TECHNOLOGY SCAN:
AUTONOMOUS VEHICLES

WITH INPUT FROM

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METHODOLOGY

1. Dataset used for the report

The patent dataset was retrieved on 19 April 2019 and comprises worldwide patent applications relating to autonomous vehicle technologies published in 2009-2018.

Relevant business information, market data, and national policies that are available from commercial databases or on the web are also used to support the findings of the report.

2. Counting the number of inventions

This report counts the number of inventions by the number of unique patent families. Counting individual patent applications will result in double counting as each patent family may contain several patent publications if the applicant files the same invention for patent protection in multiple destinations. As a patent family is a group of patent applications relating to the same invention, analyses based on counting one invention per unique patent family can reflect innovation activity more accurately.

3. Formulation of search strings

To ensure optimal recall and accuracy of the data sets retrieved, the search strings used in this study were formulated by incorporating keywords (and their variants), as well as relevant patent classification codes and indexes, e.g. International Patent Classification (IPC) and Cooperative Patent Classification (CPC).

4. Grouping of technology domains

Grouping of individual patent documents into the respective technology domains was carried out based on patent classifications codes, text-mining and semantic analysis of the patent specifications in particular claims, titles, abstracts, as well as a manual review of the individual patent applications.

5. Growth rate calculation

Annual growth rate refers to the average annual growth and was derived by using the best-fit exponential line method for the set of data, $y = a*e^{bx}$, where b is the growth rate.

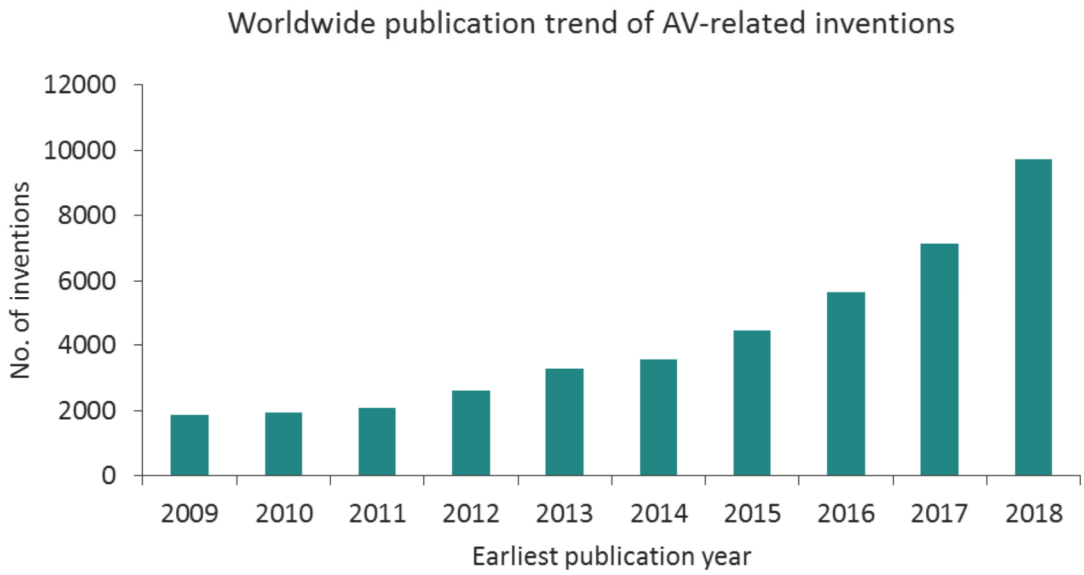
CONTENTS

INTRODUCTION

With the potential to radically transform the transport system and improve our lives, autonomous vehicles (AVs) have garnered strong traction around the world and the AV market is forecasted to reach about USD 560 billion by 2026.[1] Vehicles with varying levels of self-driving capability are already commercially available. Most automobile manufacturers have pledged to have at least semi-autonomous systems available by 2020, and many industry experts predict that it will take only a few more years after that for fully autonomous cars to hit the road.[2]

