continue, witness the large number of people who work as "freelancers" – fully 34 percent of the work force now work as independent contractors, moonlight on more than one job, are temporary workers, or operate small private firms with flexible hours.[6] This has implications for peak-hour congestion, as well as for travel demand forecasting.

Demand for mass transit has increased nationwide (with a large fraction of this growth in the New York metropolitan region). Despite this national trend, WMATA has lost five percent of their passengers over

[3] "Street Smart: The Rise of Cities and the Fall of Cars" – Sam Schwartz
[4] David Levinson, University of Minnesota.

[5] Kleiner Perkins Caufield Byers, ***Internet Trends*** May 27 2015.
[6] "Freelancing in America" Freelancer's Union and Upwork, (September 2014); reported by Kleiner Perkins Caufield Byers, ***Internet Trends*** May 27 2015.

the last five years. Have these people shifted to private cars or one of the new forms of urban mobility, or do they simply travel less than they did before?

2.2.3 Implications for TransAction

The traditional demand for transportation has changed. In sum, the pace of growth for automobile travel is likely to be less rapid than in the past – although still positive. Interest in non-traditional mobility options (including not traveling at all) has increased. Forecast models should reflect these evolving trends and preferences.

2.3 New Pressures on Decision Making

Transportation decision making has always faced a combination of pressures. The lack of adequate funds has been a problem for some time and the NVTA itself is a sign of progress in Virginia. Funds are still inadequate, meaning that finding projects with the most attractive rates of return will always be part of decision making. As discussed elsewhere in this memo, at some point in the future new technologies such as autonomous vehicles can offer some help by improving the effective capacity of existing infrastructure.

Groups with specific, narrowly defined interests are certainly not new, but the growth of social media seems to have increased the number of these organizations and helped them speed their actions. One challenge for the NVTA will be to highlight the regional economic and social benefits that a long-range plan can provide.

Public interest appears to have increased regarding climate change and sustainability in general. But, with the exception of a few places, including California and Vermont, there are few significant changes to public policy. The number of electric cars continues to grow, but from a very small base.

Continued concern over climate change and greenhouse gas emissions will lead to policies aimed at reducing the use of carbon-based energy. The NVTA's focus on reducing congestion should also stimulate important environmental benefits from smoother flow of traffic as well as diversion of some trips to other modes.

2.4 New Mobility – Near Term

These activities are already underway. Some thirty years ago the United States deregulated airlines, trucking, and railroads. The result stimulated new services and attracted new aviation and truck providers nationwide. No such deregulation took place in urban transportation and until recently the pace of change in new urban services was slow. This has changed in recent years stimulated in part by new technologies (smart phones, near universal GPS etc.) and changing demand (Millennials as a prime example).

New services and organizations have actively changed (and in many cases ignored) current practices and rules. The result can be characterized as de facto deregulation of urban transportation, resulting in a similar burst of new services and new providers as occurred in intercity modes in an earlier generation.

2.4.1 Shared Vehicles

Shared cars and shared bicycles (ZipCar and Capital Bikeshare among many others) are now common in urban areas around the world. It is interesting to see some of the auto manufacturers in this business (e.g., Daimler, BMW, Ford) as well as major rental car companies (Hertz, Enterprise etc.). Both shared cars and shared bicycles have been expanding.

Electric bicycles are a new option. These make longer bike trips practical and may help expand the market for bikes. Issues remain about how they mix with slower bikes and faster auto traffic. There is some experience in Europe with these. Another version involves electric scooters. These can be folded to carry on a bus. Scoot is a company that operates a fleet of small motorcycles in San Francisco as part of a shared vehicle system.

Mini cars – think "covered motorcycles" – will be on the market soon. For example, Scoot in partnership with Nissan, just introduced four-wheel, two-person vehicles in San Francisco. These are part of their shared vehicle program. Roadable golf carts are also coming into use, although they seem best suited for warm climates. While convenient and low cost, there are also safety implications in mixed traffic.

2.4.2 New Variations on "Taxi"

A growing number of transport networking companies use smart phone applications to link riders with vehicles. Uber and /Lyft are the best known. These services are billed as ride sharing, but really compete with taxis and some transit service. The basic service provides limousines or so-called "black cars."

More typical networking services use shared cars – in most cases vehicles owned by individuals. These provide lower rates than taxis during normal traffic, with higher rates during peak periods (surge pricing). In most cities, they offer expanded coverage – covering areas that taxis often do not serve well or demographic groups that some taxis appear unwilling to serve.

Uber, Lyft, and related networking companies face a growing number of regulatory confrontations and legal battles. Most of these disagreements are with taxi firms that take advantage of local regulations (often with active support from their regulatory agencies). These disagreements are particularly fierce in Europe, even involving physical fights.

Other disagreements in the US concern pressure to require common accessibility standards. What are the implications of these higher costs on this type of services? Lyft has proposed a parallel set of vehicles that would come equipped with wheel chair accessibility.

