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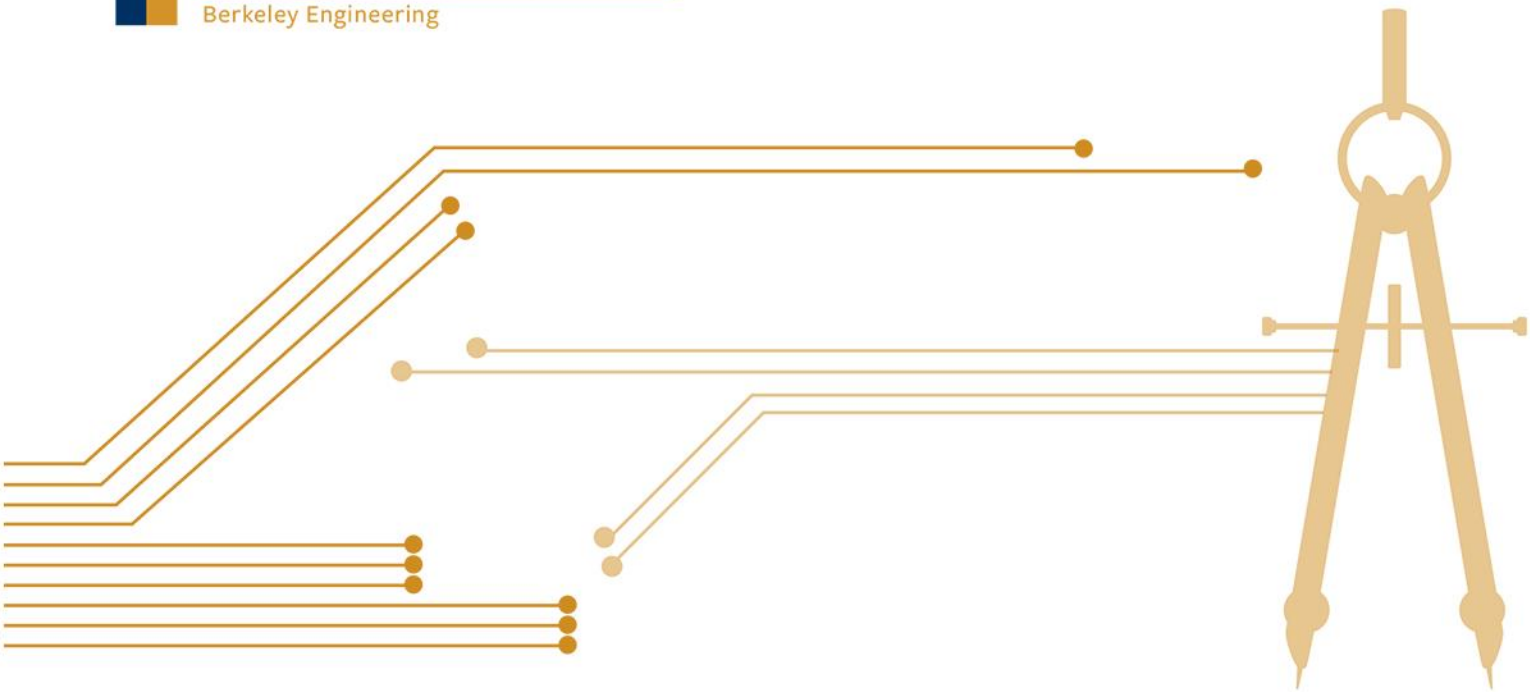

Autonomous Vehicles – A Landscape Study

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1. Executive Summary

Autonomous vehicles (AVs) are a present-day reality as we approach year 2020. The ecosystem they create presents enormous investment opportunities in developing the fundamental technologies, defining the global standards, and creating new business platforms. By 2025, the projected societal value created by AVs is up to USD$1.9 trillion annually. This paper is a landscape study providing snapshots of the today's reality and offering glimpses into tomorrow's possibility.

2. Introduction

Autonomous vehicles (AV) are an impending reality [1] with 33 states in USA alone introducing legislation related to self-driving cars in 2018. Major landmarks in 2018 involving AV included the following: Waymo minivan driving over 8 million autonomous miles, with 1 million miles driven a month [2], expected market of for AVs to reach US $65.3 billion by the end of forecast period (2016-2027) [3] and the advent of high-speed low latency 5G networks to support crowd sourcing and vehicle communications [4]. Additionally, there has been significant development of automated infrastructure to support AVs [5]. For example, the US state of Virginia has enacted legislation that allows AV developers to use more than 70 miles of state roadways to test and develop self-driving cars. Another example of autonomous infrastructure for rigorous deployment and testing is the development of the fake city called "Mcity" in University of Michigan to build and test AV interactions with passengers, pedestrians and bicyclists [6]. Despite the landmarks achieved by the AV technology, significant public skepticism continues to exist around the issue of "safety", where 64% Americans are concerned with sharing roads with AVs [7] and the US congress being unable to pass legislature to speed up development of self-driving vehicles before the end of 2019 [8]. Nevertheless, the automotive industry continues to shell over 77 billion Euros per year on R&D around AVs with the sole aim of visualizing the autonomous future with reduced congestion, improved safety standards, improved land usage and road capacity, and most important of all improved quality of life for consumers with productive usage of commute times [9].

