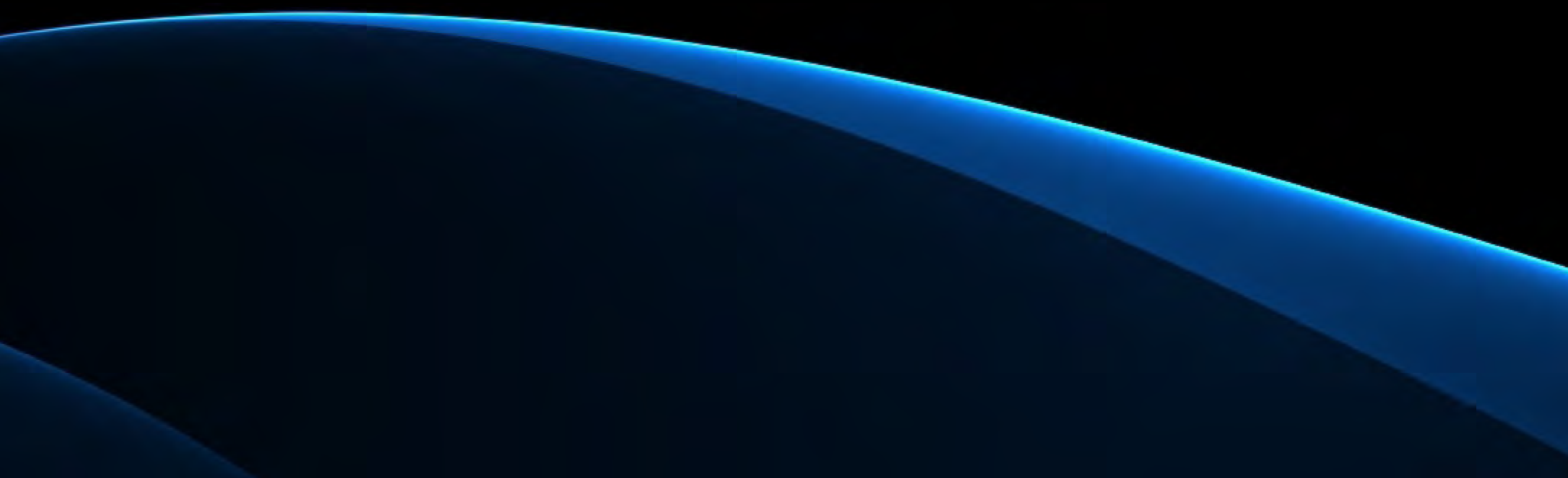
Reinventing Safety: A Joint Approach to Automated Driving Systems

In cooperation with

BOSCH

Reinventing Safety: A Joint Approach to Automated Driving Systems

Mercedes-Benz and Bosch work together to advance the development of driverless cars



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Introduction

Mercedes-Benz and Bosch are pioneers in the automotive industry, especially in automotive safety. Both companies carry out intensive research in this field and have brought many innovative safety systems and technologies to market.

Since Mercedes-Benz invented the automobile in 1886, cars proudly bearing its three-pointed star have been setting standards in vehicle safety. The groundbreaking Mercedes-Benz “Intelligent Drive” assistance systems are becoming increasingly networked as they set new milestones on the road to fully automated driving. Today, Mercedes-Benz and Bosch work together to continue to refine and advance the field of safety in road traffic.

Mercedes-Benz is bringing vehicles capable of automated driving to city streets with the aim of enhancing road safety, improving urban traffic flow and providing important building blocks for the traffic of the future. Mercedes-Benz and Bosch are not newcomers to this important endeavor. The companies first began developing and sharing their expertise in automated driving with their “Prometheus” joint project in 1986, proving the vast potential of this technology.

From Innovation to Industry Benchmark

Many innovative safety technologies that are taken for granted today were developed with Bosch and first introduced in Mercedes-Benz vehicles. Examples include:

- The anti-lock braking system (ABS), introduced in the 1978 S-Class
- The airbag, introduced in the 1981 S-Class
- The Electronic Stability Program ESP® (known generically as “electronic stability control”), introduced in the 1995 S-Class Coupé.

Milestone successes such as these continue to encourage both companies to work hard to further automated driving to achieve their mutual goal of enhancing overall automotive safety.

Mercedes-Benz and Bosch join Forces to Work on Future Mobility: Driverless-Capable Vehicles

Our next objective is to deliver production-ready vehicles capable of driverless operation within prescribed areas, also known as “operational design domains”, such as a city’s downtown district. Mercedes-Benz and Bosch joined forces in 2017 – uniting one of the world’s leading premium vehicle manufacturers with the vast system and hardware expertise of one of the world’s largest automotive suppliers – by entering into a development agreement to bring highly-automated, driverless-capable (SAE Level 4) vehicles to urban roads by the beginning of the next decade. We are currently developing the highly-sophisticated software and algorithms to enable a vehicle to operate without a human driver in complex urban traffic, as well as automatically manage malfunctions and problems by moving the vehicle to a minimal risk condition (low-risk operating mode) whenever necessary.

Shared Mobility of the Future

By introducing driverless-capable vehicles to the urban environment, Mercedes-Benz aims to enhance road safety, improve urban traffic flow and provide important building blocks for future integrated and automated transportation systems. The technology will, among other things, boost the attraction of car sharing. It will allow people to make the best possible use of their time in the vehicle, open up new mobility opportunities, and expand transportation options for customers travel-ling within urban environments, including those currently unable to drive due to a disability. The idea here is that, within a specified area, customers will be able to summon a Mercedes-Benz automated vehicle via their smartphone. The vehicle will then make its way to the user’s pick-up location and deliver the person to their specified destination.

On the Road to Automated Driving: Intelligent World Drive on Five Continents

The vision of "driverless cars" is fascinating to increasing numbers of people. However, it will still be years before all vehicles are equipped with the level of automated driving technology that will allow them to be operated in driverless mode everywhere. The sophisticated assistance systems already on the road today demonstrate the advanced stage this technology has already reached. But some missing links remain between today's vehicles and the higher automated driving features of driverless-capable vehicles.

Mercedes-Benz is continually testing and improving its automated driving technology. With its Intelligent World Drive tour Mercedes-Benz sent a test vehicle equipped with automated driving technology on an educational journey across five continents that lasted from September 2017 to January 2018. Over these five months, valuable experience was gained during automated test drives on real roads under an extraordinarily wide variety of traffic conditions.

When traffic conditions in various countries and cultures are closely observed, clear differences and characteristic features become apparent. These specific characteristics must be "experienced" in real-world traffic in order for the automated driving technology to adapt to them. "The acquisition, processing, and interpretation of highly complex traffic situations is the key to safe automated and driverless vehicles," explains Ola Källenius, member of the Daimler Board of Management responsible for Group Research & Mercedes-Benz Cars Development. "These processes are especially complex in dense urban traffic. We are therefore testing our automated driving functions very deliberately in driving situations that occur daily in major cities."

The Intelligent World Drive test project also points out just how important the international harmonization of both the legal framework for automated driving and the associated infrastructure will be to the successful market introduction of automated vehicles. Therefore, Mercedes-Benz and Bosch continue to work with governmental and industry entities to promote international harmonization in laws, regulations, and standards related to automated driving and their connected vehicle technologies.

USA

The last phase of the Intelligent World Drive was conducted in California and Nevada. In test drives in Greater Los Angeles and from there to the Consumer Electronics Show (CES) in Las Vegas, the test vehicle had to prove itself in dense urban traffic and on highways. In the process, it became familiar with the special characteristics of US road traffic.
For example, in the United States school buses are a special category of road user. When they stop and turn on their warning lights, all vehicles in their vicinity have to stop. US speed limit signs are also absolutely unique. They have completely different shapes and sizes than the speed limit signs in Europe, Australia, Asia, and Canada. The United States also has high-occupancy vehicle (HOV) lanes, as well as road markings made of raised plastic dots (Botts' Dots). And in certain situations, US drivers are also allowed to pass on the right. All of these factors place high demands on the test vehicle's sensor systems and algorithms.

Europe

The first phase begins in Germany. Here the focus was on driver behavior specifically on highways and in traffic jams.

