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Assessing the Status of Autonomous Vehicles Innovation Using Patent Data

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By

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Abstract:

The transportation industry is undergoing an unprecedented revolution as researchers in the field expect the adoption of autonomous vehicles (AV) in a not-too-distant future. Even though there is no fully automated vehicle on the road currently, several features of driver's assistance (e.g., lane departure warning, rear cameras, blind-spot warning) are integrated into most of the recent vehicles. It is therefore fundamental for industry leaders and policymakers to comprehend the state-of-the-art of AV innovation. The main purpose of this study is to assess the current status of AV innovations in the U.S. market. My analysis, based on more than 2,000 patents retrieved from the United States Patent and Trademark Office's (USPTO) PatentsView database, has five main findings.

First, there is a significant increase in autonomous vehicle patents approved by USPTO since 2010. Between 2010 to 2018, the number of patents increased by about 18 folds from 27 to 516. Secondly, in terms of AV innovators, the new entrant high-tech companies are taking over the incumbent automakers in the AV technologies. Third, industries involved in AV innovation have unequal levels of development in different technology sectors and fields. High-tech companies are leading in smart environment technologies. The incumbent automakers had an established predominance in the vehicle platform technologies. Fourth, of all the patents approved by the USPTO, about two-thirds are held by US companies, and one third held by foreign companies primarily from Asia and Europe.

Fifth, in the US, California is the epicenter of AV innovation with nearly 40 percent of US patents. Michigan holds 18 percent of the total, given the presence of traditional automobile manufacturers including Ford and GM

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1 Introduction:

The transportation industry is undergoing an unprecedented revolution as researchers in the field expect the adoption of autonomous vehicles (AV) in a not-too-distant future. AV is defined as any vehicle that can autonomously perform part or all the functions of the driver (Ménière et al., 2018) Accordingly, based on the portion of the driving actions independently performed by the vehicle itself, the Society of Automotive Engineers (SAE) – an international organization in charge of setting standards –defined six levels of automation. The autonomy ranges from no automation, where the human driver performs all driving-related tasks (level 0) to full automation, as the system takes entire control of the vehicle for any driving activity normally carried out by a human driver (level 6). The levels and their related functions are described in table 1 below.

Table 1:Levels of Vehicle Automation

SAE Automation Category	**Vehicle Function**
Level 0	The human driver does everything.
Level 1	An automated system in the vehicle can sometimes assist the human driver conduct some parts of driving.
Level 2	An automated system can conduct some parts of driving, while the human driver continues to monitor the driving environment and performs most of the driving.
Level 3	An automated system can conduct some of the driving and monitor the driving environment in some instances, but the human driver must be ready to take back control if necessary.
Level 4	An automated system conducts the driving and monitors the driving environment, without human interference, but this level operates only in certain environments and conditions.
Level 5	The automated system performs all driving tasks, under all conditions that a human driver could.

Source: DOT and NHTSA, Federal Automated Vehicles Policy, September 2016.

Moreover, as the AV technology evolves rapidly and the industry is anticipating a massive production of AVs, the SAE has adopted and issued a new version of its classification displayed in the attached annex A1 (*SAE J3016 automated-driving graphic*, 2020). Even though, there are no fully automated vehicles (i.e., level 5) on the road currently, several features of driver's assistance (e.g., such as lane departure warning, rear cameras, blind-spot warning) are integrated into most of the recent vehicles. With the rapid advancement of technology, they are predicted to be on the market pretty soon.

As AV's are expected to bring in considerable societal transformation on both economic and social aspects. Hence, proponents of AV technologies including the US government see in the adoption of AV's opportunities to increase citizens' mobility and quality of life; improve safety, minimize road accidents and the associated costs; decrease energy consumption and environmental pollution; enhance productivity and economic prosperity (Kratsios, 2020).

Particularly, the National Highway Traffic Safety Administration (NHTSA) has emphasized on four major dimensions in which AV's will benefit society: safety, economic and societal benefits, efficiency and convenience, and mobility (Lynberg, 2017).

First, the promoters allege that AV will increase mobility and provide more diversified transportation options to the many excluded individuals, including children and the elderly, the disabled individuals, the urban residents and people who do not or cannot own a car (Anderson et al., 2014; Fagnant & Kockelman, 2015). In the US, having driving capabilities still largely determines people's access to work and citizens' abilities to live independently. The commercialization of AV's will help remove those obstacles faced by millions of Americans. According to a recent study, AV's could generate employment opportunities for nearly two million people living with disabilities (Claypool et al., 2017), and create mobility options for the 49 millions of senior Americans of more than 65 years and 53 million with disability (M. Lynberg, 2017).

Secondly, AVs are expected to significantly bring down road fatalities; hence, save lives and reduce injuries. According to a DOT report, more than 94% of 2016 US car accidents, having killed more than 36,560 people, were due to human errors (Canis, 2020). AVs will be capable to not only reduce those errors but more importantly learn from the errors database to avoid reoccurrence of the same mistakes as humans do. Accidents reduction will save lives, lower injuries, and related-medical expenditures. According to an NHTSA report, car accidents in 2010 cost the economic activity $242 billion, and $594 billion as regard to deaths and injuries of people involved in those accidents (M. Lynberg, 2017). Fewer accidents will help lighten the weights of cars as heavier vehicles are meant to protect car users during fatalities. As a consequence, that will lead to more climate-friendly vehicles (Anderson et al., 2014; Fagnant & Kockelman, 2015; Zehtabchi, 2019).

Thirdly, AVs will contribute to reducing road congestion with a series of positive consequences such as reducing fuel consumption and increasing drivers' productivity as they will spend less time driving or perform other tasks while commuting (Anderson et al., 2014). Furthermore, Americans are considered being great commuters. It is estimated that Americans lost 6.9 billion hours in traffic delays in 2014 (M. Lynberg, 2017). The adoption of AV's will allow road users to benefit from those hours to increase their productivity, spend more time with their families or in leisure activities for better wellness.

For all those potential benefits, the US government shows particular interest in leading the development of AV technologies as it expects considerable to the American society and economy (Kratsios, 2020). In his report, the Chief Technical Officer of the United States, Kratsios declared that "The US government is committed to fostering surface transportation innovations to ensure the United States leads the world in automated vehicle (AV) technology development and integration while prioritizing safety, security, and privacy and safeguarding the freedoms enjoyed by Americans". He claims in the same report ((Kratsios, 2020)) that the US government foresees three prominent areas of interest that they intend to fulfill: (1) protect users and communities through giving preeminence to users' safety, strengthening cybersecurity, protecting data security and privacy, and improving mobility. (2) Promote Efficient Markets by remaining neutral, secure innovation and creativity of the US citizens, and updating and improving the regulatory environment (3) Facilitate Coordinated Efforts consisting of promoting harmonized standards and policies, providing a harmonized federal perspective, and enhancing the transportation infrastructure.

However, despite those claims, in a 2019 report on AV readiness index produced by KMPG, the US ranked fourth among the 25 most advanced countries towards AV adoption (Threlfall, 2019). That report evaluates four main factors which include technology and innovation, policy and legislation, infrastructure, and consumer acceptance as shown in table 2.

Overall rank	Country	Technology and Innovation	Policy and Legislation	Infrastructure	Consumer Acceptance
1.	The Netherlands	10	5	1	2
2.	Singapore	15	1	2	1
3.	Norway	2	7	7	3
4.	United States	3	9	8	6
5.	Sweden	6	10	6	4

Source: (Threlfall, 2019) *Autonomous Vehicles Readiness Index, KPMG, 2019.*

Table 2: Autonomous Vehicles Readiness Index.

The report indicated that the US is third in technology and innovation, sixth in consumer acceptance, eighth in infrastructure readiness, and ninth in terms of policy and regulation (Threlfall, 2019). If the US can still claim a relatively comfortable place on the technological innovation factor, it still has long to go in terms of policy and regulations. Since 2016, three reports have been produced by the US DOT and NHTSA to nourish debates on AV federal policies and regulations, and best practices that should be taken into account by states for driver regulation and a series of guidelines for automakers (Canis, 2020).

However, no federal law has been enacted to date that would significantly accelerate the adoption of autonomous vehicles. The lawmakers are confronted with several challenges among others: the new responsibility matrix between the federal and state government as opposed to the existing matrix, the number of AVs that to be allowed to test on Highways by NHTSA, the level of details of the legislation on cybersecurity, and the scope and requirements of personal data privacy (Canis, 2020). However, as with any other emerging technologies, there are potential concerns for the public associated with AV’s that will require considerable attention from policymakers and industry leaders. For instance, one of the challenges relates to the threats of cybersecurity as driving tasks and decisions will be performed by computing systems that can be hacked by malicious individuals. Additionally, as the opportunity cost of driving decreases, AVs might lead to more incentives to travel increasing the total vehicle miles traveled (VMT). Also, new features such as beds, kitchen, and workspaces might be integrated into vehicles. Subsequently, the greenhouse gas reduction promoted by the proponents might be set off by more pollutant activities associated with AV's new models.

Despite all the above-mentioned potential impacts, the AV innovation is on a continuous trajectory. Researchers in the field expect fully AV to be commercialized in the next five years (Kratsios, 2020; Ménière et al., 2018).

For all the above-mentioned reasons, the invention accelerates in the field and the race to lead the AV commercialization is highly competitive among the traditional incumbent automakers and their newly emerging competitors from the high-tech industry Hence, understanding the current status of the AV inventions is primordial for all the stakeholders.

This study is intended to provide an assessment of the state-of-the-art of AV- inventions in the U.S. market by drawing on the patent data retrieved from the United States Patents and Trademark Office (USPTO). For clarity purposes, this analysis is exploratory using data to describe patterns and draw conclusions. The main research question is “what is the status of-the-art of AV innovation in the United States? Specifically, it answers a series of questions that will include but not be limited to: what is the trend of AV patents approved by USPTO between 2000 and 2018? What are the leading companies and technologies in the AV patent industry? What roles do educational institutions play in AV patenting? And what is the geographical distribution of patent owners? I perform the analysis using a sample of more than 2,000 AV patents by using data query tools (*PatentsView Query*, 2020) covering the period of 2000 through 2018.

The remainder of this paper is organized as follows. In the next section, I review the relevant literature on AV innovations and research related to using patents data as a measurement of innovation. Second, I will explain the methods used for data collection. The third section will provide results and discussions The fourth section will conclude the study and provide recommendations for further use by researchers, policymakers, and industry leaders

2 Literature review:

In this section, I discuss the search strategy and selection criteria that guided the literature review. Then, I discuss the commonly used techniques by scholars to measure innovative performance with a particular focus on the patent count analysis technique used in this study.

2.1 Search strategy and selection criteria:

The literature review search was primarily conducted using RIT Summon, ProQuest, Google Scholar engines, and the Web of Science. The search was done with a combination of keywords "patent analysis," "autonomous vehicle," "self-driving". A preliminary elimination led me to keep the most recent scholarly reviewed articles starting from the year 2000 for further analysis as those papers were built on previous literature. A final in-depth analysis of the methods used, technological sectors covered, and scope of the analysis led to keep only eight papers that mainly covered patent analysis as a technique of measurement of the innovative performance related to new technologies and AV technology in particular. The matrix below summarizes the key components of those papers

	Name of the article	Author (s)	Methods	Data Source	Sectors covered
1.	Measuring Innovation in the Autonomous Vehicle Technology	Maryam Zehtabchi	Cooperative Patent Classification (CPC). - CPC only. - CPC codes combined with keywords	Espacenet and USPTO	Terrestrial AV
2.	Patents and Self_driving_vehicles EPO_study	Yann Ménière, Ilja Rudyk, Lucas Tsitsilonis	Used patent applications filed with the EPO or international (PCT) applications that entered into the European phase) in the period **1990-2017**.	EPO's most recent patent data (including as yet unpublished patent applications) and advanced technology expertise in the field to identify SDV inventions.	Covered only level 4 (Highly automated) and level 5 (Fully automated of Society of Automoti Engineers (SAE)
3.	Patterns of knowledge development and diffusion in the global autonomous vehicle technological innovation system: a patent-based analysis	Donghui Meng, Xianjun Li*, Yongfeng Cai and Jiaxin Shi	Evolutionary analysis of Patent citations A comprehensive and dynamic picture is depicted through our evolutionary analysis covering 5,986 AV patents applied for from 1997 to 2016 worldwide from the Derwent Innovation database as our data source.	5,986 AV patents applied for from 1997 to 2016 worldwide from the Derwent Innovation database as a data source.	7 relevant sectors (automotive, machinery, aircraft/defense, electronics, information/software service, mobility/logistics service, research). - Focused on five key technology categories (control and actuation, perception and localization, computation, communication, and system integration).
4.	Autonomous vehicle Technology development: A patent survey based on main path analysis	Rico L.T. Cho, John S. Liu, Mei Hsiu-Ching Ho	Patent citations analysis of 7,810 patents obtained from a combination of a series of keywords.	7,810 patents from the Derwent Innovation database as a data source. From 1980 to May 2018	7,810 patents citations
5.	Patent Statistics As an Innovation Indicator - Evidence From The Hard Disk Drive Industry	Mitsuru Igami and Jai Subrahmanyam	Empirical method - They investigated the statistical relationship between patent statistics and actual innovations in the market, exploiting the empirical context of the HDD industry	Disk/Trend Report on 178 firms between 1976 and 1998	Hard Disk Drive (HDD) Industry
6.	Patent rights and innovative activity: evidence from national and firm-level data	Brent B Allred and Walter G Park	Empirical Method: 1. Update information about world patent regimes. 2. Examined diverse aspects of innovative activities: R&D, domestic patenting, and foreign patenting. 3. Assed the differential impacts of patent reform on Northern vs Southern economies. 4. Analyzed the 'nonlinear' effects of patent reform.	WIPO for patents data DataStream for R&D data	1965 to 2000 for patents data 1995 to 2000 for R&D data With a sample of 2,446 companies from 35 countries.
7.	Measuring innovative performance: is there an advantage in using multiple indicators?	John Hagedoorn, Myriam Cloodt	1. Studied the innovative performance nearly 1,200 companies in four high-tech industries, 2. Used indicators: R&D inputs, patent counts, patent citations, new product announcements.	1. Amadeus, Compustat, the Fortune 500 list, and Worldscope for R&D data 2. USPTO for patents and patents citations 3. RDS Business & Industry databank owned by the Gale Group for new product announcements	Four high-tech industries: 1. Aerospace and defense 2. Computer and office machinery 3. Pharmaceuticals 4. Electronics and communication
8.	A literature review on the state-of-the-art in patent analysis	Assad Abbas, Limin Zhang, Samee U. Khan	Literature review of patent analysis	ScienceDirect, ACM digital library, IEEE digital library, and CiteSeerX.	

