

Vehicular automation



Figure 1: The ESA Seeker autonomous rover during tests at Paranal

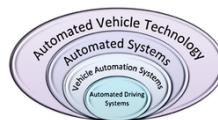


Figure 2: Automated vehicle system technology hierarchy

Vehicular automation is using technology to assist or replace the operator of a vehicle such as a car, truck, aircraft, rocket, military vehicle, or boat. Assisted vehicles are semi-autonomous, whereas vehicles that can travel without a human operator are autonomous. The degree of autonomy may be subject to various constraints such as conditions. Autonomy is enabled by advanced driver-assistance systems (ADAS) of varying capacity.

Related technology includes advanced software, maps, vehicle changes, and outside vehicle support.

Autonomy presents varying issues for road, air, and marine travel. Roads present the most significant complexity given the unpredictability of the driving environment, including diverse road designs, driving conditions, traffic, obstacles, and geographical/cultural differences.

Autonomy implies that the vehicle is responsible for all perception, monitoring, and control functions.

SAE autonomy levels

The Society of Automotive Engineers (SAE) classifies road vehicle autonomy in six levels:

- 0: No automation.
- 1: Driver assistance, the vehicle controls steering or speed autonomously in specific circumstances.
- 2: Partial automation, the vehicle controls both steering and speed autonomously in specific circumstances.
- 3: Conditional automation, the vehicle controls both steering and speed under normal environmental conditions, but requires the driver to be ready to take control in other circumstances.
- 4: High automation, the vehicle travels autonomously under normal environmental conditions, not requiring driver oversight.
- 5: Full autonomy, where the vehicle can complete travel autonomously in any environmental conditions.

Level 0 refers, for instance, to vehicles without adaptive cruise control. Level 1 and 2 refer to vehicles where one part of the driving task is performed by the ADAS under the responsibility/liability of the driver.

From level 3, the driver can transfer the driving task to the vehicle, but the driver must assume control when the ADAS reaches its limits. For instance an automated traffic jam pilot can drive in a traffic jam, but otherwise passes control to the driver. Level 5 refers to a vehicle that can handle any situation.

Technology

Software

Autonomous vehicle software generally contains several different modules that work together to enable self-driving capabilities. The perception module ingests and processes data from various sensors, such as cameras, LIDAR, RADAR, and ultrasonic SONAR, to create a comprehensive understanding of the vehicle's surroundings. The localization module uses 3D point cloud data, GPS, IMU, and mapping information to determine the vehicle's precise position, including its orientation, velocity, and angular rate. The planning module takes inputs from both perception and localization to compute actions to take, such as velocity and steering angle outputs. These modules are typically supported by machine learning algorithms, particularly deep neural networks, which enable the vehicle to detect objects, interpret traffic patterns, and make real-time decisions. Furthermore, modern autonomous driving systems increasingly employ sensor fusion techniques that combine data from multiple sensors to improve accuracy and reliability in different environmental conditions.

Perception

The perception system is responsible for observing the environment. It must identify everything that could affect the trip, including other vehicles, pedestrians, cyclists, their movements, road conditions, obstacles, and other issues. Various makers use cameras, radar, lidar, sonar, and microphones that can collaboratively minimize errors.

Navigation

Navigation systems are a necessary element in autonomous vehicles. The Global Positioning System (GPS) is used for navigation by air, water, and land vehicles, particularly for off-road navigation.

For road vehicles, two approaches are prominent. One is to use maps that hold data about lanes and intersections, relying on the vehicle's perception system to fill in the details. The other is to use highly detailed maps that reduce the scope of real-time decision-making but require significant maintenance as the environment evolves. Some systems crowdsource their map updates, using the vehicles themselves to update the map to reflect changes such as construction or traffic used by the entire vehicle fleet.

Another potential source of information is the environment itself. Traffic data may be supplied by roadside monitoring systems and used to route vehicles to best use a limited road system. Additionally, modern GNSS enhancement technologies, such as real-time kinematic (RTK) and precise point positioning (PPP), enhance the accuracy of vehicle positioning to sub-meter level precision, which is crucial for autonomous navigation and decision-making.