China

A city of millions. Countless people, bicycles, motorcycles, and ever more cars – as well as the distinctive features of Chinese traffic. Here the test drives focused on driving behavior in extremely dense traffic with a wide variety of road users.
In addition to traffic signs in Chinese script, there are lane markings that have different meanings depending on their context. For example, the broad white lines that are used to indicate crosswalks all over the world can also be found on Chinese highways, but there they indicate the minimum distance between vehicles. The sensor systems of automated and autonomous vehicles must recognize and correctly interpret such features. This also applies to speed limits, which may differ for different lanes – and seven-lane intersections that are crossed simultaneously by dozens of bicycles and pedestrians during rush hour.

South Africa

Traffic in South Africa poses some very unusual challenges, such as traffic signs that are unique to this country, wild animals on the road, and pedestrians crossing the road unexpectedly.
During automated test drives on the West Cape and in Cape Town, the test vehicle rose to these South African challenges. It focused mainly on the pedestrian detection system. There are lot of pedestrians in South Africa's cities and countryside. Some of them walk in the roadway or cross the street in unusual traffic situations. On national roads outside towns and villages, and even on major highways, drivers have to constantly look out for pedestrians crossing the roadway. This places correspondingly high demands on the sensor systems of automated and autonomous vehicles. Cameras and radar systems must recognize pedestrians and interpret their movements correctly so that the vehicle can react in milliseconds if necessary.

Australia

Drivers making a right turn from the left lane, flashing speed limit signs, kangaroos hopping across the road – during the third stage of the Intelligent World Drive, the test vehicle had to master automated test drives on country roads, highways, and city traffic with a whole new set of specific requirements.
The route began in Sydney, continued through Canberra and Albury, ending up in the urban traffic of Melbourne. One focus of the test drive was the validation of the digital map data of HERE. The system also had to recognize the country-specific traffic signs.

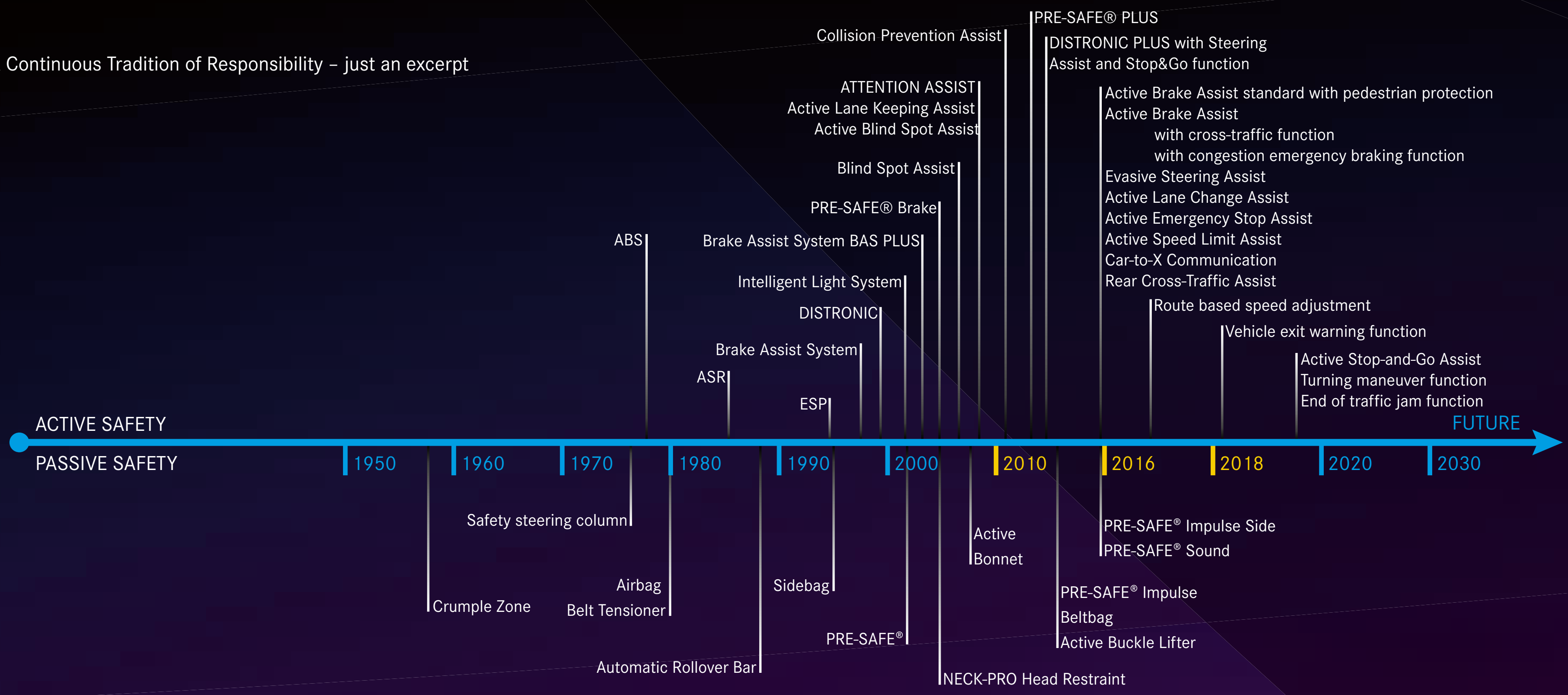
In addition, the engineers tested a new lighting technology. The test vehicle was equipped with the innovative DIGITAL LIGHT system. Inside the headlight prototypes, chips containing more than one million pixels per headlight provide anti-dazzle, continuous high beams in HD quality. Among other things, DIGITAL LIGHT can project light tracks onto the road in order to communicate with its surroundings.

The Safety Heritage of Mercedes-Benz

Mercedes-Benz can proudly point to decades of innovation in automotive safety systems that have set the standard for safe vehicles, as it continues to set the pace of progress in both active safety systems and occupant protection systems. Many of these innovative systems are now standard equipment on vehicles across the industry.

The Figure below shows the timeline of safety systems introduced on Mercedes-Benz vehicles. It ranges from the introduction of the Crumple Zone in 1959 all the way up to current systems that prevent ear drum ruptures and pull the driver and passenger out of the way of a side-impact crash.

