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ScienceDirect

Transportation Research Procedia 44 (2020) 226–233

Transportation Research Procedia

www.elsevier.com/locate/procedia

LOGI 2019 – Horizons of Autonomous Mobility in Europe

How Do Autonomous Cars Work?

Ján Ondruš[a,]*, Eduard Kolla[b], Peter Vertal'[b] and Željko Šarić[c]

[a]*University of Zilina, Faculty of Operation and Economics of Transport and Communications, Department of road and urban transport, Univerzitná 8215/1, 010 26 Zilina, Slovak Republic*

[b]*University of Zilina, Institute of Forensic Research and Education of University of Zilina, Ulica 1. mája 32, 010 01 Zilina, Slovak Republic*

[c]*University of Zagreb, Faculty of Transport & Traffic Sciences, Department of Traffic Accidents Expertise, Borongajska 83a, 10 000, Zagreb, Croatia*

Abstract

The automotive industry is one of the most important industries in Europe. This industry is responsible for 14% of total production and capital investment in the European manufacturing sector. The following rise of driverless vehicles is going to have a major impact on businesses and professionals. Automated vehicles could replace corporate fleets for deliveries or transporting employees, for example. And workers could gain productive hours in the day by working instead of driving during daily commutes. Innovations in this field are also poised to completely change the car insurance industry by reducing accidents - a new report predicts that accidents will drop by 80% by 2040. The interconnection and synchronization of radar and ultrasonic sensors and optical cameras allow completely autonomous driving. This article deals with the description of autonomous cars, specifically their classification, technology, components, working, potential advantages and obstacles.

Peer-review under responsibility of the scientific committee of the LOGI 2019 – Horizons of Autonomous Mobility in Europe.

Keywords: Autonomous cars; SAE level; technology; components; working; UFO

1. Introduction

The year 2020 should present a breakthrough in the road transportation as the companies should be able to buy the first autonomous vehicles ever. This is possible thanks to the modern electronic assistance systems, which nowadays are already able to direct the vehicle in the line, keep the distance from the ahead driving car, and park autonomously. (National Highway Traffic and Safety Administration, 2013).

* Corresponding author. Tel.: +421415133526.
E-mail address: jan.ondrus@pedas.uniza.sk

Peer-review under responsibility of the scientific committee of the LOGI 2019 – Horizons of Autonomous Mobility in Europe.
10.1016/j.trpro.2020.02.049

And what do you mean by Autonomous Car? A word autonomous is derived from a Greek roots.

Autonomous = autos + nomos (SELF) + (GOVERN)

So, Autonomous car is a vehicle that can drive itself from one point to another without assistance from a driver; in other words, with an autopilot system. Other definition states, that an autonomous car is a vehicle that is capable of sensing its environment and navigating without human input.

2. History

Experiments have been conducted on automating cars since at least the 1920s; promising trials took place in the 1950s and work has proceeded since then. The first self-sufficient and truly autonomous cars appeared in the 1980s, with Carnegie Mellon University's Navlab and ALV projects in 1984and Mercedes-Benz and Bundeswehr University Munich's EUREKA Prometheus Project in 1987. (Kalašová et al., 2018) Since then, numerous major companies and research organizations have developed working prototype autonomous vehicles, including Mercedes-Benz, General Motors, Continental Automotive Systems, Autoliv, Bosch, Nissan, Renault, Toyota, Audi, Hyundai Motor Company, Volvo, Tesla Motors and Peugeot. As of the year 2010 the Google company has been developing its autonomous vehicle. In July 2013, Vislab demonstrated BRAiVE, a vehicle that moved autonomously on a mixed traffic route open to public traffic. In 2013, the government of the United Kingdom permitted the testing of autonomous cars on public roads. Prior to this, all testing of robotic vehicles in the UK had been conducted on private property. As of the year 2014 the company Tesla Motors has been installing the autopilot, which is a semiautonomous driving assistant, in all its vehicles. In 2014 the Government of France announced that testing of autonomous cars on public roads would be allowed in 2015. In Europe, cities in Belgium, France, Italy and the UK are planning to operate transport systems for driverless cars, and Germany, the Netherlands, and Spain have allowed testing robotic cars in traffic. (Skrucany et al., 2017) In 2015, five US states (Nevada, Florida, California, Virginia, and Michigan) together with Washington, D.C. allowed the testing of fully autonomous cars on public roads (Ballay et al., 2018)