Based on the deployment and adoption of a variety of autonomous functionalities in highway and urban settings, the forecast is that AVs are expected to constitute around 50% of vehicle sales, 30% of vehicles, and 40% of all vehicle travel by 2040 [9]. Additionally, estimates show that the direct societal value that will be created will be between 0.2 and 1.9 trillion dollars annually by 2025 [10]. Besides the direct effect to automakers, other domains that will be significantly impacted by AVs are: 1) mobility, networking, and connectivity, 2) sensors and validation, 3) data security, 4) automated highway systems (AHS), and 5) rider experience and engagement. In this project, we analyze the pros and cons introduced to these domains by AVs to enable comprehension of the overall societal as well as technological landscape that now lies less than a decade away.

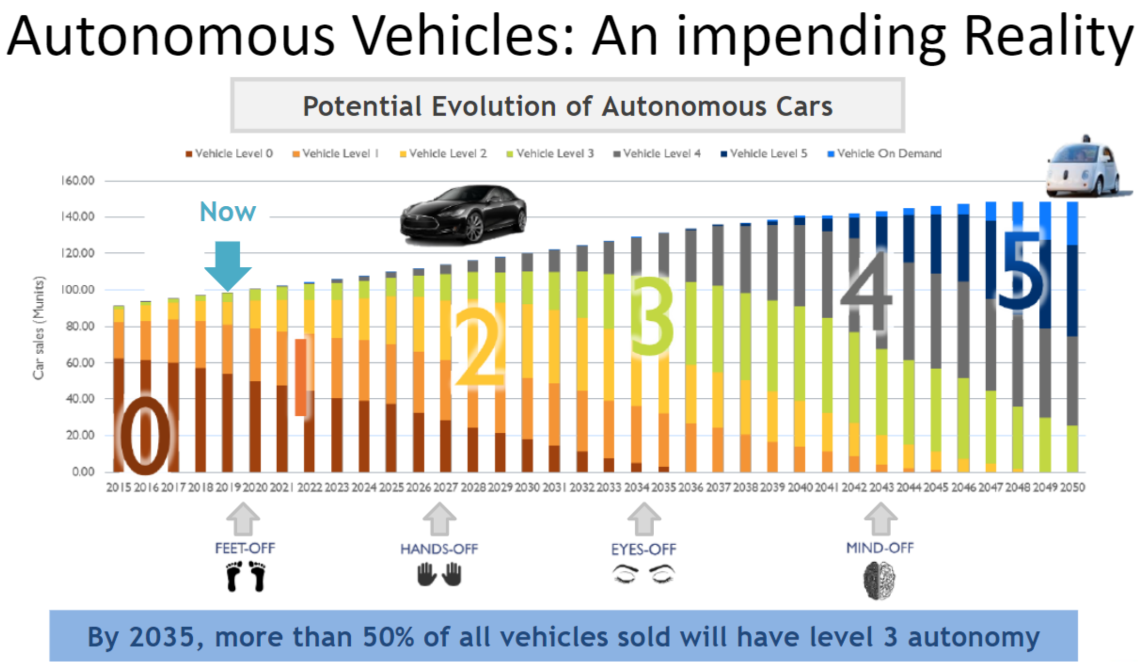

Figure 1: Potential evolution of autonomous vehicles

3. Mobility, Networking, Connectivity

Communication and connectivity are key to the development of autonomous vehicles. The V2X communication supports vehicles to communicate with other vehicles (V2V), pedestrians (V2P), network(V2N), and surrounding infrastructure (V2I).

There are currently two key standards for V2X (Figure 2).

Figure 2: Battle over standard

- **IEEE 802.11p/DSRC**: 802.11p defines wireless access in vehicular environments (WAVE) including dedicated short-range communications (DSRC) devices in vehicles and roadside units (RSUs). It's an amendment to the popular 802.11 wireless (Wi-Fi) networking standards. DSRC operates in the 5.9 gigahertz (GHz) band with a bandwidth of 75 megahertz (MHz) and an approximate range of 1,000 meters.

- **C-V2X**: C-V2X is designed to support active safety and help enhance situational awareness by detecting and exchanging information using low-latency direct transmission in the 5.9 GHz Intelligent Transportation System (ITS) band for V2V, V2I, and vehicle-to-pedestrian (V2P) situations, with no need for cellular subscription or any network assistance. C-V2X is defined by the Third Generation Partnership Project (3GPP) Release 14 specifications, including PC5-based direct communications, with a clear evolution path towards 5G New Radio (5GNR).

Published in 2016, C-V2X has quickly gained momentum and broad ecosystem support. The auto industry is divided over the two standards. Toyota and GM are the main supporters of DSRC. On the other side are brands including Ford, BMW and Mercedes that have joined chipmaker Qualcomm, cellular providers and others to push for C-V2X.

C-V2X benefits from being based on technology that was intended for high speed mobile applications and has further improved specifically for automotive use cases. Key benefits of C-V2X are summarized below.

Future proof, providing a progression to 5G: C-V2x will evolve to facilitate new capability in the 5G era. In the meantime, the dual modes of LTE C-V2X meet all the requirements of the automotive industry. A wide range of business models are possible: Business models leveraging the multiple modes of C-V2X could include infotainment, traffic information, realtime mapping, telematics and data analytics.

Economies of scale will develop more rapidly: Many automotive OEMs believe C-V2X will be less expensive to implement than IEEE 802.11p/DSRC.