A Continuous Tradition of Responsibility – just an excerpt



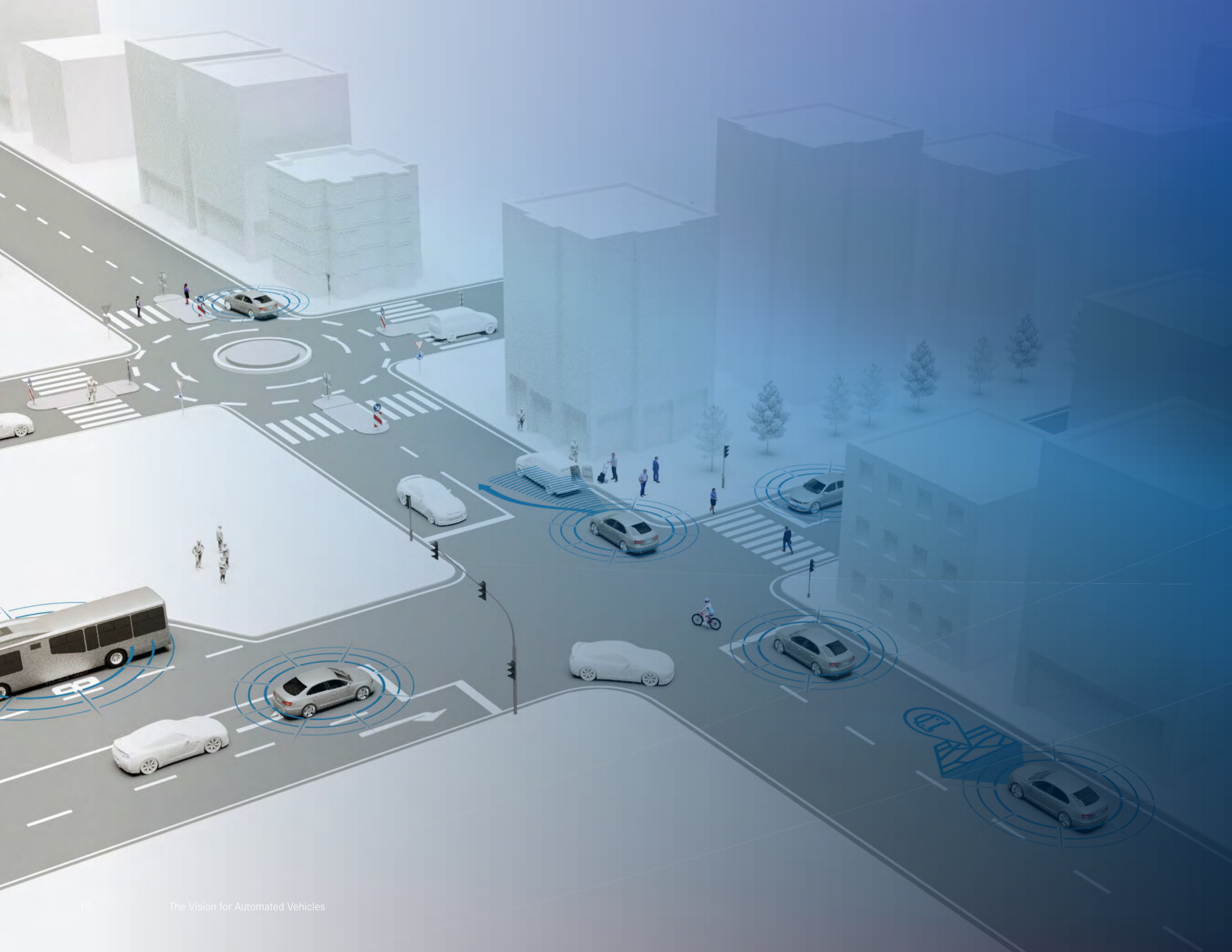
The Vision for Automated Vehicles

Mercedes-Benz and Bosch share a vision of a future with fewer traffic accidents and less stress. We are working to achieve this vision through automation, electrification and connectivity. Automation is one of the biggest drivers of change in the transportation sector. It has the potential to make mobility safer for all – most of the accidents are caused by human error – while reducing traffic congestion. Thanks to the automated driving capability, a vehicle can also be a private retreat that allows us to use our time on the move as we wish.

The F015 concept vehicle, named “Luxury in Motion,” is a purpose-built research vehicle intended to show what an automated Mercedes-Benz vehicle may look like in the future.

The planned Mercedes-Benz automated vehicle will come with systems that are integrated within a digital infrastructure which is capable of connecting to a Fleet Operations Center, data sources from public agencies (e.g., traffic signal data from local road authorities) and data from other vehicles. It will also have an interface to the cloud where status reports, as well as relevant traffic, weather, incident, and construction information can be accessed. These automated vehicle features will serve to optimize planning for each customer’s journey.

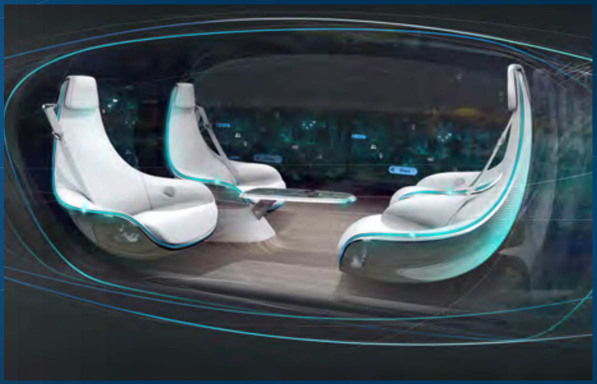
The F015 Luxury in Motion, a research vehicle, shows what an automated Mercedes-Benz vehicle may look like in the future.



Overall Design Approach

Safety guides the design of the Mercedes-Benz automated vehicle from concept to deployment. The fundamental objectives are:

- Adhere to the applicable legal rules
- Only drive within the prescribed operational design domain
- Drive defensively
- Automatically achieve a minimal risk condition when necessary



Safety Assurance Aspects

An important goal for automated vehicles is to reduce the potential for accidents and to mitigate risks for passengers and other road users by operating like a defensive and attentive driver who consistently monitors the driving environment and responds appropriately and safely to changing conditions. To that end, system safety is incorporated into the vehicle's design, development, testing and validation with a sharp focus on the following four key safety assurance aspects:

System Safety

Functional safety includes identifying and planning for potential hazards that may occur due to a malfunction in safety-critical electrical and electronic systems. We employ established international process standards (such as ISO 26262) to help us pinpoint and mitigate potential hazards during the design and development process. Additionally, we consider aspects of "Safety of the Intended Functionality" (SOTIF) which describes a methodology for identifying functional insufficiencies in the system as designed, and deriving countermeasures. By optimizing the design and/or providing redundant components or systems we can best ensure the automated vehicle's essential functions remain operational, even when a malfunction occurs.

Accurate and Reliable Environmental Sensing

One of the most important tasks for the automated vehicle is to accurately and reliably detect relevant and potentially hazardous objects and events in the driving environment. This includes, but is not limited to, other road users, foreign objects, animals in the roadway, pavement markings, and signs and signals. It further extends to a wide variety of events, such as emergency vehicles, construction zones, and traffic incident scenarios that require extraordinary measures. Based on both companies' extensive experience with driver assistance systems, we are developing a robust, comprehensive and integrated sensor set.

Safe Automated Vehicle Behavior

As the vehicle sensors detect objects and events in the environment, the vehicle must appropriately react to them. Therefore, the design process incorporates a safety-oriented, defensive driving style developed to avoid at-fault crashes with other road users, while avoiding or mitigating crashes caused by others.

Learning and Continuous Improvement

Mercedes-Benz constantly monitors and analyzes the system performance of its vehicles in the real world in order to continuously improve them. This includes detailed analysis of field data, as well as customer feedback and diagnostic data.

Safety Process

Development of a safe automated vehicle requires the manufacturer and its suppliers to implement specific processes to guide all aspects of the design of the automated vehicle, including hardware and software. Mercedes-Benz, as a vehicle manufacturer, and Bosch, as a supplier, have extensive experience in using these processes, tools and methods in the development of driver assistance systems.

To address system safety during development, we use standardized tools and methods, such as:

- ISO 26262 – “Road vehicles – functional safety”: An extensive safety implementation process standard that includes a “Hazard Analysis and Risk Assessment”, which is a method to evaluate the risks caused by malfunctioning behavior. ISO 26262 also specifies methods to rate and address each identified hazard in order to eliminate or substantially mitigate the harm that could otherwise result from it. This standard also specifies independent audit procedures for verifying compliance. Daimler AG, the parent company of Mercedes-Benz, was the original driver of ISO 26262, which is adapted from the generic industry standard, IEC 61508 – “Functional safety of electrical/electronic/programmable electronic safety-related systems.”
- Deductive analysis: A top-down approach to identify causal chains between hazards and their root causes. Fault Tree Analyses (FTAs) are widely used across all industries.
- Inductive analysis: A method widely used in the automotive industry is the Failure Modes and Effects Analysis (FMEA), which helps to identify possible hazards during system design.
- A process for iteratively identifying functional insufficiencies of automated driving systems and deriving countermeasures to address the resulting risk (Safety of the intended functionality (SOTIF)).

Today’s driver assistance systems already provide a high level of safety and comfort

Vehicle Architecture

Because safety is paramount for automated vehicles, safety concerns are key to the vehicle's architecture and development process. For this, relevant industry standards, such as ISO/IEC 15504 – "Information Technology – Process Assessment", a software validation method, as well as safety standards, such as ISO 26262 "Road Vehicle – Functional Safety" are utilized. These industry standards provide valuable guidelines for developing and producing safer products, in addition to embedding traceability and accountability in the development process. Overall, this development process provides:

1. A clear specification of where and under which conditions (e.g., location, weather, time of day, etc.) the automated vehicle is designed to operate. Within that operational design domain, requirements are collected and analyzed for the automated vehicle, including its capability to operate in compliance with relevant safety and traffic laws and regulations.