3. Classification of Autonomous Cars

A classification system based on six different levels (ranging from none to fully automated systems) was published in 2014 by SAE International (Society of Automotive Engineers), an automotive standardization body, as J3016. Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. This classification system is based on the amount of driver intervention and attentiveness required, rather than the vehicle capabilities, although these are very closely related. On 30 September 2016, the SAE updated it standard classification for the levels of driving automation. In addition to setting these mutually exclusive levels of driving automation, this technical report designates standard terminology for ideas related to vehicles containing automated systems. (Standard SAE J3016, 2016) This standard corresponds to levels defined by Germany Federal Highway Research Institute (BASt) and roughly corresponds to National Highway Traffic Safety Administration (NHTSA). (National Highway Traffic and Safety Administration, 2014). So here are the six levels:

Level 0 (No automation): This is where the vast majority of cars and trucks are today. The driver handles steering, throttle, and braking (ST&B)monitoring the surroundings, as well as navigating, and determining when to use turn signals, change lanes, and turn. But there can be some warning systems (blind-spot and collision warnings).

Level 1 (Driver assistance): Vehicles in this level can handle S or T&B, but not in all circumstances, and the driver must be ready to take over those functions if called upon by the vehicle. That means the driver must remain aware of what the car is doing and be ready to step in if needed.

Level 2 (Partial assistance): The car handles ST&B, but immediately lets the driver take

over if he detects objects and events the car is not responding to. In these first three levels, the driver is responsible for monitoring the surroundings, traffic, weather, and road conditions.

Level 3 (Conditional assistance): The car monitors surroundings and takes care of all ST&B in certain environments, such as freeways. But the driver must be ready to intervene if the car requests it.

Level 4 (High automation): The car handles ST&B and monitoring the surroundings in a wider range of environments, but not all, such as severe weather. The driver switches on the automatic driving only when it is safe to do so. After that, the driver is not required.

Level 5 (Full automation): Driver only has to set the destination and start the car, the car handles all other tasks. The car can drive to any legal destination and make its own decisions on the way. (Standard SAE J3016, 2016)

The above levels are important because they serve as general guidelines for how technologically advanced a car is. The biggest difference is that, starting at Level 3, the automated driving system becomes able to monitor the driving environment.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Fig. 1. SAE's levels of driving automation. Source: Standard SAE J3016, 2016

Note:
***Dynamic driving task** includes the operational (steering, braking, accelerating, monitoring the vehicle and roadway) and tactical (responding to events, determining when to change lanes, turn, use signals, etc.) aspects of the driving task, but not the strategic (determining destinations and waypoints) aspect of the driving task. **Driving mode** is a type of driving scenario with characteristic dynamic driving task requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, closed-campus operations, etc.). **Request to intervene** is notification by the automated driving system to a human driver that s/he should promptly begin or resume performance of the dynamic driving task.*

4. Advantages and Obstacle

Potential Advantages - an increase in the use of autonomous cars would make possible such benefits as:

- Fewer traffic accidents and traffic collisions (resulting deaths and injuries and costs).
- Increased roadway capacity and reduced traffic congestion due to reduced need for safety gaps and the ability to better manage traffic flow.
- Higher speed limit for autonomous cars.
- Reduction of physical space required for vehicle parking.
- Reduction in the need for traffic police and premium on vehicle insurance.
- Reduction in car theft, due to the vehicle's increased awareness.
- Removal of the steering wheel
- Fuel Economy.
- Relief of vehicle occupants from driving and navigation chores, allowing them to do other tasks or to rest during their long & intense traffic journeys.
- Minimizes speed differentials between vehicles.
- Automatic throttle reduction and brake management.
- Reduction of physical road signage and smoother ride.
- There would be no need to pass a driving test or gain a driving license as everyone would be able to drive.

