MADRONA
VENTURE GROUP

Convert I-5 into an

AUTONOMOUS VEHICLE CORRIDOR

Tom Alberg, Managing Director at Madrona Venture Group, Daniel Li, Senior Associate at Madrona Venture Group and Craig Mundie, Former Chief Research and Strategy Officer at Microsoft

1 | EXECUTIVE SUMMARY

Last September, Madrona Venture Group collaborated with Craig Mundie, former chief technology officer of Microsoft, to publish a vision paper for an autonomous vehicle corridor between Seattle and Vancouver BC to dramatically reduce congestion and improve safety.

Since then, we have seen an incredible number of significant announcements in the field of automated, connected, electric, and shared (ACES) vehicles. They have included endorsements of these technologies by top government officials, announcements by all the major automotive manufacturers of the accelerated introduction of autonomous vehicles, and learnings from the rapid innovations in the relevant fields of machine learning, radar and computer vision.

It now seems appropriate to update our original I-5 Corridor paper for the 2017 Cascadia Corridor Innovation Conference. In this paper, we highlight recent developments in the autonomous vehicle space and make specific proposals as to how government leaders, traffic planners and business can begin to plan to integrate autonomous and shared vehicles into our transportation plans, specifically for the I-5 Corridor. Beyond those who are directly involved in planning our transportation systems, this dialogue should include local employers (such as Boeing, Costco, and Nordstrom) and companies developing these technologies (such as Microsoft, Amazon, Mighty AI, and Echodyne).

Shortly after the release of our 2016 paper, President Obama said in a WIRED interview, "The technology is essentially here… We have machines that can make a bunch of quick decisions that could drastically reduce traffic fatalities, drastically improve the efficiency of our transportation grid, and help solve things like carbon emissions that are causing the warming of the planet."

Earlier this year in Washington state, Governor Inslee echoed these sentiments by signing an executive order promoting the development of autonomous vehicles in Washington, emphasizing "transformational societal benefits: reducing injuries and saving lives lost to vehicle collisions, reclaiming time spent in traffic, maximizing our ability to move people and goods quickly throughout the state, improving mobility for the elderly and disabled, reducing property damage and serving as an important tool in our efforts to combat climate change."

We have also seen major announcements from companies like Ford which promoted its autonomous vehicle leader to CEO of the company, Tesla's NHTSA investigation showing a 40% decrease in accidents with Autopilot enabled, and Audi introducing an autonomous car into production for delivery next year.

Given the pace of progress, we are confident that we will have a significant number of autonomous vehicles on our roads in the next five to ten years, and we need to plan for that future now. We propose that by 2040, at the latest, all of I-5 be completely autonomous, and no human-driven cars be allowed on the highway. This would reduce congestion, reduce emissions, make it easier to platoon vehicles (enabling autonomous vehicles to travel at high speeds with little space between vehicles), and reduce traffic accidents and fatalities.

We propose this transition being phased-in incrementally. The first step would be allowing autonomous vehicles into HOV lanes, the next step would be dedicating a lane to autonomous vehicles, and the final step would be expanding until all lanes are autonomous only. Regulators may want to phase these steps in with vehicles reaching various levels of the NHTSA/SAE autonomous driving framework (e.g., Level 3 automatic braking and lane control or 4 automatic control of all aspects of driving without the need for human intervention). We believe the first step of allowing autonomous vehicles in the HOV lanes could begin immediately with Level 3 and higher vehicles. A dedicated lane (each way) for autonomous vehicles could occur as soon as we have a significant number of such vehicles on our roads which could be 2025 or earlier if a tipping point has occurred. We can imagine that limiting non-autonomous vehicles to one lane on I-5 could occur beginning in 2030, which would mean at least three exclusive lanes for autonomous vehicles from Seattle to Everett, two exclusive lanes from Everett to Marysville and one north of Marysville to Vancouver's downtown area.

What does it take to get to this future? On the technology side, not much. We will likely have the technology to operate fully autonomous cars (Level 5) in the next 3 years, especially for well-mapped, frequently traveled roads, with known weather and surface conditions (such as I-5). Tesla claims its most advanced system will be capable of Level 5 later this year (for a definition of the Levels please see the last page of this report). Regulators will need to pay attention to the transfer of the technologies from labs and startups to the real world to make sure it happens in a safe way, but they will also need to take into account the dramatic reduction in overall traffic accidents and deaths from the introduction of autonomous vehicles.

WE PROPOSE THAT BY 2040, AT THE LATEST, ALL OF I-5 BE COMPLETELY AUTONOMOUS, AND NO HUMAN-DRIVEN CARS BE ALLOWED ON THE HIGHWAY.