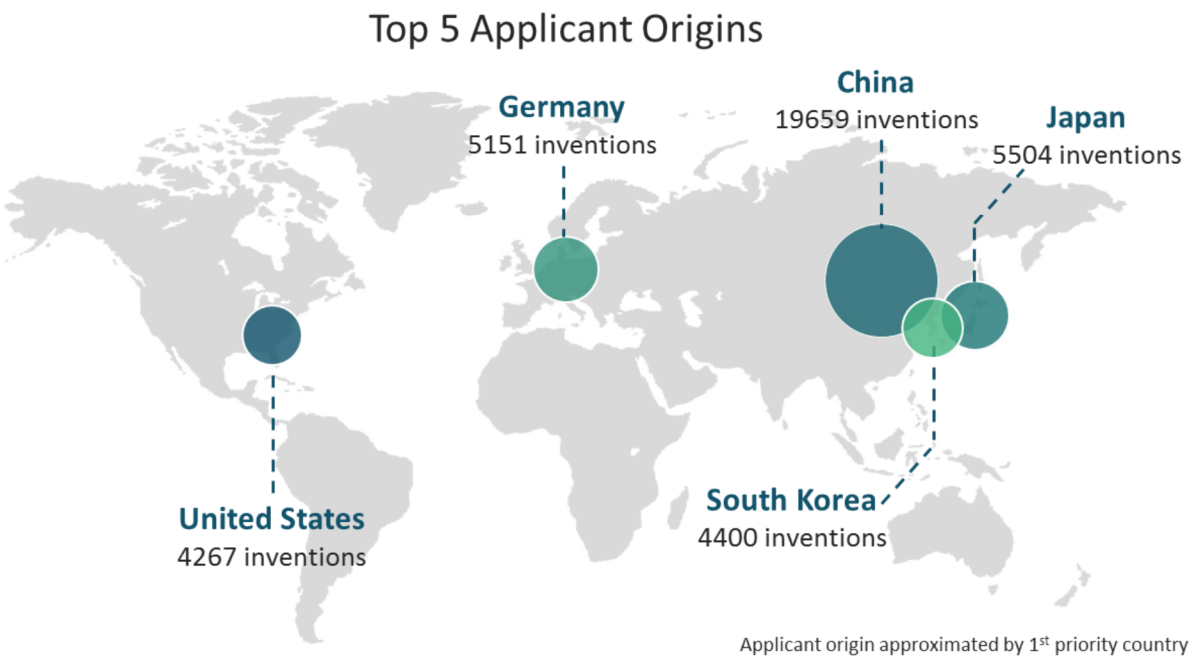
The development of autonomous driving is propelled by various technological advancements that are helping pave the way to full autonomy. This report looks at the worldwide patent applications relating to AV technologies published in 2009-2018. Specifically, it covers 4 technology domains – 1) sensor technologies, 2) navigation and localisation, 3) decision making, and 4) communication. In addition to providing a quick overview of the current trends and the technology leaders in the respective domains, this report also provides insights into the race to innovate in tomorrow's mobility solutions.

WORLDWIDE PUBLICATION TREND OF AV-RELATED INVENTIONS



Billions have been poured into technology research and development (R&D) as various players race to get self-driving cars on the road. Accompanying the huge investment is a high level of technological innovation output. A total of ~42 thousand inventions relating to AV technologies were published in the last decade. In particular, the innovation activities in the most recent 5 years of 2014-2018 were fast increasing at 24.9% per annum, significantly outpacing the annual growth of 14.4% in the earlier 5-year period of 2009-2013. This indicates that the competition is heating up and the technology space is getting increasingly congested. With such continual investment, various players are expected to churn out further inventions making the already crowded technology space difficult to manoeuvre.