5G will be able to better carry mission-critical communications for safer driving and further support enhanced V2X communications and connected mobility solutions since its extreme throughput, low latency, and enhanced reliability will allow vehicles to share rich, real-time data, supporting fully autonomous driving experiences.

The start of C-V2X in-vehicle commercial deployment foreseen for 2020/2021 globally. At CES 2019, Ford has announced that it will deploy C-V2X in all its new vehicle models in the US by 2022. A roadmap is shown in Figure 3.

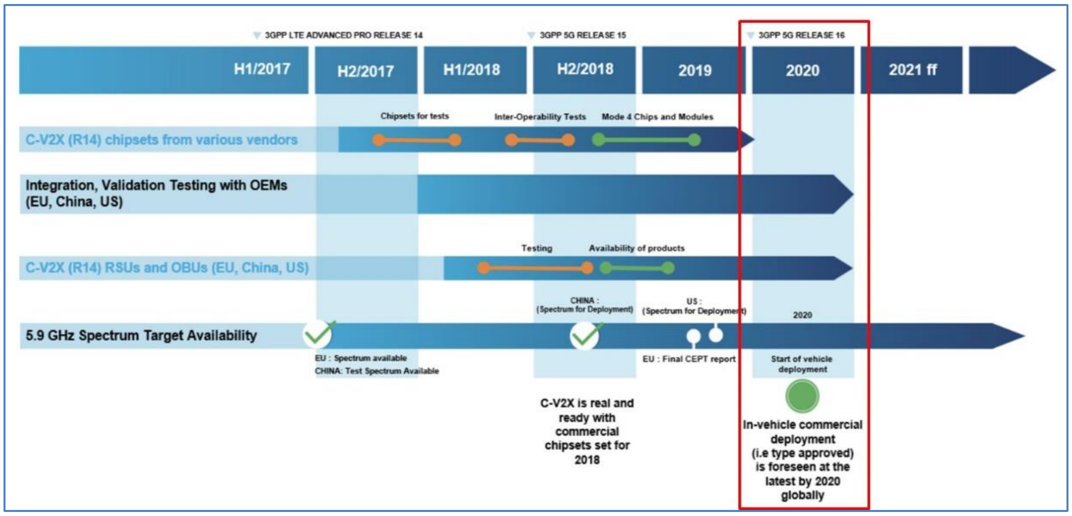

Figure 3: C-V2X roadmap

4. Sensors and Validation

To support autonomous driving, number of sensors in vehicle will increase significantly to well over 100. *(Source: Ashutosh Tomac, JLR R&D, 3rd Annual Sensors in Automotive Summit, Jan 2018)*.

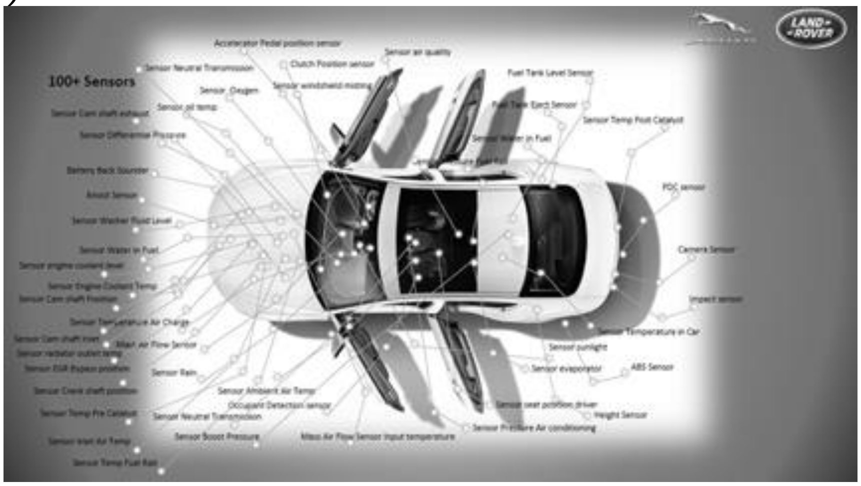

Figure 4: Over 100 sensors to support autonomous driving

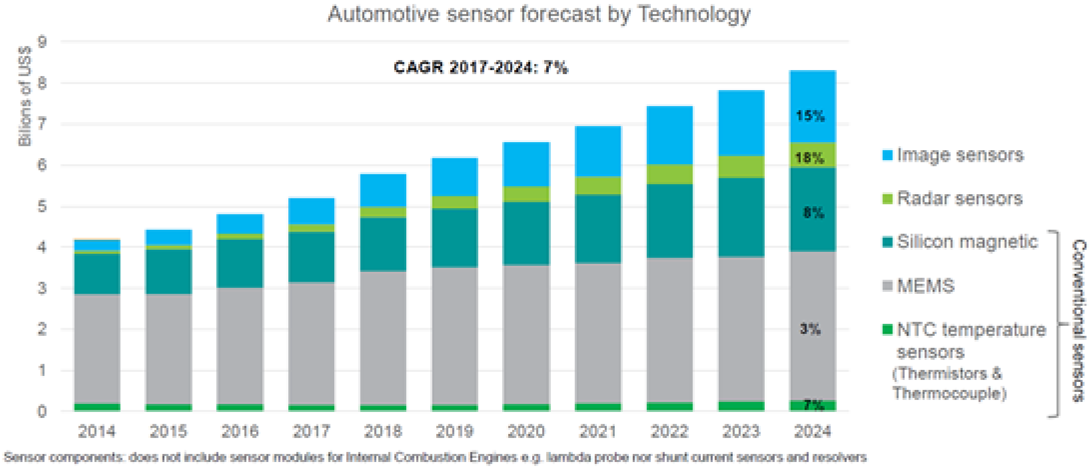

Figure 5: The projected market CAGR increase will be 7% from 2014 to 2024 (Source: IHS Markit: MSEC 2018 - Autonomous and Electric Cars: What's in for Conventional MEMS and Sensors).