Table 3: Matrix of reviewed papers

2.2 Innovation measurement techniques:

It is fundamental to make a distinction between invention and innovation. While the former is defined as the development of a new idea for a new product or process, the latter refers to the implementation or the commercialization of the former (Ahuja & Lampert, 2001; Schumpeter, 1934). The focus of this study is the initial creation of an idea that fulfilled the conditions of being patented. Hence, by innovation throughout this paper, I am referring to the creation of ideas that are novel, non-obvious, and useful which might not be a perfect measurement of the innovation.

The most commonly used tools to capture the innovative performance include patent citations count, research and development (R&D) expenditures, new product announcements, and survey-based measurement (Hagedoorn & Cloodt, 2003). In fact, Hagedoorn and Cloodt (2003) investigated the advantage of combining multiple indicators to measure the innovative performance of companies. For that purpose, the authors studied nearly 1,200 companies from four different industries – aerospace and defense, computer and office machinery, pharmaceuticals, and electronics and communications - and collected data about R&D inputs, new product announcements, patent counts, and patent citations.

The authors claimed that they found no significant systematic disparity amongst R&D inputs, patent counts, patent citations, and new product announcements. Further, they concluded that any of these indicators including patent counts could be used to ascertain the degree of the innovative performance. Therefore, the patent count analysis will be the focus of this study, and I used patent data statistics as the measurement tool of AV innovation.

2.3 Patent data analysis to measure innovative performance:

A patent is defined as the legal right given to an inventor to exclude others from making, using, selling, offering for sale, or importing their invention in the US for a certain period of time. In compensation of that right, the inventor is required to disclose the information to the public to build on by replicating, modifying, or circumventing (Levin, 2004). Moreover, in order to qualify for the patent, the invention must be novel, non-obvious, and useful (Schoenmakers & Duysters, 2010). Accordingly, the patent system is meant to fulfill two principal roles: promote invention by protecting inventor's rights to benefit from their investment and intellectual efforts, and stimulate knowledge spur through disclosure of the invention to potential users of the information (Levin, 2004; Schoenmakers & Duysters, 2010). Hence, a patent representing a unique invention is considered as a major instrument that contributes to an increase of the knowledge base.

An invention needs to reach the commercialization phase to be an innovation (Levin, 2004). Therefore, it is arguable that patent counts analysis might not be perfect as a measure of innovation, for patents do not necessarily lead to innovation and not all inventions are patented by their inventors. However, researchers have found that patent data analysis is one of the most acceptable measurement techniques of innovation. They even claimed that a thorough analysis of patent data provides insights that cannot be obtained by arbitrary judgments (Igami & Subrahmanyam, 2019).

In fact, one of the most comprehensive studies to measure innovation in the AV industry using patent counts was conducted by Zehtabchi (2019). Her study concerned only highly automated vehicles (level 4) and fully automated vehicles (level 5), and she focused on terrestrial AV technologies and combined Espacenet and USPTO data sets. She found that AV innovations have surged since mid-2000 due to a technological shift in the industry from the traditional automotive-related technologies towards emerging technologies and innovations in Artificial Intelligence (AI), robotics, and mobility services. She further argued that AV innovations developed by both auto and tech companies remain home-based in their respective locations (for example Detroit for automotive companies and Silicon-Valley for high-tech companies). However, there appears to be a slight move in the geography due to prominent role East-Asia has started winning in the field as more Chinese, and Korean companies are becoming active players. She shows that the AV-related patent applications are dominated by companies (accounting for 70% of the total, with the remaining held by individuals). Universities and public entities are owners of only 10% of AV patents.

Researchers at the European Patent Office (Ménière et al., 2018) conducted a similar study on AV innovation using patent data. The authors observed a similar trend in AV patent applications between 2011 and 2017. They also find that AV technology is dominated by both automakers and technology companies. Moreover, they show that both US and EU are leading the path in AV innovation with Germany being the dominant country among the European countries. According to Meniere et al. (2018), AV patent owners seek larger international protection of their inventions by applying beyond their national intellectual property protection agencies.

Other studies used patent data to measure the knowledge spillovers related to AV technology (Igami & Subrahmanyam, 2019; Meng et al., 2019). In their study, Meng et al. (2019) analyzed citations of nearly 6,000 patents in seven sectors - automotive, machinery, aircraft/defense, electronics, information/software service, mobility/logistics service, and research - and focused on five key technology categories - control and actuation, perception and localization, computation, communication, and system integration. They used data collected from the Derwent Innovation database to investigate the impact of AV technological innovation on the development and diffusion of the knowledge base. They used the number of patents and patent citations to measure respectively knowledge development and its diffusion.

The authors found that sectors have different start times, speed of growth, and yearly shares of patents. Thus, the quantity of knowledge development and diffusion is uneven in various technology categories. For instance, they found that the automotive and electronics sectors developed faster at the early stage and remained the two top rankings over time. In the meantime, the machinery sector went through a continuous decline, while the research and defense sectors started in during the years 2002 through 2006 and the mobility service sector emerged only 2015 but showed the highest growth rate between 2012 and 2016. They also argued that sectors and technology categories do not play equal roles in the diffusion of the worldwide knowledge base. Some sectors showed more intra-sector knowledge spillover while others had more tendency to spillover beyond their sectors (inter-sectorial spillover). Finally, they noted that there existed important evolutionary tendencies in knowledge development and diffusion.

In their survey study using patent citations, Cho, Liu, & Ho (2019) explored diverse patent technologies to determine the most prominent technologies in the AV industry. The authors found that the communication system will continue to rise to enhance vehicle-to-everything (V2X) technologies. They further argued that perception-related inventions will further incorporate artificial intelligence, automakers, and technology companies will cooperate to develop AVs.

Igami and Subrahmanyam (2019), in their empirical study on 178 firms in the Hard Disk Drive (HDD) industry questioned the efficacy of patent data as innovation measurement. The authors contended that patent data helps forecast innovation more than arbitrary estimates and the forecast becomes more insightful with finer processing. The study further claimed that patents prediction is conditional on conglomerates and larger firms than it is on startups and smaller firms. And the study concluded that the relationship between patent and innovation is unpredictable in the case of patent reforms. Thus researchers should pay attention when analyzing patent data from different companies over time.

Hagedoorn and Cloodt (2003), studied the innovative performance of a large international sample of approximately 1,200 companies in four high-tech industries to assess the significance of using multiple indicators. The study established that there is no significant systematic disparity amongst R&D inputs, patent counts, patent citations, and new product announcements (Hagedoorn & Cloodt, 2003). The authors further claimed that the innovative performance of the four indicators is highly correlated for the sample globally and individually, except for the aerospace and defense industries outside North America. They also argued that in high-tech sectors, innovative performance can be generally measured by any of the four indicators.

Researchers also investigated the relationship between patent rights enforcement and innovation and diffusion in developed countries compared to developing countries (Allred & Park, 2007). Allred and Park (2007) argued that patent reforms have positive impacts on innovation, as well as a slightly positive impact on diffusion up to a certain level from which level markets have net negative impacts. However, they claim that, in developing countries, innovation does not appear to be positively impacted by patent reforms.

In a survey of the literature, Abbas et al. (2014) discussed the practical utility of patent analysis. The authors asserted that patent analysis takes a significant place in business strategy definition and decision-making processes within organizations. They further contended that new sophisticated tools of patent data extraction, processing, and visualization are even more beneficial. The study claimed that the most accepted techniques to analyze patent data among researchers are text mining and data visualization. While both are meant to provide decision-makers with insights about the state-of-the-art of the technology, the first, they stated, consists of extracting and processing information from structured and unstructured data, and the second is a visual representation of patent information to analyze results.

Besides the above papers that looked into AV innovation, some researchers have been exploring the potential impacts of its adoption. One of the most recent studies in that category was conducted by Kaplan et al. (2019), which performed a basic economic analysis on the adoption of AV's. They asked the question "What are the major economic implications of the adoption of AVs?" First, they argued that though the cost of AV acquisition may be high at the beginning, the private acquisition will dominate over time. They also claimed that the personal miles traveled, vehicles miles traveled, and vehicle miles traveled per capita will rise. Further, they supported that AVs will expand the automobile sector, enhance product differentiation, resulting in and gain from infrastructure improvement, develop domestic tourism, and create new alternatives for rural transportation. However, they believed that AVs adoption may face concerns and result in unintended consequences. Hence, they claimed that AVs adoption may be delayed by accidents, fatalities, political, and risk concerns, although economic aspects may be favorable for a swifter adoption.

Moreover, they claimed that the adoption and its regulatory framework will differ based on demography, infrastructure, and geography. To them, more affluent individuals in developed regions will first adopt privately-owned AVs before low-income regions with less developed infrastructure. Finally, they hypothesized that the effects of AVs on greenhouse gas are uncertain to quantify as it will be determined over time by the combined effects of several competing factors. Those factors will include the Vehicle Miles Travelled, expected to increase; the energy use of vehicle, that will be affected by vehicle weight and the new functionalities of the AV's. While the former is predicted to be more efficient as technologies improve and vehicles become lighter in weight, the latter is expected to increase energy consumption.

This study adds to the field of literature by using a unique scope (autonomous vehicle), the data source, (USPTO), the methodology (patents analysis), and the covered period (2000 to 2018). Consequently, it sets a precedent for AV patent data analysis from USPTO patent data. It answers questions that will provide industry leaders and policymakers specific insights on the near-future of the autonomous vehicles key players and technological areas to pay attention to in the United States.

3 Methodology:

The data of this study were collected from USPTO's PatentsView database using data query tools. In this section, I will describe the approach for data gathering and cleaning to obtain my final sample of AV patents.

The US Patent and Trademark Office (USPTO) is the federal agency in charge of receiving, analyzing and approving patents, and registering trademarks in the US. Created since 1802, the USPTO is responsible to provide counsel to the president of the US, the secretary of commerce, and US government agencies on intellectual property (IP), policy, protection, and enforcement.

3.1 Data collection:

AV innovation and technological development depend on numerous inventions of technologies applicable to different industries (Zehtabchi, 2019). Therefore, identifying AV patents is a complex task. No single words are agreed upon by inventors and scientists to identify them, nor exclusive Cooperative Patent Classification (CPC) codes could be used to precisely collect all needed data. Consequently, to gather the initial data for this study, I first conducted searches using the keywords "autonomous vehicle" and "self driving" in the database of PatentsView. More specifically, I downloaded the patent data for 16 variables related to different aspects of the patent, assignees, inventors, and cooperative patent classification. Table 3 provides details of the downloaded variables.

Table 4: Variables used for the study

Variables	Definition	Example
assignee_country	Country of origin of the patent assignee	US
assignee_organization	organization name if the assignee is an organization	Google Inc. & Waymo Llc
assignee_state	State of the assignee	CA
assignee_type	classification of the assignee (1 - Unassigned, 2 - US Company or Corporation, 3 - Foreign Company or Corporation, 4 - US Individual, 5 - Foreign Individual, 6 - US Federal Government, 7 - Foreign Government, 8 - US County Government, 9 - US State Government. Note: A "1" appearing before any of these codes signifies part interest	2
inventor_country	Country of origin of the patent inventor	JP
inventor_state	State of the inventor	NY
patent_number	Patent unique number	3930271
patent_year	Patent publication year	2018
patent_abstract	abstract text of the patent	A golf glove is disclosed h…
patent_title	title of patent	Golf glove
cpc_category	CPC category (primary or additional)	primary

cpc_group_id	CPC group id: https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html	A63B
cpc_group_title	description of CPC group	SOIL WORKING IN AGRICULTURE OR FORESTRY;
cpc_section_id	cpc section (A = Human Necessitites, B = Performing Operations; Transporting, C = Chemistry; Metallurgy, D = Textiles; Paper, E = Fixed Constructions, F = Mechanical Engineering; Lighting; Heating; Weapons; Blasting Engines or Pumps, G = Physics, H = Electricity, Y = General Tagging of New Technological Developments)	A
cpc_subgroup_id	cpc subgroup id: https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html	A63B71/146
cpc_subsection_id	cpc subsection id: https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html	A63

I first conducted a preliminary data screening and comparison with similar studies and removed all patents that belonged to CPC sections not relevant to AV technologies. Those CPC sections were A (Human Necessities), C (Chemistry and Metallurgy), and D (Textiles and Paper). Also, all patents where the CPC section was marked as **None** were dropped. Therefore, the remaining data consisted of patents with the CPC sections B (Performing Operations and Transporting), E (Fixed Constructions), F (Mechanical Engineering, Lighting, Heating, Weapons, Blasting Engines or Pumps), G (Physics), H (Electricity), Y (General Tagging of New Technological Developments).

For the purpose of this study, I used the approach by the European Patent Office (EPO) to classify AV patents (Meniere et al., 2018). Then, I compared the results with the CPC codes identified by the World Intellectual Property Organization (WIPO) to determine the final sample. It is a sample of more than 2,000 AV-related patents approved by USPTO between 2000 and

2018. It included all patents that matched with the CPC classification and the technologies fields (table A2) done by EPO and complemented by the WIPO study.