TOP 5 APPLICANT ORIGINS

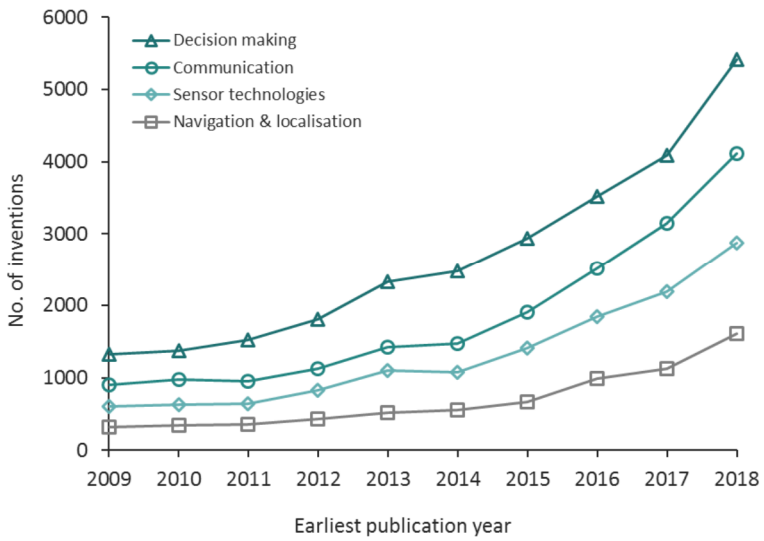


Accounting for more than 45% of the global AV-related inventions published in 2009-2018, China is the most active country in AV-related technology innovations in the last 10 years. The high innovation output is consistent with its ambition to become a dominant player in the smart mobility space. 290 cities in China have initiated 'smart-city' pilot projects, including 93 that focus on mobility involving driverless cars.[3] In addition, the Chinese government has also laid out national guidelines for testing self-driving cars as it looks to keep pace with the world leaders in a global race to develop autonomous vehicles.[4]

Ranking at the second to the fifth, respectively, are Japan, Germany, South Korea, and the U.S., each of which accounted for around 5 thousand inventions. Their AV-related innovations stem from their strong foundation in core technologies, particularly in the automotive industry.

There were around 20 inventions contributed by Singapore local applicants. While the level of innovation output is not significant in number compared to the most innovative countries, it shows an increasing trend that is consistent with the growing importance of AV in Singapore as most of the local inventions were published in the recent years.

AV-RELATED TECHNOLOGY DOMAINS



With close to 27 thousand inventions published, *Decision making* represents the largest AV-related domain. It encompasses technologies such as emergency braking, lane keeping, adaptive cruise control, collision avoidance, and parking assistance. These technologies enable highly automated and driverless cars to handle complex traffic situations and function in adverse weather conditions. *Communication* such as vehicle-to-vehicle and vehicle-to-infrastructure communication, and *Sensor technologies* including lidar, sonar, radar, and cameras were also well studied, registering around 19 and 13 thousand inventions in the last decade, respectively.

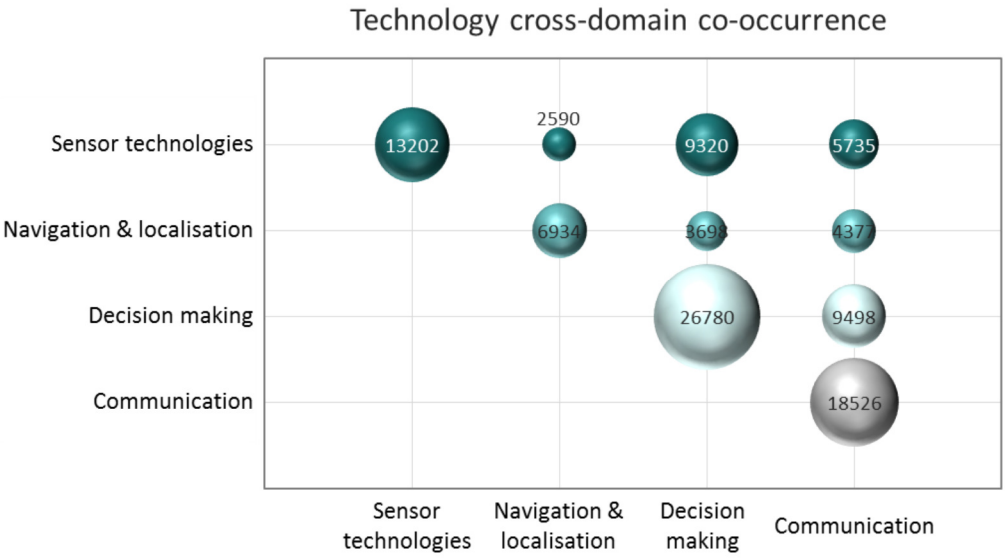
The competitiveness of these three well-explored domains is also reflected by the large portfolio sizes of the top players, many of which are renowned original equipment manufacturers (OEMs) and OEM parts suppliers in the automotive sector. Among them, for example, are Toyota Motor - the world's sixth-largest company in the world,[5] and Robert Bosch – the world's largest OEM parts supplier.[6] The intensive ring-fencing by these players with large patent portfolios could make the market entry difficult for players without a strong technology foundation.

