TOYOTA AUTOMATED DRIVING

Whitepaper | August 2020

TOYOTA

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MESSAGE FROM TOYOTA RESEARCH INSTITUTE CEO GILL PRATT

As Toyota President Akio Toyoda has said, "the automotive industry is facing sweeping, once-in-a-century changes." They are driven by innovations in four technology categories – Connected, Automated, Shared and Electrified – each with its own challenges and opportunities.

For automated driving, the challenges include complex technical problems in perception, prediction and planning, and a range of social, ethical and policy issues for citizens, regulators and lawmakers to consider.

While simpler to focus on technical issues, the social, ethical, and policy challenges facing automated driving are the most difficult. Since no technology can perfectly predict human behavior, some crashes will still occur wherever vehicles with automated technology travel the same roads with human-driven vehicles and pedestrians. Even if automated driving technology can be made, on average, much safer than human driving, it may be difficult for society to accept the remaining inevitable injuries and fatalities when a vehicle with automated technology is involved in a crash.

Of course, society has faced similar questions before. In medicine, for example, patients must sometimes risk adverse outcomes in the hope of being cured. In general, we have come to accept such risks, so there is reason to hope a similar understanding could evolve for vehicles with automated technology. But going for a drive is not the same as fighting a life-threatening illness. Traffic crashes are sufficiently rare to conceal the potential safety benefits of automated driving, and news of technology-caused crashes tend to be greatly amplified in human perception. Societal acceptance will likely take time and will not be easy.

As a result, some may ask why any company would take on the challenge of developing a system for automated driving. For Toyota, two of the most compelling reasons are: 1) automated driving technology offers the chance to dramatically reduce the more than a million human-driven traffic fatalities that occur around the world every year, and: 2) automated driving technology could provide mobility for a rapidly growing segment of society – the elderly – for whom loss of mobility leads to loss of independence and lower quality of life. As we have seen since Toyota first began researching automated driving in the 1990s, we continue to see the technology's potential to help everyone get where they want and need to be... safely.

We hope the public shares our belief mobility can be a source of inspiration, and automated driving offers the chance to share joy in the experience of driving and a way to improve quality of life for everyone. Most importantly, because risk can never be completely eliminated, we hope the public will work with us as partners in the development of automated driving technology to improve the safety, availability of mobility and, in turn, quality of life for as many people as possible.

Dr. Gill Pratt
Chief Scientist and Executive Fellow for Research, Toyota Motor Corporation
Chief Executive Officer, Toyota Research Institute

INTRODUCTION

More than 80 years ago, Kiichiro Toyoda launched a department inside Toyoda Automatic Loom Works to investigate what was then a relatively new technology: automobile engines. This move, which laid the foundation for the Toyota Motor Corporation, reflected a critical insight: Automobiles would revolutionize society – not because the automobile was a machine that could move, but because it was a machine that could dramatically amplify human mobility.

Today, technology is once again poised to expand what is possible for mobility. Connected vehicles – the power of big data – sharing, and vehicle electrification change the concept of the car. At the same time, steep declines in the cost of sensors, exponential growth in computing power and the rapid improvement of Artificial Intelligence (AI) systems have opened the door to advanced systems for automated driving. At Toyota, we see the extraordinary potential for this technology. Just as we did so many decades ago, we are remaking our company to meet this new challenge.

Importantly, Kiichiro Toyoda's insight in the 1930s remains true today. The value offered by today's groundbreaking technology is not in the machines themselves, but in what they offer to society. As a result, our ultimate goal is not to create automation for cars, but rather to expand autonomy for people. We are working to create the tools that will help people get where they want and need to be, and to create a society where mobility is safe, convenient, enjoyable, affordable and available to everyone.

As we pursue this vision, we are guided by a commitment to safety – both in how we research, develop, and validate the performance of vehicle technology and in how we aim to benefit society. Despite their tremendous positive benefits, cars and trucks are involved in crashes that annually result in more than a million fatalities worldwide. Our research into automated driving is an extension of Toyota's long-standing focus on improving automobile safety, and it advances our ultimate goal of helping realize a future without traffic injuries or fatalities.