More profound changes may come from recent court battles in the US over whether or not drivers for these network companies are employees and thus required to receive benefits. Early rulings have been against the new firms. In addition, at least one city (Seattle) has mandated union negotiations. These rules would change the underlying economic structure of the network business, likely causing significant changes in the nature of the services that they offer.

2.4.3 Carpools and Private Bus Service

Uber (Uber Pool) and Lyft (Lyft Line) have developed carpooling services, although firms such as Ride Amigos, Zimride and Waze (testing in Israel) also have systems to match riders with vehicles – think app-based "slug lines" or "cyber hitchhiking." Uber and Lyft use discount pricing to encourage service along fixed routes, this is very close to direct competition with transit. Lyft claims their San Francisco carpool service now has more riders than the original Lyft service. Uber just announced that they would begin to offer this service in the DC metro area. Lyft has a vision that would expand this carpooling to include drivers who are not formally part of their network.

Several firms have begun to develop private transit operations that compete more directly with public transit. Bridj is a new firm that operates in DC and Boston. Their business model is to provide flexible, high-quality bus service for specific sub-markets. Their service is more expensive than traditional transit, less expensive than a cab, and uses vans or small buses rather than full-size buses. Is this simply "cream skimming" from transit or a long overdue form of competition that will improve quality for all? Their business model means they are unlikely to serve lower density regions or low-income travelers. Similar service was started in the Bay Area but is now out of business due to problems regarding compliance with ADA accessibility regulations and relatively high costs (they used full sized buses).

Some private firms provide bus service for their employees (Apple and Google in the Bay Area and Microsoft in Seattle are commonly cited examples). Government agencies offer similar services between offices, although not with the WiFi and related service provided by corporate buses. What is the potential for similar services in Northern Virginia?

2.4.4 Freight Delivery

Similar services have begun to develop for local freight delivery. Amazon has joined Uber and other firms already in the transport networking business to provide local package delivery services. These take advantage of private vehicles to provide rapid delivery times. As with many of these new services, do these trips substitute for more traditional freight delivery or do they represent a new service, with additional traffic and additional economic value?

2.4.5 Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) have been used to help manage transportation operations for some time. But, new sources of near real-time information from GPS-based probes and advances in wireless communication now make it possible to implement ITS tools in an integrated and dynamic fashion. As a result, public transport agencies have a new, integrated set of tools to help manage traffic congestion and transportation in general.

One term for this approach is Integrated Corridor Management. Full-scale field tests have taken place in San Diego and Dallas. Many of VDOT's proposals for I-66 incorporate these techniques. In sum, they reduce traffic congestion by improving the flow of traffic and, where possible, add additional roadway capacity. These techniques can be applied to expressways as well as major arterials. These actions often include one-way pricing to shift traffic from peak to off-peak periods. The express lanes in Northern Virginia along the I-495 beltway and I-95 are stand-alone examples of this approach.

Examples of ICM techniques include active traffic management techniques such as dynamic shoulder lanes, dynamic lane use control, dynamic speed limits, queue warning, adaptive ramp metering, dynamic merge control, adaptive traffic signal control, transit signal priority, and dynamic lane reversal or contraflow lane reversal. Beyond congestion pricing, there are many related techniques that can be applied to transit, to parking and to demand management.

The transportation system can also take advantage of ITS advances in the area of Transportation Demand Management (TDM). With the robust new information, individuals and agencies can track decisions and provide real-time updates for travelers. This information can also support a series of dynamic actions, ranging from speed limits that vary based on expected congestion, to using tolls and transit fares that vary based on traffic volumes. This leads to a more efficient use of the overall regional transportation network.

Applied across modes, ICM and TDM will have a significant positive impact on Northern Virginia travel. The techniques and technologies are a good complement to TransAction's proposed corridor-based approach.

2.4.6 Public Policy

What are the public policy implications from these new services and institutions? In particular, how do transit agencies address the issues of competition from new private providers? One option would be to use Uber/Lyft for public service (say elderly and handicapped) or for certain corridors or rural areas or for last mile connections. This could be handled via a performance-based procurement open to private and public agencies. Public agencies could also develop their own apps just as a growing number of taxi coalitions have begun to compete with Uber and other firms.

The public sector could fight deployment, usually with new regulations. Are these services taking away traditional transit and taxi customers? Some transit advocates call this "cream skimming." While data are limited, Uber and Lyft claim they help transit by providing last mile type services rather than competing.

Since the technologies and travel behaviors are so new, broad legal and policy issues are in their early stages with active debate regarding public policy options.

2.4.7 Implications for TransAction

A key question: which parts of Northern Virginia are best suited for which of these types of services? Do these have potential beyond higher density areas, such as in parts of Loudoun County?