One of the major drivers in the demand is the needs for redundancy to minimize sensors malfunction induced-accidents. The sensors will enable the communication between cars, and cars to infrastructure. To ensure safety, it also provides the capability to sense objects and pedestrians.

Figure 6: Sensors enabling autonomy within a vehicle

(source: https://www.engadget.com/2017/06/03/here-collection-vehicle-v3-hd-mapping-computex/)

Three main types of sensors are driving the advancement on the autonomous driving:

1. Imaging Radar
    - Imaging radars operating at 77/79 GHz allows for object recognition that 24GHz radar is not capable of providing
    - Enable object tangential velocity on its path to avoid collisions
2. 1500nm LiDAR
    - Long wavelength improves long range object sensitivity up to 200m away that's not capable with 900nm wavelength LiDAR
3. Inertia measurements
    - New inertia measurements unit provide dead reckoning measurement that's critical in emergency situation where radar, LiDAR and GPS might not work, providing additional safety backup

Current sensor market is very concentrated with major players around the globe:

- Continental AG (Germany)
- Tele Tracking Technologies Inc. (U.S.)
- Delphi Automotive (U.K.)
- Denso (Japan)
- NXP Semiconductors (Netherlands)
- Robert Bosch Gmbh (Germany)
- Valeo (France)
- Asahi Kasei (Japan)

This market will be a very challenging sector to participate even though the market size is significant, the demand for price reduction will be imminent, therefore, lowering the profitability.

Having advanced sensors is the foundation for the autonomous driving, however, recent research still shows 84% of the drivers want the option to take over even in complete self-driving vehicle, and just 16% are comfortable to use full autonomous system for a journey. (https://internetofbusiness.com/public-concerns-autonomous-ford-safety-report/). One of the significant concerns for consumers over autonomous driving is safety and reliability. Significant efforts have been placed on this front by numerous companies. Among all, Waymo has logged the most miles at 1.3M.

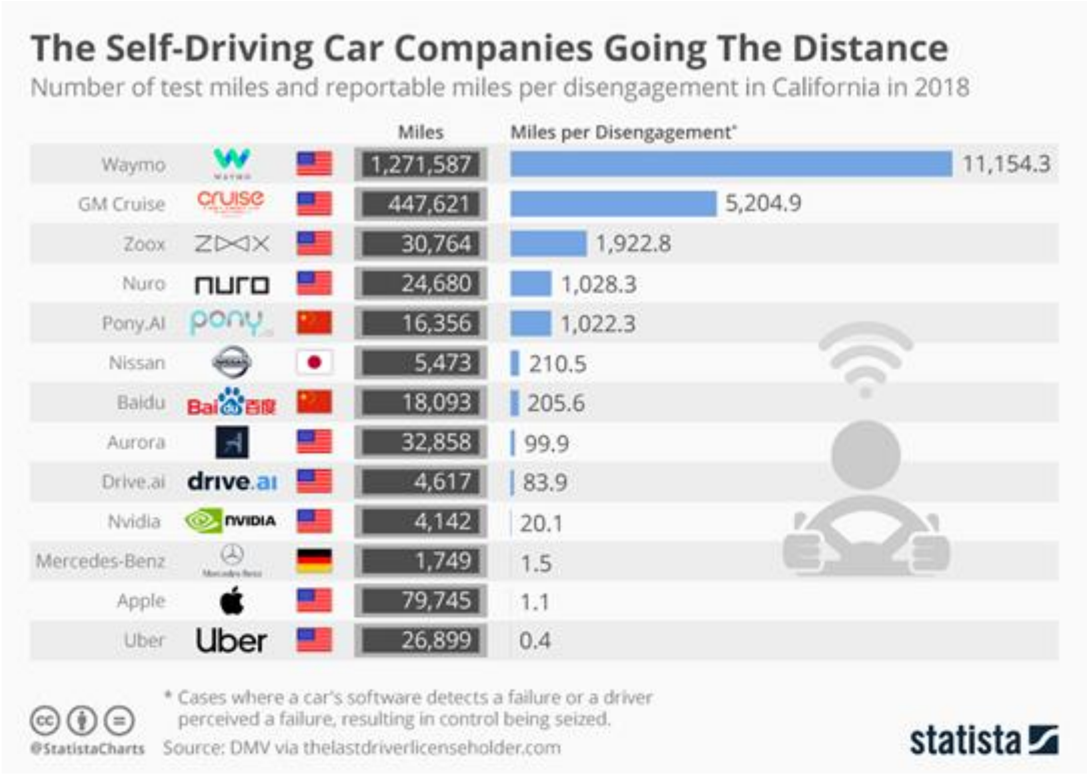

Figure 7: Self-driving car test miles in California in 2018

(source: https://www.ecnmag.com/article/2019/02/paving-way-verify-and-validate-design-first-generation-automated-driving-vehicles)

To reference to the standard with aircraft, the expectation is 1 billion hours of testing between catastrophes. Also, the numbers of scenarios to validate explode to over 14 billion miles of testing.