3.2 Patents categorization based on the European Patent Office (EPO) study:

To identify the AV-related patents, I build my search strategy based on the EPO paper (Ménière et al., 2018). The EPO study consisted of three logical steps. The first step is creating a map that linked AV technologies identified by technology experts and the ranges of the Cooperative Patent Classification (CPC) determined by patent classification experts. That led to a concordance table between AV technologies and CPC ranges. secondly, they collected AV patent applications from the EPO database through a full-text search which were complemented by other subqueries to include patents related to artificial intelligence, cloud computing, and V2X communication. At that stage they performed multiple iterations to minimize the errors in the data. Thirdly, they mapped all the patents identified with technology fields to obtain cartography of AV technologies.

In their study Ménière, et al. (2018) categorized patents involved in AV innovation into two main technology sectors: The first technology sector is the **Automated Vehicle Platform (AVP)** that comprises automation technologies that are embodied in the vehicle itself. She further subdivided AVP technologies into three different technology fields. (1) Perception, analysis & decision (PAD), consisting of inventions that allow vehicles to make decisions autonomously. (2) *Vehicle handling (VH)* - comprising technologies of the automated parts of the vehicle. And (3) subcategory is *Computing* that encompasses hardware and software inventions.

The second technology sector is the **Smart Environment (SE) that** includes technologies that allow AVs to communicate among themselves and with exterior elements. She also divided SE into two technology fields. (1) *Communication* – including inventions that assure connectivity and corresponding infrastructure and (2) *Smart Logistics* – comprising inventions to handle traffic management, vehicle identification, automated parking, and electricity source interfaces with electricity sources (Ménière et al., 2018). Please refer to table 4 for more details on the classification of technology fields and subfields).

Using on table 4 and based on the cpc_subgroup_id's, I performed a backward coding of every single patent based on the technology sub-field of the patent. Hence, patents were classified in 35 sub-fields that were later aggregated in the five technology fields. Communication (5), smart logistics (3), perception, analysis & decision (11), computing (10), and vehicle handling (6). And finally those five technology fields were grouped into the two technology sectors. Since the patents contain multiple cpc_subgroup_id's, some patents were counted multiple times and belong to different technology sub-fields, fields, and sectors.

3.3 Data comparison with World Intellectual Property Organization (WIPO) Study:

In a different study using patent data from WIPO, Zehtabchi (2019) had used a two-step methodology. First, she identified a limited number of patents that belonged to AV technologies with certainty. Then a second larger group of AV patents was identified through a combination of CPC codes with a series of keywords such as "autonomous", car, lorry, etc. in the patent title or abstract (Zehtabchi, 2019). To make sure no relevant patents were left out for our analysis, I performed a cross-comparison to include any CPC id or range that existed in the WIPO study (Zehtabchi, 2019). We found that there existed only two cpc_group_ids, B60Y and G06T2 in the WIPO study that did not exist in the EPO study.

Hence, I added in the classification program those two cpc_group_id's to make sure no relevant patent was left out of the study. However, despite the addition of those two cpc_subgroud_id's, the size of the sample (the number of unique patents) did not increase. Therefore, we could then affirm that all patents related to those two cpc_group_id's were already taken into account in the sample obtained based on the EPO patent categorization model.

After this step of mapping and categorization with the two studies (EPO and WIPO), I still had some patents in the initial downloaded data that could not be matched. Consequently, I considered those patents as not relevant to our study and deleted them from the sample of the study.

3.4 The same company in different geographic locations:

For the purpose of this study, organizations located in different countries were considered as different entities. For instance, Toyota US and Toyota Japan were counted as two different organizations. Where necessary, complementary information will be provided about those organizations if their total number of patents were aggregated across the world.

4. Results and Discussions:

In this section, I describe the findings from my descriptive analysis of the patent data and associated variables. The analysis will cover patent trends from 2000 to 2008; identify patent applicants (assignee organization), and their company profiles; determine the leading industries, and technologies they innovate in; and the geographical origin of the patent owners.

4.1 A steep increase in autonomous vehicles patents at the USPTO since 2010:

The first step of the analysis consisted of understanding the pace of AV innovation. The variable assessed was patent date indicating the date when the patent was granted by USPTO. Usually, there may exist some lags separating the exact date of the invention by the inventor, the date they submit a patent application to USPTO, and the date when the patent granted to the assignee. Hence, it is worthwhile highlighting that the invention might have occurred several years before the date displayed in this study. The analysis of patent trends over the years shows a significant surge in AV patenting starting from 2010. Before 2010, the number of AV patents progressed at a flat pace ranging around a dozen patents yearly. The number of patents nearly doubled to 27 from 15 between 2009 and 2010. Since then, it took up with a high rise to reach 515 patents in 2018, exceeding a growth rate of 1,800% in less than a decade as shown in figure 1.

This steep rise can be explained by the digital transformation the world is going through since the fourth industrial revolution – information revolution. New technologies such as Artificial intelligence, Robotics, and Mobility services have emerged since then.

A major development in AV innovation was brought about by the Defense Advanced Research Projects Agency (DARPA) in 2007 through its project *the DARPA Urban Challenge: Autonomous vehicles in City Traffic*. After the first challenge in 2004, DARPA ran its second competition which gathered 89 teams from industry and academics to compete for the advancement of the AV industry (Buehler et al., 2009). In the end, six teams successfully completed the challenge by driving 60 miles in a Californian urban environment, interacting with other vehicles and objects, and respecting the driving rules of the State of California. DARPA projects aim to indicate the areas of possibilities for future technologies and let other agencies and organizations take those technologies forward for more development and eventual diffusion. Hence, the increased interest of industries and organizations into the AV technologies innovation since 2007.

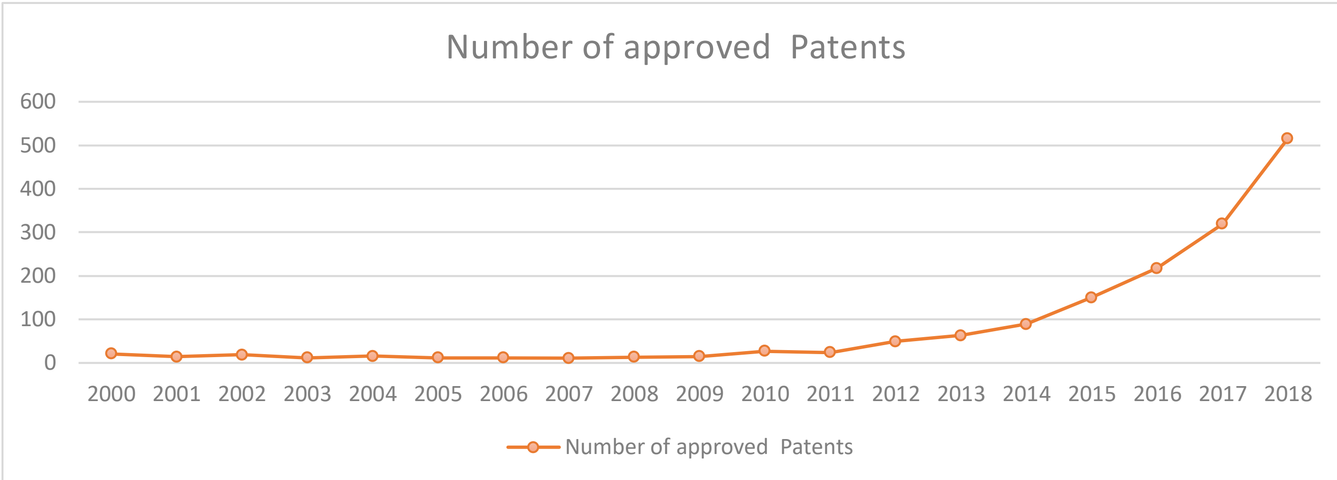

Figure 1: Number of approved patents by USPTO

3.5 Incumbent automakers are sharing the lead of AV innovation with high-tech companies:

To examine the key innovators in the AV area, I focus on the assignees of the identified AV patents. After dropping the 159 patents in the sample that were not assigned to any type of organization, I find that the AV innovations are dominated by both high-tech and the traditional automotive companies (figure 2). The lead is taken by Google & Waymo from the high-tech industry. Google & Waymo (240), from the high-tech industry, has the double of the number of AV patents owned by Ford (121 patents), and a more than two-and-half the of AV patents owned by the third company, GM (89 patents).

The results also show that, in the top 10 patent owners, 44% of the 852 patents are owned by five automotive companies owning, 49% by four high-tech companies, and 7% owned by State Farm from the insurance industry. As a consequence, technology companies such as Google, Uber, and Mobileye, unknown in the automobile industry a decade ago, started competing with the auto-industry giants Ford, GM, and Toyota. This observation is consistent with previous research findings. For example, Cho et al. (2019) concluded the same trend to continue as communication systems and perception technologies combined with artificial intelligence will continue to prosper. They further asserted that automotive and high-tech companies will need strong collaboration for an effective autonomous vehicle industry(Cho et al., 2019).

Though the form of collaboration is yet to be determined, Zehtabchi (2019), believed that traditional automakers will continue to lead in the vehicle platform technology sector while the high-tech companies will keep their leadership in the smart environment technology sector. Therefore, to go beyond their areas of predilection, automakers and high-tech companies will need to cooperate among them using mergers and acquisitions, licensing out, recruiting talents across their respective industries.

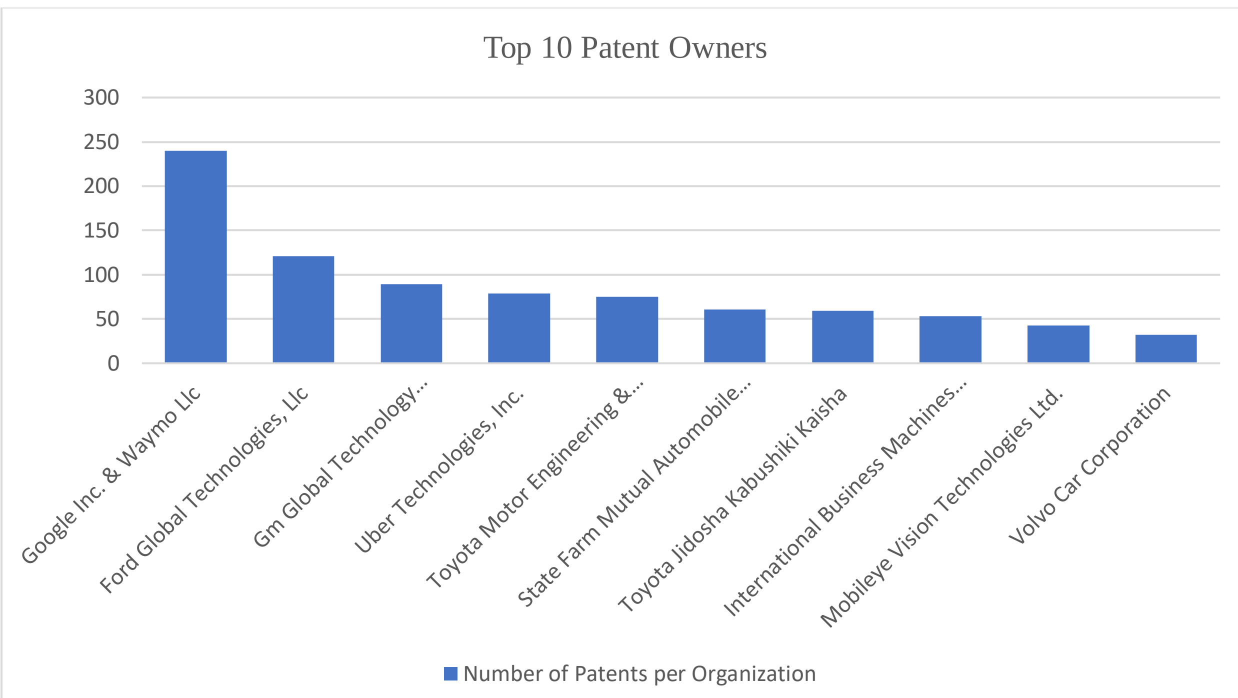

Figure 2: Number of patents per Organization

3.6 High-tech companies overtook incumbent automakers in 2013:

In order to determine the leading industry in AV innovations, I categorize the assignee organizations into automobile companies, technology companies, research institutions, and others. First, I trimmed the data sample to keep organizations having a minimum of 5 patents. Though only 69 out of the 503 initial organizations satisfied that criterion, they accounted for more than 70% of the. Then, I defined four industry categories based on the main industry of the organization as indicated on their websites (table A3). The first category – **automotive** - comprised car manufacturers (e.g., Toyota, GM, Ford) and related industry (e.g., machinery). The second – **high-tech** business organizations having Information Technologies (IT) as their main industry. It included companies like Google, Uber, Baidu. The third industry called education institutions – included universities, institutes, and, other research institutions having their core activity in academia. The fourth category – others – consisted of any organizations that did not belong to the previous three.

The results suggest that automotive companies led the AV innovation until the end of the 2000 decade (figure 3). That observation is consistent with what one could expect as any expected innovation in the vehicle industry should be controlled by the incumbent car manufacturers. However, since the beginning of the current decade, high-tech companies started to take a steady advantage as research in the AV industry became prominent. The general progression of patent publication was slow between 2010 and 2013 for both industries probably as companies were still to file the inventions and USPTO to approve them. For example, Google & Waymo and GM had their first one AV patent approved in 2011 and a cumulative of 10 patents until 2013. Figure 3 below, illustrates the timid growth and the abrupt emergence of AV patents especially from both incumbent and the new entrant-organizations before and after 2013.

