Business Innovation Observatory

Self-driving vehicles and industrial applications

Case study

Internal Market, Industry, Entrepreneurship and SMEs

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Creating value through self-driving vehicles

Key market

21 million	**500** billion €
autonomous vehicles sold annually by 2035	autonomous vehicle market will become a €500 billion market in the next 20 years

Overall benefits of self-driving vehicles

Autonomous vehicles will contribute a total of €17 trillion to the EU GDP (by 2050)	Increased road safety and reduced congestion	Environmental benefits due to green technologies and efficient driving

Key lessons learned for SMEs

- Take advantage of increasingly affordable prices of self-driving technology and hardware components
- Aim for broad applicability of solutions by placing them on as many markets as possible with a particular focus on the promising markets (such as Germany, the US, and Asia-Pacific)
- Consider engaging in partnerships with universities or other public-private initiatives, and at the same time try to develop working applications as soon as possible by testing in real-life situations
- Participate in global accelerator programmes to create a strong network of investors, media and clients
- Adjust recruitment procedures to adapt to the shortage of domain specialists by focusing on skills or commitment rather than education attainment, or by hiring talent in other EU and non-EU countries

Use cases

				
Local delivery robots	Infrastructure-less indoor navigation technology	3D Ultrasound echolocation sensors	Full vehicle automation technology	Electric and autonomous shuttles

Insights for business intermediaries and policy-makers

- Align legislation to the technological advances in autonomous vehicles
- Adapt safety certification to driverless vehicles
- Focus public support on business accelerators

Executive summary

Self-driving, or autonomous vehicles, which can navigate without a human operator, are increasingly being adopted in a variety of industrial settings. Solutions like infrastructure-less indoor navigation, 3D ultrasound sensor systems or technology for full automation of vehicles, which are some of the solutions presented in this case study, have already been introduced as innovative industrial applications.

In addition to becoming a €500 billion market within the next 20 years, autonomous vehicles will lead to increased road safety, reduced congestion, and environmental benefits due to green technologies and efficient driving.

Insights from the management of the firms that developed the successful innovative solutions presented in this case study suggest that companies should pay particular attention to the following:

- take advantage of increasingly **affordable prices** of self-driving technology and hardware components;
- aim for **broad applicability** of solutions by placing them on as many markets as possible with a particular focus on the promising markets (such as Germany, the US, and Asia-Pacific);
- consider engaging in **partnerships** with universities or other public-private initiatives, and at the same time try to develop working applications **as soon as possible** by testing in real-life situations;
- **participate in global accelerator programmes** to create a strong network of investors, media and clients;
- **adjust recruitment procedures** to adapt to the shortage of domain specialists by focusing on skills or commitment rather than education attainment, or by hiring talent in other EU and non-EU countries.

Business intermediaries and policy makers can support the development of innovative solutions by addressing and providing support to some of the issues that are highlighted in this case study. First, autonomous driving technology is advancing at an incredible speed and legislators need to act quickly in order to take advantage of the growth potential in this area.

Second, **safety certification** should be adapted to driverless vehicles by allowing testing through simulators. Moreover, certification should ensure a high level of cybersecurity for these vehicles.

Finally, public support should be focused on **business accelerators** in the field, which can provide access to valuable networks and are more easily accessible than innovation grants.

Guide to the case study

This case study was developed under the Business Innovation Observatory. It describes the self-driving vehicle market and its socio-economic potential, focusing on some innovative industrial applications. It showcases five successful European companies that responded to business and technological challenges concerning autonomous vehicles. Based on the experience of the companies, the case study describes the main drivers for innovation and growth on the self-driving vehicles market, which can serve as an inspiration for other Small and Medium Enterprises (SMEs) and as an insight for policy-makers and business intermediaries.

1 Self-driving vehicles: from concept to reality

1.1 Introduction to the self-driving vehicles market

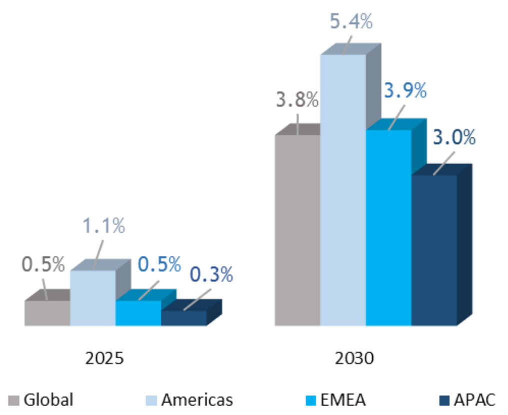
Self-driving vehicles (also referred to as autonomous or automated vehicles) are those designed to navigate without a human operator. Thanks to specific technology, driving functions are transferred to a computer. Over the last few years, many of the major vehicle manufacturers, suppliers, and technology companies have begun projects or collaborations in order to develop innovative industrial applications related to the self-driving vehicles market.

This case study focuses on some of the industrial applications of autonomous vehicles, such as logistics, warehouse management and delivery.

Market potential

Global sales of fully autonomous vehicles (level 4 and level 5 vehicles) are expected to reach 600,000 units per annum by 2025, and 21 million units per annum by 2035, with around 76 million vehicles with some level of autonomy[1] sold by 2035 (IHS Markit, 2016). According to IHS, the self-driving vehicles potential will drive a compound annual growth rate of nearly 63% between 2020 and 2040, improving mobility in various use cases and business models. The penetration rate will reach from 3 to 6% in the different regions in the next 15 years (see Figure 1). The autonomous vehicle industry is expected to become a €500 billion market within the next 20 years (LeSage, 2016).

Figure 1 - Self-driving light-vehicle market penetration rate



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Main figures

- The US is expected to see the earliest deployment of autonomous vehicles, as it works through challenges posed by regulation, liability and consumer acceptance
- Europe, Middle East and Africa are expected to be driven by technology advancement in Western Europe
- Volumes in China are likely to be driven by consumer demand for new technologies and the large number of vehicles expected to be sold
- Japan and South Korea will be supported by regional consumer affinity for technology

Source: IDC, 2016

Source: IHS Markit, 2016[2]

The biggest autonomous vehicle market, the self-driving car market, is expected to grow between €37.4 billion and €68.5[3] billion between the years 2025 and 2035 (Boston Consulting Group, 2016)[4]. The autonomous electric bus sector is expected to grow annually by 29% between 2016 and 2020 (Technavio, 2016b), while the autonomous truck sector will grow by 60,000 vehicles per year by the year 2035 (Eisenstein, 2016).