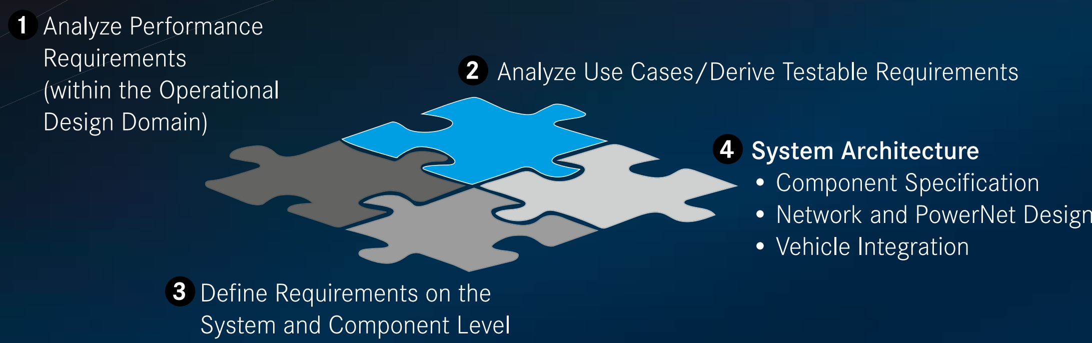
2. Analysis of use cases (real-life situations) relevant for the safe performance of an automated vehicle within its operational design domain. From these use cases required capabilities can be derived. Examples of common use cases are "driving through a 4-way stop" or "stopping at a crosswalk and giving the pedestrian(s) the right-of-way." Each use case requires certain functions, abilities and responses from the vehicle. The description and interaction between these use cases ultimately determines the architecture of the automated vehicle.

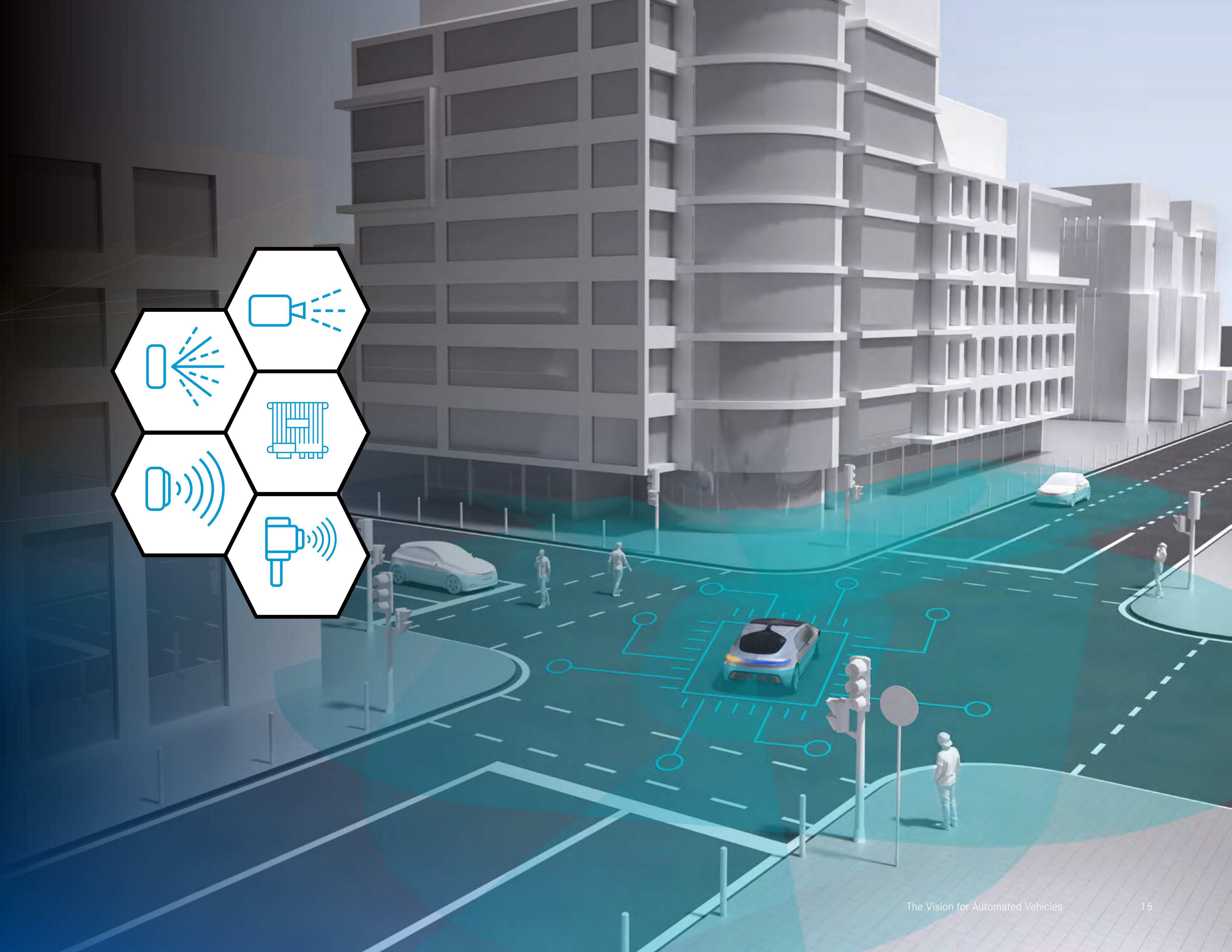
3. Defined requirements that can be tested on the system and at component levels, such as, for example, those for radar sensors or sensor fusion algorithms. The collection of these testable requirements can then be input to the design and functionality for the various use cases.

4. A system architecture, including the final component specification, "Network & Power-Net Design", culminates in the integration requirements in the vehicle.

This system design strategy facilitates a comprehensive approach to testing, verification and validation for safety assurance at all levels of performance, from individual components and subsystems to the vehicle as a whole.

Of course, the vehicle also needs to be fault tolerant and able to properly function even if a system shows an error. For this we design redundancies into our system which make the vehicle robust in its operation and which allow the vehicle to reach a minimal risk condition when needed.





Operational Design Domain

The operational design domain describes the precise conditions under which an automated vehicle is designed to operate and includes such things as speed, range, time-of-day, weather conditions, the presence or absence of certain types of roadway infrastructure, as well as the geographical area in which the automated vehicle is designed to operate. Our automated vehicle is “geo-fenced,” meaning that, in addition to other limitations, its operational design domain is further defined with a precise, high-definition map that tightly defines the vehicle’s prescribed area of operation; by design the vehicle is prevented from leaving this area. Mercedes-Benz determines the operational design domain(s) for its automated vehicles in specific target cities by analyzing environmental conditions ranging from traffic and infrastructure to lighting, signs and road types, as well as applicable legal requirements.

A suitable route for a given ride request is calculated at the Fleet Operations Center within this geo-fenced area. It can also take into account information such as real-time road conditions, traffic information and weather to ensure the automated vehicle can execute the driving assignment before a dispatch order is processed and the automated vehicle is commanded to proceed to the designated location.

Adverse weather conditions (such as heavy rain or snowstorms) may require the temporary suspension of the mobility service of the vehicle, as they constitute an operational design domain limitation. Such conditions are closely monitored prior to dispatching the automated vehicles for passenger pick-up or relocation. Similarly, the vehicles’ sensors are continuously monitored by the perception system during operation in order to detect whether environmental conditions are reducing the ability of the vehicle’s sensors to perceive its operating environment. Should environmental conditions deteriorate to the point that the automated vehicle is unable to accurately and reliably perceive its operating environment during a given trip, the automated vehicle will automatically transition to a minimal risk condition. This could, for example, include measures such as turning on the hazard flashers, temporarily parking the automated vehicle and/or summoning assistance from the Fleet Operations Center.

One important aim of the automated vehicle mobility service is to continually expand the operational design domain of the fleet vehicles. The ultimate goal for Mercedes’ automated vehicle mobility service is to operate at any time of day and in as many geographical areas and environmental conditions as possible.

The Vision for Automated Vehicles


Verbrauch l/100km
180°-Ansicht

Object and Event Detection and Response

The Perception System, Environment Modeling and Behavior Planning and Prediction activities of an automated vehicle are commonly defined by the general term “object and event detection and response” (OEDR). This term is the same one used to describe the behaviors humans rely on to drive safely.

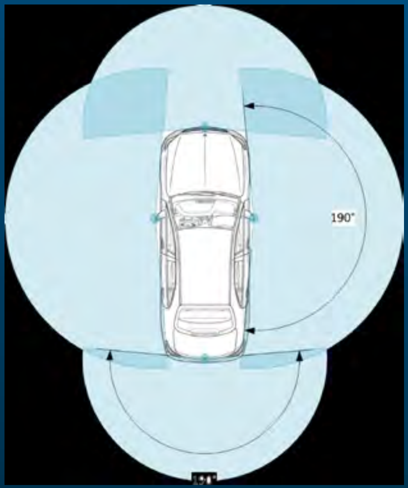
We design the automated vehicle’s OEDR capabilities by analyzing relevant scenarios the vehicle will encounter in traffic. These include both commonly and rarely encountered situations. How the vehicle handles any given traffic situation is determined both by applicable traffic laws and by principles of safe and defensive driving. Reliable OEDR performance is achieved by a well designed system of sensors, actuators and computing resources. Redundancies are applied in a way that in case of a malfunction the vehicle can still respond appropriately. The various components responsible for the OEDR are described in more detail below.