It is not easy to find detailed information on the impact of these new services on transportation. Are they a substitute for existing services, a provider of net new mobility, or a bit of both? That is, do they stimulate demand? More trips are good for the economy and social connections. Or do they just take trips away from other modes – transit, walking, taxi, personal car etc.? Such a transfer of demand need not be a bad outcome, although there are implications for the financial strength of transit. The steady stream of new entrants creates new forms of mobility plus confusion about the future.

Good, consistent data are hard to find so there is over-reliance on anecdotes with a few data points provided. Uber and Lyft have become more active with the public sector, but they will likely continue to be selective in what data they release. Both firms have offered to provide data for Northern Virginia as part of TransAction.

What are implications for car ownership and urban structure? These services provide options to car ownership and thus might encourage higher density development. Reduced per capita car ownership has broad implications both for the environment and land use (fewer parking garages, for example).

2.5 New Mobility – Long Term

As a new source of mobility, the development of self-driving, or autonomous vehicles have received the most attention. But there is also considerable uncertainty. This comes from:

- Confused terminology;
- Multiple types of autonomous vehicles;
- Market uncertainty over how quickly remaining technical problems will be overcome and the nature of the market for these new vehicles; and
- Claims regarding the potential impacts of these vehicles.

This discussion of long-term mobility focuses on autonomous vehicles—their potential, limitations, and what they mean for TransAction.

2.5.1 Terminology

Automated vehicles operate independently along certain roadways. Connected vehicles share real-time information with other vehicles (termed V2V) and with others via the infrastructure (V2I). Autonomous vehicles are both automated and connected. The National Highway Traffic Safety Administration (NHTSA) has a four-stage set of automated levels – although these do not include the degree to which vehicles are connected. The Society of Automotive Engineers (SAE) has a similar five-level categorization. **Figure 2-2** shows the driver's role for each of the five levels in the SAE system. One way to summarize these is that Level 2 is "feet free – hands remain on wheel"; level 3 is "hands free – driver can carry out other functions but needs to stay alert" and Levels 4 and 5 are "brain free."

2.5.2 Models for Deployment

There are two, quite different visions for how these markets might develop. The USDOT has advocated using DSRC (Dedicated Short Range Communication) radios and a portion of wireless bandwidth that the Federal Communications Commission (FCC) has dedicated to transportation applications to support very rapid (ten times per second or better) communication among vehicles to maximize safety benefits. This model depends on federal regulations to mandate equipping all new vehicles with this equipment. Early next year NHTSA is expected to mandate this for vehicles produced in 2019 or 2020. The USDOT model also assumes public agencies (presumably state DOTs) would install infrastructure sensors along major roadways to exchange real-time information with vehicles. One implication of this focus on new car sales is that it will take considerable time to deploy this system given the pace with which the current vehicle fleet turns over.

A second, very different model, has been advocated by many of the private firms who are developing autonomous vehicles. They emphasize market forces rather than government regulations to speed deployment of the technology. They advocate for other (but as yet not well defined) means for vehicles to communicate with each other. While these firms see no need for infrastructure sensors (V2I) some firms see value in improved pavement marking, and all firms worry about possible future inconsistent motor vehicle regulations.

It is too early to tell which of these alternatives will win out – most likely both will be deployed in parallel for a while. The V2I model does not have a practical business plan and to date no state DOT has proposed to implement this. National costs are estimated at $3-5 billion.

2.5.3 Deployment Status and Prospects

While the press tends to focus on full automation, partially autonomous vehicles (NHTSA level 2) will be deployed first. Tesla just released a simple version of level 2 automation in some vehicles. This only works on certain roads (mostly expressways) and in good weather and requires the driver to keep their hand on the wheel or be available to take control of the vehicle in seconds. Other manufacturers plan to include similar systems in some models starting in 2016. These offer a key opportunity to test public acceptance and price sensitivity. NHTSA level 3 vehicles should be available in the next few years – perhaps as soon as 2020.. These provide an opportunity for the driver to read, watch video etc., although they still must stay in the driver's seat.