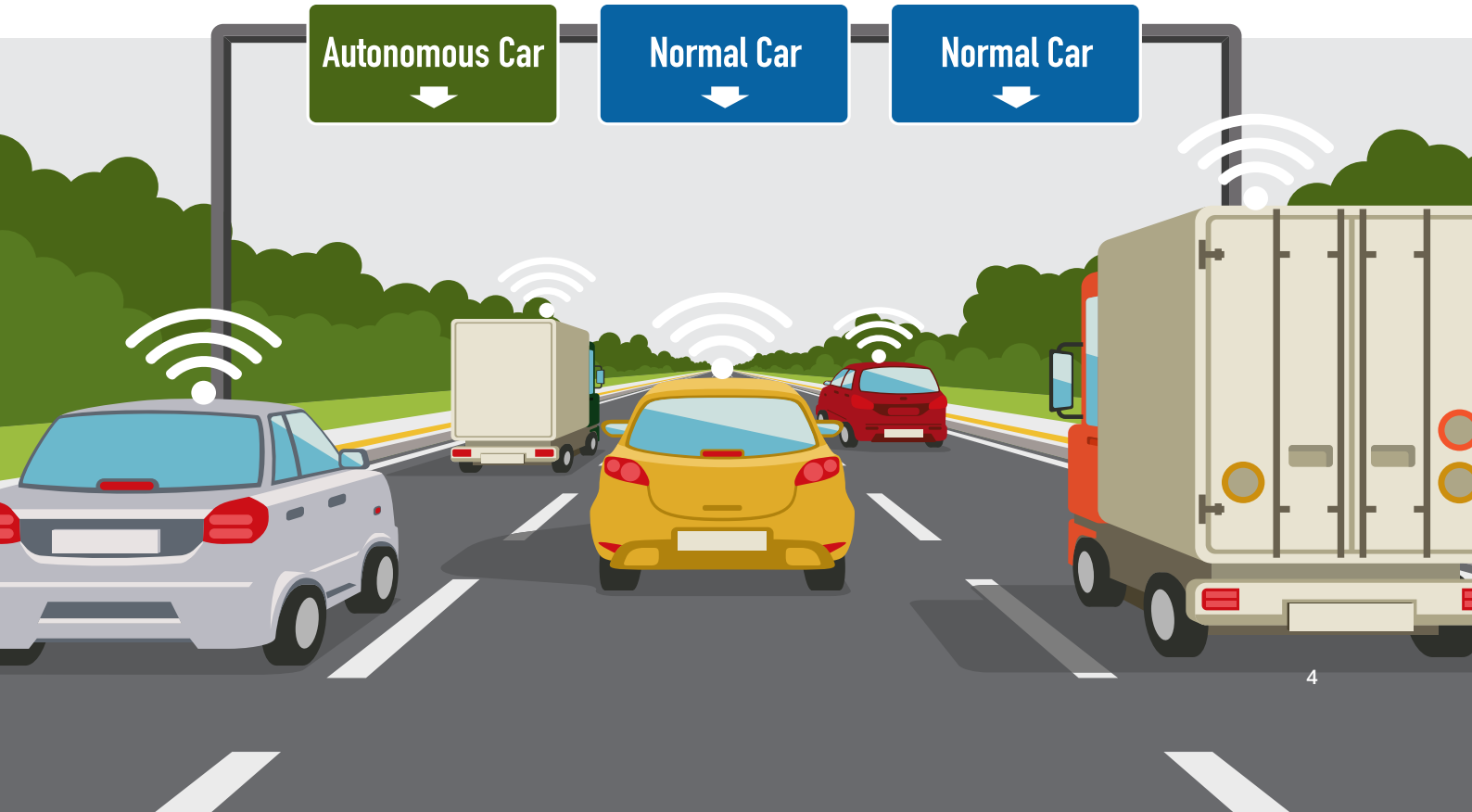
In order to accelerate the introduction of autonomous vehicles onto I-5 and integrate with existing transportation plans, we propose that a joint task force of key transportation decision makers and planners, as well as representatives of businesses involved in autonomous vehicle innovation from both sides of the border, be created to develop a detailed plan for deployment of autonomous vehicles on I-5.

The task force would recommend specific timelines to phase in different portions of the plan, adjustments to existing lanes and other implementation details. The governmental members of the task force could include representatives from the Washington State Department of Transportation (WSDOT) and the British Columbia Minister of Transportation. Involved business members could include Challenge Seattle, ACES and Vancouver development and innovation organizations.

Technical assistance to the task force could be provided by the University of Washington's Co-Motion Mobility Innovation Center and the University of British Columbia.