- Enhanced mobility for children, the elderly, disabled and poor people.
- Commercial car sharing. (Kalašová et al., 2018, Stiller et. al, 2007)

Potential Obstacle - in spite of the various benefits to increased vehicle automation, some foreseeable challenges persist:

- Liability for damage.
- Loss of driving related jobs (for all driving professions, including lorry drivers, bus drivers, taxi drivers, etc.).
- Loss of privacy.
- Self-driving cars could potentially be loaded with explosives and used as bombs.
- Susceptibility of the car's navigation system to different types of weather.
- Temporary construction zones which are not posted to any maps or data bases.
- Determination of the severity of traffic lane obstacles, as in the question of safely straddling a pothole or debris.
- Current police and other pedestrian gestures and nonverbal cues are not adapted to autonomous driving.
- In case of failure of main sensor and backup sensors the vehicle can create a chance of accident.
- A failure or a bug in the system can lead to fatal accidents and loss of lives - software reliability.
- Cyber Security (in addition, there is the risk of automotive hacking through the sharing of information through V2V (Vehicle to Vehicle) and V2I (Vehicle to Infrastructure) protocols).
- Implementation of legal framework and establishment of government regulations for self- driving cars.
- Reliance on autonomous drive produces less experienced drivers for when manual drive is needed.
- Resistance for individuals to forfeit control of their cars.
- Diminish the use of public transport.
- Artificial Intelligence (AI) is still not able to function properly in chaotic inner-city environments.
- Ethical and moral reasoning come into consideration when programming the software that decides what action the car takes in an unavoidable crash. (Jurecki et al, 2017, Kalašová et al., 2018)

Challenges

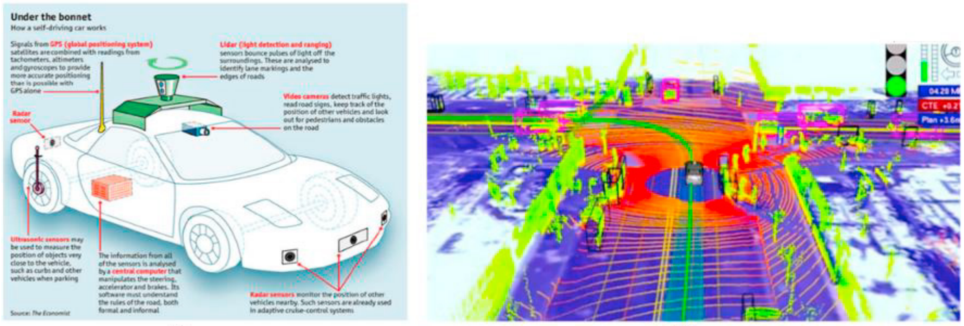
- Future of transportation and mankind.
- Susceptibility of car's navigation system to different types of weather, for example snowy conditions.
- Traffic signal detection.
- Legal issues.
- High cost of manufacturing. (Kalašová et al., 2018)

5. How does an autonomous car actually work?

Driver sets a destination and car's software calculates a route and starts the car on its way. A rotating, roof-mounted LIDAR sensor monitors a 60-meter range around the car and creates a dynamic 3-D map of the car's current environment. A sensor on the left rear wheel monitors sideways movement to detect the car's position relative to the 3-D map. Radar systems in the front and rear bumpers calculate distances to obstacles. (Kubáňová and Kubasáková, 2018) Artificial intelligence software in the car is connected to all the sensors and has input from Google Street View and video cameras. The AI simulates human perceptual and decision- making processes and controls driving systems such as steering and brakes. The car's software consults Google Maps for advance notice of things like landmarks and traffic signs and lights. An override function is available to allow a human to take control of the vehicle. Individual vehicles may benefit from information obtained from other vehicles in the vicinity, especially information relating to traffic congestion and safety hazards. Vehicular communication systems use vehicles and roadside units as the communicating nodes in a peer-to-peer network, providing each other with information.