History

Automated vehicles in European Union legislation refer specifically to road vehicles (car, truck, or bus). For those vehicles, a specific difference is legally defined between advanced driver-assistance system and autonomous/automated vehicles, based on liability differences.

AAA Foundation for Traffic Safety tested two automatic emergency braking systems: some designed to prevent crashes and others that aim to make a crash less severe. The test looked at popular models like the 2016 Volvo XC90, Subaru Legacy, Lincoln MKX, Honda Civic, and Volkswagen Passat. Researchers tested how well each system stopped when approaching moving and nonmoving targets. It found that systems capable of preventing crashes reduced vehicle speeds by twice that of the systems designed to mitigate crash severity. When the two test vehicles traveled within 30 mph of each other, even those designed to lessen crash severity avoided crashes 60 percent of the time.

Sartre

The Safe Road TRains for the Environment (Sartre) project's goal was to enable platooning, in which a line of cars and trucks (a "train") follow a human-driven vehicle. Trains were predicted to provide comfort and allow the following vehicles to travel safely to a destination. Human drivers encountering a train could join and delegate driving to the human driver.

Tests

Self-driving Uber vehicles were tested in Pittsburgh, Pennsylvania. The tests were paused after an autonomous car killed a woman in Arizona. Automated busses have been tested in California. In San Diego, California, an automated bus test used magnetic markers. The longitudinal control of automated truck platoons used millimeter wave radio and radar. Waymo and Tesla have conducted tests. Tesla FSD allows drivers to enter a destination and let the car take over.

Risks and liabilities

Ford offers Blue Cruise, technology that allows geofenced cars to drive autonomously.

Drivers are directed to stay attentive, and safety warnings are implemented to alert the driver when corrective action is needed. Tesla, Incorporated has one recorded incident that resulted in a fatality involving the automated driving system in the Tesla Model S. The accident report reveals the accident was a result of the driver being inattentive and the autopilot system not recognizing the obstruction ahead. Tesla has also had multiple instances where the vehicle crashed into a garage door. According to the book "The Driver in the Driverless Car: How Your Technology Choices Create the Future," Tesla automatically performs an update overnight. The morning after the update, the driver used his app to "summon" his car, and it crashed into his garage door.

Another flaw with automated driving systems is that unpredictable events, such as weather or the driving behavior of others, may cause fatal accidents due to sensors that monitor the surroundings of the vehicle not being able to provide corrective action.

To overcome some of the challenges for automated driving systems, novel methodologies based on virtual testing, traffic flow simulation and digital prototypes have been proposed, especially when novel algorithms based on Artificial Intelligence approaches are employed which require extensive training and validation data sets.

Implementing automated driving systems poses the possibility of changing built environments in urban areas, such as expanding the suburban regions due to the increased ease of mobility.

Challenges

Around 2015, several self-driving car companies including Nissan and Toyota promised self-driving cars by 2020. However, the predictions turned out to be far too optimistic.

There are still many obstacles in developing fully autonomous Level 5 vehicles, which is the ability to operate in any conditions. Currently, companies are focused on Level 4 automation, which is able to operate under certain environmental circumstances.

There is still debate about what an autonomous vehicle should look like. For example, whether to incorporate lidar to autonomous driving systems is still being argued. Some researchers have come up with algorithms using camera-only data that achieve the performance that rival those of lidar. On the other hand, camera-only data sometimes draw inaccurate bounding boxes, and thus lead to poor predictions. This is due to the nature of superficial information that stereo cameras provide, whereas incorporating lidar gives autonomous vehicles precise distance to each point on the vehicle.