In the next few years there are going to be important questions around jobs and automation (what types of driving will still require humans, if any?), business models and tax revenue (will transportation be offered as a service, or will consumers still buy cars?), and how these disruptive technologies and business models will benefit all income groups by increasing availability to the elderly and infirm and significantly lowering existing transportation costs for everyone.

This 2017 update to our original vision paper highlights some of the key innovations in the autonomous vehicle industry this last year, our proposal for how the cities of the Cascadia Corridor can prepare for this autonomous future, and a set of recommended focus areas that regulators, consumers, and companies need to be aware of in the coming months and years.



2 | INTRODUCTION & RECAP

Situated less than 150 miles from one another, Seattle and Vancouver have an excellent opportunity to improve the connectivity between these two key cities in the Cascadia region. At last year's Cascadia Conference, presenters from Microsoft, the Boston Consulting Group, and local and national government all highlighted the unique relationship between these two cities as well as their shared histories, industries, and academic partnerships.

Nevertheless, one of the key challenges between fostering more collaboration and innovation between Seattle and Vancouver is transportation. For that reason, at last year's Cascadia Conference, Madrona Venture Group released a white paper with a vision of what an autonomous vehicle corridor between Seattle and Vancouver BC could look like. The paper stimulated a healthy discussion on the pros and cons of such a system, and we believe this type of dialogue is critical for regional transportation planning. Most importantly, however, since our initial publication, the opportunity and benefits for an autonomous corridor on I-5 seem to have become only more immediate and impactful. Accordingly, the Cascadia Corridor should begin to take steps to integrate and accelerate the introduction of autonomous vehicles on I-5.

An autonomous vehicle corridor between these two cities would phase in gradually. Initially, I-5 should allow autonomous vehicles to share the HOV lanes, as has been implemented by California for electric vehicles. As autonomous vehicles become more widely produced, HOV lanes would become dedicated exclusively to autonomous vehicles. Then, additional lanes would be dedicated to

autonomous vehicles, until the final phase of this plan when non-autonomous vehicles would be excluded from traveling on I-5 except for certain defined times, such as weekends or off-peak hours. Early phases of this plan could be implemented immediately, and the final phases could occur in ten to twenty years.

This autonomous vehicle corridor would reclaim productive hours, reduce congestion, improve the travel experience, and reduce accidents on I-5. Committing to this autonomous vision and building out a plan for the region to intelligently and carefully prepare for autonomous vehicles would not only benefit all who use this corridor but would also demonstrate to the world our region's status as a leading global center of innovation where government and private enterprises work in partnership to solve human problems.

There are many benefits that stem from autonomous vehicles, but one of the principal benefits is that they allow drivers to recapture all their time otherwise lost behind the wheel. This is at least two and a half hours from Seattle to Vancouver. It is difficult to place a dollar value on lost productivity in traffic, but one source has estimated this at more than $1 trillion a year in the United States. The other significant benefits from autonomous vehicles include substantial reductions in vehicle accidents and deaths, less environmental damage, increased capacity of existing roads, reduction of the need for constructing more freeways and lanes, increased use of shared vehicles, reduced congestion, and lower transportation costs for people of all income levels.

These benefits have been cited many times over the last several years by automakers, technology companies, think tanks, and policy-makers, and now we are beginning to see more data to support these claims. For example, after the NHTSA investigation following the 2016 Tesla Autopilot crash, investigators found that crash rates involving Tesla cars dropped by almost 40% since the wide introduction of Autopilot, Tesla's self-driving feature.

CRASH RATES INVOLVING TESLA CARS DROPPED BY ALMOST 40% SINCE THE WIDE INTRODUCTION OF AUTOPILOT, TESLA'S SELF-DRIVING FEATURE.

3 | KEY INNOVATIONS IN CASCADIA REGION

GOVERNOR JAY INSLEE'S EXECUTIVE ORDER ON AUTONOMOUS VEHICLE TESTING AND TECHNOLOGY

In June of 2017, Governor Inslee signed an executive order to encourage pilot testing of autonomous vehicles on Washington roads and called together a working group to ensure companies that develop autonomous vehicle technologies are well supported by the state of Washington.

The executive order followed ongoing work in the state legislature around regulation and licensing for autonomous vehicles, and it is a strong show of support for the companies developing autonomous vehicle technology in Washington state. Governor Inslee signed this executive order in the offices of Echodyne, a local startup focused on building solid state radar systems that can be used in drones and autonomous vehicles, with representatives from companies such as General Motors, Google, and Uber present.