That is why we are working to help consumers both enjoy the benefits of this research in the near term, while we continue to work on the most advanced technologies for the future. We have made advanced driver assistance systems (ADAS) available across nearly all new Toyota and Lexus vehicles through Toyota Safety Sense and Lexus Safety System+. These packages, which include underlying automated driving components like Automatic Emergency Braking and Lane Keep Assist, are available as standard or optional equipment on new Toyota and Lexus vehicles in Japan and Europe, while nearly every model and trim level sold in the United States provides it as standard equipment.

> The value offered by today's groundbreaking technology is not in the machines themselves, but in what they offer to society.

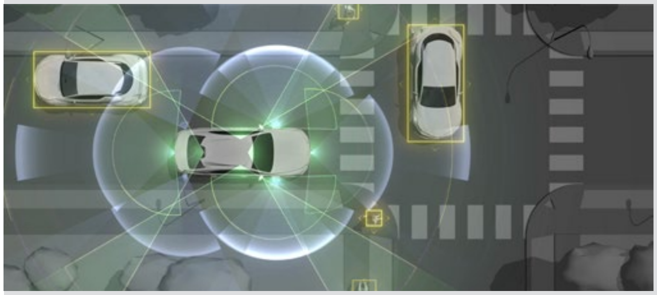
Looking ahead, we follow those same priorities in our research. We are working aggressively to develop vehicles that will use the "Toyota Chauffeur" automated driving approach but have also prioritized research and development of nearer term "Toyota Guardian™" active safety technology. We believe Toyota Guardian – which uses Toyota's underlying automated driving technology to support and protect a driver by amplifying the driver's capabilities – is an approach that can save more lives sooner, prior to bringing Chauffeur to market.

As with any technology revolution, the impact of automated driving will go well beyond cars and trucks to include new business models and product categories, ranging from mobility service platforms to personal robotics solutions. Major challenges remain, but we are inspired to help lead the way toward the future of mobility as we continue to focus on enriching lives around the world with safe and responsible ways of moving people.

THE PROMISE OF AUTOMATED DRIVING TECHNOLOGY

Toyota is guided by its Global vision, which calls on the company to "lead the way to the future of mobility, enriching lives around the world with the safest and most responsible ways of moving people." This mission influences everything we do, including making high-quality cars and trucks, constantly innovating and working to safeguard the environment.

Automated driving is a natural next step in Toyota's growth as a mobility company. It expands upon traditional automotive capabilities to help people get to where they want and need to be, while offering the potential to benefit all of society by helping to eliminate traffic fatalities and injuries, reshape cities, reduce emissions, and achieve our ultimate goal: mobility for all.



IMPROVING SAFETY

First and foremost, Toyota is committed to automated driving because the technology offers the promise of a world with far fewer casualties from crashes. According to the World Bank, there are about 1.25 million worldwide traffic fatalities annually and far more traffic injuries. Automated driving technology could drastically reduce this number by helping to prevent crashes caused by human error. Our work on this technology follows from our commitment to safe driving with a goal of developing a car that would never be responsible for causing a crash and that can avoid or mitigate many crashes caused by other vehicles or external factors on the road.

This focus on safety carries through to all of Toyota's research and development of systems for automated driving. This means testing and validation to help ensure the proper performance of new technologies before their market introduction and a focus on expanding the adoption of potentially life-saving features to non-self-driving vehicles.

MORE EFFICIENT TRANSPORTATION

Beyond their core safety benefits, systems for automated driving may help make traffic smoother and more efficient. This could provide meaningful improvements to air quality through reduced emissions and to the quality of life of drivers through shortened and more predictable travel times. The technology would also expand the number of people able to experience the joy of driving, while also significantly improving the quality of time spent in a vehicle during routine commuting or long drives.

Vehicle automation also holds the promise of increasing access to vehicle travel to a larger portion of the world's population through affordable, on-demand mobility models. Combining automated technology with Mobility as a Service (MaaS) will help increase personal mobility, especially for people with physical limitations. This type of on-demand transportation could potentially transform cities and support more economically vibrant and efficient communities. For example, parking areas in urban centers could be repurposed for people rather than vehicles, with MaaS vehicles using automation helping cities evolve into more environmentally-friendly spaces with greatly reduced emissions, traffic and noise.