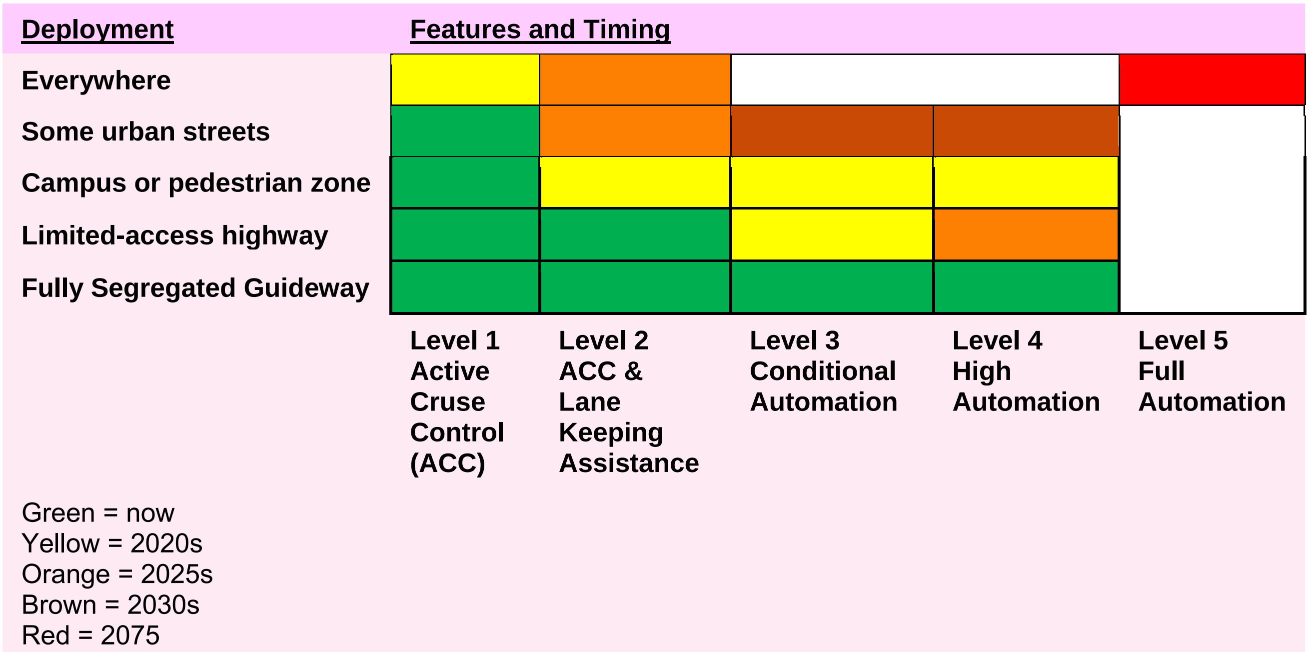
Fully autonomous (all roads, all weather) Lots of speculation exists about when these vehicles might appear on the market. For example PATH (research arm of the University of California at Berkeley and Caltrans) says not before 2075. **Figure 2-3** was prepared by Steve Shladover from PATH and shows his estimates of the pace of deployment for different levels of autonomous vehicles. This is a conservative forecast. Others (Google and other technology firms) say "five years" or 2025-2030 for fully autonomous vehicles. Of course, it will take time for these new vehicles to spread through the fleet.

Figure 2-2: Driver's Role in the Autonomous Vehicle System

Level	Example Systems	Driver Roles
1	Adaptive Cruise Control OR Lane Keeping Assistance	Must drive other function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes – and others)	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic Jam Pilot Automated parking	May read a book, text, or web surf, but be prepared to intervene when needed
4	Highway driving pilot Closed campus driverless shuttle Driverless valet parking in garage	May sleep, and system can revert to minimum risk condition if needed
5	Automated taxi (even for children) Car-share repositioning system	No driver needed