Governor Inslee cited the "transformational societal benefits" and "roughly 94 percent of automobile accidents … caused by human error" as key reasons for introducing this executive order. In particular, he said, "One thing I know about radar, it doesn't drive drunk, it doesn't drive distracted. We humans are good at a lot of things, driving cars isn't necessarily one of them compared to the automated processes that are digital and foolproof. I just have huge confidence in the safety aspects of this."

According to the Seattle Times, the framework for pilot testing autonomous vehicles laid forth in Governor Inslee's executive order is similar to the regulations in Arizona, Colorado, Georgia, Michigan, Tennessee, and Texas. Ensuring that our region remains competitive with other states and provinces while creating a safe regulatory framework to test new technologies is a critical piece to moving this technology forward.

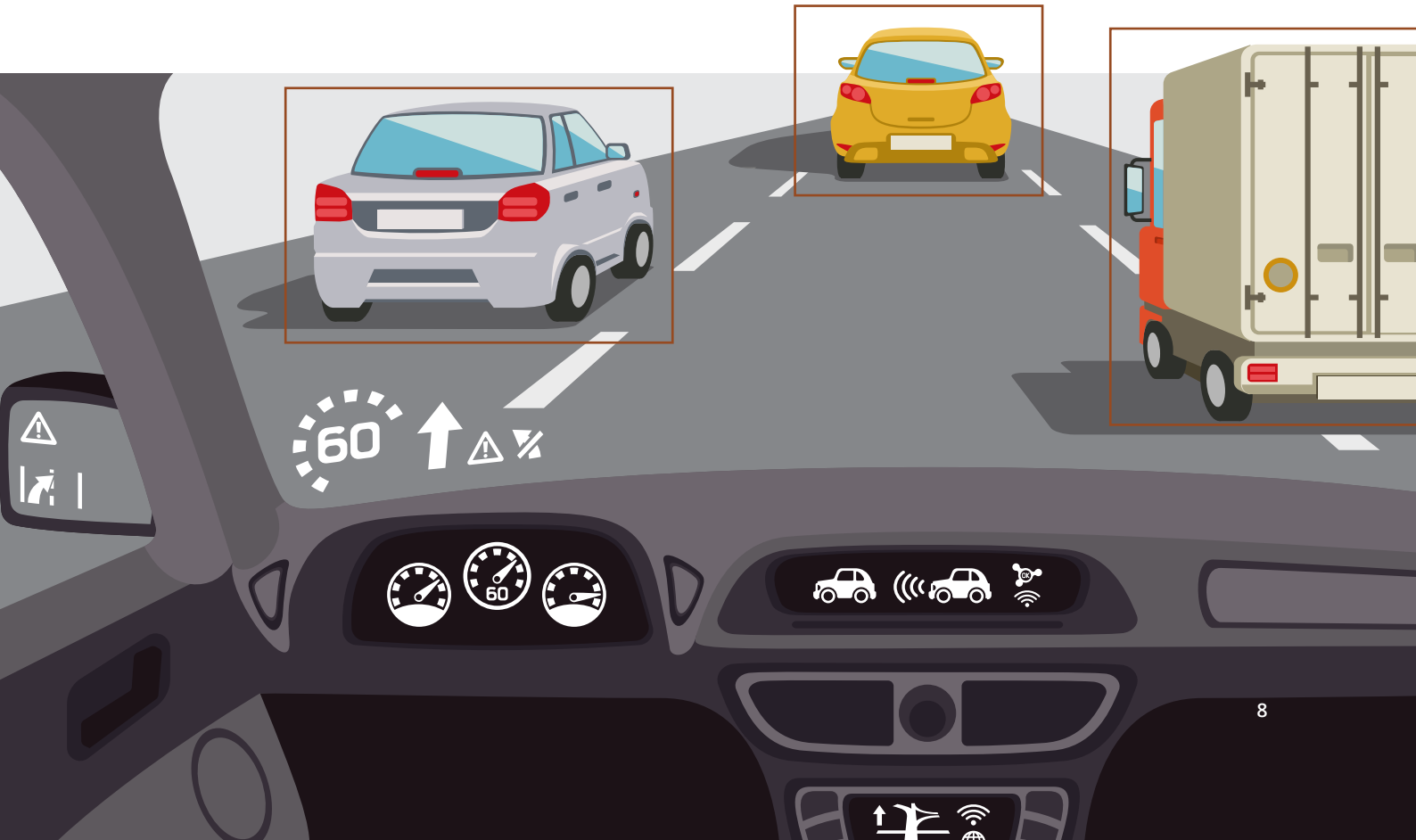
FORMATION OF THE ACES NORTHWEST NETWORK

During March 2017, several local technology, transportation and development companies worked together to create the ACES Northwest Network, to accelerate the introduction of vehicles with ACES (automated, connected, electric, and shared) technology into the Seattle area transportation system. Members include Inrix, Paccar, Nvidia, Uber, Lyft, Amazon, Kemper Development, Puget Sound Energy, MightyAI, and Echodyne. This group is working together to share materials, knowledge, and experiences. They are also partnering with public sector leaders to develop projects and pilots testing ACES technologies.