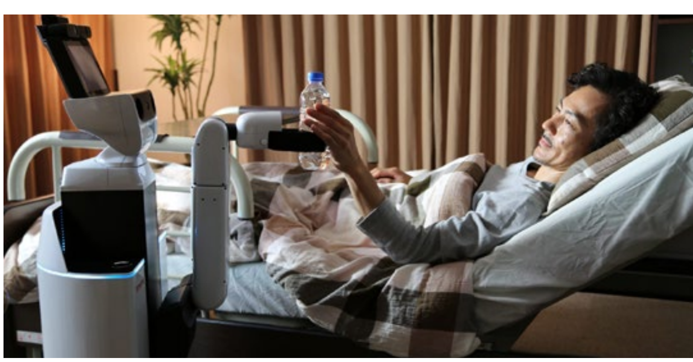
A REVOLUTION BEYOND CARS

Toyota believes the technology behind automation will bring sweeping benefits and mobility solutions that extend far beyond cars and trucks. AI offers the potential to revolutionize and improve the daily lives of millions by creating new categories of technologies and services.

Toyota is leveraging its research in automated driving to create new mobility solutions, such as robots with enhanced perception, reasoning and manipulation that can offer expanded freedom of movement for all, including people with limited mobility associated with age, illness or disability.

For example, assistive robots could someday empower and enable people who might otherwise be restricted in their ability to move around their homes or in their communities. These systems show promise in helping seniors "age in place" with dignity rather than moving into assisted living facilities – an important potential benefit given current demographic trends in many countries.