Navigation and localisation, on the other hand, has been less explored, with less than 7 thousand inventions published in the same 10-year period. As the domain is less crowded with reduced head-to-head competition, it may represent an area that is easier for companies to establish their footprints.

Sensor technologies	Navigation & localisation	Decision making	Communication
Robert Bosch [448]	Robert Bosch [245]	Toyota Motor [983]	Toyota Motor [817]
Valeo [351]	Toyota Motor [242]	Robert Bosch [867]	Robert Bosch [568]
Denso [344]	Denso [182]	Daimler [673]	Denso [555]
Toyota Motor [317]	Daimler [127]	Denso [667]	Ford [427]
Ford [288]	Honda Motor [122]	Hyundai Motor [467]	Daimler [367]
Hyundai Motor [271]	Hyundai Motor [119]	Valeo [452]	GM [316]
Daimler [257]	Nissan Motor [118]	Audi [352]	Hyundai Motor [293]
Hyundai Mobis [207]	Ford [117]	Ford [339]	Honda Motor [257]
GM [168]	Audi [116]	BMW [333]	BMW [228]
Audi [154]	Valeo [115]	Hyundai Mobis [315]	Valeo [228]

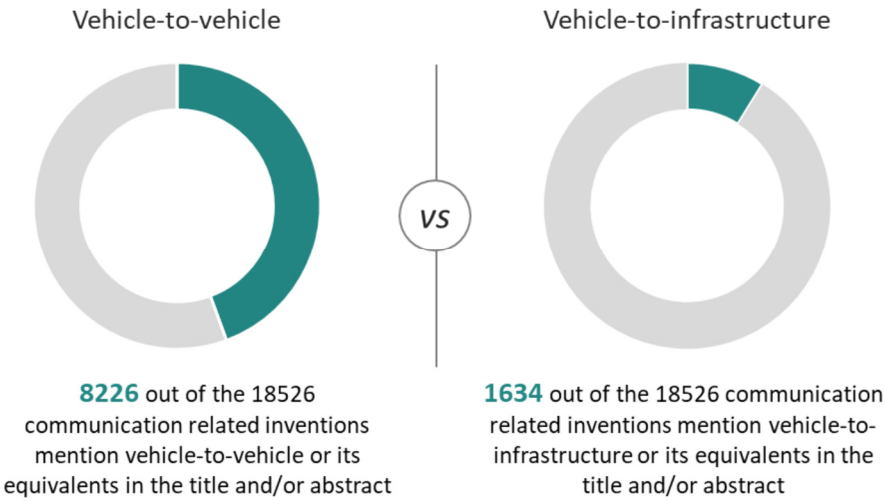
The number in the parentheses represents the number of published inventions owned by the applicant.

For a vehicle to be truly autonomous, it needs to have full awareness of not only itself but also its environment. This requires a seamless system integration of various technologies ranging from sensors for perception, communication with its surrounding cars and infrastructures, to data processing and decision making. The strong interaction between the different domains is also captured by the sizeable overlaps as shown in the cross-domain co-occurrence. When developing a specific technology, it is important to also consider how the technology would interact with other systems upstream and downstream.