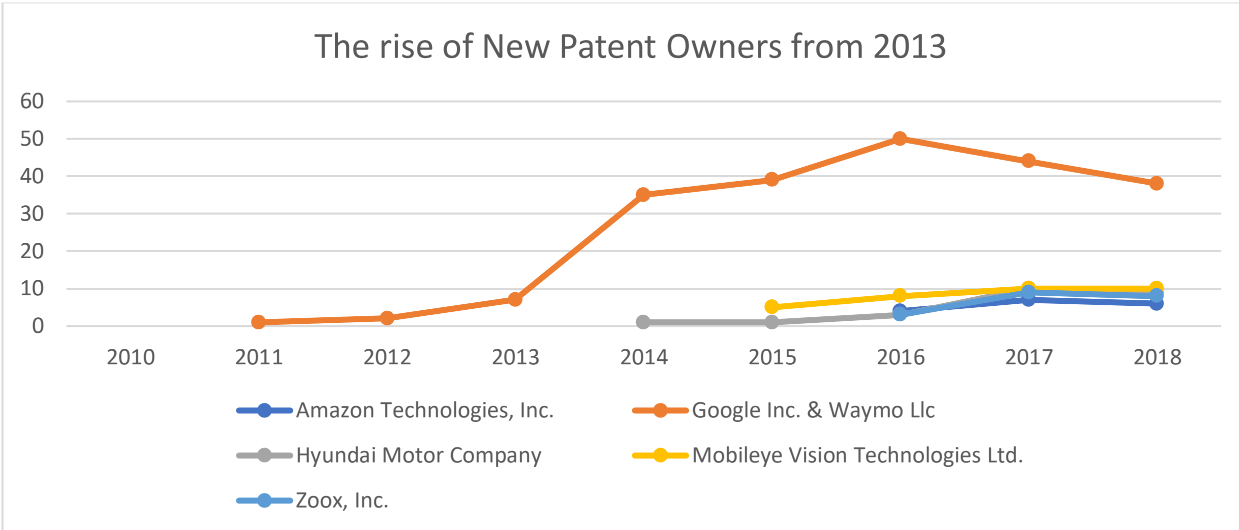

Figure 3: The Rise of New Patent Owners

Beginning in 2014, the number of patents entered in a drastic cycle of augmentation in their inventions in both automotive and high-tech industries. In 2014 alone, high-tech companies had at least 41patents granted by USPTO, more than the total number of patents they had from 2010 to 2013. The increase continued over the years to reach 176 patents in 2018, to reach 1,855% growth rate compared to 2012 for companies having a minimum of five patents. The same pattern was also observed with automotive companies. In 2018, their number of patents increased by 1,078% up to 165 patents, from 20 patents in 2012.

In the meantime, the education institutions category remained stagnant with one or two patents only per year. In contrast, the category “others” e comprising all the remaining companies made a stride of tenfold from 3 to 31 patents. The assignee organizations in the “Others” category, State farm, All-Stat, and Gray & Company, are mainly from the insurance industry

Overall, though the AV innovation is going through a continued increase, the surge in AV innovation was larger for high-tech companies than it was for automotive companies. That trend is expected to continue as the more sophisticated automated systems require more technological-related inventions.

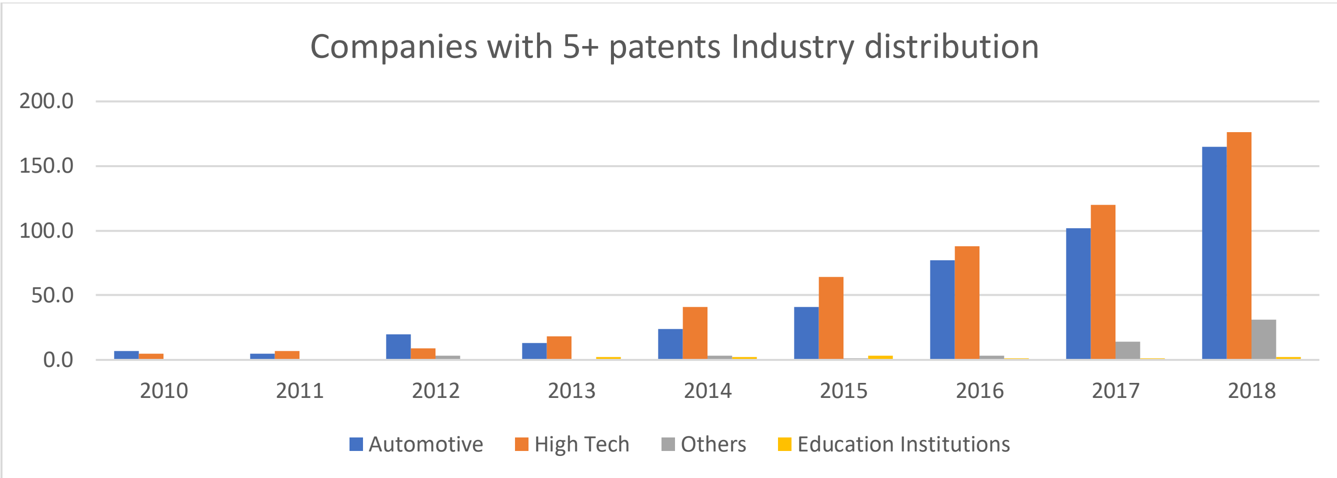

Figure 4: Industry Distribution of AV Innovators (5+ patents)

3.7 Automated Vehicle Platform is the dominating technology sector:

In order to comprehend technology areas where inventors are making more prowess, I coded all patents based on their CPC group id into the two technological fields: the *automated vehicle platform* and the *smart environment*, as defined in Méniere, et al. (2018). During the processes of coding, I found that some patents could belong to both technology sectors, as a single patent document contain several CPC-group-id's Therefore, there existed double counting for those patents.

The analysis of the data shows that except in 2011, the number of patents in the automated vehicle platform technology sector consistently increased year-to-year. It reached 506 in only 2018 from 27 in 2010. In the meantime, smart environment innovations continued on a rather slower upturn to 96 from 9 between 2010 and 2018. Hence, the innovation in the vehicle platform grows annually almost three times higher than that of the smart environment (figure 5).

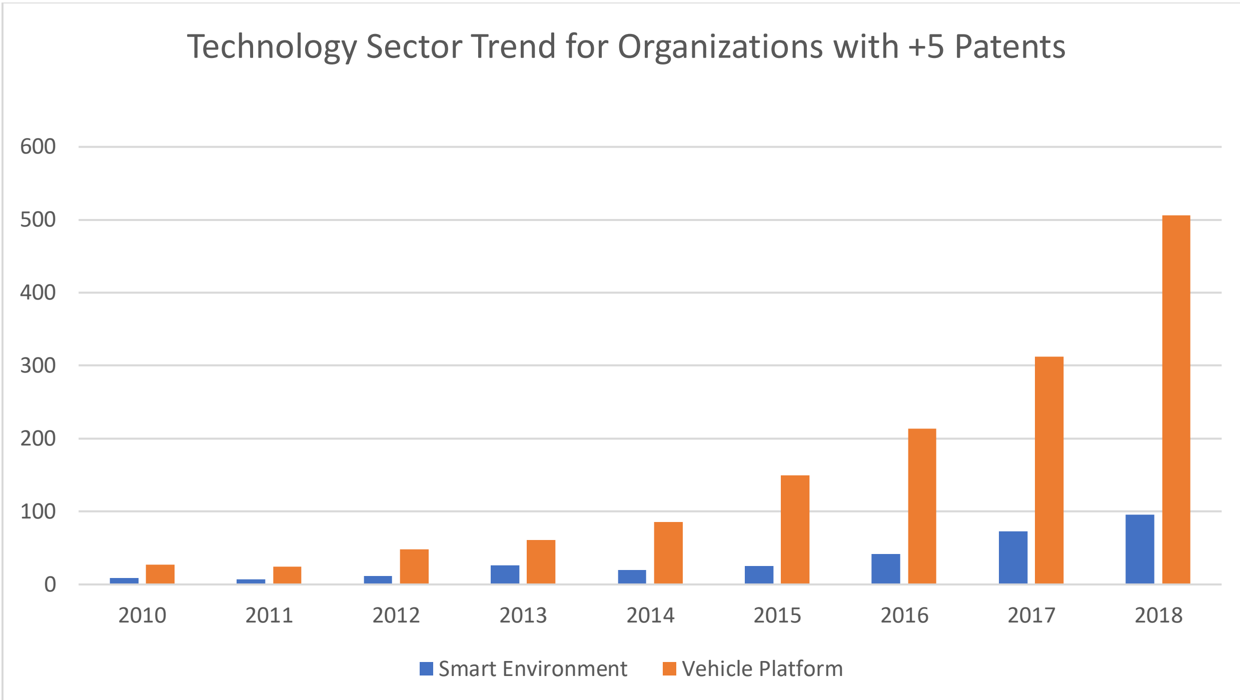

Figure 5: Technology Sectors Trend

However, a closer analysis of the trend indicates that despite the greater number of patents in the vehicle platform technology sector, the annual growth rate is similar for both technology sectors as indicated the figure 6. From 2010 to 2014 for instance, the growth rate of patents in smart environment technology was higher or equal to that of the vehicle platform. Then the vehicle platform technology growth rate dominated for the next two years in 2015 and 2016 before slightly declining in 2017 and taking over in 2018.

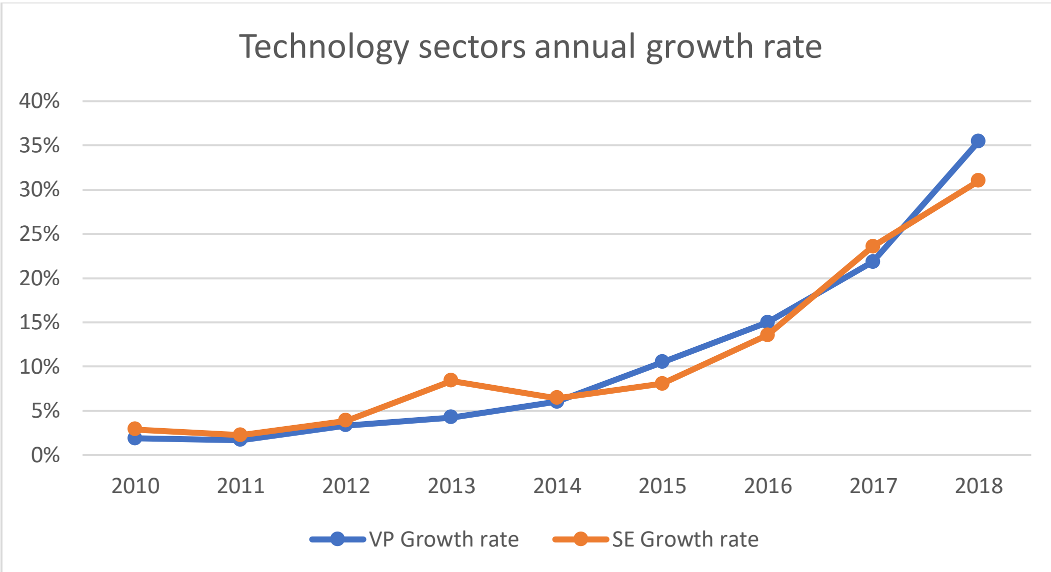

Figure 6: Technology Sectors Annual Growth

3.8 Perception, Analysis & Decision is the most prominent technology field:

At this step, I investigated the level of technological development in different five technology subfields. The purpose of the investigation was to highlight details of inventions performed by organizations in the fields of AV innovation. The technology fields as defined by Meniere et al. (2018), are the subdivided technology sectors into the five specific components that enable and control the automated vehicle. Table 4 provides details of the five technology fields and their related sub-fields.

AV Sectors	Technology Fields	Technology Sub-fields
1. Smart Environment	1.1. Communications:	1.1.1. V2I (Infrastructure) Communication, anti-collision, infotainment, cellular network, signal encryption security:
		1.1.1.1. 5G Network:
		1.1.1.1. MM-Wave antenna arrays technology:
		1.1.1.1. Cloud for learning & updating high definition maps, including traffic data as well as algorithms for object detection, classification, and decision-making via wireless communication:
		1.1.1. Intelligent/smart roads & vehicle connectivity; wireless communication emergency & road assistance services.
	1.2. Smart logistics:	1.2.1. Traffic monitoring, traffic congestion & fleet management:
		1.2.2. Delivery on-demand & automated parking:

		1.2.3. V2G (grid) Connection, electricity grid, inductive battery recharging, recharging stations & roads, vehicle identification & e-billing.
2. Automated vehicle platform:	2.1. Perception, Analysis, and Decision:	2.1.1. Sensing (multiple sensors including Lidar, sonar, radar & cameras for object & obstacle detection, classification & tracking).
		2.1.1.1. Long-range radar for adaptive cruise control, emergency braking, pedestrian detection, collision avoidance & short-medium range radar for cross-traffic alert, park assist with side and rear collision warning.
		2.1.1.2. Lidar for environment mapping, surround view, blind spot detection, park assistance.
		2.1.1.3. Camera for lane departure warning & control, traffic sign recognition, surround view with digital side and rear-view mirror.
		2.1.1.4. Other types of sensors.
		2.1.2. Sensor fusion, semantic understanding, world model creation, localization & navigation (data fusion).
		2.1.3. Driving conditions & drive assist systems, drive stability, safety & comfort.
		2.1.3.1. Specifically for urban driving.
		2.1.3.2. For off-road driving.
		2.1.3.3. Vehicle stability, dynamic chassis control (suspension & steering), conjoint control of stability systems.
		2.1.3.4. Passenger comfort, safety & security, safety assist, adaptive light control, night vision.
	2.2. Computing:	2.2.1. Computer hardware & computer architecture.
		2.2.1.1. Quantum computers: high performance, low-power-consumption systems on a chip with high reliability, robustness & hacker-proof capability.
		2.2.1.2. Parallel processing & redundant systems, supervisory systems, monitoring for fault recognition & recovery.
		2.2.1.3. Bus systems, multi-tasking, parallel processing, optical multiplex systems.
		2.2.2. Computer software.
		2.2.2.1. Artificial intelligence, neural networks & fuzzy logic, genetic algorithms, deep learning machine training.
		2.2.2.2. System prioritization.
		2.2.2.3. Diagnostics & fault management (monitoring autonomous system operation, detecting faults & generating recovery solutions).
		2.2.2.4. Energy management.
		2.2.2.5. Trajectory generation & reactive control (decision-making, planning of vehicle path trajectory & maneuvers).
	2.3. Vehicle handling:	2.3.1. Steering, braking & suspension.
		2.3.2. Powertrains (motors, ice, transmission).
		2.3.2.1. Battery electric vehicles.
		2.3.2.2. Hybrid vehicles.
		2.3.2.3. Efficient internal combustion engine vehicles (new fuels, dual fuels, natural gas):
		2.3.2.4. Magnetic levitation vehicles / personal mobility pods:

Table 5: Technology sectors and fields subdivision

To perform the analysis, I coded every patent based on the technological subfield it belongs to. Again, I had multiple counting as the same patent could belong to multiple technology fields based on their cpc_group_id's. The results show that organizations have a disparate number of inventions in the technology fields (figure 7). For instance, *Perception, Analysis, and Decision* (PAD) technology field represented the largest portion for 1,081 patents representing 44% of all the patents approved by USPTO between 2010 and 2018. It was followed by *Vehicle handling* (VH) with the third of the patents or 824 patents. Smart logistics and computing followed with 12% and 9%, respectively; and the communication totaled only 47 patents representing 2%.