6. Technology used

Autonomous cars use a variety of techniques to detect their surroundings, such as radar, laser light, GPS, odometers, and computer vision. Advanced control systems interpret sensory information to identify appropriate navigation paths, as well as obstacles and relevant signage. Autonomous cars have control systems that are capable of analyzing sensory data to distinguish between different cars on the road, which is very useful in planning a path to the desired destination. (Anderson et al., 2014) The systems used in the autonomous car consist of (see fig. 2a):



a) b)

Fig. 2 Components in an autonomous car (a), (Source: The Economist), the detail of virtual 3D map from the Lidar (b). Source: authors

LIDAR (Light Detection and Ranging): It is a remote sensing technology which measures distance by illuminating a target with a light beam and analyzes the reflected light. It is mounted on the roof of the vehicle on a cylindrical enclosure which rotates 360 degree and is the most important device in the Autonomous vehicles. Lidar consists of emitter, mirror and receiver. It maps a 3D structure of environment and location on the road in 360°. It uses laser, ultra violet, visible light or infrared light to image objects. The emitter sends out a laser beam that bounces off a mirror that is rotating along with the cylindrical housing at 10 revolutions per minute. (Chang et al., 2019, Yum et al., 2019) After bouncing off objects, the laser beam returns to the mirror and is bounced back towards the receiver, where it can be interpreted into data. This data is fed in to the computer which generates high precision 3D map of the surrounding environment (see fig. 2b). The vehicle can use the map to avoid objects. This accuracy of this map is in centimetres because the wavelength of light used is very small and is able to reflect of all types of surfaces and small objects.

RADAR (Radio Detection and Ranging): This equipment can estimate the mutual velocity of the object and the vehicle, using the electro-magnetic waves. During the measurement it sends out a signal, than it waits until it is sent back. The frequency of the sent back signal is in case of mutual movement slightly changed (Doppler's effect); therefore it is possible to instantly calculate the velocity of the forehead driving vehicle. (Šarkan et al., 2017) The radar, compared to Lidar, uses a bigger wave length and lower signal energy. It is however not able to describe the shape of the scanned space. It can also have a problem with non-metal items, or items which have a specific shape. Most of the radars work in the range of approximately 77 GHz and the scanning beam is relatively directional. The radar scans the road in front of the vehicle up to approximately 200 meters distance. Some vehicles use two radars with different ranges. The Radar systems are installed on the front and rear bumper of the vehicle. Radar detects the surrounding environment and the central computer combines this result with that of the Lidar system. The radar system are used for detecting oncoming vehicles, their speed, other obstacles, for self parking, blind spot detection, lane-change assistance, adaptive cruise control, side impact warning, cross-traffic alert. etc. (Gestmair et al., 2019)

ULTRASONIC SENSORS: These are mounted on various sides of the vehicle to detect objects very near the vehicle or measure the position of other vehicles during parking. These sensors provide parking assistance, collision warning, lane departure among other functions.

VIDEO CAMERAS: They are installed at the top of the front glass, near the rear view mirror and build real-time 3D images of the road ahead. These are used to detect the traffic lights, traffic signs, unexpected things like animals or pedestrians, etc. They also detect different road signs like "STOP" signs, zebra crossings, sign boards etc. Video cameras also help in recognizing certain gestures which other sensors can't comprehend like hand waving or traffic cones. (Yun et al., 2019)

GPS (Global Positioning System): It is a space-based satellite navigation system that provides current location and time information anywhere on earth where there is an unobstructed line of sight to four or more satellites. It is the basis of all the maps that vehicle uses while on the road. All satellites broadcast at the same two frequencies, 1.57542 GHz and 1.2276 GHz. GPS uses satellites to gather information about the current position of the vehicle.

GPS keeps the vehicle on its intended route with an accuracy of 30 centimetres. By using the GPS a map of the area is loaded into the central computer. With GPS other systems are used to determine the complete position.

INERTIAL MEASUREMENT UNIT (IMU): Data from GPS alone is less accurate. So, this data is combined with outputs from the IMU. IMU uses a combination of accelerometers, gyroscopes and magnetometers. IMU is an electronic device which measures and gives information about the vehicle's velocity, orientation, gravitational forces etc. IMU helps GPS system to work when signals are unavailable such as in tunnels, bad weather conditions and when electromagnetic interference is present. (Yun et al., 2019)

CPU or Computer: All the data obtained from each and every sensor systems is fed to the central computer, which process this data at high speed. The central computer is a very powerful processing unit mounted on the inside of the vehicle. With the help of highly sophisticated software makes the required decision and sends the output to electro-mechanical units like automatic steering, throttle and breaking systems. This computer is also connected to the internet and GPS system to provide real time monitoring and updates.