Environmental Perception

The environmental perception system consists of sensors and perception algorithms. The environmental perception system converts raw sensor data into recognizable objects and is crucial to the reliable performance of the automated vehicle while operating on public roadways. Extensive design efforts are undertaken by Mercedes-Benz and Bosch in order to achieve robust performance.

360-Degree Environment Perception with Surround Vision

Below you can see a scenario taken by our surround vision cameras. Our algorithms are able to classify objects and their surroundings in the scene e.g. cars and motorcycles are highlighted in dark blue, pedestrians in red and the road in maroon.



Mounting positions and coverage area of surround vision cameras.


Front camera


Rear camera


Camera right exterior mirror


Camera left exterior mirror

Design of the Sensor Setup & Perception System

In designing the automated vehicle's sensor setup and environmental perception algorithms, Mercedes-Benz and Bosch not only address routine operation, such as remaining in the travel lane and observing traffic lights and signs, but we look at a large number of so-called "corner" use cases – scenarios that are especially challenging for an automated vehicle. Although corner use cases may be relatively rare occurrences, an automated vehicle must be capable of reliably dealing with them should they occur.

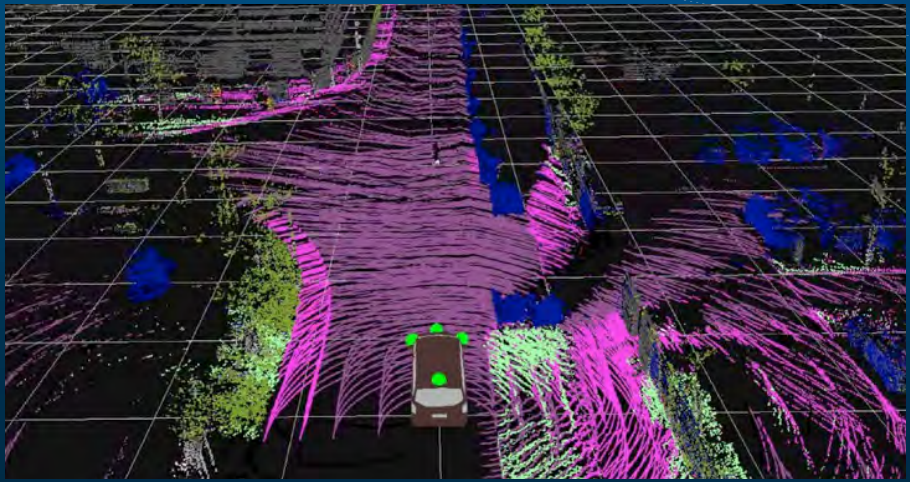
https://aaafoundation.org/prevalence-motor-vehicle-crashes-involving-road-debris-united-states-2011-2014/

http://www.6d-vision.com/lostandfounddataset

For example, the sensor setup is designed to consider the corner use case of road debris and lost cargo. This corner use case factored into more than 200,000 police-reported crashes in the U.S. between 2011-2014 and resulted in a total of approximately 39,000 injuries and 500 deaths. To reliably detect road debris we use "Deep Learning" techniques for interpreting data from the cameras and light detection and ranging (lidar) sensors in the vehicle. We collected tens of thousands of example images with road debris and lost cargo for this purpose. In addition, we made a part of this dataset publicly available to the rest of the automotive industry to foster the sharing of pre-competitive information that will serve to enhance the safety of all automated vehicles in the future.

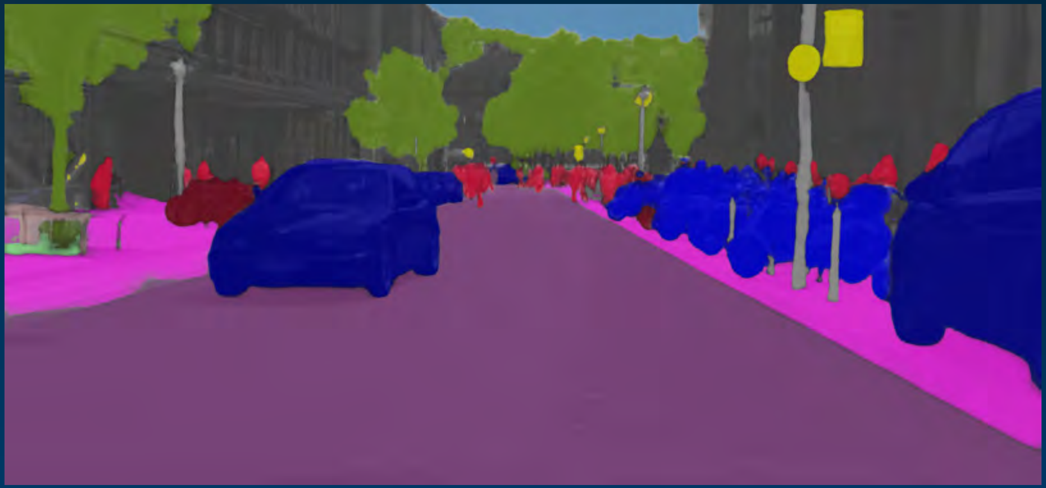
The images below show example results obtained with the lidar sensor and camera systems from our targeted sensor setup. Purple denotes space available for driving; yellow denotes lost cargo.

Deep Learning algorithms have enabled tremendous progress to be made in the field of artificial intelligence and machine learning for automated driving systems. This technology substantially improved perception capabilities and is now an integral part of our sensing and perception systems.



The images on the right show results generated by Deep Learning algorithms. The so-called “semantic information” in the image classifies objects as roadways, trees, pedestrians, etc. In these sample diagrams, vehicles are shown in blue, pedestrians in red, the road in purple, and traffic signs in yellow. All relevant classes of objects and infrastructure are separated by the Deep Learning system. This includes objects and items partially blocked from the automated vehicle’s perception system, such as pedestrians partially hidden by other vehicles.