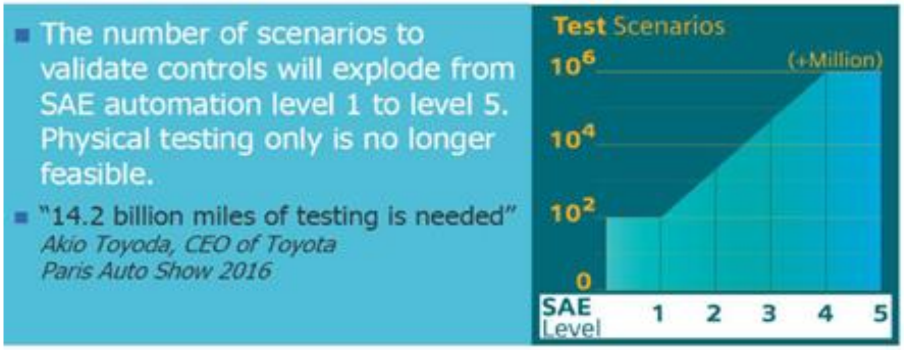

Figure 8: Test scenarios for validation

As seen from the chart, it is obvious that the current validation system is not feasible to support such rigorous demand. This presents a unique opportunity to use simulation as ways for validating all components working under all conditions. The global simulator market is expected to reach 2.4B USD by 2025, from 1.7B USD in 2019, at a CAGR of 6.32%

Figure 9: Simulation market

(source: https://www.marketsandmarkets.com/Market-Reports/driving-simulator-market-171814690.html?gclid=CjwKCAjwzPXlBRAjEiwAj_XTEcSRtPODHUDzj97sUD5QBzNX4fwww_khRJYCRs63QX548cDm86ywxhoCl4QQAvD_BwE)

Partnership formations allow integration of hardware and SW knowhows of different companies to reduce validation cycle times. Numerous partnerships have formed.

- Waymo: Carcraft – Daily simulations for autonomous miles.
- NVIDIA/AIMotive – Simulations.
- Cognata/Metamoto – Sensor Integration.
- Hardware-centric Integration and Simulation.

5. Data Security

The addition of numerous, and interconnected, sensors and CPUs expose a vehicle to a significant risk of data corruption, and/or data theft. A V2i vehicle, by definition, must be connected to the outside world, often with multiple access points. Each of these points is an opportunity for data attack.

Simply put, increased interconnectivity, increases the opportunity for attack.

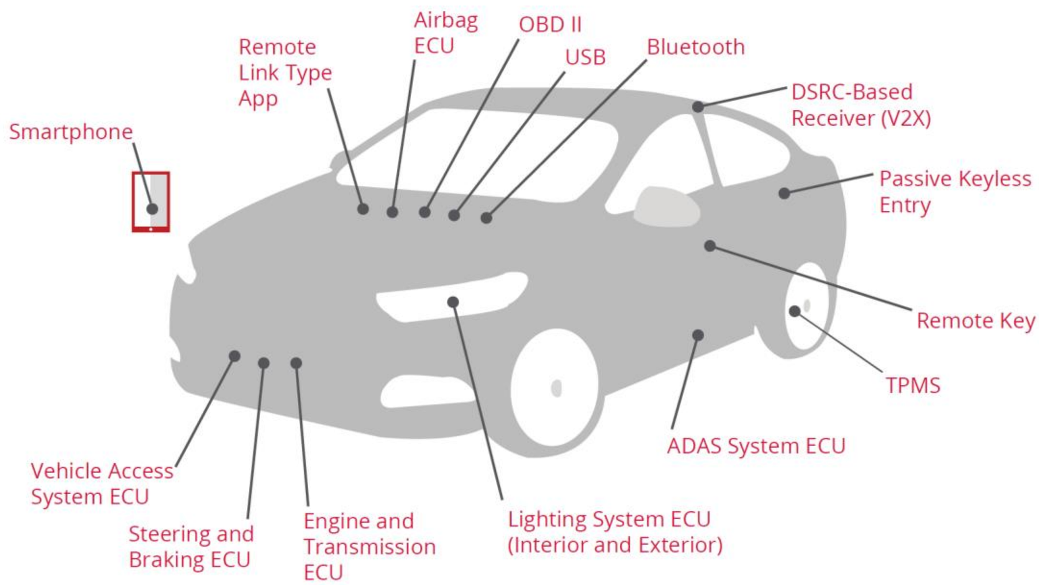

Figure 10: Fifteen of the most exposed attack surfaces on a next generation vehicle

Next generation vehicles, and interconnected infrastructure, must be hardened against these threats. As the threats are distributed across multiple systems, the security solutions require a distributed architecture. Hardware (CPU and sensors) and software systems will require development to prevent tampering. These solutions will take advantage of cryptographic techniques, encryption keys, and other digital security protections.