Example Systems at Each SAE Automation Level
Source: Steve Shladover, PATH

Figure 2-3: Estimates of the Pace of Market Introductions

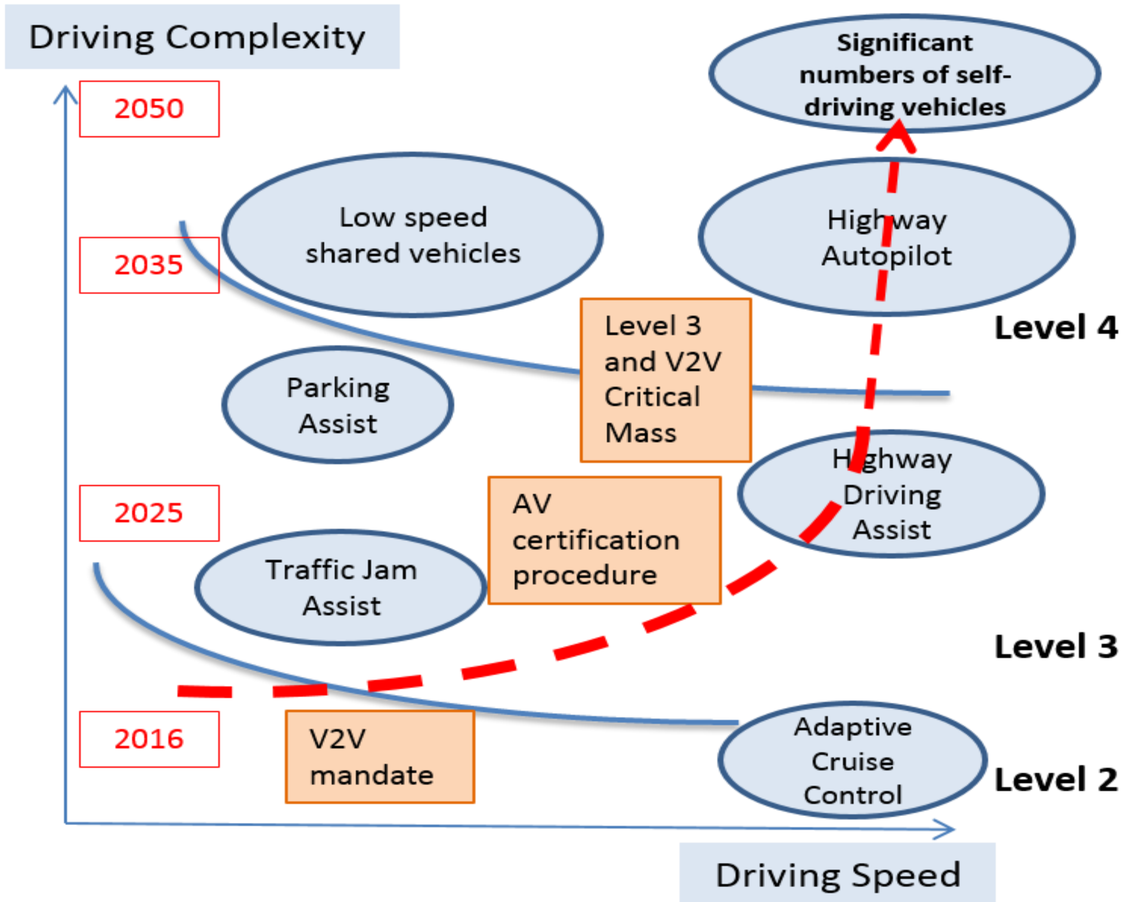


Source: Steve Shladover, PATH

Figures 2-4 and 2-5, prepared by Texas Transportation Institute, illustrate alternative pathways to the absorption of autonomous vehicles.[7] The first shows an "evolutionary" pathway, with level 3 vehicles (hands free) not reaching the market until around 2035. This assumes that manufacturers will deploy the technologies in new cars step-by-step. The second figure shows a "revolutionary" pathway with Level 3 vehicles appearing between 2020 and 2025. This is probably closer to the view of Google and other Silicon Valley firms. Regardless of how soon these vehicles are available, there are likely to continue to be serious concerns regarding cyber security.

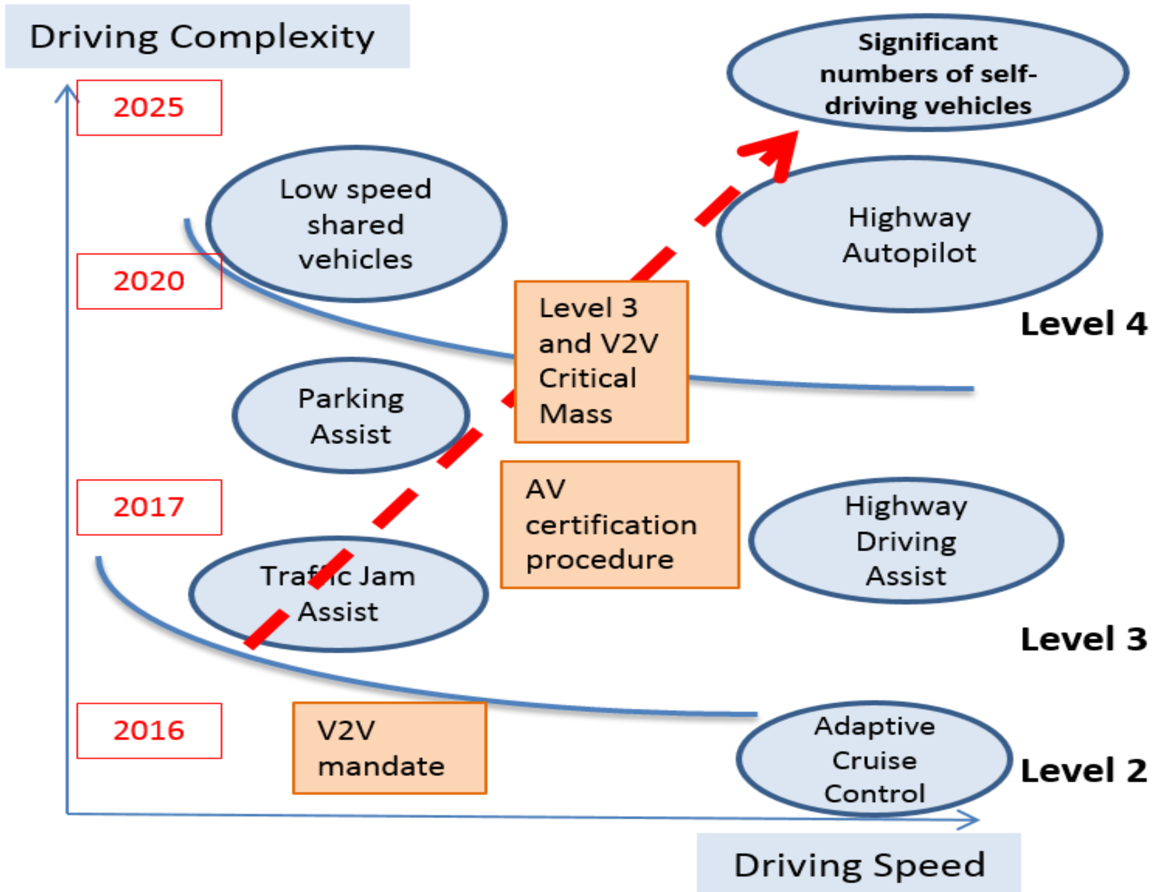
[7] Texas Transportation Institute, Paths of Automated and Connected Vehicle Deployment: Strategic Roadmap for State and Local Transportation Agencies, (September 2015).