As a sub-sector of the self-driving vehicles market, the mobile robots market[5] was valued globally at €2.3 billion in 2015. It is expected to reach €4.8 billion by 2020, with an annual growth rate of 15.8% (Technavio, 2016).

[1] SAE International identifies 5 levels of automation as follows: level 0 stands for no automation, level 1 for driver assistance, level 2 for partial automation, level 3 for conditional automation, level 4 for high automation, and level 5 for full automation.

[2] Americas: North- and South-America; EMEA: Europe, Middle-East and Africa; APAC: Asia-Pacific.

[3] All figures in US$ have been converted in € based on average US$/€ exchange rate in 2016.

[4] Analysts estimate also that between 2 and 15 years self-driving cars will be on the roads (Yadron, 2016).

[5] Covering Unmanned Ground Vehicles (UGV), Unmanned Aerial Vehicles (UAV), and Unmanned Maritime Vehicles (UMV).

Table 1: Global market of unmanned ground mobile robots, by sector in 2015 (€ millions)

Industrial	Warehouse	Medical and Healthcare	Agriculture, Mining and Forestry	Defence	Total
757.8	250.9	864.9	237.5	220.5	**2331.6**

Source: Technavio, 2016

Applications

The expected growth of the market of self-driving vehicles is connected to their widespread industrial applications. Automated robots are already used extensively in the following areas: *Warehousing, Medical and healthcare, Agriculture, Mining and forestry,* and *Defence*.

In Warehousing, self-driving vehicles, and more specifically **autonomous delivery robots** may radically change logistics and delivery of goods. It is expected that package-delivering drones/vehicles and micro-buses making commutes efficient and cheap are going to be among the technologies that will define the next decade in cities (O'Donnell, 2016). For example, Daimler AG will invest more than €500 million over the next five years to develop an advanced ecosystem of vans, flying drones, and robots in order to speed up the delivery of packages and people (Korosec, 2016). Wheeled, autonomous delivery robots are already making their first deliveries (Etherington, 2016) and self-driving vehicles are being used in warehouses of major industries to sort, move, store, pick up, and deliver materials and goods in and out of the warehouse. As it will be further analysed in the following section, Europe is assisting to the success of companies providing applications, which allow for a more dynamic, precise and cost-less warehouse management. Although robots have been around in warehouses for a while, the new generation will be entirely autonomous and will not require any investments in infrastructure such as buried wire, tape or laser along pre-set routes (Fortune, 2016). This will allow for increases in flexibility and efficiency.

In the Medical and Healthcare industry, self-driving vehicles are being used to improve the flow of logistics. Automated vehicles are mainly used to transport surgical tools, medical supplies and mobile laboratory specimens. They are deployed for both intra-departmental and inter-departmental use, and provide on-demand and scheduled transport of these items, which allows nurses to focus on value-adding activities.

In the agricultural industry, self-driving vehicles are mainly used for automatically ploughing and fertilising the farmlands. Besides this, orchards can be sprayed autonomously, minimising human exposure to hazardous pollutants (Benady, 2016).

In the mining industry, field robots, known as autonomous haul systems trucks (AHS), are used for carrying heavy loads of ores from the mine to the processing centre. Haul trucks can be used for dumping and loading at mining sites. In the forestry industry, self-driving vehicles are used for planting and harvesting trees, especially on difficult terrain like for example the Scandinavian forests (Billingsley, Dunn and Visala, 2007).

Finally, in the defence industry, self-driving vehicles are used to avoid putting soldiers at risk. By using autonomous minesweepers, military trucks, and even autonomous weapons, the defence sector has a big stake in the development of self-driving vehicles (McMahon, 2016).

Current developments

The rise of **autonomous delivery robots** is also witnessing a change in traditional delivery methods. Every year Americans and European consumers receive about 20 billion deliveries, and make about 130 billion trips to pick up groceries or other small items (Terdiman, 2015). The boom in electronic commerce has forced logistics companies to find new faster ways to deliver packages to customers (Korosec, 2016). Autonomous robots can play a large role in the growing delivery business, particularly in the so-called last-mile deliveries. These robots are expected to limit last-mile costs, which may rise by up to 70% by 2030 due to congestion costs, environmental pressures, and increasing transportation costs (Ernst & Young, 2015).

In Europe, **autonomous shuttles** have recently driven their first miles on public roads. The number of self-driving shuttle test projects is rising together with an increasing interest of policy-makers, city planners, and mobility experts. At the moment, autonomous shuttles navigate on fixed routes with controlled environments and are mainly used in college campuses, airports and theme parks. Eventually, however, they will be able to drive completely autonomously. In both Finland and Greece, driverless vehicles are allowed on public roads and more projects are expected to follow in France, Italy and other European countries (Kelly, 2016). The province of Gelderland in the Netherlands is even working on its own autonomous shuttle project, showing the need for knowledge development on this topic as well as the urgency for novel mobility solutions (Murgia, 2016).

All these developments are made possible by **improvements in the available technology**, both in software and in hardware. On the software side, machine learning is a big driver for progress, while on the hardware side, major improvements in technological capabilities and drops in prices are seen. Currently, Light Detection and Ranging (LIDAR) sensors and camera technology are most frequently used in self-driving vehicles, although there is growing consensus on the limitations of their capabilities, indicating the need for further research (Dennehy, 2016).

Overall, the self-driving vehicles market is characterised by developments having to do both with the range of applications within different areas and sectors, and to the improvement in technologies aimed at enhancing performance. The innovative solutions identified for this case study concern both developments.