PACCAR AND NVIDIA PARTNERSHIP FOR LEVEL 4 SELF-DRIVING TRUCKS

In March of 2017, Paccar and Nvidia announced a partnership at the Bosch Connected World conference to build self-driving truck technology. At the announcement, they showed a demo of a self-driving truck with Level 4 capabilities, which means it can handle all normal driving situations without any intervention from a human driver.

Paccar is a Bellevue, WA-based company which is a global leader in the manufacture of trucks, and they are making strategic investments in autonomous technology. According to Nvidia, there are more than 300 million trucks worldwide, which are driven more than 1.2 trillion miles annually. Autonomy will be a major change in the trucking market, and working with a local partner who understands the market to develop strategy and regulation will be critical.



4 | KEY INNOVATIONS ACROSS THE US

UBER'S PUBLIC AUTONOMOUS VEHICLE PILOT IN PITTSBURGH

In September of 2016, Uber launched the first, large-scale public demonstration of autonomous vehicles with a fleet of vehicles in Pittsburgh, the headquarters of their Advanced Technologies Center. These test vehicles were staffed with a backup driver and engineer to take control in case of an error and to take notes on the experience, but they largely operated without issues. Journalists and other riders were impressed.

Since this first pilot, many other startups and large companies have released video demos and offered live demos of autonomous technology in various sites around the world, and today nearly every large technology or automotive company has announced they are working on building technologies for autonomous vehicles.

PRESIDENT OBAMA AND US DOT POLICY DOCUMENT ON AUTONOMOUS VEHICLES

In September of 2016, President Obama and the head of the Department of Transportation, Anthony Foxx, released guidelines on how the United States plans to handle self-driving cars at a national level. President Obama subsequently participated in an interview with WIRED magazine, where he told the public

> **"The technology is essentially here. We have machines that can make a bunch of quick decisions that could drastically reduce traffic fatalities, drastically improve the efficiency of our transportation grid, and help solve things like carbon emissions that are causing the warming of the planet."**

The DOT Guidance was subdivided into four categories: (1) vehicle performance guidance for automated vehicles, (2) model state policy, (3) NHTSA's current regulatory tools, and (4) new tools and authorities. Addressing the importance of keeping abreast of these technologies at a national level was a key catalyst to making the public more comfortable with these technologies and likely led companies to be more comfortable making investments in this space.

PRIVATE SECTOR PARTNERSHIPS

Over the course of 2016 and 2017, hundreds of companies announced self-driving car, truck, and shuttle projects. However, there were an equal number, if not more, of major announcements between companies announcing collaborations and partnerships.

Bosch, for example, is one of the largest automotive suppliers in the world, and they have been working on several different aspects of autonomy from sensors and hardware to the software that will drive these vehicles. Bosch has announced a multitude of partnerships, including with Mercedes-Benz to build self-driving cars for city applications, with Baidu for mapping software, with TomTom to develop new uses for radar sensors, with Sony for imaging technology, and with Nvidia for graphics processing units.

Technology companies like Uber and Lyft are also aligning themselves with automakers who can supply them with vehicles for their ride-sharing networks, and consortia are forming around providers of mapping data, which is critical for piloting autonomous vehicles.

The number and scale of these partnerships suggests that this industry is both very early and very fast-moving. Companies and governments need to work closely together to ensure technologies are being developed and introduced safely and securely.

NHTSA TESLA AUTOPILOT INVESTIGATION

In May 2016, a Tesla Model S collided with a tractor trailer in Florida and resulted in fatal injuries to the driver. Because the Tesla was being operated in Autopilot at the time of the collision, the NHTSA conducted a thorough six-month investigation into the crash and Tesla's Autopilot program.

This was one of the first public investigations into autonomous vehicle data, and the results were incredibly promising. TechCrunch even reported that "the report clears Tesla's Autopilot system of any fault in the incident, and in fact at multiple points within the report praises its design in terms of safety, and highlights its impact on lowering the number of traffic incidents involving Tesla vehicles overall."

Specifically, the NHTSA noted that crash rates involving Tesla vehicles dropped by nearly 40% after the introduction of Autopilot, which suggests that even today's early autonomous driving systems can perform better than humans. If this technology can continue to improve, we would expect the accident rates of autonomous vehicles to continue to decrease drastically and very quickly be unequivocally better than human driving.