Figure 2-4: An Evolutionary View of the Growth of Autonomous Vehicles – from Texas Transportation Institute



Source: Adapted from European Technology Platform on Smart Systems Integration

Figure 2-5: A Revolutionary View of the Growth of Autonomous Vehicles – from Texas Transportation Institute



Source: Adapted from European Technology Platform on Smart Systems Integration

Other deployment models have been proposed. For example, automated shuttle buses can provide service for campus-like settings where specific routes exist. These vehicles can also provide "last mile" service to and from transit stations. Examples exist in Europe, Singapore, and a few in the US. Some of these will also be able to travel on local streets.

Another option would focus on local service – slow speed, smaller vehicles. Milton Keynes in the UK has proposed a network of two-passenger pods that would respond to individual requests. Greenville South Carolina has a similar idea, perhaps using modified golf carts. These might resemble ground-based personal rapid transit. These vehicles are consistent with the shared car business model that already exists.

And, of course, many partial deployments will happen, just as a growing number of non-autonomous vehicles already come equipped with lane tracking systems, automatic cruise control and automated breaking. Self-parking applications represent another option that can be independent of other autonomous features. On-street parking options already exist and some auto manufacturers have options that will park a car in a garage.

2.5.4 Considerations for Autonomous Vehicle Deployment

Retrofitting will be a key to determining the pace of deployment. There is considerable uncertainty regarding the potential market demand for this new way to operate vehicles. In particular, the ultimate cost and reliability of retrofit equipment is still unknown. One firm has a $10,000 retrofit for Audi vehicles for use on expressways in good weather – similar to what Tesla has begun to offer.

Freight – intercity truck platoons receive a lot of press as well as investment dollars. What is the urban equivalent of this? Uber and Amazon have same-day urban freight deliveries under way using private cars and several early stage firms have entered the market. Autonomous vehicles sound like a logical next step.

Connected vehicles remain the focus of the USDOT. Vehicle to vehicle communication in real time is a vital step in achieving the potential gains in roadway capacity possible with autonomous vehicles. Are there practical options beyond USDOT's focus on short-range communications technology? Many of the private sector developers believe they can find options, but these have yet to be deployed (5G wireless is one concept, but the deployment schedule is uncertain). Telecom firms have asked the FCC to transfer part or all of the 5.9 Ghz bandwidth so they can expand WiFi and related services. The outcome of these requests is not yet known.

Advocates of autonomous vehicles point to three major benefits:

- Greatly improved safety since 90 percent of vehicle crashes are blamed on driver error – there were roughly 33,000 auto related fatalities in the US in 2014 and 1.2 million worldwide;
- Improved access for people who are mobility impaired whether due to disabilities or age; and
- Improved roadway capacity since there will be fewer crashes and autonomous vehicles will be able to reduce space between traveling vehicles.

Are there equity issues? Will the new vehicles be more expensive? What are net cost implications of mobility as a service models? The cost of Uber and Lyft services should drop considerably if compensation does not need to be shared with the driver. What are implications if lower income drivers continue to purchase used cars that are not equipped?

Amazon and Google among others are looking for commercial applications for drones. Will these substitute for local pick-up and delivery? Where will these be allowed to operate? Are there safety implications? What will FAA regulations allow? This technology seems to be at a very early stage.

3D printing has received considerable attention. Does it have implications for business location and transportation? Is localized manufacturing practical on a large scale? This will reduce long-haul shipping.

2.5.5 Implications for Planning

The advent and market penetration of autonomous vehicles has several key implications, including roadway/highway design both national and state standards:

- Possible gains in roadway capacity
- Possible declines in car ownership
- Possible cost reductions to own or use vehicles (mobility as a service example)
- Vehicle Miles Traveled – increase or decrease?