Technical challenges

- **Software Integration:** Because of the large number of sensors and safety processes required by autonomous vehicles, software integration remains a challenging task. A robust autonomous vehicle should ensure that the integration of hardware and software can recover from component failures.
- **Prediction and trust among autonomous vehicles:** Fully autonomous cars should be able to anticipate the actions of other cars like humans do. Human drivers are great at predicting other drivers' behaviors, even with a small amount of data such as eye contact or hand gestures. In the first place, the cars should agree on traffic rules, whose turn it is to drive in an intersection, and so on. This scales into a larger issue when there exists both human-operated cars and self-driving cars due to more uncertainties. A robust autonomous vehicle is expected to improve on understanding the environment better to address this issue.
- **Scaling up:** The coverage of autonomous vehicles testing could not be accurate enough. In cases where heavy traffic and obstruction exist, it requires faster response time or better tracking algorithms from the autonomous vehicles. In cases where unseen objects are encountered, it is important that the algorithms are able to track these objects and avoid collisions.

These features require numerous sensors, many of which rely on micro-electro-mechanical systems (MEMS) to maintain a small size, high efficiency, and low cost. Foremost among MEMS sensors in vehicles are accelerometers and gyroscopes to measure acceleration around multiple orthogonal axes—critical to detecting and controlling the vehicle's motion.

Societal challenges

One critical step to achieve the implementation of autonomous vehicles is the acceptance by the general public. It provides guidelines for the automobile industry to improve their design and technology. Studies have shown that many people believe that using autonomous vehicles is safer, which underlines the necessity for the automobile companies to assure that autonomous vehicles improve safety benefits. The TAM research model breaks down important factors that affect the consumer's acceptance into: usefulness, ease to use, trust, and social influence.

- The usefulness factor studies whether or not autonomous vehicles are useful in that they provide benefits that save consumers' time and make their lives simpler. How well the consumers believe autonomous vehicles will be useful compared to other forms of transportation solutions is a determining factor.
- The ease to use factor studies the user-friendliness of the autonomous vehicles. While the notion that consumers care more about ease to use than safety has been challenged. It still remains an important factor that has indirect effects on the public's intention to use autonomous vehicles.
- The trust factor studies the safety, data privacy and security protection of autonomous vehicles. A more trusted system has a positive impact on the consumer's decision to use autonomous vehicles.
- The social influence factor studies whether the influence of others would influence consumer's likelihood of having autonomous vehicles. Studies have shown that the social influence factor is positively related to behavioral intention. This might be due to the fact that cars traditionally serve as a status symbol that represents one's intent to use and his social environment.

Regulatory challenges

Real-time testing of autonomous vehicles is an inevitable part of the process. At the same time, vehicular automation regulators are faced with challenges to protect public safety and yet allow autonomous vehicle companies to test their products. Groups representing autonomous vehicle companies are resisting most regulations, whereas groups representing vulnerable road users and traffic safety are pushing for regulatory barriers. To improve traffic safety, the regulators are encouraged to find a middle ground that protects the public from immature technology while allowing autonomous vehicle companies to test the implementation of their systems. There have also been proposals to adopt the aviation automation safety regulatory knowledge into the discussions of safe implementation of autonomous vehicles, due to the experience that has been gained over the decades by the aviation sector on safety topics.

Ground vehicles

In some countries, specific laws and regulations apply to road traffic motor vehicles (such as cars, bus and trucks) while other laws and regulations apply to other ground vehicles such as tram, train or automated guided vehicles making them to operate in different environments and conditions.

Road traffic vehicles

An automated driving system is defined in a proposed amendment to Article 1 of the Vienna Convention on Road Traffic:

(ab) “Automated driving system” refers to a vehicle system that uses both hardware and software to exercise dynamic control of a vehicle on a sustained basis.

(ac) “Dynamic control” refers to carrying out all the real-time operational and tactical functions required to move the vehicle. This includes controlling the vehicle’s lateral and longitudinal motion, monitoring the road environment, responding to events in the road traffic environment, and planning and signalling for manoeuvres.

This amendment will enter into force on 14 July 2022, unless it is rejected before 13 January 2022.

An automated driving feature must be described sufficiently clearly so that it is distinguished from an assisted driving feature.

There are two clear states –a vehicle is either assisted with a driver being supported by technology or automated where the technology is effectively and safely replacing the driver.