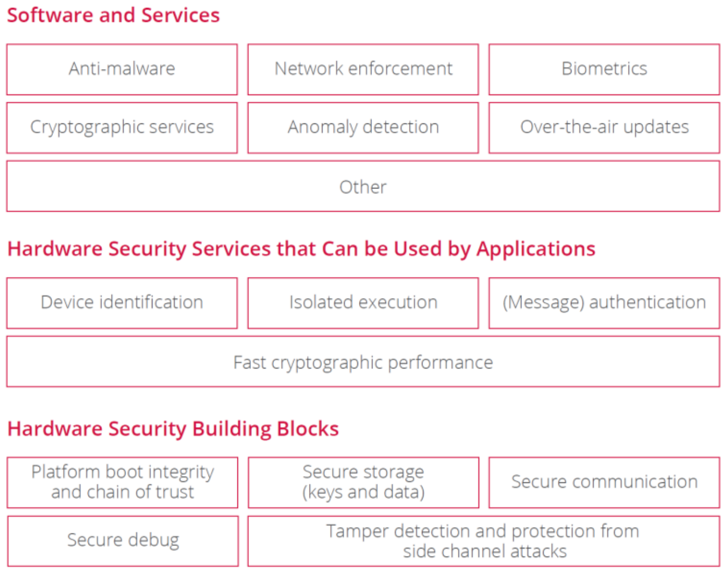

Figure 11: Areas opening to security business development

A future vehicle may have a “Check Security” light located right next to today’s “Check Engine” light.

6. Automated Highway Systems (AHS)

The progression and advance in sensors, mobility and connectivity, and computing naturally led to the advent of autonomous vehicles (AVs) that will within a decade become a daily reality in our evolution. Similarly, the eventual proliferation of autonomous vehicles will give rise to a future with automated highway systems (AHS) and smart roads. Roads and highways will adapt to the evolving technology to reduce traffic congestion, better safety performance, decrease in pollutant emissions, and enhance scalability to keep pace with population growth.

Traffic volume can increase more than 50% each decade, and the highway system capacity cannot keep up with the demand. Compounding the issue is urban peak-hour traffic congestion that worsens exponentially. Research has shown that building more lanes is not viable because of limited rights-of-way, cost, citizens' concerns about the impact on the quality of life in their communities, and environmental requirements. AHS is a solution to increase traffic flow capacity.

AVs operate just like drivers, moving on the road as individual elements, sensing and responding to the external environment and conditions. They are uncoordinated. An AHS networks, links, coordinates, and regulates the AVs just like the internet routing and managing data transmissions. **Error! Reference source not found.** shows a block diagram of a concept for an AHS hierarchy; the system is divided into two parts: 1) the onboard, vehicle system, and 2) roadside system.

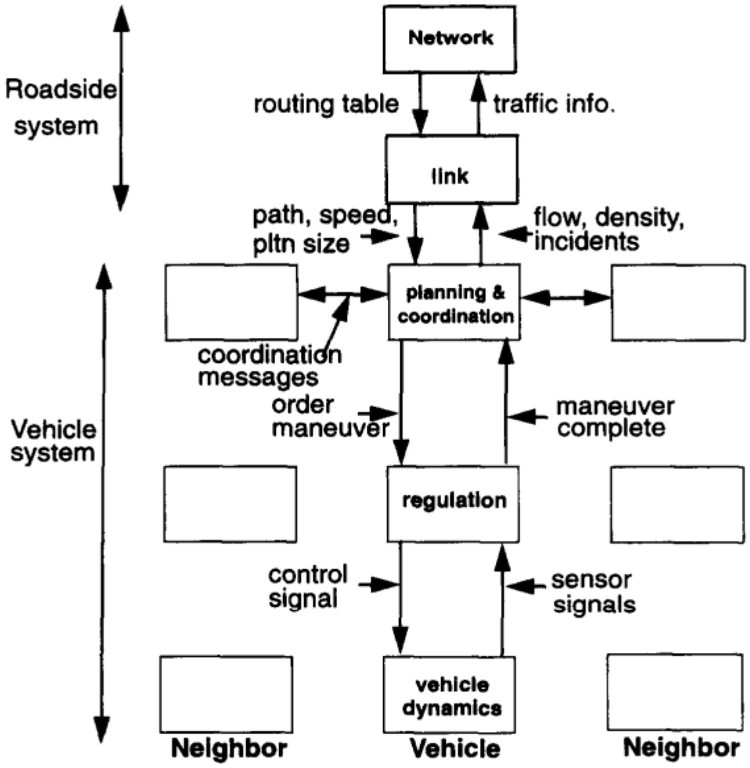

Figure 12: AHS control hierarchy

(source: "An Automated Highway System Link Layer Controller for Traffic Flow Stabilization," Perry Y. Li, Roberto Horowitz, Luis Alvarez, Jonathan Frankel, and Anne M. Robertson, University of California, Berkeley, 1997)

The concept of an AHS has the promise of delivering stop-free traffic flow and vehicle platooning (the stacking of vehicles into closely spaced groups) that allows the road to accommodate more cars and to significantly increase traffic density. Just like big data created our current "Data Economy," transportation changes with autonomous vehicles and Automated Highway Systems will engender a new roadway, infrastructure economy that certainly will further expand the Data Economy.

While concepts of AHS have existed for decades, the standards have yet to be defined. Whoever is first to develop and define the standard will capture a predictability enormous market in many trillions of USD. New concepts of traffic systems will emerge. While still in a distant future, AHS and its necessary ecosystem offer Investment opportunities that warrant forward-looking considerations.

7. Rider Experience and Engagement

The mid-1900s were characterized by a massive boom in consumer culture, with automobiles being one of the main developments that expanded people's access to leisure activities. Nearly a century later, the role of vehicles is once more being redefined, as plans to merge interactive screens with autonomous driving are becoming an escalating reality. Screens dominate nearly every aspect of daily life - work, social interactions, the news - except for the time people spend in cars commuting to and from work, travel, or school.