MOBILITY

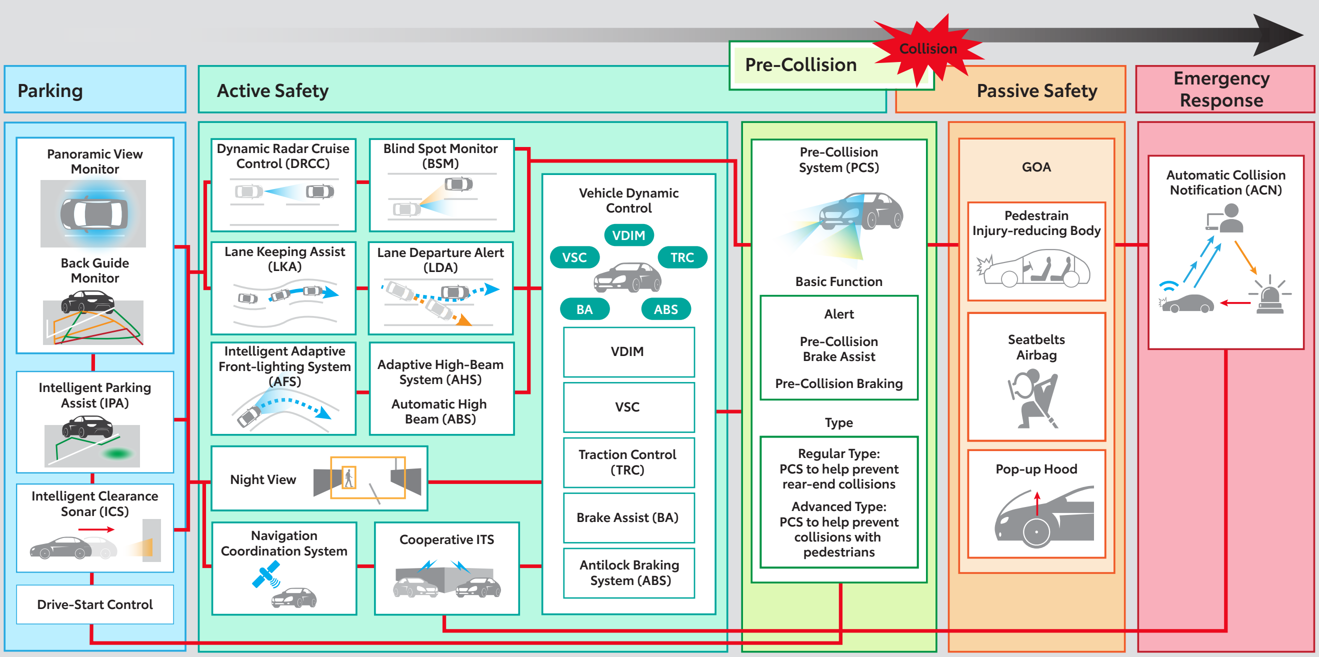


CORE PRINCIPLES

SAFETY APPROACH

Since the 1990s, Toyota has worked to develop automated driving technologies through the framework of our Integrated Safety Management Concept. This approach focuses on technologies that could mitigate the risk of collision at each stage of driving, including Parking, Active Safety, Pre-Collision Safety, Passive Safety and Rescue.

We accomplish this by working in each category to improve safety along three distinct pillars: people, vehicles and the traffic environment. This approach allows us to expand our focus, looking beyond the potential of new vehicle safety technologies to include expanded safety education programs and new partnerships with governments and other stakeholders that can improve the construction of roads and other traffic infrastructure.



ITS: Intelligent Transport Systems

VDIM: Vehicle Dynamic Integrated Management
VSC: Vehicle Stability Control
BA: Break Assist
ABS: Antilock Braking System

PCS: Pre-Collision System

GOA: Global Outstanding Assessment

In addition to looking forward, we also strive to learn from the past. This includes studying actual collisions in order to meet and push beyond the industry's ever-higher safety standards. Toyota analyzes the causes of vehicle-related collisions and occupant injuries by using a range of investigation data. Using technologies like Toyota's Total Human Model for Safety (THUMS), we simulate crashes to help develop safety technologies. In addition, we conduct experiments on actual vehicles before we launch new technologies. Post-launch, we evaluate the effectiveness of the technologies by assessing any crashes that might occur.

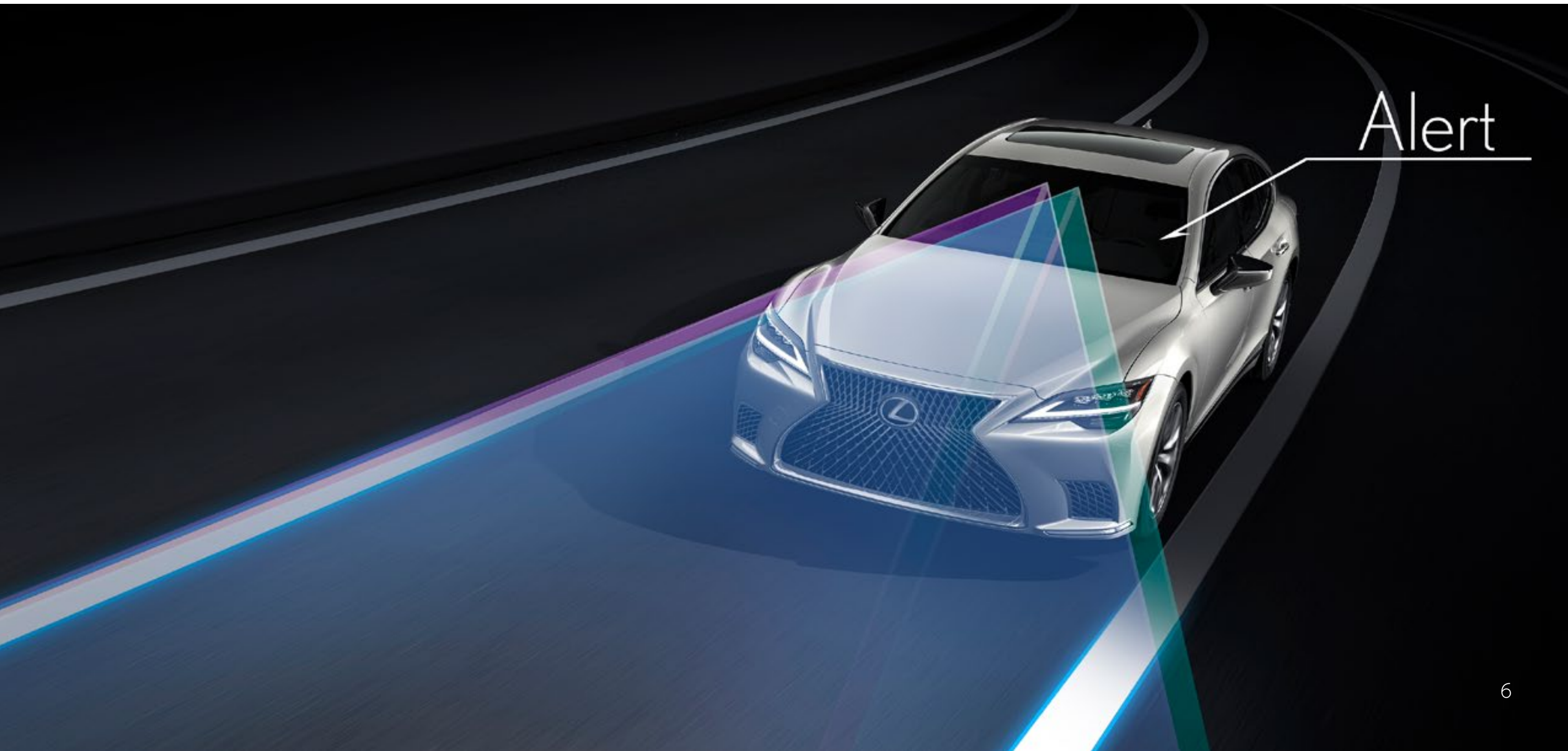
Collectively, this strategy has resulted in meaningful safety improvements, as each new advancement in technology or design expands the range of potential collisions the vehicle can prevent or mitigate.