Ground vehicles employing automation and teleoperation include shipyard gantries, mining trucks, bomb-disposal robots, robotic insects, and driverless tractors.

There are many autonomous and semi-autonomous ground vehicles being made for the purpose of transporting passengers. One such example is the free-ranging on grid (FROG) technology which consists of autonomous vehicles, a magnetic track and a supervisory system. The FROG system is deployed for industrial purposes in factory sites and has been in use since 1999 on the ParkShuttle, a PRT-style public transport system in the city of Capelle aan den IJssel to connect the Rivium business park with the neighboring city of Rotterdam (where the route terminates at the Kralingse Zoom metro station). The system experienced a crash in 2005 that proved to be caused by a human error.

Applications for automation in ground vehicles include the following:

- Vehicle tracking system system ESITrack, Lojack.
- Rear-view alarm, to detect obstacles behind.
- Anti-lock braking system (ABS) (also Emergency Braking Assistance (EBA)), often coupled with Electronic brake force distribution (EBD), which prevents the brakes from locking and losing traction while braking. This shortens stopping distances in most cases and, more importantly, allows the driver to steer the vehicle while braking.

- Traction control system (TCS) actuates brakes or reduces throttle to restore traction if driven wheels begin to spin.
- Four wheel drive (AWD) with a centre differential. Distributing power to all four wheels lessens the chances of wheel spin. It also suffers less from oversteer and understeer.
- Electronic Stability Control (ESC) (also known for Mercedes-Benz proprietary Electronic Stability Program (ESP), Acceleration Slip Regulation (ASR) and Electronic differential lock (EDL)). Uses various sensors to intervene when the car senses a possible loss of control. The car's control unit can reduce power from the engine and even apply the brakes on individual wheels to prevent the car from understeering or oversteering.
- Dynamic steering response (DSR) corrects the rate of power steering system to adapt it to vehicle's speed and road conditions.

Research is ongoing and prototypes of autonomous ground vehicles exist.

Cars

Extensive automation for cars focuses on either introducing robotic cars or modifying modern car designs to be semi-autonomous.

Semi-autonomous designs could be implemented sooner as they rely less on technology that is still at the forefront of research. An example is the dual mode monorail. Groups such as RUF (Denmark) and TriTrack (USA) are working on projects consisting of specialized private cars that are driven manually on normal roads but also that dock onto a monorail/guideway along which they are driven autonomously.

As a method of automating cars without extensively modifying the cars as much as a robotic car, Automated highway systems (AHS) aims to construct lanes on highways that would be equipped with, for example, magnets to guide the vehicles. Automation vehicles have auto-brakes named as Auto Vehicles Braking System (AVBS). Highway computers would manage the traffic and direct the cars to avoid crashes.

In 2006, The European Commission has established a smart car development program called the Intelligent Car Flagship Initiative. The goals of that program include:

- Adaptive cruise control
- Lane departure warning system
- Project AWAKE for drowsy drivers

There are further uses for automation in relation to cars. These include:

- Assured Clear Distance Ahead
- Adaptive headlamps
- Advanced Automatic Collision Notification, such as OnStar
- Intelligent Parking Assist System
- Automatic Parking
- Automotive night vision with pedestrian detection
- Blind spot monitoring
- Driver Monitoring System
- Robotic car or self-driving car which may result in less-stressed "drivers", higher efficiency (the driver can do something else), increased safety and less pollution (e.g. via completely automated fuel control)
- Pre-crash system
- Safe speed governing
- Traffic sign recognition
- Following another car on a motorway –"enhanced" or "adaptive" cruise control, as used by Ford Motor Company and Vauxhall
- Distance control assist –as developed by Nissan
- Dead man's switch –there is a move to introduce deadman's braking into automotive application, primarily heavy vehicles, and there may also be a need to add penalty switches to cruise controls.

Singapore also announced a set of provisional national standards on January 31, 2019, to guide the autonomous vehicle industry. The standards, known as Technical Reference 68 (TR68), will promote the safe deployment of fully driverless vehicles in Singapore, according to a joint press release by Enterprise Singapore (ESG), Land Transport Authority (LTA), Standards Development Organisation and Singapore Standards Council (SSC).