FIRST PRODUCTION VEHICLE TO OFFER LEVEL 3 AUTONOMY

In July 2017, Audi announced that the 2018 Audi A8 would be the world's first production car to offer a Level 3 self-driving feature. Level 3 self-driving means that drivers no longer need to supervise the vehicle as it drives under certain conditions. This is different than the current Tesla Autopilot setup, where drivers are asked to keep their hands on the wheel.

For Audi that means that as long as the car is driving no faster than 60 kilometers per hour, the driver can take his hands off the wheel, read a newspaper, watch a movie, or send emails, without needing to pay attention to the road or vehicle conditions. This may not be completely street legal in every jurisdiction at launch, and Audi has announced a phased plan to ensure the technology is introduced in a safe manner.

5 | PROPOSED ACTIONS

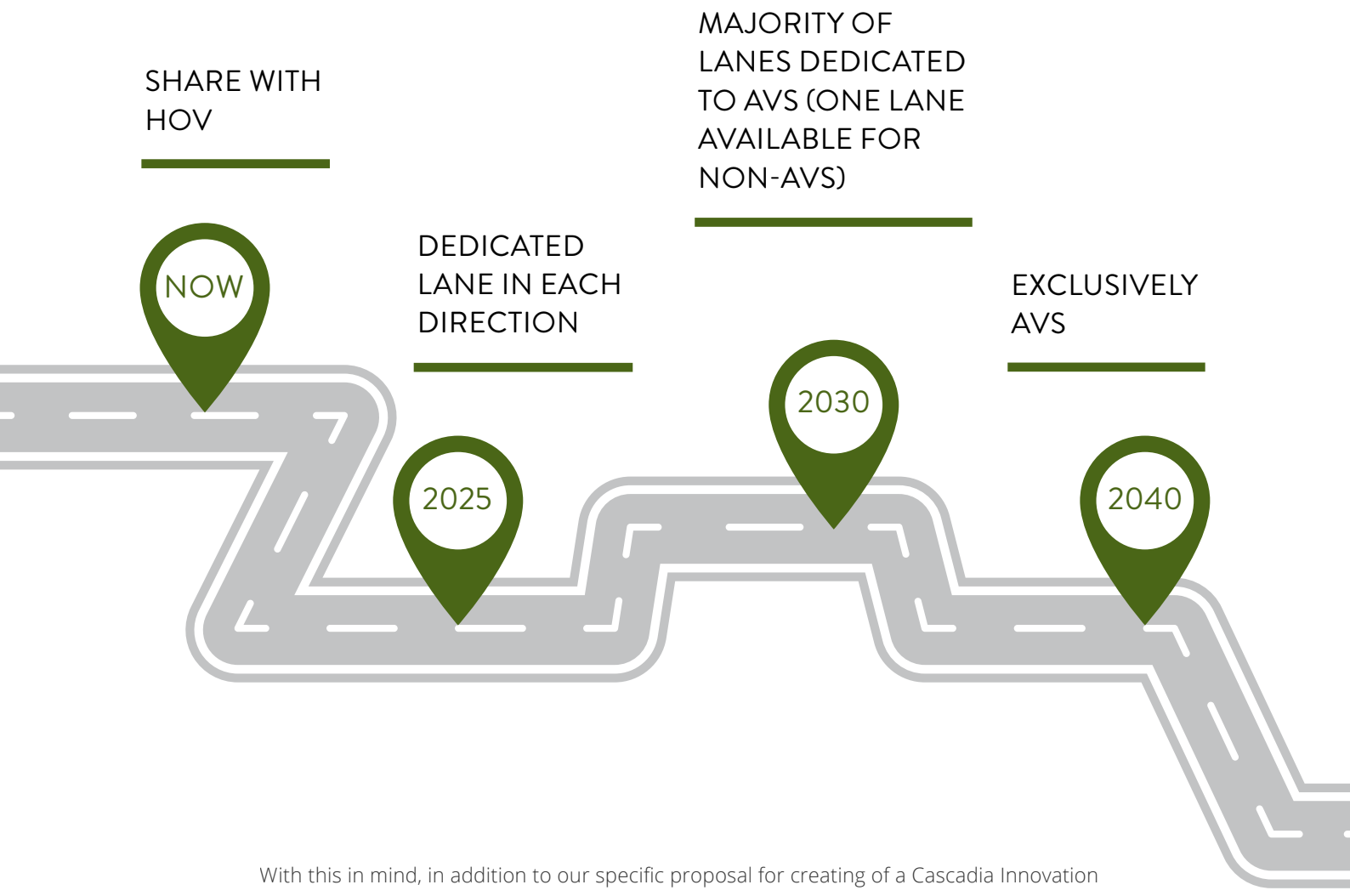
We recognize making a change to I-5 traffic rules would require a sizeable collaboration between several governmental agencies. However, we have seen across the world, the country, and in our region that change is happening extremely quickly in this sector, and there are a multitude of partnerships being formed today between all stakeholders in the world of transportation.