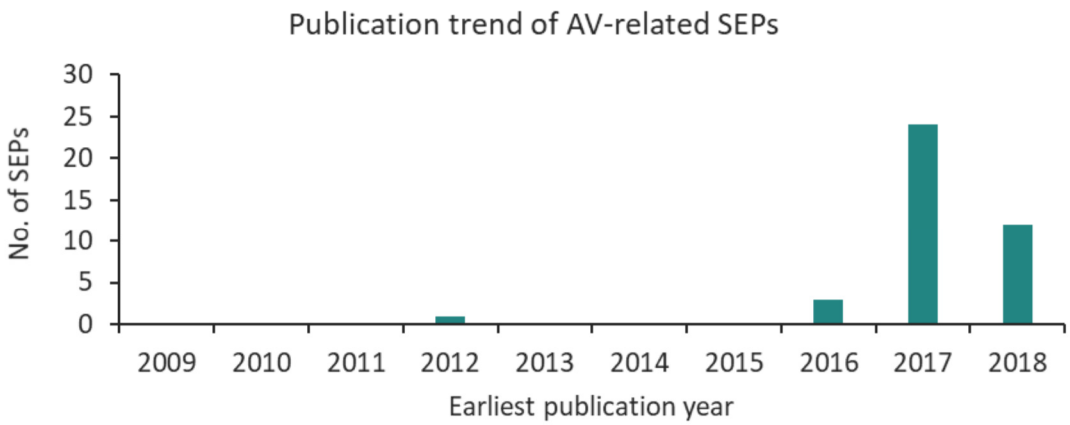


Among the ~19 thousand inventions under Communication, more than 8 thousand (44.4%) mention vehicle-to-vehicle (V2V) communication technologies, significantly higher than that of vehicle-to-infrastructure (V2I) communication technologies. This suggests that the industry has placed a much stronger emphasis on developing V2V communication in the past ten years.

Building on its on-going Smart Nation initiatives and investments in infrastructure, Singapore is in a good position to ride the innovation curve of V2V and V2I communication. The island city-state is working towards being an ideal testbed that provides the infrastructure[7] that is required for developing vehicle-to-everything communication technologies and thus becoming a leader in the domain.



EMERGENCE OF STANDARD ESSENTIAL PATENTS



Top SEP holders

8 SEPs

7 SEPs

6 SEPs

5 SEPs

4 SEPs

It is also important to note that standard essential patents (SEPs)* are emerging in the field of AV-related technologies. Within the dataset, 40 inventions were declared to be SEPs, the majority of which were published in the most recent three years. Intel leads the list of top SEP holders with 8 SEPs, followed by Huawei who has declared 7. The next three spots are occupied by Samsung, ZTE, and Qualcomm, with 6, 5, and 4 SEPs, respectively.

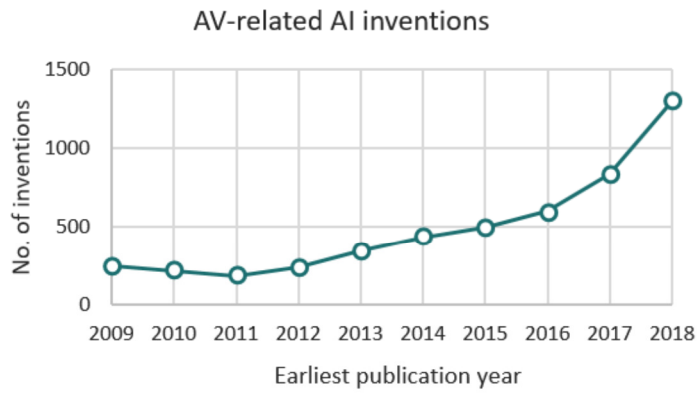
Most of the SEPs declared relate to the *Communication* domain. As communication technologies play a pivotal role in highly automated and autonomous driving, it is important to keep track of the development of AV-related SEPs, especially given the complexity involved in SEP licensing. Comprehensive monitoring of the SEP activities would enable the different users to have the right patent licensing strategy. Specifically for technology developers, knowing the SEP development is essential to ensure that their products are in accordance with the technology standards.