Shuttle



Figure 3: Parkshuttle



Figure 4: Navya Autonom Shuttle

Since 1999, the 12-seat/10-standing ParkShuttle has been operating on an 1.8 kilometres (1.1 mi) exclusive right of way in the city of Capelle aan den IJssel in The Netherlands. The system uses small magnets in the road surface to allow the vehicle to determine its position. The use of shared autonomous vehicles was trialed around 2012 in a hospital car park in Portugal. From 2012 to 2016, the European Union funded CityMobil2 project examined the use of shared autonomous vehicles and passenger experience including short term trials in seven cities. This project led to the development of the EasyMile EZ10.

In the 2010s, self-driving shuttle became able to run in mixed traffic without the need for embedded guidance markers. So far the focus has been on low speed, 20 miles per hour (32 km/h), with short, fixed routes for the “last mile” of journeys. This means issues of collision avoidance and safety are significantly less challenging than those for automated cars, which seek to match the performance of conventional vehicles. Many trials have been undertaken, mainly on quiet roads with little traffic or on public pathways or private roadways and



Figure 5: Easymile EZ10



Figure 6: King Long Apolong

specialised test sites.[citation needed] The capacity of different models varies significantly, between 6-seats and 20-seats. (Above this size there are conventional buses that have driverless technology installed.)

In December 2016, the Jacksonville Transportation Authority has announced its intention to replace the Jacksonville Skyway monorail with driverless vehicles that would run on the existing elevated superstructure as well as continue onto ordinary roads. The project has since been named the “Ultimate Urban Circulator” or “U2C” and testing has been carried out on shuttles from six different manufacturers. The cost of the project is estimated at \$379 million.

In January 2017, it was announced the ParkShuttle system in the Netherlands will be renewed and expanded including extending the route network beyond the exclusive right of way so vehicles will run in mixed traffic on ordinary roads. The plans were delayed and the extension into mixed traffic was expected in 2021.

In July 2018, Baidu stated it had built 100 of its 8-seat Apolong model, with plans for commercial sales. As of July 2021, they had not gone into volume production.

In August 2020, it was reported there were 25 autonomous shuttle manufacturers, including the 2GetThere, Local Motors, Navya, Baidu, Easymile, Toyota and Ohmio.

In December 2020, Toyota showcased its 20-passenger “e-Palette” vehicle, which is due to be used at the 2021 Tokyo Olympic Games. Toyota announced it intends to have the vehicle available for commercial applications before 2025.

In January 2021, Navya released an investor report which predicted global autonomous shuttle sales will reach 12,600 units by 2025, with a market value of EUR 1.7 billion.

In June 2021, Chinese maker Yutong claimed to have delivered 100 models of its 10-seat Xiaoyu 2.0 autonomous bus for use in Zhengzhou. Testing has been carried out in a number of cities since 2019 with trials open to the public planned for July 2021.

Self-driving shuttles are already in use on some private roads, such as at the Yutong factory in Zhengzhou where they are used to transport workers between buildings of the world’s largest bus factory.

In Hong Kong, the police and other workers use driverless vehicles.

A large number of trials have been conducted since 2016, with most involving only one vehicle on a short route for a short period of time and with an onboard conductor. The purpose of the trials has been to both provide technical data and to familiarize the public with the driverless technology. A 2021 survey of over 100 shuttle experiments across Europe concluded that low speed –15–20 kilometres per hour (9.3–12.4 mph) –was the major barrier to implementation of autonomous shuttle buses. The current cost of the vehicles at €280,000 and the need for onboard attendants were also issues.

Vehicle names are in quotes

Buses

Autonomous buses are proposed, as well as self-driving cars and trucks. Grade 2 level automated minibusses were trialed for a few weeks in Stockholm. China has a small fleet of self-driving public buses in the tech district of Shenzhen, Guangdong.