A higher number of patents in PAD and VH indicates that inventors have developed a greater number of technologies integrating more consumer safety and comfort; improved vehicle stability, steering, and braking; enhanced sensing with sophisticated lidar, radar, and cameras; objects and obstacles detection and management; and efficient internal combustion management.

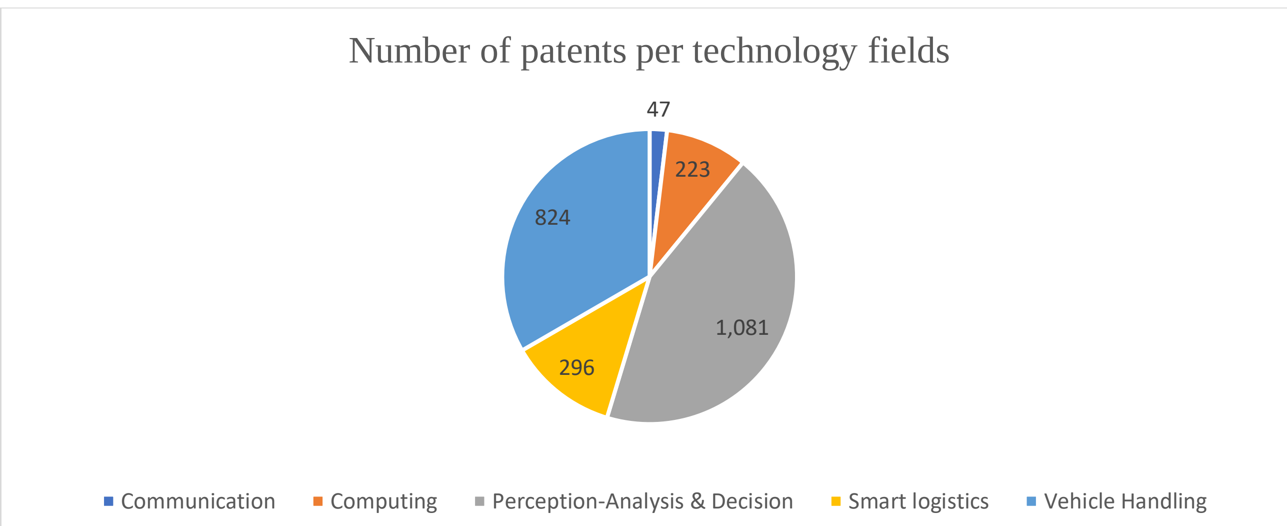

Figure 7: Technology Fields Patent Distribution

Despite the dominance of PAD and VH over the other technology fields in terms of the total number of patents during the period of our analysis, the growth rates present a different perspective. In fact, in 2010 and 2011, all technology fields had a similar number of patents and growth rates (figure 8). As a matter of fact, *Computing*, the third technology field in the number of patents has increased tenfold from 8 patents to 77 between 2010 and 2018 and it has also more than doubled from 2016 to 2018. This indicates a considerable move of the inventions towards hardware and software that comply with cybersecurity and consumer protection requirements contained in the 2016 guidelines defined by the US Department of Transportation (DOT) called *Federal Automated Vehicles Policy* (Canis, 2018).

Furthermore, innovation in smart logistics technologies involving traffic monitoring, traffic congestion, and fleet management; delivery on-demand and automated parking, has also continued increasing. It went from 9 and 7 patents in 2010 and 2011 respectively to reach 90 patents in 2018. That surge in the number of patents could also be attributed to inventors' responsiveness to the technological requirement for traffic management, vehicle identification, automated parking, and electricity source interfaces management (Ménière et al., 2018). Also, even though the *communication* technology field started with a timid trend with only 1 or 2 patents in early 2010, it is now steadily increasing since 2016 where it more than doubled to 7 patents from 2015, and quadrupled to 13 in both years of 2017 and 2018.

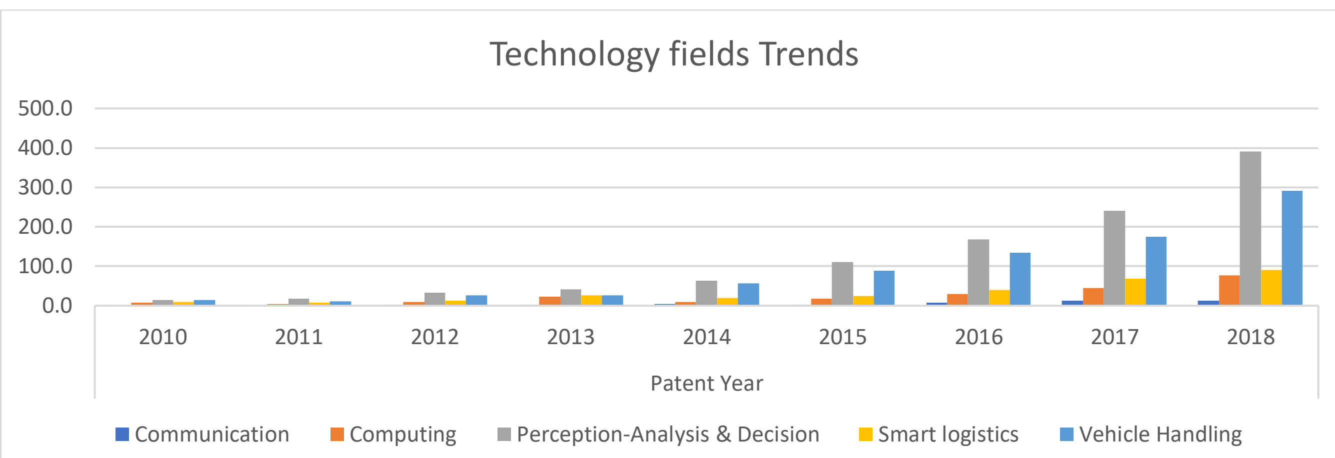

Figure 8: # of Patents by Technology field from 2010-2018.

Furthermore, I focus on companies with five patents and compare their innovation in different technology subfields between automotive vs. high-tech companies. The investigation revealed that the two industries displayed similar shares in *communication* with 7 against 8 patents of the sample for high-tech as opposed to automotive companies. However, they had a different number of patents in the four other technologies fields. While high-tech companies displayed more patents than automotive in *computing* (49 vs 30), perception, analysis & decision (336 vs 258), and smart logistics (62 vs 30); automotive companies presented more dominance in vehicle handling for with 297 patents against 264 for high-tech companies.

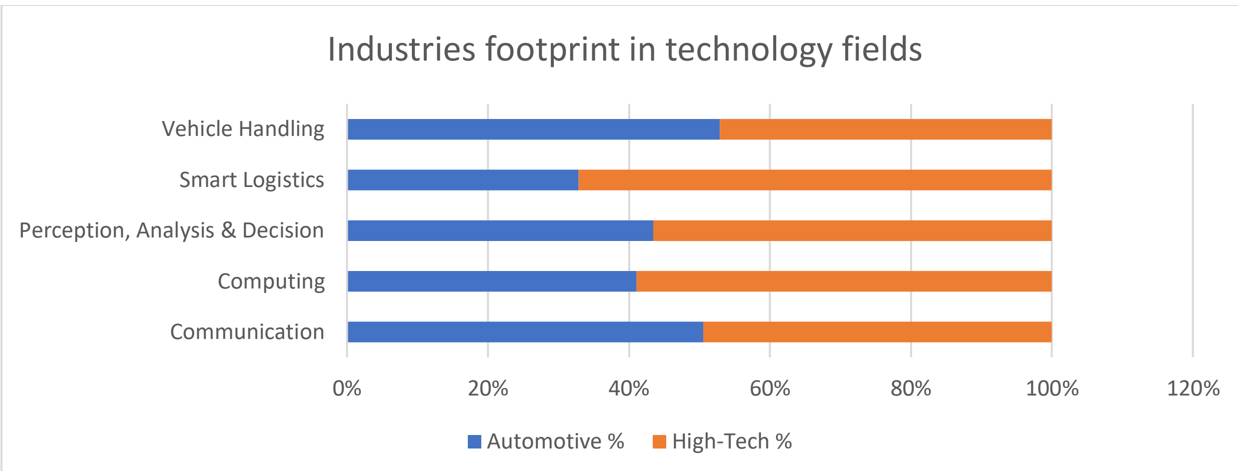

Figure 9: Industries footprint in technology fields

To examine whether corporate innovators (automotive versus high tech companies) have different technological focus, I conduct a t-test to test whether there is a significant difference in the number of AV patents for different technological fields/subfields between the two groups of firms. The test was conducted at a 95% confidence level (alpha =0.05) The results showed that, for the smart environment technologies, at a 95% confidence interval, the count of AV patents held by high-tech industry was significantly higher than that of the automotive industry (p-value = 0.0000).

This result is consistent with the observation claiming that, in smart environment technologies, high-tech companies have a certain advantage over the automotive companies. However, for the vehicle platform technologies, there was no significant difference between the two means as the p-value was 0.44. Consequently, as I previously argued too from the patent counts of the four industries, automotive companies are being caught up as high-tech companies are making progress vehicle platform technologies through a growing number of inventions in perception, analysis & decision and computing.

3.9 Education institutions play a marginal role with less than 2% of AV patents:

To grasp the place held by education institutions and public agencies, I explored the variable *assignee organization* and retrieved from the sample all the organizations having the keywords "University, Institute, Research, Agency," in their names, governmental organizations such as DoD, NASA, … were not included in this count. And I found that there existed 25 such organizations in the data set and they possessed less than 2% of the AV patents approved by USPTO in the last two decades (figure 10). With only 38 patents from all countries worldwide, educational institutions and public agencies seem to play a less active role in the race towards AV innovation or it is also possible that they do not patent for their inventions. Still, nearly two-thirds of those patents belong to US institutions such as Massachusetts Institute of Technology (MIT), Southwest Research Institute, and California Institute of Technology holding 5, 4, and 3 patents respectively. Many others own 1 or 2 patents. One of the purposes of the present study is to shed light on the potential areas of interest for organizations. Perhaps, a more active partnership between private corporations and educational institutions could not only accelerate AV innovation but also lead the latter to take a more prominent place in the field. An important step that can be undertaken by industry leaders to comprehend the underlying strategic orientation of academia.

Furthermore, a scrutiny of the types of patents held by education institutions reveals that they tend to innovate more in *perception, analysis & decision,* and *computing* than the other technology fields. Then follow *smart logistics* and *vehicle handling*, but whereas they have no patent in the communications technology field. Thereof, they have more patents in the *vehicle platform* technology sector. For instance, none of the five patents filed by MIT, the greatest patent owner among education institutions, belong to *communication*s, and only one to *smart logistics*. Meanwhile, four appear to belong to *perception, analysis & decision,* three to *vehicle handling,* and two to *computing*. While the same pattern is observed for *communications* technologies in all institutions, some institutions have many of their patents belonging to *smart logistics*.

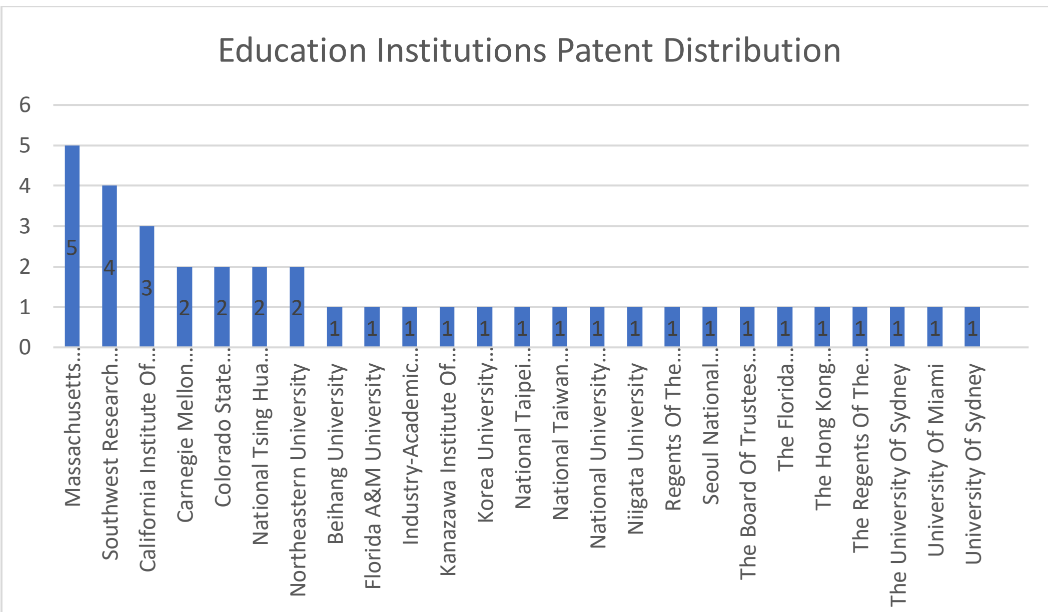

Figure 10: Education Institutions Patent Distribution

US education institutions are dominant with 63% of the patents whereas the second country, Taiwan comes with only 10%. South Korea and Japan rank as third with 7% of the patents each (figure 11).