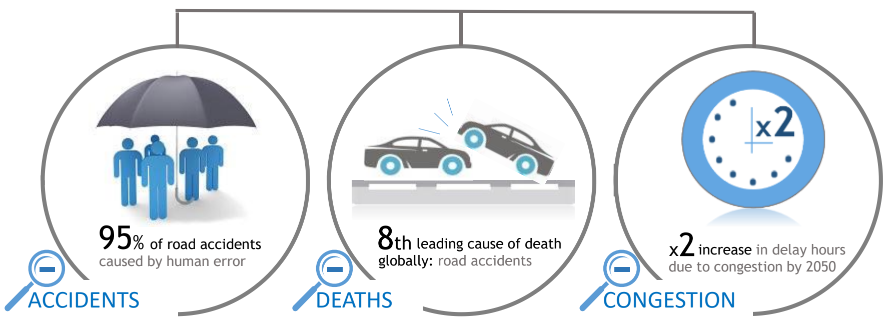
1.2 Benefits of self-driving vehicles

Safety

Self-driving vehicles are expected to provide various socio-economic benefits in Europe (Hsu, 2016). One of the major benefits of self-driving vehicles is increased personal and industrial safety. As human error is the main reason for 95% of road traffic accidents in Europe, autonomous vehicles are expected to make the roads safer (EY, 2015). In manufacturing plants, and other areas like hospitals or mines, autonomous robot vehicles can help to augment personnel safety by eliminating tasks of carrying heavy loads or repetitive strain.

Besides increased safety, better asset utilisation and reduced congestion are other benefits of the deployment of self-driving vehicles. The use of delivery robots and autonomous shuttles is expected to lower the increasing pressure on city roads. Congestion in the EU costs nearly €100 billion per year, about 1% of the EU's GDP (European Commission, 2016). Driverless systems will expand road capacity and reduce congestion by using the Global Positioning System (GPS) and sensing technologies to efficiently route vehicles through traffic conditions. Delays due to traffic conditions are expected to double by 2050 and to affect billions of urban dwellers worldwide (Figure 2).

Figure 2 – Benefits of self-driving vehicles



Source: EY, 2015b

Environmental benefits

Autonomous robot vehicles in the industry facilitate manufacturing by eliminating waste of materials during movement. The expected environmental benefits of self-driving vehicles are not only a result of more efficient driving, but are also due to the increasing use of green technologies. For example, the autonomous shuttles that are being tested today are all powered on electricity, which will decrease CO2 emissions in the cities (Philips, 2015). Robotic applications for logistics and delivery of goods are focusing on energy efficiency, through minimal emission systems.

Growth and job creation

Self-driving vehicles will also have strong economic impact in the long-run. According to Automotive World (2016), by 2050, autonomous vehicles will have contributed to a total of €17 trillion to the GDP. A study commissioned by the German Federal Ministry of Economics estimates that the German market for driver assistance systems and automated vehicles will be worth €8.8 billion and will create about 130,000 jobs by 2025

(Lutz, 2016). However, in the long term, professional drivers are expected to suffer when full automation is implemented in public transport, passenger cars and trucks (European Parliamentary Research Service, 2016)

Overall, self-driving vehicles will enable an integrated transport system which is faster, safer, and cleaner and allow the release of land for alternative use. Delivery robots will help with problems of last-mile delivery, provide cleaner transportation of goods, and help decongest overcrowded cities.

2 European success stories

This case study presents five innovative European solutions (Table 2), which address different areas of the self-driving vehicles market, ranging from providing sensors to fully-equipped self-driving shuttles.

Table 2: Selected innovative solutions

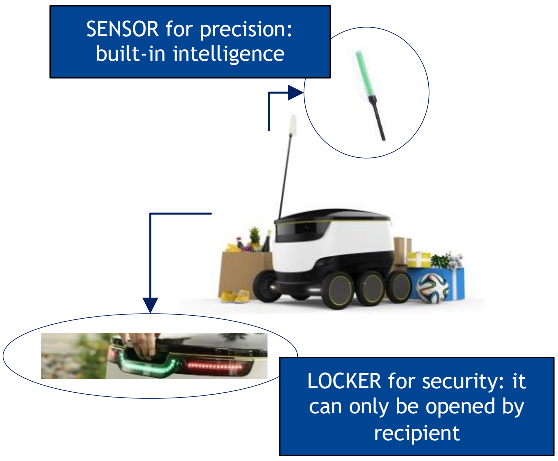
No	Innovative solution	Company	Country	Signals of success
1	Autonomous courier for local delivery	**Starship Technologies**	UK/EE	▶ Partnership with Mercedes-Benz ▶ Pilot testing in several cities in Europe and the US
2	Electric and autonomous shuttles	**NAVYA Technologies**	FR	▶ BFM Awards 2016 – "Revelation of the year" prize ▶ €30 million raised capital ▶ Greater Paris Metropolitan Area Smart City Trophy in smart mobility category
3	Optical navigation technology for self-driving robots	**Accerion**	NL	▶ Developed a patent-pending positioning technology for their innovation ▶ Raised €623,000 in two financing rounds
4	3D ultrasound-based technology for echolocation	**Toposens**	DE	▶ Capital Raised: €150,000 in grants ▶ Part of several accelerator and incubator programs ▶ First prize at the IT Innovation Summit in the category "Technology"
5	Fully self-driving enabling technology	**Aimotive**	HU	▶ Over $8 million of funding ▶ Currently engaging in partnerships with Nvidia and Volvo

More details on the showcased European innovations and the business/technological challenges that they address are provided below, also based on interviews with company representatives.

Innovative solution 1: Autonomous courier for local delivery

1	**Business challenge:** Instant and unscheduled delivery of packages is very costly through the traditional shipment methods and decreases profitability **Technological challenge:** How to establish a local delivery system that is autonomous, safe, and energy-efficient at the same time?

Figure 3 - Starship delivery robot



Source: *https://www.starship.xyz/, 2016*

Starship Technologies (UK/EE) has developed a personal courier (autonomous robot), which can change the way local delivery is performed, while addressing key technological challenges such as energy efficiency and security of delivery. Their solution combines mobile technology, specially designed robots that can carry items within a 5km radius, and a local hub system. **Clients can send requests via a mobile app and the robots' entire journeys can be monitored on a smartphone**. Thanks to its built-in intelligence, it guarantees a very high level of precision in movements.

The robots move at pedestrian speed and can navigate autonomously around objects and people. The cargo bay remains locked throughout the journey and can be opened only by the recipient. They offer minimal emissions and energy efficiency even for small deliveries.