The first autonomous bus trial in the United Kingdom commenced in mid-2019, with an Alexander Dennis Enviro200 MMC single-decker bus modified with autonomous software from Fusion Processing able to operate in driverless mode within Stagecoach Manchester’s Sharston bus depot, performing tasks such as driving to the washing station, refueling point and then parking at a dedicated parking space in the depot. Passenger-carrying driverless bus trials in Scotland commenced in January 2023, with a fleet of five identical vehicles to the Manchester trial used on a 14 miles (23 km) Stagecoach Fife park-and-ride route across the Forth Road Bridge, from the north bank of the Forth to Edinburgh Park station.

Another autonomous trial in Oxfordshire, England, which uses a battery electric Fiat Ducato minibus on a circular service to Milton Park, operated by FirstBus with support from Fusion Processing, Oxfordshire County Council and the University of the West of England, entered full passenger service also in January



Figure 7: The United Kingdom's first autonomous bus, currently on trial with Stagecoach Manchester

2023. The trial route will be extended to Didcot Parkway railway station after acquiring a larger single-decker by the end of 2023.

In July 2020 in Japan, AIST Human-Centered Mobility Research Center with Nippon Koei and Isuzu started a series of demonstration tests for mid-sized buses, Isuzu “Erga Mio” with autonomous driving systems, in five areas; Ōtsu city in Shiga prefecture, Sanda city in Hyōgo Prefecture and other three areas in sequence.

In October 2023, Imagry, an Israeli AI startup, introduced its mapless autonomous driving solution at Busworld Europe, leveraging a real-time image recognition system and a spatial deep convolutional neural network (DCNN) to mimic human driving behavior.

Modular autonomous transit is a research concept for public transit using self-driving vehicles with connectable units, or “pods”, that can adjust capacity based on passenger demand. Studies suggest these systems could improve efficiency through dynamic routing, with simulations showing reduced travel times in urban networks, though no operational systems existed as of 2025.

Trucks

The concept for autonomous vehicles has been applied for commercial uses, such as autonomous or nearly autonomous trucks.

Companies such as Suncor Energy, a Canadian energy company, and Rio Tinto Group were among the first to replace human-operated trucks with driverless commercial trucks run by computers. In April 2016, trucks from major manufacturers including Volvo and the Daimler Company completed a week of autonomous driving across Europe, organized by the Dutch, in an effort to get self-driving trucks on the road. With developments in self-driving trucks progressing, U.S. self-driving truck sales is expected to reach 60,000 by 2035 according to a report released by IHS Incorporated in June 2016.

As reported in June 1995 in Popular Science magazine, self-driving trucks were being developed for combat convoys, whereby only the lead truck would be driven by a human and the following trucks would rely on satellite, an inertial guidance system and ground-speed sensors. Caterpillar Incorporated made early developments in 2013 with the Robotics Institute at Carnegie Mellon University to improve efficiency and reduce cost at various mining and construction sites.

In Europe, the Safe Road Trains for the Environment is such an approach.

From PWC's Strategy & Report, self driving trucks will be the source of concern around how this technology will impact around 3 million truck drivers in the US, as well as 4 million employees in support of the trucking economy in gas stations, restaurants, bars and hotels. At the same time, some companies like Starsky, are aiming for Level 3 Autonomy, which would see the driver playing a control role around the

truck's environment. The company's project, remote truck driving, would give truck drivers a greater work-life balance, enabling them to avoid long periods away from their home. This would however provoke a potential mismatch between the driver's skills with the technological redefinition of the job.

Companies that buy driverless trucks could massively cut costs: human drivers would no longer be required, companies' liabilities due to truck accidents would diminish, and productivity would increase (as the driverless truck doesn't need to rest). The usage of self driving trucks will go hand in hand with the use of real-time data to optimize both efficiency and productivity of the service delivered, as a way to tackle traffic congestion for example. Driverless trucks could enable new business models that would see deliveries shift from day time to night time or time slots in which traffic is less heavily dense.

Motorcycles

Several self-balancing autonomous motorcycles were demonstrated in 2017 and 2018 from BMW, Honda and Yamaha.