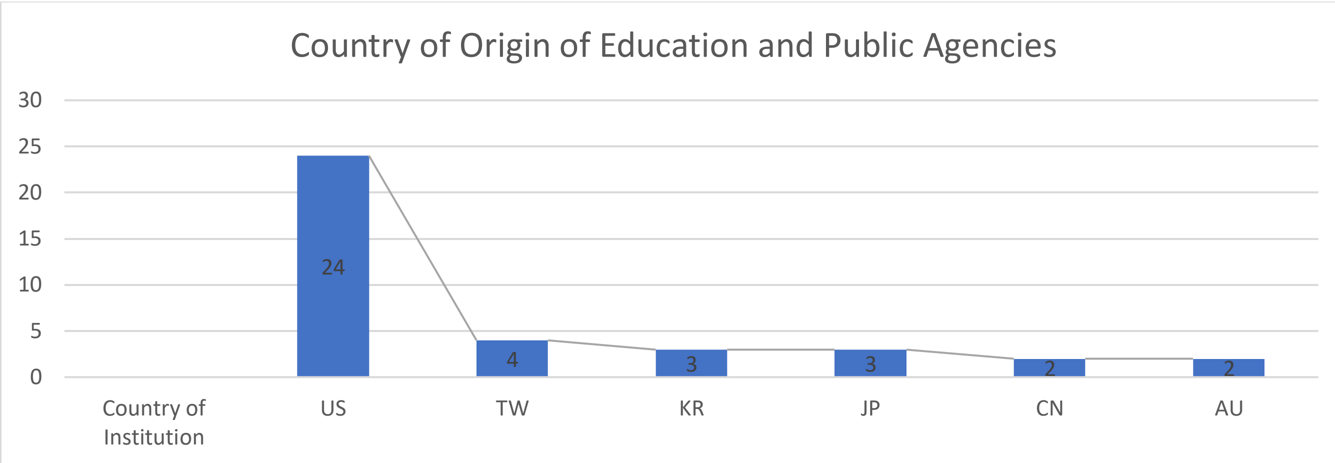

Figure 11: Country of Origin of Education and Public Agencies

3.10 US Companies own two-thirds of AV patents:

According to USPTO, the assignees' type is categorized into six main groups - US companies, US government, US individuals, Foreign companies, Foreign Government, and Foreign Individuals. Figure 12 describes the distribution of the approved patents by USPTO among the six groups. Not surprisingly, the US owns the lion's share of the total AV patents for every type of assignee organization. The largest chunk is shared by US companies for 1,372 patents (61%).

Foreign private companies owned nearly one-third of the patents (31%). This suggests that though USPTO provides *Intellectual Property* protection in the United States, more foreign companies show interest in the US market. The largest patent owners are Toyota Japan (59 patents), Mobileye (43 patents) from Israel, Volvo from Sweden (32), and Hyundai from South Korea (30 patents). Except for Mobileye, an emerging high-tech company, all those companies are from the traditional automotive industry with a substantial market footprint in the US automobile market. Thus, seeking protection for their invention in the US pertains to maintaining or expanding their market share in the country.

A tiny portion of nearly 1% is distributed among individuals and governments both US and foreign indicating that, as it is for the emerging technologies, the risk to innovate in AV industry to borne by private entities. It is important to note that the assignee type was missing for 152 patents, nearly 7% of the sample and contacts with USPTO representatives did not help to categorize those patents.

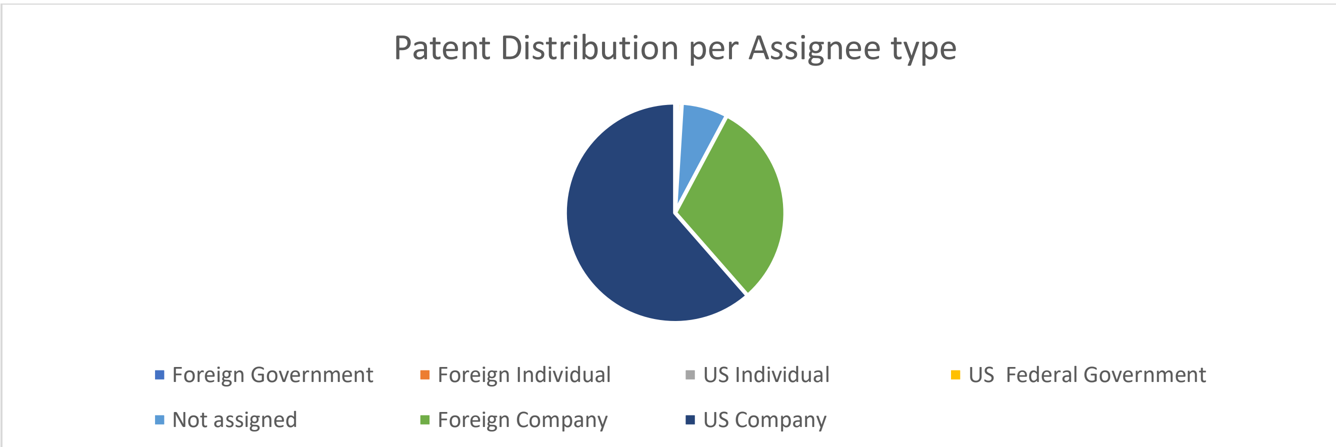

Figure 12: Patent Distribution per Assignee type

Further distribution of patents between companies in the US and those in the rest of the world indicates that US companies hold 67% of the patents and foreign companies account for 33%. According to Figure 13, foreign AV patent owners are from Japan and Germany followed by South Korea and Israel. Specifically, the most active foreign companies are Toyota Jidosha Kabushiki Kaisha of Japan for 59 patents, and Honda Motor Co., Ltd. (18 patents), Mobileye Vision Technologies Ltd. of Israel 43 patens, Volvo Car Corporation of Japan for 32 patents and Hyundai Motor Company of South Korea for 30 patents.

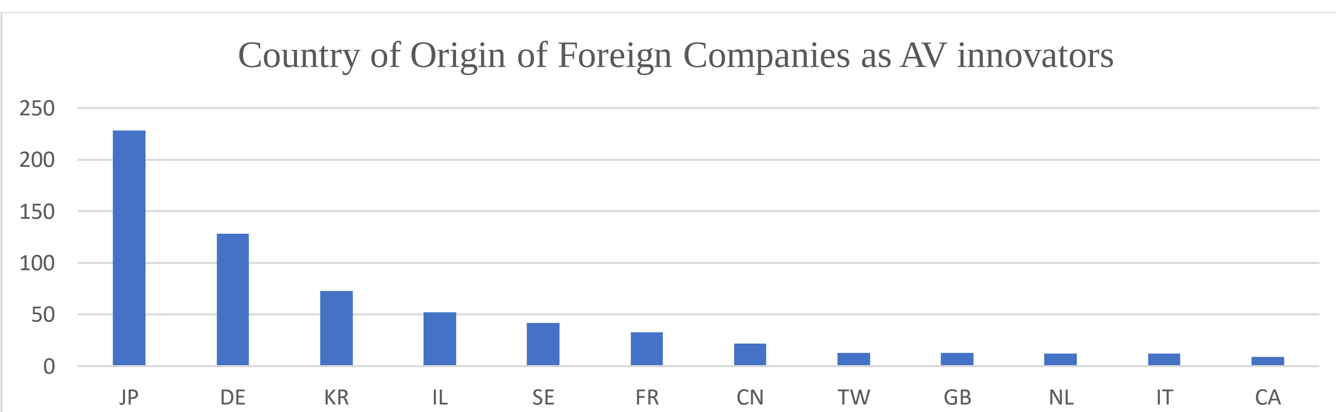

Figure 13: Country of Origin Foreign Companies AV innovator

The same pattern is observed with individual and governmental patent owners. Figure 14 describes a more detailed distribution of the remaining owned by individuals and government entities with the US and in foreign countries. As for individual innovators/assignees, all of them owned 7 patents, 5 belong to U.S individuals, and the two remaining patents are assigned to foreign individuals. In the data set, those 7 patents do not have assignee, therefore, the assignee organization is marked "None". As far as the 15 patents belonging to government entities are concerned, only one of them belongs to the French government represented by "*Commissariat à l'Energie Atomique Et Aux Energies Alternatives".* The other 14 of them representing 93% are assigned to the US federal government represented by the Secretary of Navy of 7 patents, the Administrator of National Aeronautics and Space Administration (NASA) for 3 patents, and the Secretary of Army and Secretary of Air Force for 2 patents each.

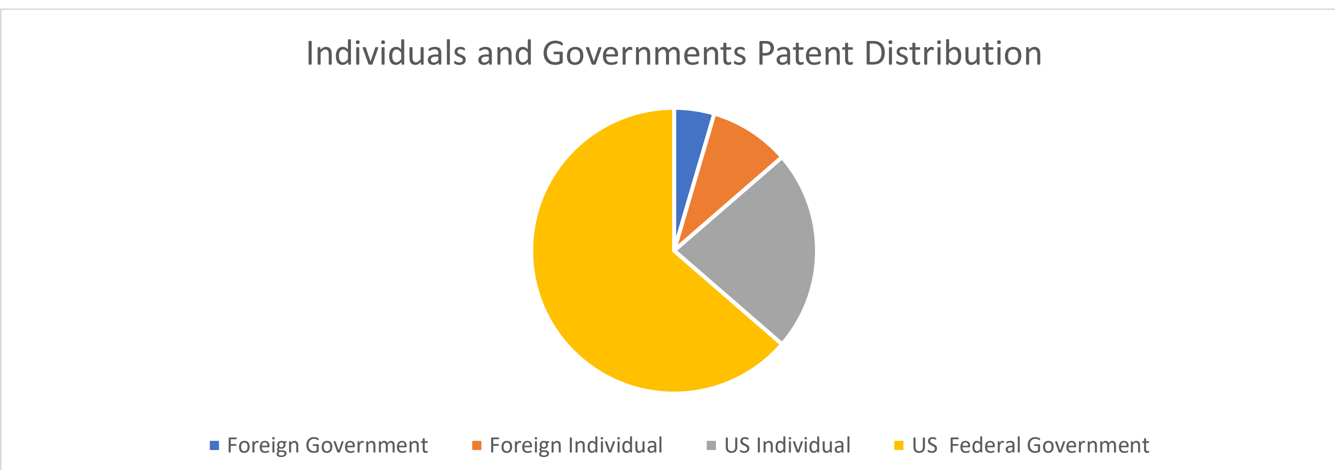

Figure 14: Individuals and Governments Patent Distribution

3.11 In the US, California is leading the AV innovation:

Figure 15 describes the geographic distribution of the U.S. AV patents (based on the state location of the patent assignees) The first striking result is that 13 of the 50 states have no records of patents assignee. I also found that California, with 528 patents (nearly 40% of US patents), is the most active state in the US. Alone, California state accounts for more patents than the total patent of the bottom 34 states put together. The greatest contributing companies are Google & Waymo (240 patents), Uber (79 patents), International Business Machines Corporation (53 patents), Mobileye Vision Technologies Ltd (43 patents), Baidu (28 patents), and Amazon, iRobot Corporation, and Zoox with 27 patents each. This result is consistent with the prominence place of high-tech companies gaining control over the AV innovation technologies.

The second most active state is Michigan with 18% of US patents, largely due to the two giant automotive companies Ford Global Technology (Ford) and General Motors Global Technologies Operations (GM) who own for 121 and 89 patents, respectively. Illinois has about 9% of the total US AV patents, and this is mainly because of the state's insurance companies as State Farm (61 patents) and All-State (9 patents). The remainder is mainly shared among Caterpillar, Boeing, and Deer & Company owning respectively 24, 12, and 8 patents. Massachusetts comes as the fourth state with 72 patents out of which 48 are owned by only three high tech companies – iRobot (27 patents), Symbotic (12 patents), and Nutonomy (9 patents).

Moreover, 12 states account for 90% of the patents in the US while the bottom 50% of the States contribute less significantly to AV innovation as they only have a total of 146 patents representing 10% of US patents. The three least active states are New Mexico, Oklahoma, and Wyoming accounting for only 1 patent each. This result shows that AV innovation is highly disproportionately distributed within the US. While high-tech industry patent owners are dominantly in Silicon-Valley, the patent owners from the automotive industry are located in the geographic area of the traditional auto-makers Michigan and Illinois. Moreover, states like

Massachusetts and New York that would not be mentioned as auto industry locations are now appearing important for the AV innovation thanks to the new technology.