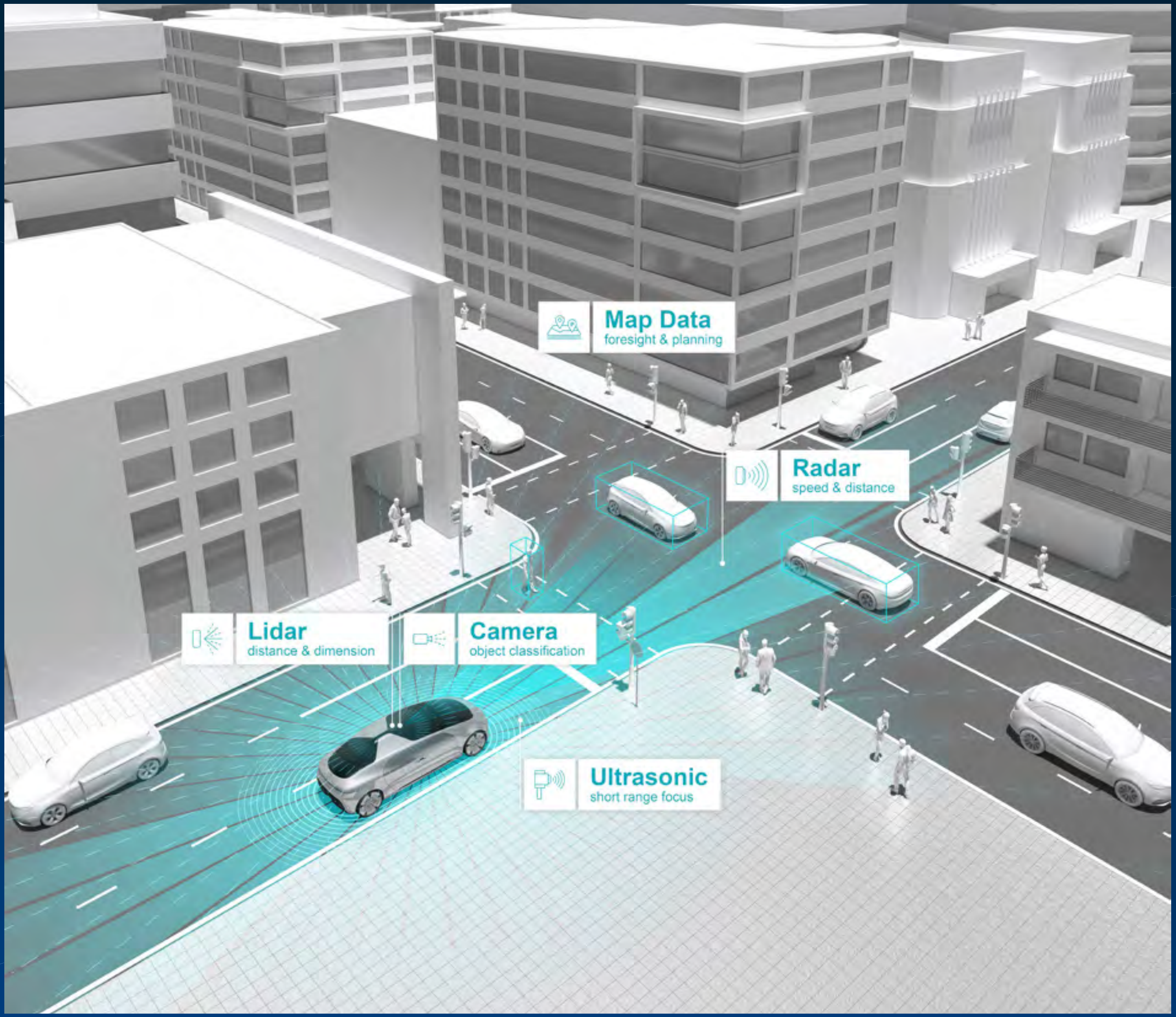
Supervised Deep Learning algorithms require a vast amount of annotated data to yield such results. A large database is used to cover numerous weather and lighting conditions to enable the automated vehicle to function under a wide range of environmental and lighting conditions.



The Sensor Set

The customized sensor setup for the automated vehicle consists of radars, lidars, cameras and ultrasonic sensors, as well as microphones. This sensor setup provides a 360 degree field-of-view around the vehicle. Different sensors overlap in their fields-of-view where necessary for a more robust perception capability and to enable the vehicle to handle all relevant use cases.

Each sensor technology brings specific strengths to the overall perception system for the extensive detection tasks required of an automated vehicle. The challenge in designing a sensor setup is to combine these sensing concepts in such a way that the various technologies complement each other best to achieve the required perception capability. This is called "Sensor Fusion" (see next section). In addition, the sensor setup and its integration into the E/E architecture is designed so the automated vehicle is still able to achieve a minimal risk condition in the unlikely event of a system failure.



Sensor Fusion, Environment Modeling and Behavior Planning

Driving safely and smoothly in complex urban environments requires detailed and ongoing awareness of the real-time traffic situation, coupled with the ability to forecast future traffic developments. This is necessary for the automated vehicle to safely and appropriately execute all driving maneuvers such as following a vehicle, changing lanes, yielding, merging or navigating turns and intersections. These functions are performed by the Sensor Fusion, Environment Modeling and the Behavior Planning modules.

In the Sensor Fusion module input is taken from all the automated vehicle's sensors and, via sophisticated algorithms, combined into an accurate and comprehensive representation of the immediate environment. This is how the vehicle both "sees" and interprets what it sees. The environment representation includes moving objects such as other vehicles, pedestrians, bicycles, animals and so on, as well as non-moving objects, such as parked cars, curbs, traffic lights, etc.

Environment Modeling then takes the environment representation from the Sensor Fusion and combines it with additional sources of information, thereby creating a much more comprehensive picture of the traffic situation in the vicinity of the automated vehicle. It combines three major inputs:

- The comprehensive representation of the operating environment provided by the Sensor Fusion system;
- a high-definition digital map with the location of the automated vehicle and other vehicles and objects;
- and the "driving mission" the automated vehicle has been assigned.

The Environment Modeling module takes information from the Sensor Fusion system and augments and enhances it using additional contextual knowledge about the real-time traffic situation. It can then determine where an object is located relative to the automated vehicle within the high-definition digital map and assess potential future movement. In other words, the system anticipates and predicts what other objects on the roadway might do.

The behavior of each object in the automated vehicle's real-time operating environment can be predicted based on various factors. These include the topology of the road network and context-specific semantic information such as location, type and position of objects and infrastructure and applicable traffic rules. It can also take into consideration inferred relationships between different objects and between those objects and the automated vehicle. The Environment Model provides a constantly updated, real-time, comprehensive representation of the immediate operating environment, which the automated vehicle requires in order to safely operate in traffic.

The Behavior Planning Module plans the most desirable, feasible and appropriate sequence of driving maneuvers to achieve the automated vehicle's route objectives. This module tightly integrates the interpretative and predictive information from the Sensor Fusion and Environment Module with maneuver planning to enable the automated vehicle to drive its route, constantly and flexibly adapting to changing situations in real time. Our goal is to negotiate with other vehicles in a manner similar to a human driver at merge points and intersections. How its actions will likely influence the behavior of surrounding vehicles and pedestrians is also taken into account.

The Motion Planning component of the software directs the motion of the automated vehicle in traffic. The automated vehicle's trajectory is validated based on detailed collision risk assessments and feasibility evaluations. The Motion Planner also employs collision avoidance and mitigation strategies to quickly react to unpredictable events and suddenly-appearing objects.

Fallback and Minimal Risk Condition

While Mercedes-Benz and Bosch emphasize providing the highest quality products, the possibility of a rare component or system malfunction or performance degradation remains. Therefore, we are designing the capability of dealing with such conditions into the automated vehicle. In order to increase both safety and customer satisfaction, the automated vehicle includes levels of degraded or stepped-down performance called “Degradation Levels”. These Degradation Levels help to ensure that the vehicle provides the best possible fallback performance given the particular failure in question and prevailing circumstances, and that it achieves a minimal risk condition when necessary. The minimal risk condition will depend on the prevailing conditions at the time of the failure occurrence and the nature of the specific malfunction or performance degradation.

Failure-dependent Degradation and Minimal Risk Condition Achievement

Performance degradation can happen gradually, ranging from a speed reduction all the way down to a controlled stop maneuver in order to achieve the minimal risk condition. The system response will differ depending on the scenario.

Note that the Mercedes-Benz automated vehicle is also designed to revert to a miminal risk condition if it detects conditions outside of its operational design domain.

Continue Driving

At least until the end of the current trip, if the failure does not affect automated vehicle performance. Fleet Operations Center decides on further measures.

Degraded mode

Adapt operating performance or mission to remaining vehicle capabilities.

Achieve a minimal risk condition

If the remaining system performance is not sufficient to complete the mission, transition to a minimal risk condition will be performed, e.g., a controlled stop outside of an active lane of traffic, when possible.

Automated Vehicle Validation

All Mercedes-Benz vehicles provide excellent active and passive safety features. With the aim of achieving equal safety quality for the automated vehicle, the validation process starts with hardware components, such as sensors (e.g. cameras, lidars, radars, ultrasound sensors, and microphones), computing modules and actuators. Bosch, as the supplier for these items, uses hardware test benches, hardware-in-the-loop test setups and simulations to validate the performance and robustness of individual components, as well as combinations of components and subsystems. After these tests are successfully performed to demonstrate robust functionality under the most challenging environmental and operational conditions, Mercedes-Benz conducts further rigorous tests of these components and subsystems as installed in the automated vehicle. The tests are conducted in the lab, on test tracks, in simulated, virtual test-driving environments and also on public roads.

Software components of the automated vehicle are tested and validated on different levels. The source code itself must meet stringent quality requirements, many of which are already standardized in the automotive domain. In addition, different aspects of the software behavior and functionality are tested either in a hardware-in-the-loop bench test environment, or in virtual test drive simulation by running a multitude of scenarios based on previously recorded data. Those simulations are performed continuously to test the system and make its behavior resilient. This means we are simulating a wide variety of traffic situations, including many that rarely occur, to improve the vehicle's behavior and make it more robust.