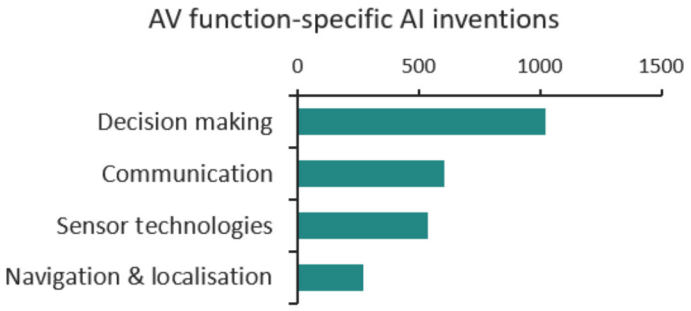
*A standard-essential patent (SEP) is a patent claiming technology that must be used in order to comply with a technical standard. It differs from other patents in that any subsequent or related invention within the technology concerned must inevitably use the patented invention specified in the SEP and licensing is, therefore, usually not an option.

STATE OF AV-RELATED AI TECHNOLOGIES

At full automation, self-driving cars operate with no human intervention. That is, all decisions are made by machines that must have some form of artificial intelligence (AI). Indeed, AI has been gaining strong traction from the industry. The top automobile manufacturers and OEMs have also been very active in developing AI technologies, especially for the purposes of driver/vehicle recognition, driver behavior analysis, and speech/gesture command.

AI inventions specific to the four AV-related domains, however, are much less explored, with only 1451 inventions recorded in 2009-2018. Expectedly, the majority of the inventions are directed to assist decision making. The top players have relatively small portfolio sizes relating to AV function-specific AI technologies, with the top player Ford having only 40 inventions published in the last 10 years. Chinese universities and small medium enterprises (SMEs) constitute half of the top 10 players. The lack of companies with large technology portfolios and the presence of universities and SMEs among the top players are further indications of the nascency of the area. Application of AI to AV technologies thus represents a potential area for further R&D.





Top players

Overall AV-related AI inventions	AV function-specific AI inventions
Hyundai Motor [227]	Ford [45]
Ford [157]	Hyundai Motor [24]
Denso [134]	GM [23]
Toyota Motor [128]	Toyota Motor [21]
Honda Motor [112]	Dalian Loulan Tech [20]
Volkswagen [111]	Daimler [19]
Audi [106]	South China Univ Tech [17]
GM[102]	Univ Elect Sci Tech China [17]
Daimler [84]	Beijing Kuangshi Tech [16]
Robert Bosch [56]	Shanghai Jiao Tong Univ [15]

The number in the parentheses represents the number of published inventions filed by the applicant.

CONCLUSION

In conclusion, this report provides an overview of AV-related technologies based on relevant patents applications published worldwide in the last decade. The increasingly fast-growing patenting activities indicate that there is strong interest in AV-related technologies and the space may soon get congested. At the specific domain level, Decision making, Communication, and Sensor technologies are well-studied, whereas the Navigation and localisation domain is less explored. Within the Communication domain, Singapore is in a good position to ride the innovation curve of V2V and V2I communication to develop vehicle-to-everything communication technologies. AV -related SEPs and the use of AI for autonomous driving are fast emerging. While SEPs represent a space that needs to be closely monitored given the complexity involved in SEP licensing, AV function-specific AI development is still at its nascency and is an area of R&D opportunities.

REFERENCES

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3. South China Morning Post: *China to spearhead US$1 trillion autonomous driving revolution*
4. http://english.gov.cn/state_council/ministries/2018/04/13/content_281476110368454.htm
5. Fortune Global 500 List 2018
6. Automotive News: 2018 Top Suppliers
7. AV testbeds in Singapore include the Jurong Innovation District where the CETRAN AV Test Centre is located, the one-north district, the National University of Singapore (NUS), Singapore Science Park 1 and 2, Sentosa and Jurong Island.

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