Trains

The concept for autonomous vehicles has also been applied for commercial uses, like for autonomous trains. The world's first driverless urban transit system is the Port Island Line in Kobe, Japan, opened in 1981. The first self-driving train in the UK was launched in London on the Thameslink route.

An example of an automated train network is the Docklands Light Railway in London.

Also see List of automated train systems.

Trams

In 2018 the first autonomous trams in Potsdam were trialed.

Automated guided vehicle

An automated guided vehicle or automatic guided vehicle (AGV) is a mobile robot that follows markers or wires in the floor, or uses vision, magnets, or lasers for navigation. They are most often used in industrial applications to move materials around a manufacturing facility or warehouse. Application of the automatic guided vehicle had broadened during the late 20th century.

Aircraft

Aircraft have received much attention for automation, especially for navigation. A system capable of autonomously navigating a vehicle (especially aircraft) is known as autopilot.

Delivery drones

Various industries such as packages and food have experimented with delivery drones. Traditional and new transportation companies are competing in the market. For example, UPS Flight Forward, Alphabet Wing, and Amazon Prime Air are all developing delivery drones. Zipline, an American medical drone delivery company, has the largest active drone delivery operations in the world, and its drones are capable of Level 4 autonomy.

However, even if technology seems to allow for those solutions to function correctly as various tests of various companies show, the main throwback to the market launch and use of such drones is inevitably the legislation in place and regulatory agencies have to decide on the framework they wish to take to draft regulation. This process is in different phases across the world as each country will tackle the topic independently. For example, Iceland's government and departments of transport, aviation, police have already started issuing licenses for drone operations. It has a permissive approach and together with Costa Rica, Italy, the UAE, Sweden and Norway, has a fairly unrestricted legislation on commercial drone use. Those countries are

characterized by a body of regulation that may give operational guidelines or require licensing, registration and insurance.

On the other side, other countries have decided to ban, either directly (outright ban) or indirectly (effective ban), the use of commercial drones. The RAND Corporation thus notes the difference between countries forbidding drones and those that have a formal process for commercial drone licensing, but requirements are either impossible to meet or licenses do not appear to have been approved. In the US, United Parcel Service is the only delivery service with the Part 135 Standard certification that is required to use drones to deliver to real customers.

However, most countries seem to be struggling on the integration of drones for commercial uses into their aviation regulatory frameworks. Thus, constraints are placed on the use of those drones such as that they must be operating within the visual line of sight (VLOS) of the pilot and thus limiting their potential range. This would be the case of the Netherlands and Belgium. Most countries let pilots operate outside the VLOS but is subject to restrictions and pilot ratings, which would be the case of the US.

The general trend is that legislation is moving fast and laws are constantly being reevaluated. Countries are moving towards a more permissive approach but the industry still lacks infrastructures to ensure the success of such a transition. To provide safety and efficiency, specialized training courses, pilot exams (type of UAV and flying conditions) as well as liability management measures regarding insurances may need to be developed.

There is a sense of urgency related to this innovation as competition is high and companies lobby to integrate them rapidly in their products and services offerings. Since June 2017, the US Senate legislation reauthorized the Federal Aviation Administration and the Department of Transportation to create a carrier certificate allowing for package deliveries by drones.

Watercraft

Autonomous boats can provide security, perform research, or conduct hazardous or repetitive tasks (such as guiding a large ship into a harbor or transporting cargo).

DARPA

Sea Hunter is an autonomous unmanned surface vehicle (USV) launched in 2016 as part of the DARPA Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) program.

Submersibles

Underwater vehicles have been a focus for automation for tasks such as pipeline inspection and underwater mapping.

Assistance robots

Spot

This four-legged robot was created to be able to navigate through many different terrain outdoors and indoors. It can walk on its own without colliding into anything. It uses many different sensors, including 360-degree vision cameras and gyroscopes. It is able to keep its balance even when pushed over. This vehicle, while it is not intended to be ridden, can carry heavy loads for construction workers or military personnel through rough terrain.