Overall, the Starship platform aims at increasing the speed and lowering the price of shipments. The company's objective is to achieve 99% autonomy of the robots, which means there will be a very small element of human oversight in case the autonomous courier meets unforeseen obstacles.

Innovative solution 2: Electric and autonomous shuttle

2	**Business challenge:** The waiting time for on-site employees, their flow of displacement, and the associated transportation costs are sources of inefficiency for the industry **Technological challenge:** Autonomous shuttles need to fuse together an enormous amount of information from different sensors and to analyse it quickly in order to take optimised and safe routes

Figure 6 - Navya Arma

Source: http://navya.tech/, 2016

The **NAVYA ARMA (FR)** is an electric and autonomous shuttle that can transport up to 15 people and drive at a speed of 45 km/h. Its batteries can be recharged by induction and can last from 5 to 13 hours, depending on the configuration and the traffic conditions. The shuttle does not require any special infrastructures and can easily change routes, thus achieving shorter waiting times and higher efficiency in transporting.

The shuttle uses LIDAR Sensors allowing precise positioning and obstacle detection; GPS Real Time Kinematic to determine the position of the vehicle; an odometer, estimating the velocity of the vehicle and confirming its position; and camera stereovision for analysis of the environment.

Navya's vehicle is intended for personnel, visitors or service agents on private sites, in environments such as urban areas, industrial sites, hospitals, and airports. The fleet of self-driving vehicles may provide a higher frequency, which would reduce the waiting and transport time, while decreasing the transportation costs. Currently, each autonomous shuttle can transport 2,000 to 3,000 passengers per day.

Innovative solution 3: Optical navigation technology for self-driving robots

3	**Business challenge:** Self-driving vehicles in warehouses manufacturing plants can bring many benefits, but their integration may be slow and the needed infrastructure could be costly **Technological challenge:** One of the main challenges with self-driving vehicles is the provision of accurate indoor positioning without infrastructure

A solution based on optical navigation technology, developed by **Accerion (NL)**, provides navigation in dynamic environments without the need for investments in additional infrastructure, such as magnets, induction lines, or radio beacons. This solution simplifies the introduction of autonomous robots in a cost-effective manner. It supports arbitrary routes and can allow reaching higher speeds than conventional technologies. The solution can be used indoors and outdoors, on mixed ground surfaces. This enables applications in manufacturing plants, warehouses, agriculture, hospitals, and leisure vehicles, where GPS reception is typically non-existent or limited.

Innovative solution 4: 3D ultrasound-based technology for echolocation

4	**Business challenge:** Different types of sensors are available on the market, but often their cost is too high **Technological challenge:** Developing a sensor that is both low-cost, highly-applicable and provides at least the same precision as existing devices

The **Toposens 3D (DE)** ultrasound sensor makes it possible for machines and robots to see with sound and better perceive their surroundings. Following similar principles of the echolocation as bats, the sensor can identify very small objects by emitting ultrasound signals and receiving their reflections. The result is very high recognition precision as well as low energy usage due to the small size of the device. Due to the lack of optical components, the sensor is highly suitable for sensitive environments that have a need for privacy protection.

The sensor can be used to perceive 3D positions of objects and people, and allows detecting, counting and pathway tracking of people. The data generated by this device can be used in industrial infrastructure, retail analytics, smart homes, and public transport.

Figure 4 - Toposens 3D Sensor

Source: http://www.toposens.com/, 2016

Innovative solution 5: Fully self-driving enabling technology

5	**Business challenge:** How to deploy accessible self-driving vehicles faster to market without compromising safety **Technological challenge:** Providing software that enables fully (level 5) self-driving vehicles, which can operate on a global scale and in all weather conditions, is a particularly challenging task.

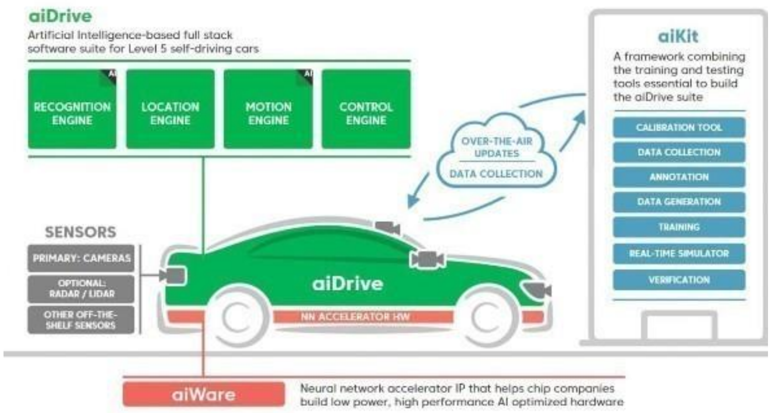
Aimotive (HU) developed a system (called aiDrive) that can make vehicles completely autonomous and able to operate in all-weather circumstances and all over the globe. Its application is scalable and can be used in a variety of vehicles such as cars, trucks, and trams.

The solution uses neural networks and machine learning and builds on four software engines:

- *a recognition engine*, which combines and processes sensor data using a convolutional neural network based segmentation model capable of recognising more than 100 different object classes;
- *a location engine*, which enhances conventional map data with 3D landmark information, and can work with any default navigation systems;
- *a motion engine*, which receives positioning and navigation output from the Location Engine and combines it with the predicted state of the surroundings to determine the correct trajectory for the vehicle (see Figure 5);
- *a control engine*, which allows the vehicle to be controlled through low level actuator commands (e.g. steering, breaking, acceleration).

The company's objective is to deliver a product that would see the environment just as a human being can see it, which is why the technology is vision-based.