THE MOBILITY TEAMMATE CONCEPT

Toyota's development philosophy for automated driving is the Mobility Teammate Concept (MTC), an approach built on the belief people and vehicles can work together in the service of safe, convenient and efficient mobility.

The MTC combines all of Toyota's research into automated driving and merges it into a vision in which people and vehicle "team up" to monitor and assist each other whenever necessary. In the near term, this approach capitalizes on the different skills humans and machines bring to the challenge of safe driving. Indeed, thanks to the power of connected systems and cloud-based technology, this sharing of responsibilities means intelligent vehicles might one day improve continually, with every car and truck potentially benefiting from the experience of many drivers.

Importantly, MTC is a philosophy built on the belief people should have choices, and technology should amplify rather than replace human capability. Instead of removing humans from any engagement with their own mobility, it allows people to enjoy the freedom and joy of driving if they choose, while also benefiting from the capabilities of automated driving when they need or wish.



THE FUTURE OF THE DRIVER – VEHICLE RELATIONSHIP

The emergence of automated driving has raised new questions about the future of the personally-owned vehicle and about the long-term relationship between car and driver.

For some, this is an easy question with little significance. To them, a car is just a means of transportation used to move from one place to another, not much different than a train or a plane. At Toyota, we see a car as something more – a feeling we know many people share around the world that is captured by the Japanese word “Aisha,” or “My car, I love it.” And we do not think this relationship will cease any time soon.

What is it about the connection between people and cars that generates so much love?

We believe it’s a relationship that is fundamentally different from those we have with many other machines. A car is a safe, personal space with a comfortable and relaxing environment. Almost everything about it, inside and out, can be customized to express our unique identity. Over time, the car itself changes to reflect who we are and the lives we lead. Most importantly, the car amplifies us – allowing us to travel further, faster and with less effort in the company of and with the goal of joining loved ones. What’s more, we control the car. We press the accelerator, and the car moves us the way our legs do, but with more power. We turn the steering wheel, and it is as if we ourselves are changing our body’s direction of exploration.

Each customization we make to our car also helps to build a deep and meaningful relationship between it and us. Our car becomes the only one like it in the world: a unique reflection of our own life. We pamper, abuse and use our cars extensively, and they carry the marks of this relationship: a sticker here, a coffee stain there, and that time where we made a tear in the back seat and never bothered to get it fixed. At a more social level, cars belong to families and are sometimes passed on to the next generation, carrying with them the histories of our lives and relationships. Over time, a car stops being just a mode of transportation and becomes something we love.