Regulation

The British Highway Code states that:

By self-driving vehicles, we mean those listed as automated vehicles by the Secretary of State for Transport under the Automated and Electric Vehicles Act 2018.

—The Highway Code –27/07/2022, p. 4

The UK considers the way to update its British Highway Code for automated code:

Automated vehicles can perform all the tasks involved in driving, in at least some situations. They differ from vehicles fitted with assisted driving features (like cruise control and lane-keeping assistance), which carry out some tasks, but where the driver is still responsible for driving. If you are driving a vehicle with assisted driving features, you **MUST** stay in control of the vehicle.

—proposed changes to The Highway Code

If the vehicle is designed to require you to resume driving after being prompted to, while the vehicle is driving itself, you **MUST** remain in a position to be able to take control. For example, you should not move out of the driving seat. You should not be so distracted that you cannot take back control when prompted by the vehicle.

—proposed changes to The Highway Code

Concerns

Lack of control

Through the autonomy level, it is shown that the higher the level of autonomy, the less control humans have on their vehicles (highest level of autonomy needing zero human interventions). One concern regarding the development of vehicular automation is related to the end-users' trust in the technology that controls automated vehicles. According to a nationally conducted survey made by Kelley Blue Book (KBB) in 2016, it was shown that the majority of people would choose to have a certain level of control behind their own vehicle rather than having the vehicle operate in Level 5 autonomy, or in other words, complete autonomy. According to half of the respondents, the idea of safety in an autonomous vehicle diminishes as the level of autonomy increases. This distrust of autonomous driving systems proved to be unchanged throughout the years when a nationwide survey conducted by AAA Foundation for Traffic and Safety (AAAFTS) in 2019 showed the same outcome as the survey KBB did in 2016. AAAFTS survey showed that even though people have a certain level of trust in automated vehicles, most people also have doubts and distrust towards the technology used in autonomous vehicles, with most distrust in Level 5 autonomous vehicles. It is shown by AAAFTS's survey that people's trust in autonomous driving systems increased when their level of understanding increased.

Malfunctions

The possibility of autonomous vehicle's technology to experience malfunctions is also one of the causes of user's distrust in autonomous driving systems. It is the concern that most respondents voted for in the AAAFTS survey. Even though autonomous vehicles are made to improve traffic safety by minimizing crashes and their severity, they still caused fatalities. At least 113 autonomous vehicle related accidents have occurred until 2018. In 2015, Google declared that their automated vehicles experienced at least 272 failures, and drivers had to intervene around 13 times to prevent fatalities. Furthermore, other automated vehicles' manufacturers also reported automated vehicles' failures, including the Uber car incident. A self-driving Uber car accident in 2018 is an example of autonomous vehicle accidents that are also listed among self-driving car fatalities. A report made by the National Transportation Safety Board (NTSB) showed that the self-driving Uber car was unable to identify the victim in a sufficient amount of time for the vehicle to slow down and avoid crashing into the victim.

Ethical

Another concern related to vehicle automation is its ethical issues. In reality, autonomous vehicles can encounter inevitable traffic accidents. In such situations, many risks and calculations need to be made in order to minimize the amount of damage the accident could cause. When a human driver encounters an inevitable accident, the driver will take a spontaneous action based on ethical and moral logic. However, when a driver has no control over the vehicle (Level 5 autonomy), the system of an autonomous vehicle needs



Figure 8: A prototype of an autonomous Uber car being tested in San Francisco, California

to make that quick decision. Unlike humans, autonomous vehicles can only make decisions based on what it is programmed to do. However, the situation and circumstances of accidents differ from one another, and any one decision might not be the best decision for certain accidents. Based on two research studies in 2019, the implementation of fully automated vehicles in traffic where semi-automated and non-automated vehicles are still present might lead to complications. Some flaws that still need consideration include the structure of liability, distribution of responsibilities, efficiency in decision making, and the performance of autonomous vehicles with its diverse surroundings. Still, researchers Steven Umbrello and Roman V. Yampolskiy propose that the value sensitive design approach is one method that can be used to design autonomous vehicles to avoid some of these ethical issues and design for human values.