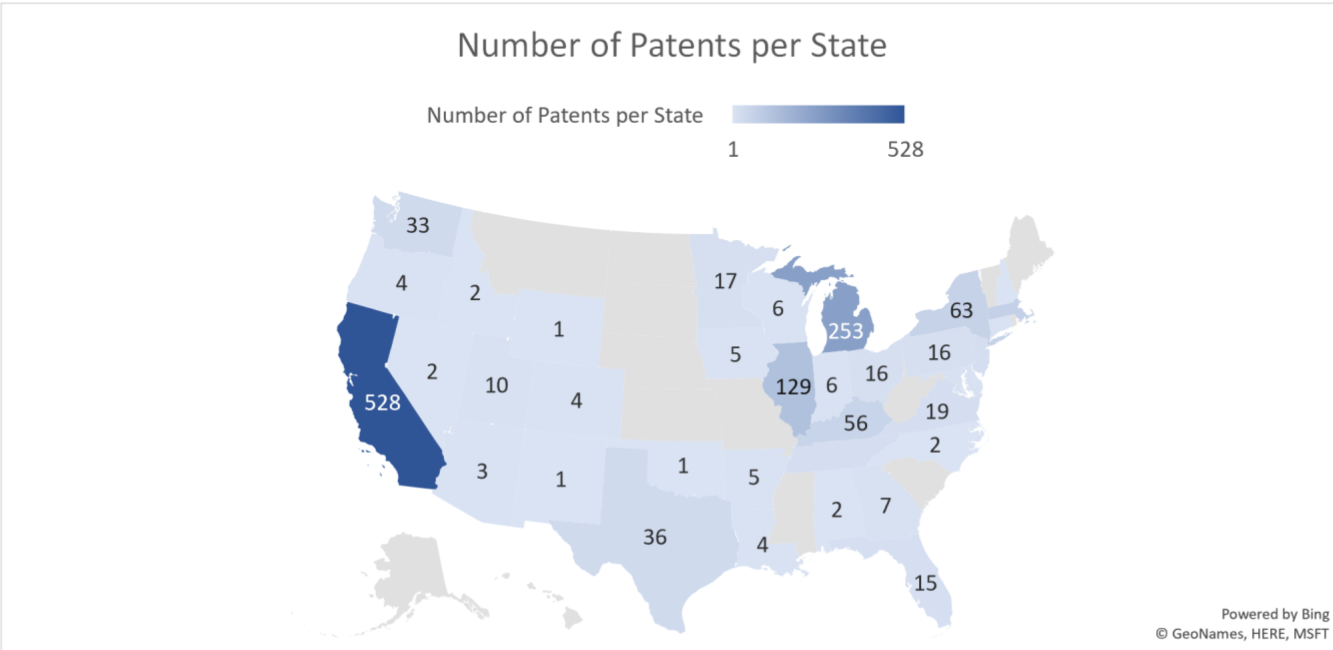

Figure 15: US Patent Distribution among States

These eight findings have shed light on major trends and the state of the matter of AV patent innovation. The next section will conclude and provide policymakers and industry leaders with recommendations for the future of the AV industry.

4 Conclusion and Implications:

AV technology is bringing a dramatic revolution into the transport industry as technological innovation is getting close to fully automated vehicles. This study aims to provide industry leaders, policymakers, researchers, and public opinions with insights about the current state-of-the-art of the innovation in the AV industry through a thorough analysis of patent data approved by USPTO between 2010 and 2018. There are four main conclusions as to the results of this study.

First, there is a significant increase in autonomous vehicle patents approved by USPTO since 2010. Between 2010 to 2018, the number of patents increased by 1,800% from 27 to 516. A similar trend was observed by researchers who studied AV patent applications at the EPO. Between 2011 and 2017, the annual growth rate of patents applied at EPO increased by 330% (Ménière et al., 2018), indicating a continuously drastic rise in AV inventions both in the US and Europe patent offices.

Secondly, though the traditional automotive and the new entrant high-tech industries are both accelerating in AV innovation, the latter is taking over the incumbent automakers in the field and that trend is expected to continue as technological innovation will remain the keystone of the AV innovation.

Third, AV innovations encompass different technology fields. High-tech companies are leading in smart environment technologies (communications and smart logistics). The incumbent automakers had an established predominance in the vehicle platform technologies (vehicle handling; perception, analysis & decision; and computing). However, they are now losing that leadership to high-tech companies as more inventions are being carried out in perception, analysis & decision and computing technology fields. The insurance industry is emerging with a growing share of patents since the second half of 2010. Educational institutions occupy a smaller place with less than 2% of all the patents.

Fourth, of all the patents approved by the USPTO, 61% belong to US companies, 31% to foreign companies principally from Asia and Europe, 1% is shared among individuals and government entities, 7% are unassigned. In the meantime, at the EPO, European and US applicants are the highest contributors with a slight dominance of Europe (Ménière et al., 2018). According to the same study, Europe and the US are followed by Japan with less than half of US patents. As a result, the US confirms its leadership compared to any other country in the world as regards the number of AV patents. Fifth, in the US, California is the epicenter of AV innovation with nearly 40% of US patents thanks to its high-tech companies. Michigan holds 18%, thanks essentially to Ford and GM. Illinois holds 9% through State Farm and All-State. Consequently, the AV innovation in the US (which is the leader of the world) is fundamentally led by the states that are home for US high-tech and automotive industries.

4.1 Implications for the industry:

The exponential increase in AV patenting accentuated by the fourth industrial revolution, digital disruption is expected to be seriously challenging for the transportation industry. On one hand, the AV technologies constitute serious disrupters that may be very costly for incumbent automakers. For some, balancing investment in legacy infrastructure and technology and AV initiatives will be complex decisions and tradeoffs might be difficult to find. On the other hand, AV requires technologies to manufacture the body of the vehicle composed of chassis, engines, dominated by the incumbent automotive companies. High-tech companies not only do lack experiences in the automotive industry but also may not be able to match in terms of required investment to catch up. Besides, the disparity among industries (automotive vs high-tech) in different AV technology fields is an indication of the complexity of bringing the AV to the road by one single industry.

Consequently, companies within and across industries must identify the best possible strategies for the successful commercialization of their inventions. This study provides industry leaders with insights to take the right types of partnership and collaboration they need. Depending on the context, they might choose among mergers and acquisitions (M&A), recruiting talents from competing organizations, licensing in and/or out specific technologies. The emergence of high-tech startups might an opportunity for larger companies to compensate for potential areas where they need complementarity.

4.2 Implications for policymakers:

For policymakers, keeping track and understanding AV inventions and their potential implications will be a tedious task to accomplish as companies move faster than regulatory boards adopt. Also, defining the right regulatory framework at the right time, and provide necessary adjustment with a fast-speed rhythm of the invention will require a lot of anticipation, and abilities to take rapid measures of correction which is irreconcilable with the normal legislative process characterized the slowness and political considerations. As the safety and security of users should be of high priority, the regulator must manage the liability regimes among car manufacturers, software companies, insurance companies, and vehicle users at the federal, state, and local levels.

The results of this study could also serve policymakers to identify technological fields where less progress is made by companies and accordingly initiate the most appropriate policy actions. More than three-fourths of the inventions captured in the studied sample belong to two technologies (vehicle handling and perception, analysis & decision) and the rest is for the three other technology fields (computing, communication, and smart logistics). Hence, the government may either incentivize through direct funding, tax credits, or prizes as they have already done through DARPA AV challenges in 2004, and 2007 to fill the gaps in those technology fields.

Besides, policymakers should overcome the challenges to establish a coordinated and harmonized federal law and regulation. That will foster testing; resolve the concerns of the opponents to the AV adoption related to cybersecurity, personal data privacy, and the responsibility matrix of different stakeholders. Another policy action may include continued efforts of collaboration among industries and companies through guidelines, facilitation, and public-private partnerships that could help the US to not only maintain its leadership in AV technological innovation but also accelerate AVs adoption in a not-too-distant future.

4.3 Implications for researchers and future work:

Despite the time constraints and challenging communications with USPTO, this study laid out foundations on comprehending the major patterns of AV innovations using USPTO patent data. More experts are needed for data analysis to understand the unmatched patents, and more active collaboration with USPTO representatives is required for missing data and incorrect data entries. However, the results of this study should be understood with the inherent limitations of patent data search and analysis methodology. Also, though I had several exchanges with USPTO PatentsView representatives, I needed to move forward without having their feedback on some data quality issues and the subsequent analysis. Moreover, some analyses were performed on subsets of the sample because it was difficult to integrate the entire data set specifically on assignee organizations, assignee type. For instance, to determine the industry types of patent assignees and technologies develop in, I used organizations having a minimum of five patents. That might not provide a full picture of the industry situation. Another limitation is that I used the EPO classification of AV technologies to analyze USPTO data. The results might have been different if a similar classification was done involving USPTO experts.

Consequently, future research should consider establishing a more collaborative relationship with USPTO to get their inputs and feedback on data quality.

Also, the data set could be improved with a more comprehensive search strategy complemented with more surveys and interviews involving PatentsView representatives. Furthermore, it will be essential to work with a multi-disciplinary group of stakeholders including industry leaders, technology specialists, researchers, and representatives from regulatory entities to establish a cartography of AV technologies based on the USPTO database. That will significantly increase the scope of the study with a larger number of patents. Hence, provide more comprehensive results.

Another area of improvement is to investigate the quality of the patents I analyzed in this study. Fundamentally, I focused our analysis on the statistics of patent counts which does not necessarily determine the validity and the usefulness of those patents to the innovation market. Therefore, further studies could explore the diffusion and the adoption of those inventions using patent citation techniques for instance.

Finally, though patent statistics and innovative performance might be highly correlated, the former could not be used as an absolute predictor of the adoption of new technologies. Consequently, complementing this study with other innovation measurement techniques such as survey-based information collection with companies will help refine the findings and provide stakeholders with more insightful inputs they can take forward.

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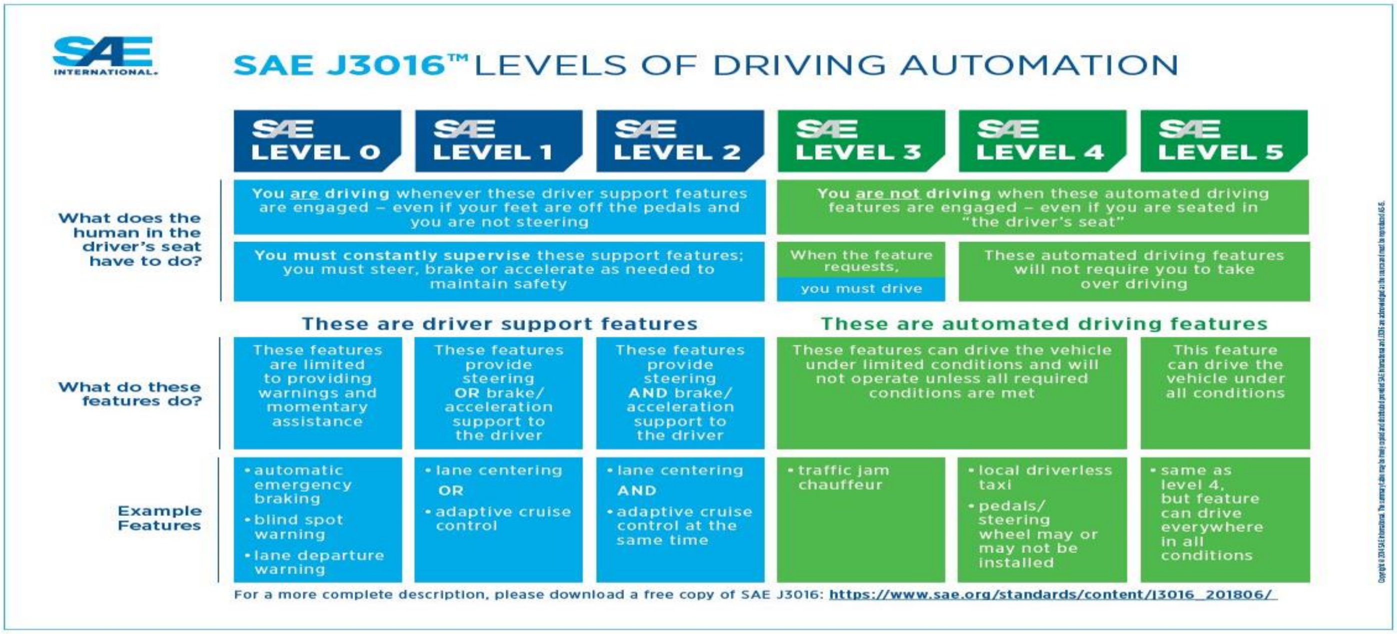
Annex:

A1. SAE- J3016 – Six Level of Driving Automation.



A2. Cartography of AV technologies and CPC codes ranges.