In this exception, autonomous vehicles bring a massive untapped $200 billion market potential of in-car entertainment. The profitable promise of in-car entertainment has catalyzed the race between tech and automobile giants alike to incorporate these recreational applications in autonomous vehicles. The finish line for the first wave of in-car entertainment being incorporated in cars is set between 2020 and 2021, with companies like Intel and Warner Brothers, Renault, Audi and Walt Disney, and Honda announcing their partnerships and concept models as early as 2016, and especially during the 2019 Consumer Electronics Show.

Today and especially in most congested cities, people spend a lot of time driving. Recent surveys indicate the average American spends more than 300 hours per year behind the wheel. A transporting consulting firm, INRIX, in another study found that in the U.S. alone, traffic jams cost Americans $305 billion in 2017.

Figure 13: A Congested highway

Also, according to another survey of 130,000 car owners across nine countries, most people expressed they would use their time more productively if they didn't have to actively drive and only one third of people expressed they would still pay attention to the road.

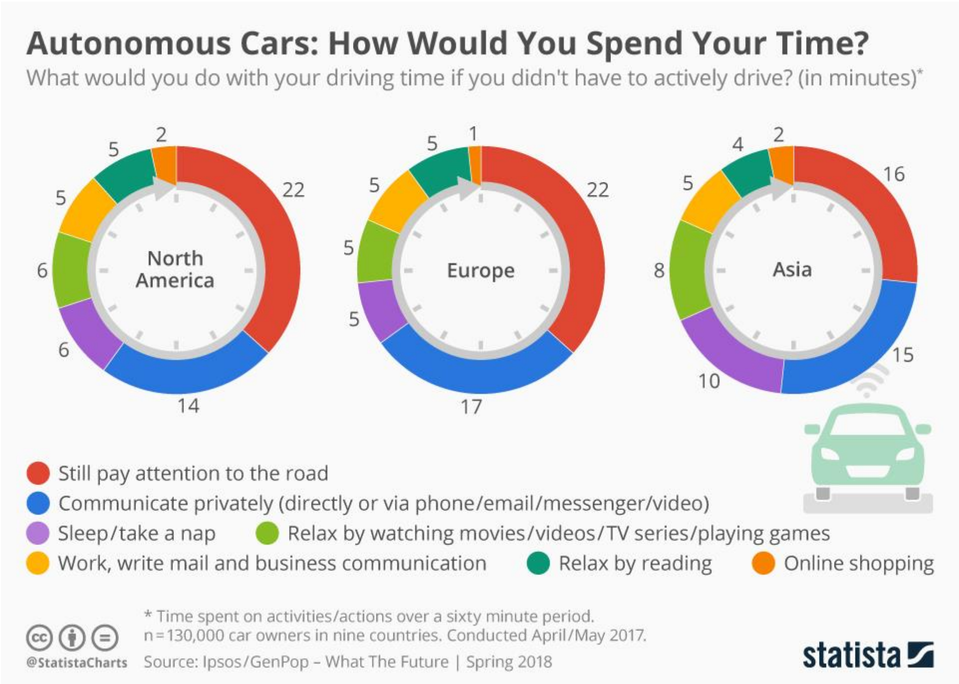

Figure 14: Estimated time spent on in-car activities

Even today without autonomous vehicle, many drivers do some non-driving activities while driving. A 2015 survey conducted by AT&T with the responses from 2,000 people, showed 7-in-10 people engage in smartphone activities while driving including social media (40%), web browsing (30%) and even video chatting (10%).

Figure 15: Guilt-free texting while driving

Intel predicts that AV could free up more than 250 million hours of commuting time per year in the world's most congested cities. Considering the fact that by 2020, it is projected that almost 98% new cars will be connected to the internet and with passengers buckled in place, AV serves as an ideal platform for entertainment providers and advertisers to capitalize on and turning the commute time into a productive time.

Figure 16: Virtual reality entertainment in-car will become a reality

Audi, Disney, and Marvel have partnered with Holoride to develop in-vehicle games and streaming. Holoride makes VR content based on the car's data/movement. The goal is to use this technology in ride sharing vehicles like Uber as well.

Figure 17: Interactive windshield

Hyundai's virtual touch screen is expected to act as an interactive windshield, a popular concept, expected to be seen in BMW's iNEXT autonomous vehicles as well.

As early as 2016, Volvo, Netflix, and Ericsson unveiled their partnership to curate in-vehicle media as cars grew increasingly autonomous, and their project, coined "Concept 26", is expected to manifest itself as an interactive screen within the dashboard.

In-car technology is not limited to only entertainment, however. This technology can be used for informative purposes as well, such as online courses or conducting business meetings on the go. BIS Automotive predicted that the global in-vehicle entertainment market will reach $52.2 billion by 2022.

Associated with these significant developments are also requirements for greater bandwidth and an adequate means of buffering content for a smooth streaming experience. In areas of high traffic, this is especially important, however, autonomous cars can use their technology to evaluate the conditions of a particular area and pre-load the content and play it back later, if needed. These requirements can account for even more job opportunities in the field of artificial intelligence in and of themselves, ultimately resulting in a win-win scenario.