The implications for improved roadway capacity are important for long-range planning. How large might these impacts be? USDOT's "Beyond Traffic" report says there could be as much as a five-fold increase in roadway capacity once most of the fleet converts to autonomous vehicles. This estimate draws on simulation studies. These studies provide a wide range of estimates, with a five-fold increase on the high end. Estimates of a potentially doubling in effective highway capacity are more common.

Any such increase in roadway capacity has implications for what types of future transport investments will be needed. They also provide significant gains in overall mobility – an effective doubling of roadway capacity could provide a four-fold increase in access to jobs and labor. This has important economic and social implications. Many key issues have not yet been analyzed carefully. What level of market penetration is needed in order to begin generating these gains? Is ten percent ownership enough? Twenty percent? If vehicles cannot communicate directly, might there be a decline in effective capacity – field tests seem to show this.

Will there be a change in car ownership patterns? Is this just a continuation of current trends or a sea change in how we provide transportation? Many of the new players in transportation (Uber, Google …) seem to view autonomous vehicles as a key part of the move towards mobility as a service (MAAS) where most people will buy mobility as needed rather than owning a car that sits idle more than 90 percent of the time. This could have great impacts on insurance costs, parking demand, and housing footprints and locations. Several simulation models of this mobility as a service model claim that a fleet ten percent the size of current number of vehicles could provide the same or better quality of service. These models may work better in higher density areas.

Cost plays a vital role in determining the speed with which the market will grow. Can the costs drop enough to make the new vehicles competitive? The costs of key technology components have already dropped considerably – LIDAR systems from six figures to less than $10,000. Is this enough? How much are people willing to pay for this new technology?

J.D. Power's survey of drivers found that consumers were willing to pay $800 for traffic jam assist (similar to what Tesla offers now) and $2,500 for limited autonomous driving capabilities. The level of interest in new technology within vehicles showed relatively little variation across age and income groups – although interest was strongest among younger groups. [8]

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[8] "Automated Vehicles and Public Perception," Kristin Koolidge, J.D. Power at 2015 Automated Vehicle Symposium, (July 2015).

Will VMT increase (more suburban commuting) or decrease (reduced car ownership in higher density areas)? Perhaps we will see both types of change. Will an emphasis on shared vehicles mean increased VMT as empty vehicles relocate to serve different users? What are the land use implications?

2.5.6 Implications for TransAction

Key issues relate to impacts on automobile ownership, overall VMT, transit use, road design, and land use implications.

How will these vehicles be regulated? The Commonwealth of Virginia has already begun this process, with test regions that include parts of Northern Virginia. Regulations for new vehicles will likely include a test phase (already started by VDOT), early deployment, and operations. One unknown is whether or not there will be national regulations.

Are there practical actions that the region could take in order to encourage safe deployment of these vehicles? One option is more "white paint" to support those autonomous vehicles that rely on cameras. Does it make sense to deploy high technology lanes for properly equipped vehicles in order to take advantage of deployment? Does it make sense to deploy sensors needed for infrastructure portion of V2I? Will VDOT carry this out? Will USDOT help fund this?

Will overall VMT increase or decrease? How will these changes vary by corridor and by sub-area? Will there be a modal shift? In particular, does the mobility as a service model compete with traditional transit service or does it encourage more transit usage? There are likely to be different impacts on bus versus rail service, with bus more likely to lose customers to more flexible services.

Many fully autonomous vehicles will be electric powered, in part since this makes it easier to control some functions. What are the implications for wide-spread electric-charging stations?

2.6 New Institutions

Private and public organizations are taking on new roles with the expansion of new technologies and choices.

2.6.1 Evolving Roles

Many of the players in near-term and long-term new mobility are private firms. Most are new to transportation or new to these types of services (for example some auto manufacturers are now part of the shared car business). This raises questions:

- Will they be around for the long haul? What will happen when they are "forced" to become profitable and raise their rates? Are all of these new models sustainable?
- How will public agencies interact with them? Will partnerships develop? Or will old and new institutions become adversaries?
- These new institutions represent tangible investments in urban transportation by the private sector. How might we take advantage of these investments? How might we influence their actions in order to help meet public sector objectives? Some firms have begun to recognize value in working with public agencies. These include promises to share data.

- What are the implications for the structure and function of existing public institutions that plan, design, construct, and operate systems and infrastructure? There will be a continued need for public agencies to work with private entities to establish technical standards, ensure safety, and equitably manage public investment.

2.6.2 Implications for TransAction

The new institutions involved in urban transportation create opportunities and uncertainty. The long-term motivations for these new, mostly private firms, is not yet clear. As yet, there is no history of sharing data on the volume and nature of the mobility that they provide. While this may change (at least for the larger, better established firms) the lack of consistent data makes near term planning difficult. In addition, one strength of private firms is the ability to start or stop new services quickly.