INTELLIGENT
WORLD DRIVE
DIGITAL LIGHT

Simulation Methods

Simulation is a very important method for validating the automated vehicle's operation. The objective is to test and improve the automated vehicle's performance by using computer-generated environmental input data in combination with data generated by virtual test-drive software to replicate the operating environment in a computer simulation. By varying either or both the synthesized automated vehicle input data and the virtual test drive environment, we are able to conduct exhaustive and reproducible tests of the automated vehicle's performance. This includes very challenging and hazardous scenarios and circumstances which can be tested much more rapidly, safely and comprehensively than performing track and on-road testing alone.

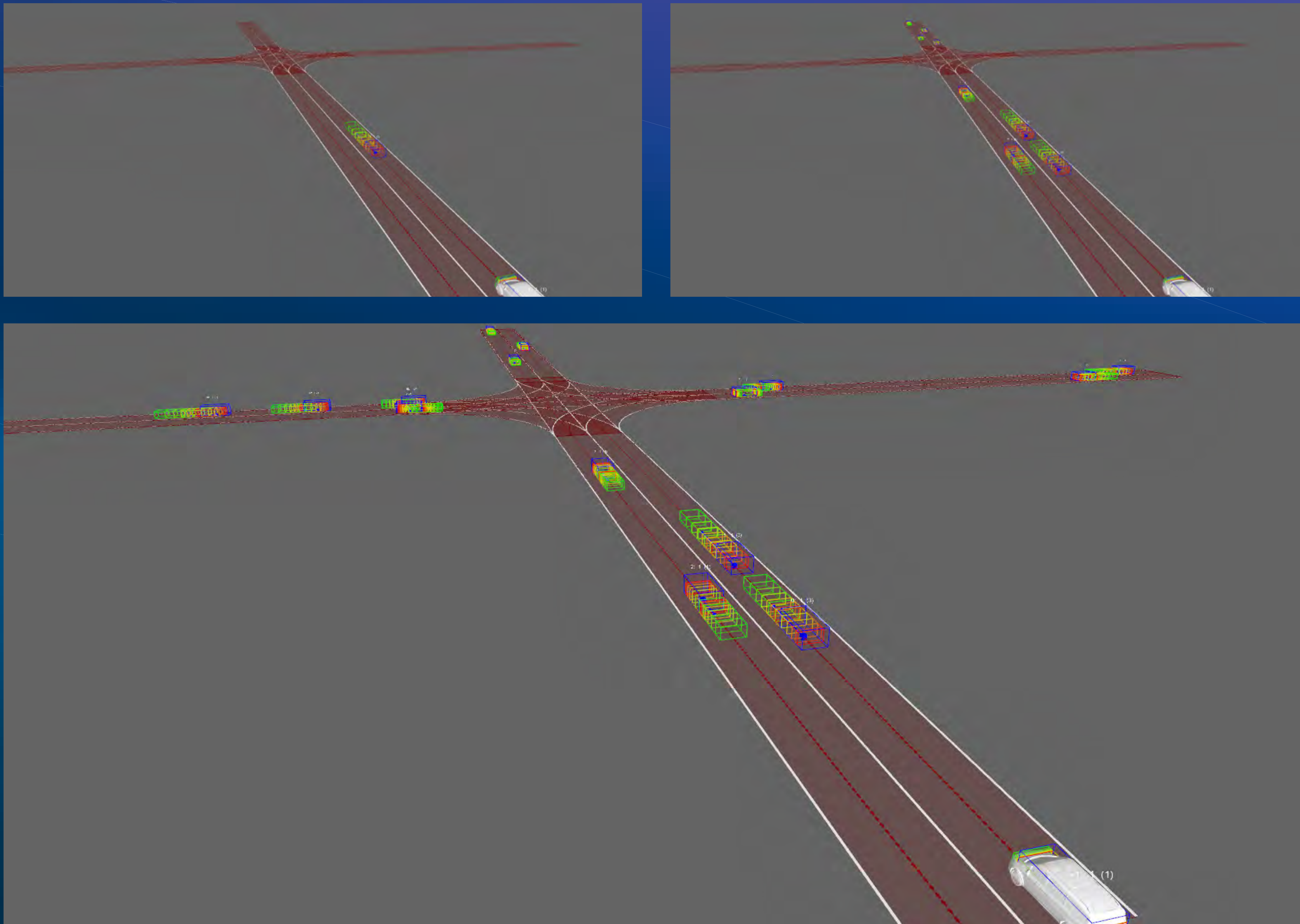
The basis for virtual test drive simulation begins with digitized driving scenarios. Each consists of a map, traffic participants (including their behavior plan), static objects, additional parameters (lighting, weather conditions, etc.) and the automated vehicle's starting condition and mission. The traffic participants can be either static or dynamic and include other road users, such as other vehicles, pedestrians and bicycles. These scenarios are systematically defined and catalogued in order to ensure comprehensive coverage of traffic situations found in the automated vehicle's intended operational design domain.

The various components of the automated vehicle are tested both individually and in combination using virtual test drive simulations. To do this efficiently, thousands of simulations are run simultaneously.

In addition to testing and validating the operation of the automated vehicle when it is functioning normally (even under challenging circumstances), we also use simulation to validate fallback performance and ensure the automated vehicle is capable of achieving a minimal risk condition when needed.

We apply the same evaluation methods to both simulation and actual test drives on closed tracks and on public roads, allowing us to compare and verify the results between simulated and real scenarios.

Variations on a traffic scenario with a variety of traffic participants and lighting conditions



Simulation of an intersection scenario for the development of path planning algorithms with a variety of leading, oncoming and crossing vehicles

Human Machine Interface

Because automated vehicles will not have a driver, it is important that they can communicate with the passenger(s) to provide a variety of information, such as current location, time-to-destination and emergency instructions.

This communication needs to be intuitive and easy to understand for a wide range of passengers, including those with hearing or visual disabilities, as well as those with mild cognitive impairment. If a passenger experiences an emergency, he or she needs to be able to easily stop the vehicle and/or initiate communication with the Fleet Operations Center, while receiving swift feedback that their message has been received and further action is being taken. The same applies if the vehicle or Fleet Operations Center needs to communicate with the passenger(s): If there is a problem that requires the passenger to be alerted, it must happen quickly and clearly.

The ability of the automated vehicle to communicate with other road users is also important. Much of the communication that takes place between people in traffic today happens through gestures or eye contact. Therefore, the automated vehicle needs to replace this communication with other appropriate means.

Mercedes-Benz is designing intuitive interface concepts for its automated vehicle in order to ensure that communication with it is as natural and as universally accessible as possible.

Vehicle Cybersecurity

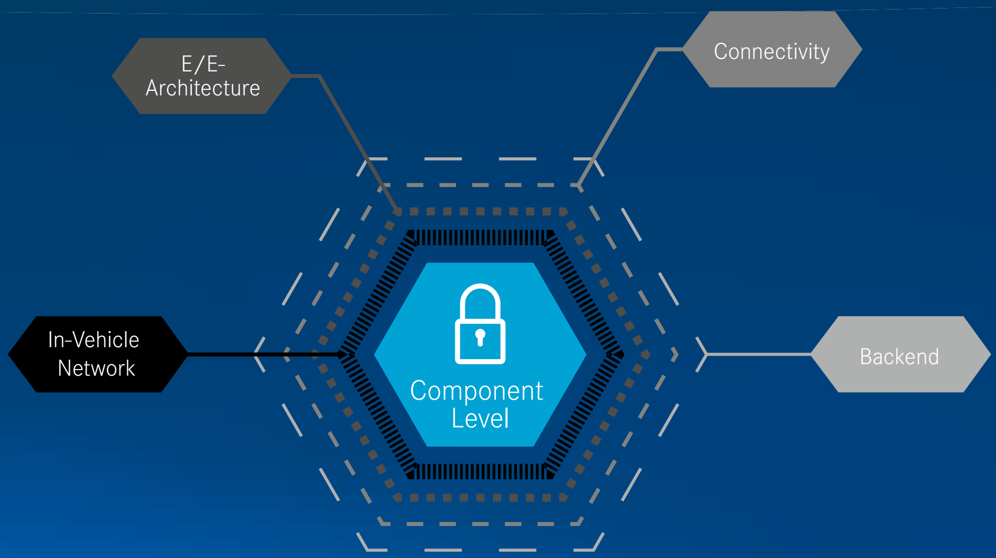
Vehicle cybersecurity is an essential component of keeping the vehicle, passengers and other traffic participants safe. To achieve end-to-end security, Mercedes-Benz and Bosch follow a defense-in-depth approach. Their robust and holistic design includes all layers of the product and service – from the autonomous vehicle and its components (e.g., sensors) to the Fleet Operations Center and backend servers – in the security engineering process.