7. Analysis of Case Study No. 1 – intervention of advance driver assistant system

The next part describes our research of some specific parts of the autonomous vehicles. In particular we focused on testing the vehicles assistant systems geared on pedestrians' detection with the possibility of the autonomous braking activation.

Since the extent of the article does not create room for analysing all case studies, we shall in this part describe only one demonstrative test. The vehicle under question was Volvo, driving approximately 48 $km.h^{-1}$. A pedestrian reaching the speed of app. 4 $km.h^{-1}$ entered the corridor of the vehicle from the left side. The movement synchronization of the vehicle and the pedestrian was established based on the precise simulation in the PC Crash 10.0. For the measurements with the vehicle a dummy placed on the UFO – (Ultra flat overrunable platform, made by the company DSD Datentechnik) was used. (Schejbalová et al., 2013) UFO enabled a fully synchronized measurement process with the vehicle, based on the data received from the movement reconstruction, using the D_GPS vehicle location. (Schejbalová et al., 2012) An example of the assistance system intervention analysis in the vehicle is pictured on the figure 3 a–c.

- The experiment begins with vehicle passing the light gateway approximately 5s and 70m prior to the collision with the pedestrian. In this momentum the pedestrian is still standing. In the momentum of the vehicle passing the light gateway, the UFA control unit evaluates the right momentum for the UFA start (the pedestrian), based on the actual Volvo vehicle velocity.
- The vehicle moves on with the constant velocity of approximately 47 $km.h^{-1}$ and in the time moment of approximately 4.3 s prior to the collision with the pedestrian the UFA starts to move with the acceleration 1 $m.s^{-1}$. Fully synchronized and automated action reproduces the action of the real collision.
- Approximately 2 s and 19 m prior to the dummy movement corridor the driver is warned by means of acoustic-visual signal at the moment, when the pedestrian is approximately 0.7 m from the vehicle movement corridor. In this moment, the Volvo does not brake autonomously yet (see fig. 3a).
- Approximately 0.8 s after the alarm activation the autonomous braking is activated approximately 13m from the dummy movement corridor (see fig. 3b). The vehicle brakes with the mean fully braking deceleration, approximately 10 $m.s^{-2}$. During the activation of the autonomous braking the driver did not intervene in the vehicle drive. During the autonomous braking, the braking pedal declines to the floor as during the normal braking.
- After approximately 2 seconds after the initial acoustic signal the collision between the vehicle and the pedestrian happens. The velocity during the collision (see fig. 3c) was approximately 12 $km.h^{-1}$ (based on the acceleration sensor and GPS) as oppose to 48 $km.h^{-1}$ during the real collision during which the driver did not happen to react to the pedestrian.

Vehicle's autonomous braking after the acoustic warning of the driver appeared in 63% case studies. The time interval between the initial acoustic and visual reaction of the system up to the very first moment of breaking stretched from 0.1 to 0.8 seconds. (Vertal' et al., 2014) A sole case identified breaking prior to the preceding acoustic warning. The measurements have proved that the abrupt driver's reaction controlling the vehicle upon the moment of warning or breaking will stop the process of warning and autonomous braking.