Taking bold, proactive action to improve the flow of people and goods along the Cascadia Corridor will allow us to begin to reap the benefits of improved transportation systems in the next few years without waiting for the construction of major new transportation infrastructure projects and their attendant massive costs and time delays. It will also send a message that Seattle and Vancouver embrace new ideas and new ways of thinking, further cementing a reputation for innovation in the Cascadia Corridor.

At the first stage, autonomous vehicles would simply join in use of the HOV lanes. I-5 from downtown Seattle to Everett is at least eight lanes with six lanes north of Everett to Marysville, all of which could accommodate a shared HOV lane. We believe the first phase of this plan for the shared use of the HOV lane should be implemented within the next year, as Level 3 and Level 4 autonomous vehicles are brought to market. As more autonomous vehicles are introduced, this shared lane could become exclusively dedicated to autonomous vehicles. From Seattle to Everett, which has eight lanes, two lanes could be dedicated to autonomous vehicles. Once two lanes are exclusively autonomous, these two lanes could become three lanes in the same space because of the smaller lane separation needed for autonomous vehicles. It may even be possible to convert one lane plus some use of the shoulder space into two autonomous lanes which would achieve an earlier increase in highway capacity.

If transportation planners can match the phase in of this plan with the adoption rate of autonomous vehicles, this plan will be less disruptive of existing usage than the proposal might appear today to planners, citizens and communities.

At a later stage, transportation authorities could consider building additional lanes in sections of I-5 north of Marysville to accommodate additional vehicles. Ultimately, I-5 would become exclusively for autonomous vehicles except during certain low traffic times at night and on weekends. This final transition will require some tipping point in terms of vehicle availability and public interest, and we believe this will happen in the next ten to twenty years, when usage and data will demonstrate the dramatic benefits of autonomy along the dimensions of safety, efficiency, and productivity.



With this in mind, in addition to our specific proposal for creating of a Cascadia Innovation Corridor I-5 taskforce, we make the following overall recommendations to our region's transportation stakeholders:

1. PLAY AN EARLY AND ENGAGED ROLE WITH EACH OTHER IN SHAPING POLICIES FOR AUTONOMOUS AND SHARED VEHICLES

The introduction of autonomous vehicle technology is too important for public and private sector decision makers to make decisions in silos. This is a sector where technology, consumer demand, and corporate investments are moving too quickly for decisions to be made in isolation.

Companies have already started working closely with one another to bring this technology to market, but we also need public sector, academic, and non-profit groups to work together with one another and the private sector. Importantly we need channels and institutions to help bring both the public and private sectors together to plan the future of these technologies.

2. INTEGRATE AUTONOMOUS AND SHARED VEHICLES INTO ALL ASPECTS OF TRANSPORTATION PLANNING AND MAINTAIN FLEXIBILITY TO BE ABLE TO MAKE CHANGES AS TECHNOLOGIES EVOLVE

Our region's transportation infrastructure will need to continue to evolve with changes in our region's growth and demographics.

Transportation technology has changed drastically over the last ten years with the introduction of ubiquitous data, smartphones, GPS, ride-sharing, and car-sharing. Highlighting the significance of these technology innovations for transportation planning in our region is one of the key goals of this paper.

Other transportation developments are occurring. Significant expansion of light rail systems in our region is underway. Also, high speed rail between Seattle and Vancouver was proposed at the Cascadia Innovation Conference in September 2016 and is currently being studied. High speed rail has had several valuable implementations in several parts of the world, and its benefits and challenges are being weighed elsewhere.

As we consider decades-long transportation projects, it is important that stakeholders develop a point of view on what transportation will look like in several decades so that we can incorporate future developments into what we are planning today. For example, will there be ride-sharing pickup, will there be car-sharing parking, and how will autonomous vehicles get people between train stations and their homes and workplaces? As these technologies are introduced and their impact on modes of transportation grow, we need to maintain flexibility to make changes in our transportation plans.

3. ENCOURAGE THE INTRODUCTION OF VARIOUS "BUSINESS MODELS"

Business models are important because they create incentives for individuals or companies to act in certain ways and can bring lower costs. As this industry evolves, companies are going to experiment with different business models. No one can predict with certainty which models will be widely adopted but new models could have a dramatic impact on costs and equity of our transportation systems.