For the $190 billion U.S. advertising industry, the car company or the ride-sharing companies (like Uber) could own the data and they can get into the advertising business because of their map data. For instance, considering the proximity of the vehicle to stores and restaurants gives advertisers a vital edge in customizing their services and catering to an incredibly specific audience. With AV accounting for their end destination, a driver on a long-haul road trip could, for example, be targeted with ads for nearby restaurants around lunch-time, and hotels to stay at in the evening using C-V2X technology.

8. Conclusion

In this work we have identified and presented domains that constitute the AV ecosystem, which will see radical developments over the next decade in terms of growth and investments. These potential domains and their expected market projections are shown in Fig. 18 below.

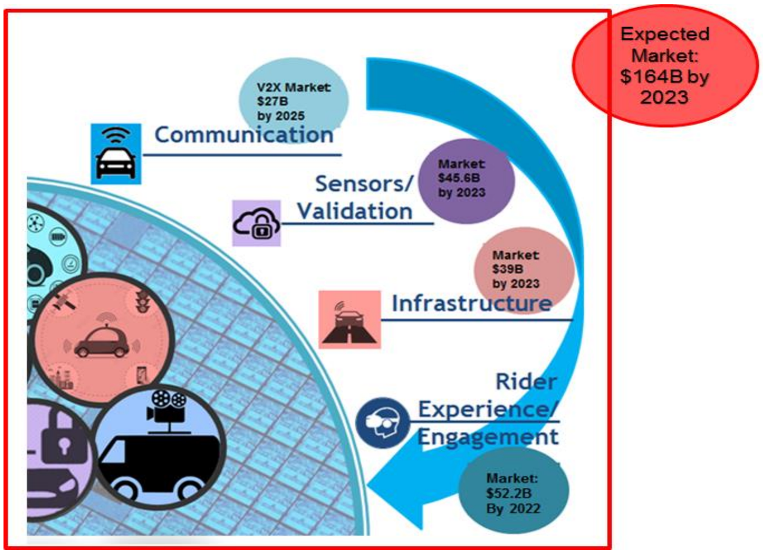

Figure 18: Domains expected to witness significant growth opportunities for AV ecosystem. These domains incorporate safety aspects and timely deployment of AVs.

Based on our analyses, the domains presented in this work will be responsible for about 10% of the expected AV market share by 2023 and these domains have significant investment scope as they are not dictated by automakers. The anticipated event-based triggers for our envisioned AV landscape are shown in Fig. 19.

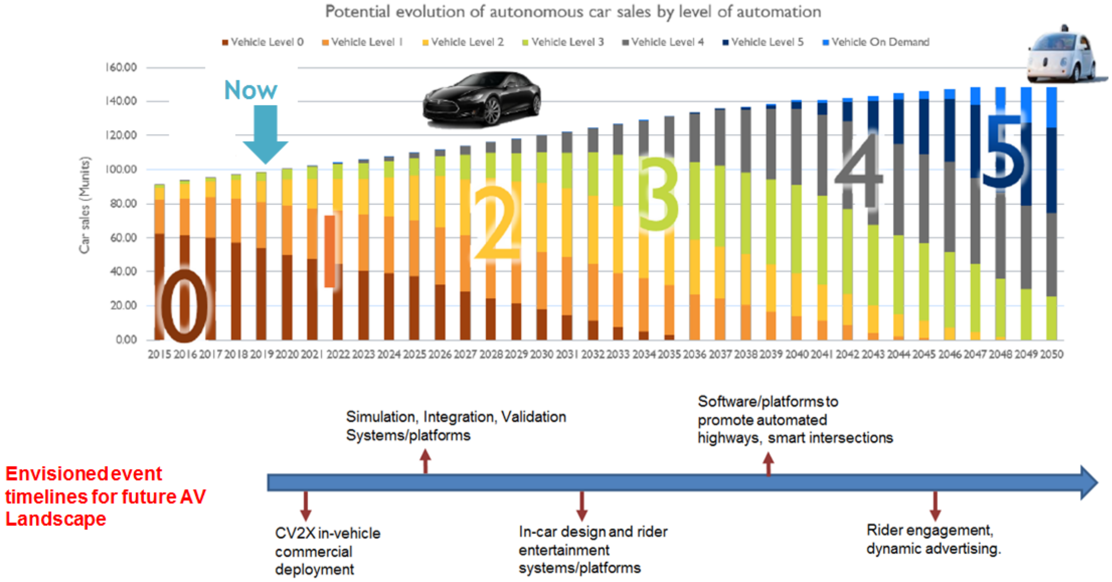

Figure 19: Anticipated event-timelines for AV ecosystem.

Our recommendations ordered by increasing investment scope are as follows:

1. All upcoming technology must adhere to the C-V2X standards.
2. Scope in hardware-centric simulation/validation platforms and sensor and data security platforms.
3. Large Scope for smart highways and automated intersections. Global vehicle flow estimation and real time path planning systems and platforms can significantly enable Level 4+ autonomy.
4. Large Scope in the domain of rider experience and engagement. In-car design, virtual conferencing, movies, dynamic advertisements and gaming (AR/VR) can significantly transform the riding experience.

   The domains presented in this work aim to assess the engagement criteria with AVs and they will be extremely relevant for level 3 to 4 transformations. Our depiction of the AV landscape is geared towards enhanced safety and trust between the AVs and its environment as we continue to rise in our smart vehicles on smart automated roads into the future.

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