Figure 5 - The Aimotive ecosystem



Source: https://Aimotive.com/, 2016

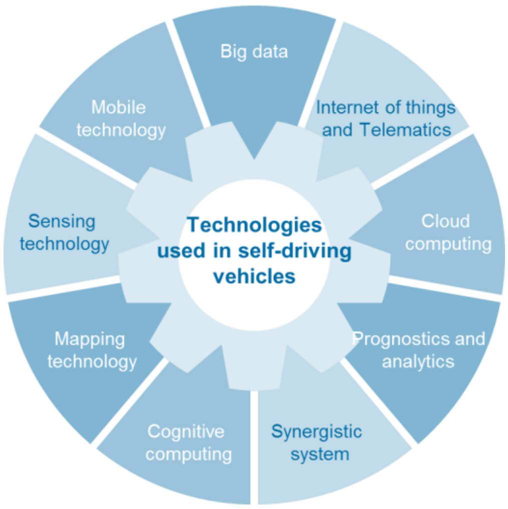
3 Drivers to innovation and company growth

The main reason why the topic of self-driving vehicles is such a 'hot' innovation is that the existing technology has now reached a level which enables a wide range of applications. The main driver for autonomous vehicles has been the rapid advances in technological capabilities in recent years. For this reason, the presentation of the drivers to innovation and growth in the self-driving vehicles domain begins with a description of the key technological advances.

3.1 Technological advances - sensing technology and artificial intelligence in self-driving vehicles

The widespread increases in scale and diversity of currently available data about personal and population-level transport is being enabled by the adoption of smartphones and improved accuracy for a variety of sensors (Stanford, 2016). This availability of data and connectivity makes possible key elements of autonomous vehicles such as real-time sensing, prediction of traffic, and route calculations. Self-driving vehicles use many diverse technologies (see Figure 7), whose advancement is accelerating and proliferating at an unprecedented rate (EY 2016b). This case study focuses only on the key ones.

Figure 7 - Technologies used in self-driving vehicles



Source: EY, 2016

Computer vision. Of all available sensors, video-as-a-sensor might emerge as the most important one, particularly in urban environments. Computer vision could support a real-time 3D map of the city that could be used for guiding self-driving vehicles (O'Donnell, 2016). In relation to computer vision, major improvements in camera technologies over the last years allowed Aimotive to develop their solution. Cameras are considered the master of classification and texture interpretation. They are also the cheapest and most available sensor and unlike LIDAR (described below), cameras can see colour, making them the best option for scene interpretation (Santo, 2016).

Light Detection and ranging technology. LIDAR sensors are capable of detecting objects as small as a pebble from more than 100 meters away (Markoff, 2015). These sensors, however, also have some disadvantages if compared to other technologies: cost (although decreasing), decreased precision in poor weather conditions, and generation of enormous amounts of data. The average LIDAR sensor costs about €7,000, increasing the need for other, more cost-efficient sensors (Tilleman and McCormick, 2016). As a consequence of its detecting capabilities, this technology will probably be used in self-driving vehicles on the roads mostly as a safety feature. Autonomous mobile robots do not necessarily need it. For example, Accerion's solution is not LIDAR-based technology. Their expectation is that within the next 5 years, better camera vision-based systems as well as radar-based systems in an array could be the future of autonomous robots. The 3D sensor system developed by Toposens, which combines ultrasound and radar is another example of a precise and cost-effective tool for people and object detection.

Artificial intelligence (AI). Transport is expected to be one of the first domains in which the general public will be asked to trust the reliability and safety of an artificial intelligence system for a critical task (Stanford, 2016). Once the hardware is sufficiently safe and robust as a result of the application of different sensor and navigation technologies, AI would enable autonomous transportation to be quickly introduced. In addition to the incredible speed of development of artificial intelligence, another related technological driver is the existing possibility for over-the-air software updates.

Improvements in satellite navigation technology. GPS, and more recently Galileo, technologies are constantly improving. An example for this is Real Time Kinematic (RTK), which is a technique applied in Navya to improve the precision of position data derived from satellite-based positioning systems. Technological advances per se are not the only explanation for the current rise of self-driving vehicles. Hardware development is a leading factor, but its affordability is equally important. An overall technology trend is for hardware to constantly become cheaper. Thus, the main value of self-driving vehicles lies in the software rather than the hardware technology. Even though Starship Technologies are using off-the-shelf hardware components, their proprietary mapping required significant investments. Furthermore, hardware components have also become miniaturised, which allows their integration in small robots.

3.2 Business models

In general, companies operating in the self-driving vehicles market can be differentiated based on whether they focus on the development of complete self-driving vehicles or specific underlying technological solutions.

- *Complete self-driving vehicle solutions*

First-movers advantage is characteristic for the two companies in this case study which developed complete self-driving vehicle solutions. Starship is the first company that already provides deliveries to clients using a robot which they designed and produced, while Navya can be considered as the first automotive company in the field of self-driving vehicles, which is already selling shuttles designed and produced by them.

- *Particular technological solutions, which currently target only specific, economically attractive segments and activities along the value chain*

Sensing technology and artificial intelligence are areas that still offer plenty of opportunities for technological and business development. For example, Accerion chose not to focus on autonomous cars simply because GPS reception is very good for cars and the technology is already available. The company focuses on areas without GPS reception, such as within buildings or behind walls. As an alternative to selling their positioning module, they are also considering licensing their technology to larger firms. A similar model is followed by Toposens. They focus on a small particular product – an echolocation-based 3D sensor, which is then offered to companies providing self-driving vehicles. Both solutions are developed as a response to a tough technological and business problem - satellite systems lack the capability to achieve high coverage and precise positioning in indoor environments, which is why indoor positioning systems generally require cost-intensive installations and are often restricted to specific buildings or even specific rooms inside a building (Attarde et. al, 2016).

> *"We have a very clear focus: we are only working on software elements. We don't have to look at hardware production which would slow us down"*
>
> **Aimotive**

Aimotive develops software which is hardware-independent, to allow the customers to decide on the sourcing of their hardware. Another component of their business model is that they offer Software as a Service (SaaS) to the automotive industry. In this way the software can be sold directly to customers.

3.3 Customers and markets – broad applicability and global outreach

As described in section 1.1, the applicability of self-driving vehicles is exceptionally broad. This leads to diverse customers and markets with a global reach. All companies in this case study are globally oriented, with Germany, the US, and Asia-Pacific region being the most promising markets.

For Accerion, the main clients (mostly companies producing autonomous robots) are in the Netherlands, the US, Turkey, and Denmark. The only drawback of becoming a company with a **global reach** at an early stage is the need to be in close contact with the customer as much as possible, which **is often difficult given the limited resources and scale**. A way to address this hurdle is to start up locally and collaborate within the local market first. Toposens, located in South Germany, operates mainly in its local area interacting closely with its clients. They offer their technology as **a platform technology that can be used for several products** and is easy to adjust, which allows them to operate in two main markets: one that focuses on autonomously moving vehicles such as robots, and one that focuses on smart buildings.