For Toyota, the relationship between cars and people is fundamental to everything we do, including our research into automated technology. We use the word "teammate" to describe our concept for automated driving because of our belief car and driver can help each other to make driving safe, comfortable and fun.

What does this relationship mean in practice? When it comes to safety, driving skills don't just differ between people. Experience, age, medical conditions or simple fatigue mean individual driving ability can change from moment to moment. That's why Toyota designs automated driving technologies with the aim of meeting these shifting needs, helping to support safe driving regardless of the driver's condition.

Of course, there are also people who want a specific driving experience and expect the vehicle to perform the way they want, when they want. That may mean a sporty driving mode in some situations and a smooth ride in others. We believe advanced vehicle technologies should respect these unique and changing needs and respond with the capability a driver desires while maintaining the appropriate level of safety support.

In short, Toyota believes cars should learn from and be responsive to their owners. Even in a future where driving is automated, we believe this connection means cars will continue to be loved, with the relationship deepening as they meet our needs and grow to reflect our unique tastes over the course of our lives together.

THE AUTOMATED DRIVING LANDSCAPE

AUTOMATED OR AUTONOMOUS?

Over decades, vehicles have become more sophisticated. Computers can increasingly handle direct involvement with key functions, such as acceleration and braking. More recently, new technologies have emerged to perform additional tasks, such as helping to keep a vehicle in its lane or intervening if a collision is imminent.

With the rise of systems that can perform some or all driving tasks, a host of terms have entered the market to describe them. These include “automated,” “highly automated,” “semi-” and “partially autonomous,” “self-driving,” and “driverless,” to name a few.

For general descriptive purposes, Toyota uses the word “automated” to describe a wide range of technology that augments or replaces direct human control during some period of time. We use the term “autonomous” to describe only those vehicles where an automated system can perform the complete dynamic driving task, essentially replacing the job of the driver, during some period of time (not necessarily indefinitely).

By contrast, much of what is currently described in public discourse as an “autonomous vehicle” is often not truly “autonomous” from human oversight or driving responsibility. Care in using these terms is important, as their application to vehicles in the market may impact consumers’ expectations and understanding about how those vehicles perform. As we implement these technologies in passenger vehicles, we believe it is important to describe accurately, or to use terminology that suggests, the actual function the vehicle can perform. We believe helping consumers understand automated driving technology is another way of promoting safety in its use.

Regardless of whether one prefers “automated” or “autonomous,” the range of capabilities of these emerging technologies cannot be described in just one word. For that, international standards organizations have developed documents to address technical aspects of automation for vehicles.

STANDARDS ORGANIZATION ACTIVITIES FOR DRIVING AUTOMATION

One example of activity is SAE International's issuance of recommended practice J3016. That document categorizes automation based on whether an automation system:

- performs acceleration/deceleration or steering,
- performs acceleration/deceleration and steering,
- monitors and responds to the driving environment,
- performs fallback of the dynamic driving task (functions required to operate a vehicle),
- is limited by an operational design domain (conditions under which a vehicle can operate).

SAE has defined levels of automation that range from no automation (labeled as "Level 0") to full automation (labeled as "Level 5") as displayed in the following chart.

SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged — even if your feet are off the pedals and you are not steering			You are not driving whenever these driver support features are engaged — even if your feet are off the pedals and you are not steering		
	You must constantly supervise these support features, you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operated unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

These levels provide valuable and useful guidance, and they serve an important role in facilitating clarity in global discussions and potential regulations around automation

TOYOTA'S APPROACH TO VEHICLE AUTOMATION

Toyota's research into automation is driven by two related but distinct objectives:

1) improving driving safety and

2) improving access to and the convenience of mobility.

We are pursuing two distinct concepts to achieve those goals with the development of each built on similar perception, prediction and planning technology.

CHAUFFEUR

For those who cannot or choose not to drive because of age, infirmity or any other reason, we are working to develop automated driving technology that will allow a vehicle to drive on its own without human oversight or fallback responsibility. We call this eventual capability Toyota Chauffeur.

We are designing Chauffeur to use an AI system to completely perform the driving function. With Chauffeur, the human will not have a role for the task of driving while the system operates (similar to SAE Levels 4 and 5).