AV Sectors	Technology Fields	Technology Sub-fields	CPC Codes
1. Smart Environment	Communications:	1.1.1. V2I (Infrastructure) Communication, anti-collision, infotainment, cellular network, signal encryption security:	G08G1/16, G08G1/164, G08G1/166, G06F21/00, H04W4/00, H04W4/44, H04W4/46, H04W12/00, H04L63/00, E01F9/00
		1.1.1.1. 5G Network:	H04W4/046, H04W36/0077, H04L67/12, Y02D70/126
		1.1.1.1. MM-Wave antenna arrays technology:	H01Q21/00
		1.1.1.1. Cloud for learning & updating high definition maps, including traffic data as well as algorithms for object detection, classification, and decision-making via wireless communication:	G07C5/08, G08G1/01, G08G1/09, G08G1/091, B60L2270/40.
		1.1.1. Intelligent/smart roads & vehicle connectivity; wireless communication emergency & road assistance services:	G08G1/02, G08G1/0967, G08G1/0968, G01S7/003, G07B15/063, G07C5/00, G07C5/12, E01F, E01F9/00, E01F9/40, H04W36/00, H04W76/50, B61L3/00.
	Smart logistics:	1.2.1. Traffic monitoring, traffic congestion & fleet management:	G05D1/0011, G05D1/0027, G05D1/0287, G05D1/0297, G08G1/00, G08G1/01, G08G1/09, G08G1/0968, G08G1/127, G08G1/16, G08G1/164, G08G1/20, G01S13/93, G10S13/931, G01S15/88, G01S15/93, G01S17/88, G01S17/93, G07C5/00 - G07C5/08, E01F9/00, B60L2240/70, B61L25/00.
		1.2.2. Delivery on demand & automated parking:	G08G1/14, G08G1/22, G08G1/202

		1.2.3. V2G (grid) Connection, electricity grid, inductive battery recharging, recharging stations & roads, vehicle identification & ebilling:	Y02T10/7072, Y02T10/7077, Y02T10/7088, Y02T10/7094, Y02T90/10, Y02T90/12, Y02T90/121, Y02T90/124, Y02T90/167, Y04S10/12, Y04S10/126, Y04S30/126, Y04S30/14, H02J5/00, H02J5/005, H02J7/00, H02J7/0027, H02J7/025, H02J50/10, B60L8/00, B60L11/1809, B60L11/182, B60L11/1822, B60L11/1824, B60L11/1838, B60L11/1842, B60L11/1846, B60L11/1848, B60L11/185, B60L2230/00, B60L2230/20, B60L2230/40, B60L2240/72, B60S5/06.
2. Automated vehicle platform:	2.1. Perception, Analysis and Decision:	2.1.1. Sensing (multiple sensors including Lidar, sonar, radar & cameras for object & obstacle detection, classification & tracking):	G01S7/00, G01S13/00, G01S15/00, G01S17/00.
		2.1.1.1. Long-range radar for adaptive cruise control, emergency braking, pedestrian detection, collision avoidance & short-medium range radar for cross traffic alert, park assist with side and rear collision warning:	G01S7/00, G01S7/02, G01S7/52, G01S13/00, G01S13/86, G01S13/87, G01S13/93, G01S15/00, G01S15/025, G01S15/87, G01S15/931, G01S17/00, G06K9/00, G05D1/00, G05D1/0257, B60W2420/52, B60Y2400/3017, B60R19/00
		2.1.1.2. Lidar for environment mapping, surround view, blind spot detection, park assistance:	G01S17/023, G01S17/06, G01S17/87, G01S17/88, G01S17/936, G01S7/48, G01S2013/9332, B60W2420/52
		2.1.1.3. Camera for lane departure warning & control, traffic sign recognition, surround view with digital side and rear-view mirror:	G06T1/0007, G06T1/0014, G06T1/20, G06K9/00362, G06K9/00785, G06K9/00791, H04N5/335, B60Y2400/3015, B60W2420/42, B60S1/56
		2.1.1.4. Other types of sensor :	B60Q5/008, B60Q2300/32, B60Q2300/33, B60Q2300/45, B81B2201/02, B60C23/0408
		2.1.2. Sensor fusion, semantic understanding, world model creation, localisation & navigation (data fusion) :	G01C21/00, G01C21/26, G01C21/34, G01S7/52, G01S15/00, G05D1/00, G05D1/0027, G05D1/0088, G05D1/021, G05D1/0212, G05D1/0276, G05D1/0287, G05D1/02, G06T1/0007, G06T1/0014, G06T1/20, G08G1/16, G08G1/161, G08G1/22, H04W4/44, H04W4/46, F16D2500/31, B60L2240/60, B60L2240/62, B60W30/16, B60W2050/008, B60W2550/402, B60W2550/408.
		2.1.3. Driving conditions & drive assist systems, drive stability, safety & comfort:	B60G17/015, B60G17/016, B60G17/0195, B60G2800/00, B60K28/04, B60W30/00, B60W40/00, F16D2500/508, G05D1/0088, G05D2201/0212.
		2.1.3.1. Specifically for urban driving:	B60K28/14, B60K31/00, B60Q1/00, B60Q5/006 B60R1/00, B60T2201/10, B60T2201/02, B60T7/00, B60T8/17558, B60Y2300/08, B60Y2300/14, B60Y2300/165, B60Y2300/18008, B60W30/06, B60W30/08, B60W30/14, B60W30/16, B60W30/17, B60W30/085, B60W30/095, B60W30/143, B60W30/146, B60W30/162, B60W30/165, B60W30/181, B60W30/18018, B60W30/18027, B60W30/18063, B60W30/18154, B60Y2300/06, B62D6/00, B62D15/02, F02D29/00, F16D2500/3128, F16D2500/50883, F16D2500/50866, F16D2500/50875, G01S13/00, G01S17/93, G05D1/00, G05D13/00, G06K9/00221, G06K9/00362, G06K9/00798, G06K9/00805, G06K9/00812, G06K9/00818, G06K9/00825, G08G1/00
		2.1.3.2. For off-road driving:	B60T2201/04, B60T2201/06, B60L2240/64, B60Y2300/02, B60Y2300/181, B60W10/119, B60W30/04, B60W30/18009, B60W30/18118, B60W2550/14, B60W2720/40, B60G17/0165, E01F9/00,

			F16D2500/3124, F16D2500/3125, F16D2500/50825, F16D2500/50841
		2.1.3.3. Vehicle stability, dynamic chassis control (suspension & steering), conjoint control of stability systems:	B60W10/04, B60W10/10, B60W10/20, B60W30/00, B60W40/00, B60L7/00, B60T1/00, B60T8/26, B60T8/175, B60T8/176, B60T13/66, B60T13/74, B60T17/18, B60T2201/03, B60T2201/09, B60T2270/40, B60G17/015, B60G17/016, B60G17/0195, B60G2800/00, B60Y2300/00, F16D2500/3125
		2.1.3.4. Passenger comfort, safety & security, safety assist, adaptive light control, night vision:	B60C23/0408, B60R21/00, B60R22/00, B60R25/00, B60Q1/08, B60Q1/40, B60Q1/346, B60Q1/448, B60Q1/525, B60Q1/1423, B60Q2300, B60Q5/00, B60Q9/004-B60Q9/008, B60K28/00, B60K28/06, B60K2350/1028, B60K2350/1052, B60K2350/2052, B60L3/04, B60N2/002, B60W2040/0818, B60W2040/0872, B60W2040/0881, G02B27/01, G06K9/00832, G06K9/00838, G06K9/00845, G08B21/06, G08G1/005, G08G1/166, H04W4/40, H04W76/50, Y02T90/169, Y04S30/14.
	2.2. Computing:	2.2.1. Computer hardware & computer architecture:	B60W50/00
		2.2.1.1. Quantum computers: high performance, low-power-consumption systems on a chip with high reliability, robustness & hacker-proof capability:	B82Y10/00, G06N99/002, G06T1/20, H04B10/00
		2.2.1.2. Parallel processing & redundant systems, supervisory systems, monitoring for fault recognition & recovery:	B60W50/02
		2.2.1.3. Bus systems, multi-tasking, parallel processing, optical multiplex systems: .	B60R16/00, H04L12/40, H04L12/56, H04J3/06, H04J14/00, G06F8/314, G06F9/3885
		2.2.2. Computer software:	B60W50/00
		2.2.2.1. Artificial intelligence, neural networks & fuzzy logic, genetic algorithms, deep learning machine training:	B60L2260/40, B60G2600/1876, B60G2600/1877, B60G2600/1878, B60G2600/1879, G05B13/00, G05D1/0088, G05D1/0221, G06N, G06K9/00, G06T1/20
		2.2.2.2. System prioritization.	B60G17/0185, B60G2600/042, B60G2600/08, B60W50/02, G05B23/00, G06F8/314, G06F21/00
		2.2.2.3. Diagnostics & fault management (monitoring autonomous system operation, detecting faults & generating recovery solutions):	B60W50/02, F16D66/02, G07C5/00
		2.2.2.4. Energy management:	Y02T10/72
		2.2.2.5. Trajectory generation & reactive control (decision-making, planning of vehicle path trajectory & manoeuvers):	B60W30/095, B60W50/0097, G05D1/0212
	2.3. Vehicle handling:	2.3.1. Steering, braking & suspension:	B60K, B60L, B60T, B60W, B60G17/00, B60G21/00, B60G28/00, B62D1/ 00-B62D19/00
		2.3.2. Powertrains (motors, ice, transmission):	F02D, F16H, B60L15/20, B60W10/04, B60W30/18
		2.3.2.1. Battery electric vehicles: Y	02T10/70, Y02T10/90, Y02T90/10, Y02T90/12, B60G13/14, B60G2300/60, B60J1/002, B60K6/28, B60K16/00, B60K2016/006, B60L, B60T1/10, B60Y2200/90, B60Y2300/18125, B60W30/18127, B60W2510/08, B60W2710/08, H02J2007, H02J5/005, H02J7, H01M
		2.3.2.2. Hybrid vehicles:	B60K6, B60L, B60W10/28, B60W20, B60W2510/28, B60W2710/28, B60Y2200/92, B60Y2400/434,

			F02B2043/106, F02D19/0644, F02D29/00, H01M8/00,Y02T10/32,Y02T10/62, Y02T90/14,Y02T90/30,Y02T90/32, Y02T90/34, Y02T90/40, Y02T90/42
		2.3.2.3. Efficient internal combustion engine vehicles (new fuels, dual fuels, natural gas):	F01L, F02B2043/103, F02D, F16H59, F16H61, F16H63, B60Y2400/433, B60Y2400/434, B60W2510/02, B60W2510/06, B60W2510/10, B60W2510/12, B60W2710/02, B60W2710/06, B60W2710/10, B60W2710/12, Y02T10/10, Y02T10/12, Y02T10/14, Y02T10/16, Y02T10/30, Y02T10/32, Y02T10/36, Y02T90/40, Y02T90/42
		2.3.2.4. Magnetic levitation vehicles / personal mobility pods:	B60L13, B61L2210/02, B61L2210/04

A3: Industry type of Organizations (with 5+ patents)

Assignee Organization	**Number of Patents**	Industry
A.S.V., Inc.	5	Automotive
Automotive Research & Testing Center	5	Automotive
Bae Systems Plc	5	High-Tech
Massachusetts Institute Of Technology	5	Research Institute
Minolta Co., Ltd.	5	High-Tech
Murata Machinery, Ltd.	5	Automotive
Steering Solutions Ip Holding Corporation	5	High-Tech
Toyota Research Institute, Inc.	5	Automotive
Tusimple	5	High-Tech
Valeo Schalter Und Sensoren Gmbh	5	Automotive
Volkswagen Ag	5	Automotive
X Development Llc	5	High-Tech
Bayerische Motoren Werke Aktiengesellschaft	6	Automotive
Continental Teves Ag & Co. Ohg	6	High-Tech
Daimler Ag	6	Automotive
Denso Corporation	6	Automotive
France Reducteurs	6	Others
Hyundai Mobis Co., Ltd.	6	Automotive
Komatsu Ltd.	6	Automotive
Smartdrive Systems, Inc.	6	High-Tech
Wirtgen Gmbh	6	Automotive

Yanmar Co., Ltd.	6	Automotive
Brain Corporation	7	High-Tech
Cnh Industrial America Llc	7	Automotive
Continental Automotive Gmbh	7	Automotive
Deepmap Inc.	7	High-Tech
Electronics And Telecommunications Research Institute	7	Research Institute
Here Global B.V.	7	High-Tech
Mitsubishi Electric Corporation	7	Automotive
Peloton Technology, Inc.	7	High-Tech
Renault S.A.S.	7	Automotive
The United States Of America As Represented By The Secretary Of The Navy	7	Others
Wabco Gmbh	7	High-Tech
Z Advanced Computing, Inc.	7	High-Tech
Deere & Company	8	Automotive
Honda Giken Kogyo Kabushiki Kaisha	8	Automotive
Nio Usa, Inc.	8	Automotive
Samsung Electronics Co., Ltd.	8	High-Tech
Allstate Insurance Company	9	Others
Intel Corporation	9	High-Tech
Nutonomy Inc.	9	High-Tech
Hitachi, Ltd.	10	High-Tech
Lyft, Inc.	10	High-Tech
Qualcomm Incorporated	11	High-Tech
Fuji Jukogyo Kabushiki Kaisha	12	High-Tech
Honeywell International Inc.	12	High-Tech
Nissan Motor Co., Ltd.	12	Automotive
Symbotic, Llc	12	High-Tech
The Boeing Company	12	Automotive
Audi Ag	14	Automotive
Nissan North America, Inc.	17	Automotive
Honda Motor Co., Ltd.	18	Automotive
Robert Bosch Gmbh	22	High-Tech
Caterpillar Inc.	24	Automotive
Amazon Technologies, Inc.	27	High-Tech
Irobot Corporation	27	High-Tech
Zoox, Inc.	27	High-Tech
Baidu Usa Llc	28	High-Tech

Hyundai Motor Company	30	Automotive
Volvo Car Corporation	32	Automotive
Mobileye Vision Technologies Ltd.	43	High-Tech
International Business Machines Corporation	53	High-Tech
Toyota Jidosha Kabushiki Kaisha	59	Automotive
State Farm Mutual Automobile Insurance Company	61	Others
Toyota Motor Engineering & Manufacturing North America, Inc.	75	Automotive
Uber Technologies, Inc.	79	High-Tech
Gm Global Technology Operations Llc	89	Automotive
Ford Global Technologies, Llc	121	Automotive
Google Inc. & Waymo Llc	240	High-Tech

A4. Country of origin of Foreign companies

	Assignee Type
Assignee Country	Foreign Company
JP	228
DE	128
KR	73
IL	52
SE	42
FR	33
CN	22
TW	13
GB	13
NL	12
IT	12
CA	9
US	7
CH	7
AU	5
SG	4
HU	3
BB	3
AT	3
NZ	2

JA	2
FI	2
ES	2
ZA	1
PT	1
None	1
NO	1
LV	1
KY	1
IN	1
IE	1
HK	1
DK	1

A3. Top 15 States in the US:

#	Assignee State	Number of Patents per State	Frequency	Cumulative
1	CA	528	37.96%	38%
2	MI	253	18.19%	56.15%
3	IL	129	9.27%	65%
4	MA	72	5.18%	71%
5	NY	63	4.53%	75%
6	KY	56	4.03%	79%
7	TX	36	2.59%	82%
8	WA	33	2.37%	84%
9	TN	21	1.51%	86%
10	VA	19	1.37%	87%
11	NJ	18	1.29%	88%

12	MN	17	1.22%	90%
13	OH	16	1.15%	91%
14	PA	16	1.15%	92%
15	FL	15	1.08%	93%