Navya also has the advantage of being very close to their clients in the development phase of their self-driving shuttle. They have two market divisions: one that serves the public market and one that serves the private market. The goal of the first one is to serve the public by transporting people in hospitals and cities, while the private division offers services such as transporting people to attractions in amusement parks and nuclear sites. As concerns public transportation, self-driving mini-buses, such as the one offered by Navya, could be the best way to close gaps in the 'last mile' between homes and the subway (Nikolaus, 2016).

Starship technologies (with an R&D team in Estonia) and Aimotive (with an R&D team in Hungary) ensure proximity to their clients through a very active marketing policy and through establishing offices in the UK and in the US. Starship's business model revolves around large outlets, which would ideally operate their own service hubs, and out of which the robots would operate. It is expected that these outlets would incorporate the end-user tools for ordering a Starship delivery into their mobile apps (Terdiman, 2015). Currently Aimotive serves customers predominantly from the automotive industry and their solution aims to allow vehicles to drive **anywhere in the world**.

3.4 Partnerships for testing self-driving technology

Three of the companies in this case study have close **partnerships with universities**. Accerion partners with the Eindhoven University of Technology; Starship Technology is taking part in testing programmes at innovation centres at Greenwich University and the University of Arkansas; and Navya is collaborating with Cortin University in Australia, the University of Michigan, Seoul National University, and the University of Grenoble. This shows increased interest of universities in applied research, but also the global scale of innovations in self-driving vehicles.

Testing of self-driving vehicles and the necessary technology is an essential element for all the companies studied. Starship started testing their mobile robots in real-life very early in their development, which is among the main reasons for achieving first-movers' advantage. Development and testing speed is also a core value for Aimotive, but as many of their self-driving vehicles travel at high speed, they did not start testing in real-life environments before reaching some maturity of the technology.

Considering the need for real-life testing, Finland launched a project, called '**Aurora'**[6] that offers closed and public test roads for self-driving vehicles. The Aurora network, which was joined by Aimotive, pools operators who are interested in testing and developing automated driving and intelligent transport systems in extreme weather conditions, and offers them an opportunity to participate in testing and development. Furthermore, the Finnish Transport Safety Agency (Trafi) is issuing **test plate certificates** to enterprises, agencies, or other organisations engaged in research and development of automated vehicles, so that they can test their vehicles in Finland.[7]

Other EU Member States (notably the UK, Sweden, Germany, France, and the Netherlands) are also taking steps to be at the forefront of research in the self-driving vehicles sector, such as the development of a Strategy for Automated and Connected Driving (Germany)[8] and encouraging cooperation between different stakeholders (Frisoni et al, 2016). The Dutch Automated Vehicle Initiative (DAVI)[9] is another public-private initiative in the sector, which was launched as early as 2013 in Europe. Its objective is to prove the safety of autonomous vehicles and it focusses on human factors in automated driving (Hoogendoorn, 2013).

The benefits of such partnerships are clear and governments are expected to find new ways to support self-driving vehicles infrastructures (Threlfall, 2016).

None of the companies in this case study expressed interest in partnership with business intermediaries. The overall perception is that they are more useful in other less state-of-the-art industries. The advice of partners and customers is considered to be much more valuable.

[6] For more information on the project: http://www.liikennevirasto.fi/web/en/e8-aurora/aurora-network#.WFLDNlMrKM8

[7] For more information on acquiring a test plate certificate: http://www.trafi.fi/filebank/a/1475139801/c715fc7cabf057b9320be4bbd6714cbe/22483-Testing_automated_vehicles_in_Finland_2016.pdf

[8] The strategy is available on this website address: https://www.bmvi.de/SharedDocs/EN/Publikationen/strategy-for-automated-and-connected-driving.pdf%3F__blob%3DpublicationFile

[9] For more information: http://davi.connekt.nl/about_davi/

3.5 Access to finance and funding

As companies are racing to bring self-driving vehicles to the market, investment activity is heating up. Deals in the auto technology domain were up 58% in 2015, while funding jumped 154% (CB Insights, 2016). This growth can be attributed to a number of seed deals for new autonomous driving start-ups, such as the MIT spinoff nuTonomy, which builds self-driving cars and autonomous mobile robots. The two companies in this study which work with the automotive industry also show **impressive results in terms of raised capital**. After starting up in 2014, NAVYA technologies raised €34.1 million, financed by multiple parties like Group8, Robolution Capital, Keolis, Valeo, Gravitation and APDecisif Management. In 2015 Aimotive secured a $2.5 million seed fund investment, and separated from Kishonti. Less than a year later it gathered over $8 million of Series A funding. Apart from opportunities for research and development, **external funding allows non-exclusivity**. If funding is received from only one source, for example an automotive Original Equipment Manufacturer (OEM), this might lead to limiting the market and scalability of the particular company.

> *"Don't think that a European venture capitalist will come to you before you generate any revenue: this will not happen, so don't waste your time on this too early."*
>
> **Toposens**

External financing has been essential also for Accerion (which raised more than €600,000 from Kickstart Venlo and LBDF – the Limburg Business Development Fund), but its participation in the global business accelerator programme, called "Startupbootcamp HigTechXL"[10] was also very beneficial. The programme focuses on hardware start-ups because they require a lot of capital and have longer change cycles. To a certain extent this **accelerator programme has proved to be more important** to the company than the actual funding, because it gave them a solid network and led to funding opportunities quickly.

Toposens has managed to secure governmental grants of up to €150,000 (EXIST Founders Scholarship for innovative start-ups and TechFounders). Similarly to Accerion's experience, the TechFounders accelerator has been very useful, because it connected the company with clients, investors, and media. The program brings together tech start-ups with industry partners and venture capitalists, and takes zero equity.[11]

Accelerator programmes are highly valued by start-ups, but nonetheless funding remains very important. In this regard, a particular issue that was raised during the interviews are the difficulties companies are facing in applying for EU-financial support (in particular the Horizon 2020 programme, which has a Call on Automated Road Transport).[12] Companies have the perception that EU-grants are focussing on established companies developing a new product rather than on start-ups. This may lead companies to stop looking into grants and to focus only on private funding.