In contrast to dealings with state DOTs and traditional transit agencies, no formal or even informal process exists regarding how to share plans. These new organizations depend on the infrastructure provided by public agencies (including the NVTA) but are not formally part of the public decision-making process.

How can we best take advantage of these new institutions and their investments? Is there a way to leverage their services? One option might be to focus them on high-cost public services, such as transportation for elderly and handicapped travelers. While subsidies would likely still be needed, the cost may be lower and service improved.

3 Analysis: Implications of the Changes

This section highlights interactions among these trends to anticipate likely future points of change. Specifically, this section discusses how these trends might be incorporated in the TransAction planning process. These elements will be central to the discussion of how to shape the goals, objectives, and performance measures used in TransAction, as well as how to frame the scenarios for different regional growth trajectories.

3.1 Key Questions

We have already seen a burst of creativity in terms of "new" modes with shared cars, new network services, and new modes (electric scooters, for example). More dramatic changes are possible once autonomous vehicles become involved. What do these new forms of mobility mean for:

- The types of trip that they serve?
- The types of travelers that use them (demographics)?
- Which parts of the urban region are served?
- The degree to which they shift travel from other modes – private cars, public transit etc.?
- How fast will these new modes grow?
- Are there freight-related implications (both local and intercity)?

There are important positive synergies among autonomous vehicles and new urban mobility as different types of self-driving vehicles can help to reduce costs, thus improving mobility. There are interactions between these changes and the values of our residents. Indeed, the new values of the Millennial generation have helped encourage the more personal service possible with new mobility. Values will continue to evolve.

The pace with which new technologies will be deployed represents a major uncertainty. When will autonomous vehicles be ready? How fast will the public begin to use them? What form will these new vehicles take – there are options other than the fully automated "Google car." There are numerous opinions regarding the nature and pace of these changes, but no consensus has developed.

There is also uncertainty regarding the reaction of traditional transportation agencies. Should they adopt a passive role and track changes and then react to them once the trends become clear? Should they attempt to encourage those trends that appear to have positive implications for regional growth? The set of tools that could help encourage change are not clear, but could include regulations as well as infrastructure investments ranging from improved pavement markings to high technology lanes. Should procurement procedures be changed to encourage greater involvement by private institutions?[9]

Some near-term options appear attractive. For example, integrated corridor management methods have been shown to be a cost-effective way to reduce congestion along crowded corridors. This approach combines proven technologies and has shown tangible gains elsewhere in the country. VDOT's plans for I-66 incorporate many of these concepts.

3.2 Considerations for TransAction

These changes have implications for TransAction in terms of the technical analysis and larger framing of the plan.

Task 5 - Performance Measures – given the increase in the volume and quality of data, new detailed measures are now more practical. For example, GPS-based probe data provides information on traffic flows for almost every road and transit agencies now have data on vehicle location and even passenger flows. Improved measures of reliability and access are now practical.

Potential Actions:

- Incorporate GIS-based data for trip origins and destinations
- Facilitate targeted data gathering and sharing by new modes and providers
- Measures for transit should be broad enough to include service provided by private parties
- Geographic differentiation for urban and less urban areas, given pace and absorption of change

Task 6 – Develop Scenarios – The different hypotheses detailed above regarding the pace of change in technology and services will inform TransAction assumptions on how we should integrate these alternative technologies, services, and demographics. For each background scenario, the study team will

[9] One such approach is described in a report prepared for the Regional Transportation Authority in Chicago: **Determining the Equitable Allocation of Public Funding for a Regional Transit System** (October, 2013).

consider a set of trigger points that will make it possible to track the deployment of new technology and its likely implications for the scale and nature of demand for transportation in the region.

These scenarios may be linked with alternative investment packages. In the near term (say the next 2-4 years) there may be little need for a significant change in the mix of regional investments. In the longer term, however, new technology and new forms of urban mobility will likely have significant implications for the most effective regional transportation investments.

Potential Actions:

- Scenarios include trigger points for advent and absorption of each major technology
- Scenarios represent different trajectories for growth in VMT and auto ownership
- Scenarios (and corridor approaches) represent different public investment priorities; different roles of private firms and public agencies
- Scenarios represent differentiation for urban and less urban areas, given pace and absorption of change

Task 7 – Modeling – What changes are possible to make the current models adjust to these changes? Are there parameters that need to be changed? For example, do autonomous vehicles imply a lower value of travel time since drivers will be able to carry out other activities while driving? How should we adjust models for the prospect of increased roadway capacity as autonomous vehicles reduce the number of incidents and decrease vehicle headways? How will mode shifts change as new forms of mobility develop?

Potential Actions:

- Adjust model spacing between vehicles and effective roadway capacity (2x to 5x)
- Effects of changed freight movement patterns on general traffic
- Move toward electric propulsion and charging stations; effect on land use and land value
- Mode share and design assumptions; modeling and design for additional mode categories (tiny cars/electric bikes; telecommuting)

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