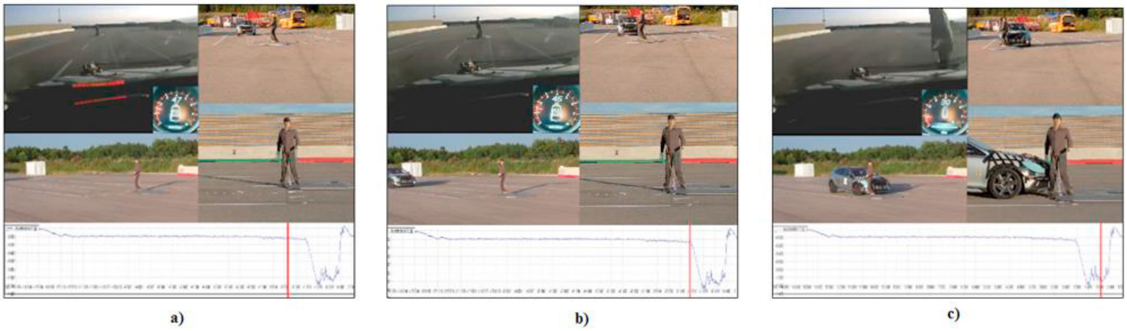


Fig. 3 Activation of the acoustic-visual signal (a), Beginning of the autonomous braking (b), The vehicle crosses the plane of movement of pedestrians (c). Source: authors

The analysis of the testing studies has proved that the system of pedestrians´ detection in Volvo V40 (produced in 2014) can autonomously stop the vehicle before the pedestrian at low speeds up to 30 km/h in case the pedestrian's walk is sufficiently predictable and the system is prepared to monitor such pedestrian with nothing preventing the camera to follow the pedestrian. It has to be noted that the system can stop the slow speeding vehicle only if excluded is any and all abrupt change in speed or direction of the pedestrian walking into the road. At speeds exceeding 30 km/h, a significant reduction of vehicle's speed before the actual clash with the pedestrian occurs, yet, by a maximum of c. 30 km/h compared to the vehicle's speed at the time of the initial reaction to the system. The total summary of the speed reduction resulting from the autonomous intervention of the vehicle is shown in table 1.

Table 1 Decrease of the velocity the Volvo vehicle during simulated scenarios

Case no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Obstacle in driver view	yes			yes				yes									yes	
Motion of the car	straight	straight	cornering L	straight	straight	straight	cornering L	overtaking R	cornering R	straight	straight	cornering L	straight	straight	straight	straight	straight	straight
Impact velocity in crash accident ($km.h^{-1}$)	23	47	12	50	32	19	41	55	18	39	32	36	45	42	40	39	30	30
Alarm		yes	yes	yes	yes	yes	yes			yes	yes			yes		yes		yes
Alarm before the crash (s)		2,0	1,0	1,7	1,5	0,5	1,6			1,9	1,5			1,1		0,6		1,5
Decrease of the velocity (%)	0	74	100	48	0	0	59	0	0	64	34	0	0	57	0	0	0	30

Source: authors

8. Conclusion

In the near future, our professional ambition and conduct will increasingly be directed towards vehicles furnished with the state of the art and sophisticated equipment. Such systems are aimed to ease and facilitate the drive, yet, they might be the cause of complication upon professional investigation of the accident. Autonomous vehicles are still a developing technology. A large number of companies and researchers have speculated about future developments and the possible effects of the vehicles. The following section describes the various visions of vehicle producers regarding the future of autonomous vehicles:

- By 2020, Google autonomous vehicle project head's goal is to have all outstanding problems with the autonomous vehicle resolved.
- By 2020, Volvo envisages having vehicles in which passengers would be immune from injuries.
- By 2020, Daimler and Ford, Mercedes-Benz, Audi, Nissan and BMW all expect to sell autonomous vehicles.
- By 2020, GM, Mercedes-Benz, Audi, Nissan, BMW, Renault, Tesla and Google all expect to sell vehicles that can drive themselves at least part of the time. (Level 3)
- By 2024, Jaguar, Daimler and Ford expect to release an autonomous vehicle. Ford predicts it will have the first mass market autonomous vehicle, but released no target date.
- By 2025, most new GM vehicles will have automated driving functions as well as vehicle-to-vehicle communication technology.
- By 2035, Navigant Research forecasts that autonomous vehicles will gradually gain traction in the market over the coming two decades and by 2035, sales of autonomous vehicles will reach 95.4 million annually, representing 75% of all light-duty vehicle sales.
- By 2040, expert members of the Institute of Electrical and Electronics Engineers (IEEE) have estimated that up to 75% of all vehicles will be autonomous. (Kalašová et al., 2018)

Acknowledgement

This publication is the result of the project implementation: VEGA no. 1/0436/18 - Externalities in road transport, an origin, causes and economic impacts of transport measures.

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