3.6 People and talent

Self-driving vehicle companies have the advantage of being in an exciting domain which attracts talent from various fields. Nonetheless, ongoing disruption in the self-driving vehicles market has led to global competition for securing and retaining talent for vehicle innovation, software, and robotics. Finding the right talent in the area is the most important issue for big companies, but also for the small ones (Carson, 2016). There is no formal education in this field, so companies need to be inventive when they recruit people. For example, Aimotive has a **recruitment procedure which provides a head start** for their future employees. They ask potential candidates with various backgrounds and levels of knowledge to go through a 2-3 week test in order to identify the right skills and engagement.

Considering the shortage of specialists, companies in the self-driving vehicles domain need to **become truly international, often hiring talent outside the EU and building complementary teams**. This is the case with bigger companies like Navya, which employs people from 20 different nationalities and more than 40 engineers, but also for smaller companies like Accerion and Toposens. The experience of Starship and Aimotive (both SMEs) shows that Eastern European Member States like Estonia and Hungary offer good opportunities to quickly build a

[10] See: http://www.hightechxl.com/about/

[11] See: http://www.techfounders.com/

[12] See: https://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/calls/h2020-art-2016-2017.html#c,topics=callIdentifier/t/H2020-ART-2016-2017/1/1/1/default-group&callStatus/t/Forthcoming/1/1/0/default-group&callStatus/t/Open/1/1/0/default-group&callStatus/t/Closed/1/1/0/default-group&+identifier/desc

critical mass of autonomous vehicle talent. Both companies fit the profile of technology-driven businesses founded in the period 2012-2015 growing at an unprecedented pace (Harvard Business Review, 2016).

3.7 External risks

The transformation to automated driving offers many benefits, but the development stages are not without their challenges (EY, 2016).

Regulation of self-driving vehicles

The most important regulation in this field is the Vienna Convention on Road Traffic of 1968,[13] which is a treaty designed to facilitate international road traffic and to increase road safety. In 2016, the Convention was amended and automated driving technologies transferring driving tasks to the vehicle will be explicitly allowed in traffic, provided that these technologies are in conformity with the United Nations vehicle regulations, or can be overridden or switched off by the driver. These changes, however, do not go far enough and do not allow self-driving vehicles to drive faster than 10 km/h. This limitation might be removed potentially by the World Forum for harmonization of vehicle regulations in 2017, but at the moment it is a legal barrier in the sector.

> *"The big question we are facing today concerns legislation. We don't know which processes will need to be fulfilled to be compliant."*
>
> **Aimotive**

With the goal of providing common terminology for automated driving, in 2014, SAE International's standard J3016 provided a Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, which is widely used. The levels of automation range from 0 to 5, where 0 represents zero automation level and 5 represents the full automation level.

Enabling intelligent transport systems and automated and connected vehicles is a horizontal task for transport policy and economic policy of the European Union (Pillath, 2016), but **EU regulation has still not come up to speed with the latest technological developments**. The GEAR 2030 High Level Group for the automotive industry concludes that for levels of automation and connectivity above 3, EU legislation changes may be needed such as traffic rules, connectivity, driving license, road worthiness, liability framework, road signs, insurance, theft and cybersecurity, and privacy and data protection (GEAR 2030, 2016). Another conclusion of the High Level Group is that automated vehicles should be introduced 'step by step' and technical challenges for fully automated vehicles in any traffic conditions are still very high for manufacturers. However, two of the companies in this case study (Navya and Aimotive) **already aim at providing the highest level of automation** through their solutions. Considering the pace of technological advances, some Member States, including the Netherlands and Finland, are developing their own regulation in order to get a first-mover advantage in this field. This could lead to diverse requirements in Member States and a disjointed market for new driverless technologies, which would act as a barrier to growth for companies and the entire sector (Plucinska, J. and Posaner, J. 2016).

Furthermore, regulators should not only focus on self-driving cars. Innovations like ground robots, for tasks such as delivery services, should also be examined. Currently, a solution to the lack of particular regulation on autonomous delivery robots is offering legal exemptions to allow vehicles to travel on pavements in specific neighborhoods, such as the Segway two-wheeled motorised transportation vehicle, which was able to get such exemptions in many locations in the USA (Markoff, 2015).

Safety certification

Regulation of automated vehicles faces challenges to establish rules and, in particular, appropriate safety requirements have to be agreed on. It needs to be decided how the safety of automated vehicles should be tested and by whom (Pillath, 2016). Safety of autonomous devices is key, and companies in this domain are concerned about the **risk of potential 'cowboy firms'**, which might negatively affect the whole market of self-driving vehicles, if they do not take sufficient safety measures.

A major barrier for companies that work on developing solutions for self-driving vehicles, which will be used on the roads, is the fact that **simulated testing still needs to be approved**. For example, at the moment Aimotive

[13] For more information on the Convention: https://www.unece.org/fileadmin/DAM/trans/conventn/crt1968e.pdf

uses software that allows the vehicle to see simulated images as if they occurred in the real world. However, certification of this type of testing is only allowed for airplanes, but not for road vehicles. Thus, real-life testing might lead to huge costs for businesses operating in the sector.

Another concern with safety certification is its cost and the time needed to obtain certification. Some companies consider current **sensor certification procedures (lasting about 2 years) too slow and the process too costly**.

According to Bloomberg Technology (2016), due to the high level of data use and connectivity in self-driving vehicles, they could be highly vulnerable to cybersecurity risks. It is clear that these risks need to be fenced off before self-driving vehicles can be deployed fully, and this should be a part of the safety certification.

Insurance and liability

Many industries will be disrupted by self-driving vehicles, but perhaps the most complex challenges will be faced by the insurance industry (Crawford, 2015). The new possible causes of accidents created by automation might interfere with the very objective of liability regimes to apportion risks, therefore an **adaptation of liability law to the new technologies and European harmonisation of the regimes** concerning the liability of owners and/or drivers of automated vehicles is necessary (Pillath, 2016).

Public reception of self-driving vehicles

A constant challenge with emerging technologies is to work out how people will respond and the degree of social acceptance.