Our main objective is to provide safety while preventing and mitigating all malfunctions due to unauthorized manipulation, interference or any kind of cyberattack.

Our security engineering process follows the principles of ISO norms 27005 and 31000 for risk-based engineering in an iterative manner:

1. Threats and Risk Analysis: What could go wrong? How bad would it be? How likely is it to happen?
2. Security Concept: What should we do about it?
3. Residual Risk Analysis: Have we done enough?

This approach is implemented in conjunction with the recommendations being developed in the automotive security norm ISO/SAE 21434. In addition to applying a methodical approach to system development, it includes the definition and use of best practices as a baseline for technical implementations, with a focus on the complete life cycle of an automated vehicle. Because control functions provided to the vehicle through wireless means by backend services are important for automated vehicles, the cyberattack surfaces resulting from the very nature of connectivity must be addressed in the security design. We therefore foster appropriate protection against attacks targeted at the backend connection.



Heritage, Cooperation, Continuous Improvement

In addition to being pioneers in automotive safety, Mercedes-Benz and Bosch are also innovators in automotive security for connected vehicles. Our contributions to cooperative research activities such as E-Safety Vehicle Intrusion Protected Applications (EVITA), Crash Avoidance Metrics Partnership (CAMP) and Automotive Open System Architecture (AUTOSAR) to name a few, have led to the specification of automotive hardware security modules for vehicles and secure communication standards for in-vehicle databuses. We are active contributors to the new automotive cybersecurity norm ISO/SAE 21434 and use platforms such as the Automotive Information Sharing and Analysis Center (Auto-ISAC) to ensure continuous improvement by sharing experiences and best practices with the rest of the automotive industry.

Auto-ISAC is designed to provide a forum for vehicle manufacturers and suppliers to share information on cybersecurity threats that could adversely affect the safety of road transportation in the U.S. Mercedes-Benz and Bosch are active members of Auto-ISAC, which is also aligned with ISO/SAE 21434 – “Road vehicles – Cybersecurity engineering” and covers the following areas:

1. Incident response
2. Collaboration and engagement with appropriate third parties
3. Governance
4. Risk management
5. Security by design
6. Threat detection and protection
7. Awareness and training

Crashworthiness

In order to protect our passengers, Mercedes-Benz continuously innovates occupant protection systems. From the invention of the Crumple Zone to countless innovations in occupant protection and accident avoidance, the “safety firsts” brought to market by Mercedes-Benz have set standards that many other automobiles follow. The fundamental design principles applied throughout the development of Mercedes-Benz’s vehicles are also applied to Mercedes-Benz’s automated vehicles.

The automated vehicle’s structure provides the foundation for the safety of its occupants. Ultra-high-strength steel and hot-formed steel alloys are used in critical load paths of the body and chassis structure in order to preserve the passenger cell and dissipate energy during a crash. Aluminum elements are also integrated into the vehicle structure and chassis to further enhance the structural rigidity and crash energy absorption properties. Advanced simulation and test methods used to develop this hybrid structure validate that it meets Mercedes-Benz’s high standards for occupant protection.

Occupant protection is further enhanced by state-of-the-art primary restraint systems and the integrated PRE-SAFE® system. In addition to reversible electronic belt tensioners, PRE-SAFE® functions provide adaptive seatbelt tensioning coupled with seatbelt load-limiting technology. The rear seat also includes LATCH anchors for the installation of child seats.

Advanced airbags provide additional occupant protection in the event of a frontal crash. The front passenger airbags are designed to provide two levels of inflation energy, depending upon crash severity. They also automatically adapt the inflation energy based on the passenger’s seat position. Finally, curtain airbags are integrated to provide head protection during a side crash.

Data Privacy, Data Recording and Post-Crash Automated Vehicle Behavior

When the automated vehicle detects that it is involved in a collision, it will transition to a minimal risk condition. The Fleet Operations center will initiate an appropriate post-crash procedure which can include measures based on a vehicle self-assessment. A Fleet Operations supervisor might perform an assessment regarding the drivability of the vehicle and will initiate necessary steps to retrieve the vehicle and passenger(s), as well as alert emergency services if required.

The automated vehicles are equipped with data recording capabilities similar to those specified for conventional vehicle event data recorders (EDRs), which enable the vehicle to store crash event-related data for reconstruction purposes. This information allows for the analysis of a particular crash event and development of appropriate countermeasures.

Secure data storage on- as well as off-board the automated vehicle is maintained in compliance with applicable privacy laws and regulations. As a member of the Alliance of Automobile Manufacturers, Mercedes-Benz also follows the “Automotive Consumer Privacy Principles” published in November 2014 and updated in early 2018. These principles incorporate Fair Information Practices and Federal Trade Commission guidance to establish a set of protections for personally identifying information used with connected vehicle technologies. They reflect the industry-wide commitment to be responsible stewards of collected information used in providing vehicle and transportation services.

Consumer Education and Training

Mercedes-Benz and Bosch take their commitment to safety seriously by informing the public of planned pilot programs and educating law enforcement and public safety officials of the capabilities of the automated vehicles. Mercedes-Benz and Bosch plan on partnering with cities to conduct pilot tests prior to the launch of Mercedes-Benz's commercial ride-hailing service using automated vehicles. In those partnership agreements there will be measures to ensure the public is informed through community engagement and outreach programs. Public safety officials, such as police and fire department personnel, will also be educated on how to interact with Mercedes-Benz's automated vehicles should the need arise. This ensures that local emergency responders will be able to understand and apply all applicable vehicle emergency procedures, as is the case for Mercedes-Benz's conventional vehicles. The measures put in place to ensure public safety will be presented and explained in community outreach information materials.

Any mobility service must be more than reliable to succeed. Mercedes-Benz automated vehicles are being designed to provide a customer experience that will be simple, intuitive and satisfying.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Federal, State and Local Laws and Regulations

Mercedes-Benz and Bosch place the utmost importance on compliance with legal requirements and the maintenance of road safety. Given that the human driver will be replaced by the automated driving system in these vehicles, there will be requirements and standards that need to be adapted in order to apply appropriately to a vehicle that has no human driver. Mercedes-Benz and Bosch are working together with other automated vehicle manufacturers and with NHTSA to identify vehicle regulations that potentially need adaptation and to find test procedures to accommodate automated vehicles.

With regard to traffic law compliance, all Mercedes-Benz automated vehicles will be designed to comply with all applicable laws and rules for the vehicles' operational design domain. For traffic laws that are not specifically related to the operation of a vehicle in traffic (e.g., ensuring that cargo is properly secured and child restraints are properly used when required), and that, as such, are not applicable to an ADS, passenger(s) using the automated vehicle will need to comply with such rules. Therefore, there is a need for state and local governments to review their traffic laws and to adjust them where needed to specify the obligations of passengers when using an automated vehicle.

In summary, Mercedes-Benz is committed to meeting or exceeding all FMVSS safety objectives with its automated vehicles. Mercedes-Benz vehicles will also be designed to comply with applicable state and local laws in all the areas that Mercedes-Benz automated vehicles will operate.

Conclusion

Do people want what technology can give them?

The vision of automated vehicles is well on its way to becoming reality. Automated vehicles promise a multitude of benefits to society ranging from increased traffic safety and mobility for those who cannot drive to reduced congestion and lower costs of transportation.

The widespread introduction of automated vehicles also comes with the potential to transform cities and the way people live and work. The car can become a work space as well as a place for people to relax and refresh while they travel.

One of the most important considerations for automated vehicles will be their market acceptance. This is dependent on the public seeing their potential benefits and on driverless-capable vehicles meeting customer expectations for safety, reliability and comfort.

Therefore, during the design and development of the automated vehicle, Mercedes-Benz and Bosch are putting safety and reliability at the very center of process design, system development, selection, and testing and validation. The long and distinguished heritage of both companies in vehicle safety will guide the introduction of Mercedes-Benz automated vehicles to public roads that earn the trust of customers, while providing a superior mobility experience as we usher in the next exciting chapter in the future of mobility!

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