For example, today, states are facing a large potential revenue shortfall from gas taxes. As gas prices fall, more cars become electric and people start sharing vehicles, revenue from the gas tax decreases. This means there is less revenue to fund maintenance of roads and other transportation initiatives.

One of the alternatives to a gas tax is a usage-based or vehicle-miles-traveled tax which anchors taxes to road usage, which could better align revenue and maintenance costs. Introducing a new tax could also have unintended consequences so they need to be considered carefully. For example, if usage taxes are too high, companies operating self-driving vehicles could go to greater lengths to keep cars close to urban centers rather than send them to more rural areas, limiting the growth of this technology outside of urban centers.

4. FOCUS ON WHAT MATTERS

Many autonomous vehicle discussions focus on questions like what should an autonomous vehicle do if it needs to choose between hitting a group of 5 elderly people or a group of 2 young people; or what if autonomous vehicles create more congestion because they lower the cost of transportation for everyone?

These questions are important, but they are often distractors to the greater benefits of autonomous vehicles and are impediments to their safe and secure introduction. In the classic example of the trolley problem where a car must choose to either swerve and hit 2 people or continue ahead and hit 5 people, not only are there already legally-defined rules for how such a car should operate, there are also a limited number of incidents that have this type of structure. The broader benefit of a significant reduction in traffic accidents and fatalities from human error vastly outweighs this edge case that often takes an oversize amount of attention and focus.

5. PLAY TO OUR REGION'S STRENGTHS

The Cascadia region has long been an innovation hub, and we need to continue to bear the torch forward to future generations. Given our strong history in the technology, resources, and consumer sectors, there are likely going to be ways we can leverage our strengths to take a leadership role over other regions.

For example, while we have outstanding universities and research institutions, we do not have a lot of automobile manufacturing facilities. If there is an opportunity to fund more research at the software level of machine learning for vehicles, that may be a better bet than manufacturing autonomous cars in Seattle or Vancouver.

5 | CONCLUSION

As leaders in the global information economy, the Cascadia region needs to explore innovative ways to incorporate new technologies into our transportation planning process that can significantly reduce the cost of transportation and improve connectivity within the region.

Over the last several years, machine learning, technology, and automotive industry experts have announced plans for autonomous vehicles to be released during the next five years. This is no longer, an "if," but a "when" question. As the region moves forward in exploring different ways to connect the cities of Cascadia, autonomous vehicle technology needs to be a major consideration in any transportation plan.

Over the next five years we will continue to see a rapid pace of innovation in the transportation sector as we undergo major changes in the ways people and companies buy, maintain, and use vehicles. Already we have seen massive behavioral change in the way people move around cities with ride-sharing services like Uber and Lyft and car-sharing services like Zipcar, ReachNow, and Car2Go. We will only continue to see more as more companies experiment with different business models and technologies.

To benefit from these innovations, we recommend that lawmakers proactively partner with the private sector to encourage autonomous vehicles to operate in the state of Washington and the province of British Columbia with clear guidelines. We also recommend establishing a joint US-Canadian commission composed of private and public sector leaders who could engage the University of Washington's Mobility Innovation Center and a comparable group from the University of British Columbia to make recommendations on the best ways to incorporate autonomous vehicles in transportation planning and specifically to implement a plan for I-5.

By working together, our region will be well-positioned to take advantage of the upcoming changes to technology and transportation and secure its place as a worldwide leader in innovation where government and private enterprises work in partnership to solve major problems.

Taking on this ambitious project would set Seattle and Vancouver on the path to becoming the standard for major cities and corridors in North America and elsewhere.

BY WORKING TOGETHER,

our region will be well-positioned to take advantage of the upcoming changes to technology and transportation and secure its place as a worldwide leader in innovation where government and private enterprises work in partnership to solve major problems.

6 | AUTONOMOUS VEHICLE LEVELS

Features of autonomous vehicles can be grouped together in a uniform set of self-driving "levels," which were defined by the Society of Automotive Engineers in 2014.

LEVEL 1

Some driver assistance, one or more systems to control speed or steering, but not at the same time. Includes emergency braking, active lane control, adaptive cruise control.

LEVEL 2

Ability to control steering and speed simultaneously. Car can navigate without driver for very short periods of time – under 1 minute and less. Level 2 cars cannot control a car in all situations, including merging on to a highway or stop-and-go traffic.

LEVEL 3

Conditional autonomy. Car can be controlled by systems but will call for driver to take control if the systems are not working. Many automakers are skipping this due to the concerns about drivers who won't be prepared to take over.

LEVEL 4

No driver interaction is needed. If systems fail the car stops itself. Ford is predicting they will have cars at Level 4 by 2021.

LEVEL 5

Completely autonomous. Dirt roads, bad weather, these cars will be able to handle it all.