In the case of **autonomous delivery robots**, these can become a viable alternative to traditional delivery methods only if humans do not treat them as something to be abused (Lufkin, 2015). There are two issues that the designers of such robots should solve: making them as invisible as possible, and ensuring the security of the deliveries. Starship's experience so far proves that reception is generally positive and in many cases the autonomous robots do not even get noticed by humans. Their particular robot has already 'met' more than 2 million people and it has not been a target of abuse (O Malley, 2016).

It is quite surprising how people are receptive to **autonomous driving** even though very few people have actually experienced it so far (EY, 2015b). An EY survey of 1,000 drivers in Germany found that only 12% would categorically refuse to use a self-driving vehicle as a means of transport. This predominantly positive perception of self-driving vehicles was confirmed by the companies participating in this case study.

4 Conclusions

4.1 Key lessons learned for companies

In the self-driving vehicle segments presented in this case study (mobile robots and self-driving shuttles), vehicles are already performing real-life tasks. The technology is still being perfected, but it is already mature enough to become a major driver for growth and innovation.

► Follow the vast array of technology advancements in self-driving vehicle components

Technology advancements, such as computer vision, radars, LIDARS, and GPS, are experiencing an exponential growth both in terms of progress speed and reach. Self-driving technology is finally available and it is also affordable, which creates many opportunities for businesses in this domain.

> **Key message**
>
> Sophisticated self-driving technology is now widely available at affordable prices

Video-as-a-sensor might emerge as the most important sensor, but at the same time LIDAR technology is becoming more cost-effective and then used with more frequency. Transportation represents an example of industry that can gain efficiency and effectiveness thanks to that technology because of its safety features. New non-LIDAR based sensors are currently under development and are likely to result in further decreases in the price of self-driving vehicles’ hardware, and increases in safety and accuracy.

► Aim for broad applicability of self-driving solutions and global markets right from the start

Regardless of the type of self-driving vehicle technology (a particular solution/component or fully-equipped vehicle), applications are extremely broad and range from industry to hospitals.

The case study demonstrates that self-driving technology is already being used in warehouse management, for example through infrastructure-less indoor navigation, in delivery methods, through autonomous robots, in transportation, with self-driving shuttles.

These numerous applications lead to opportunities to diversify customers and extend global market reach.

► Identify partners and test self-driving vehicles as early as possible

Considering the exponential growth of the self-driving vehicles market, development and testing speed is a key determinant of success. Testing of self-driving vehicles and technology is essential and should be performed in real-life situations as quickly as possible. Partnerships with universities that are demonstrating considerable interest in autonomous technology provide added value in the testing phase. Public-private initiatives, like the Finnish Aurora project and the Dutch Automated Vehicle Initiative, provide very good opportunities for testing new technologies and are useful to validate the developed solution.

> **Key message**
>
> Test in real-life situations as quickly as possible and take advantage of the relevant public-private opportunities in the sector

► Participate in global business accelerator programmes

Financing for the self-driving vehicles market is increasingly available, but it might be beyond the reach of a newly established start-ups despite having innovative technology unless they have the necessary networks. Participation in global business accelerator programmes may prove as important as external financing for companies in the self-driving vehicles market, because it provides a solid global network of investors, media, and clients, and it is important to receive feedback from these stakeholders. Examples of such programmes include: “Startupbootcamp HighTechXL” (the Netherlands) and TechFounders (Germany).

► Adjust recruitment procedures to compensate for the shortage of specialists in the self-driving vehicles domain

Key message

Be ready to look for global self-driving technology talent with diverse educational backgrounds

European self-driving vehicles companies face significant difficulties in finding qualified employees, because the sector is extremely innovative and education systems have not had the time to adapt to the demand. In this difficult situation, companies have two main options: applying innovative recruitment procedures, focusing on skills and commitment rather than education background, and hiring talents outside the EU, as most companies in this sector are trying to do, in order to build mixed, complementary teams.

4.2 Insights for business intermediaries and policy-makers

Self-driving vehicles are a new technology, which would have far-reaching socio-economic consequences. Policy makers need not only to analyse and identify these consequences, but above all they need to make sure that legislation keeps up with the pace of technological advances.

► Align legislation to the technological advances in self-driving vehicles

Very often new technologies require new regulations, and the self-driving vehicles market represents no exception. Traffic rules and the regulatory framework need to be adapted rapidly.

"What is of great importance to us is the take-up of autonomous vehicles. Regulation should be adapted to the technological advances that are being made in this field."

Navya

EU regulation is not generally addressing the latest technological developments because of the rapid technological advances in the sector. This is leading to some Member States developing their own regulation, thus possibly creating disjointed markets and barriers to growth.

Furthermore, regulation should also comprise innovations like delivery robots, so that manufacturers would not have to rely on local piecemeal permissions.

► Adapt safety certification to driverless vehicles

Currently, safety tests in the EU do not have provisions for autonomous vehicles. For a business like self-driving vehicles, which relies so much on the safety of its products, certification is needed to prevent some irresponsible competitors marketing products without sufficient safety measures. Simulated testing, similar to the one in the airplane industry, should also be considered by regulators in order to allow quick tests of updates in the software of autonomous vehicles. In addition, certification should ensure high level of cybersecurity for self-driving vehicles.

► Focus public support on business accelerators

Facilitated access to funding and innovation grants can be key for start-ups, especially if they are developing innovative and untested solutions, such as self-driving vehicles. However, grants are still perceived as difficult and slow to obtain, which diminishes their attractiveness in this dynamic sector. Business accelerator programmes can provide a relatively quick access to valuable networks of investors and potential clients, which in the long-run could be even more beneficial than the availability of grants.

Appendix

Interviews and websites

Company	Website	Interviewee	Position
Toposens	http://www.toposens.com/	Tobias Bahnemann	Co-Founder and Managing Director
Navya Technologies	http://navya.tech/	Stanley Sauvaget	Business Development
Aimotive	https://Aimotive.com/	Niko Eiden	COO
Starship Technologies	https://www.starship.xyz/	Henry Harris-Burland	Marketing and Communications Manager
Accerion	http://accerion.tech/	Willem-Jan Lamers	Founder and Managing Director

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