TOYOTA GUARDIAN™

To more quickly realize the safety benefits of automated driving technology and to expand the ability of current drivers to experience the joy of driving, Toyota is developing an approach to active safety called Guardian. Guardian aims to safely blend vehicle control between the driver and an AI system, sharing roles to take best advantage of their individual skills. We call this ***blended envelope control.***

As in the flight control systems modern fighter airplanes use, the human driver retains control, but the AI translates his or her commands to keep the vehicle within a defined safety envelope. Guardian will constantly monitor the environment and step in to amplify the driver's capabilities and may intervene when a collision or other safety-critical incident is imminent. This is not done by braking alone, as in current pre-collision systems, but by employing the full range of driving actions, including accelerating, changing lanes and preventing the driver from over-reacting to a situation. Fundamentally, the system is being designed to help prevent the vehicle from being hit, to avoid hitting anything else and to stop it from going off the road.

Toyota has made significant progress applying blended envelope control between the driver and the system to automobiles. Rather than switching between the driver and the system in the event of a safety issue, there is a near-seamless blend of both working as teammates to extract the best input from each.

Guardian exists on a spectrum of capability that defines how much it can assist to protect vehicle occupants. This includes mistakes or other errors made by the driver and from external factors on the road, such as other vehicles, obstructions or traffic conflicts. The higher the Guardian capability, the greater the number and types of crashes it can help protect against.

For example, at a modest level of Guardian capability, systems like Lane Departure Alert (LDA) and Automatic Emergency Braking (AEB) can help prevent some crashes. At the highest level, Guardian capability is being developed with the goal to ensure a human-driven vehicle would never be responsible for causing a crash and also avoid many crashes that other vehicles or external factors would cause.

BENEFITS OF THE GUARDIAN MODEL

Guardian offers an important path to vehicle automation because it avoids several challenges Chauffeur faces. Chauffeur is an important technology that will make a meaningful impact on the lives of people who cannot or do not wish to drive. But its development faces significant technical and social challenges that will take time to address. In particular, the Chauffeur automation model faces several key challenges when applied to automated driving:

- Humans suffer from a basic psychological challenge known as "vigilance decrement," which makes it hard to keep one's attention and awareness engaged when monitoring for rare events over long time periods.
- Navigating the traffic environment can at times be exceptionally complicated in ways that go beyond developing technology that can handle varied environmental conditions and obey the rules law defines. A system fully capable of staying within appropriate lanes, stopping and starting at traffic lights, and navigating a route from one point or another would also encounter a traffic context defined by people and can change at any time.

At present, many deployments of Level 4-equivalent systems address these issues by operating in highly restricted Operational Design Domains, which limit the vehicles to operate in conditions, such as low speeds, fair weather, simple geography, light traffic and few other variables on the road, like pedestrians or cyclists. Wider deployment will require a significant technical and sociological leap so vehicles can recognize the road environment's physical elements and the social context and interactions between the people who use it.

We are designing Guardian to avoid many of these constraints. The underlying automated technology only intervenes when necessary. This allows human drivers to leverage their social awareness to navigate through the complicated and rapidly shifting traffic environment. In so doing, Toyota believes the Guardian approach may help us realize the safety benefits of automated technology sooner by enabling us to introduce higher levels of driver assistance into production vehicles in the near term as we continue our progress toward Chauffeur. To ensure these benefits are available to as many drivers as possible, Toyota plans to offer Guardian to others in the industry.

In addition, just as Guardian is designed to amplify the human driver's ability rather than replacing it, it might also add an extra measure of support to another automated driving system, whether provided by Toyota or any other company. For example, Toyota has announced its intention to include Guardian as standard equipment on all Toyota e-Palette platforms we build for the MaaS market, offering intervening support regardless of which automated system a fleet buyer chooses to use.

What's more, Toyota also believes Guardian will, over time, build much-needed trust and acceptance for highly automated driving technology. Automated systems are often viewed with suspicion or fear because they remove the human from vehicle control. Guardian may foster a different reaction because it is designed to amplify human performance rather than replace it and because it may highlight those situations where the automated technology provided a safety benefit.

HUMAN DRIVER CAPABILITY AND ENVIRONMENTAL DIFFICULTY

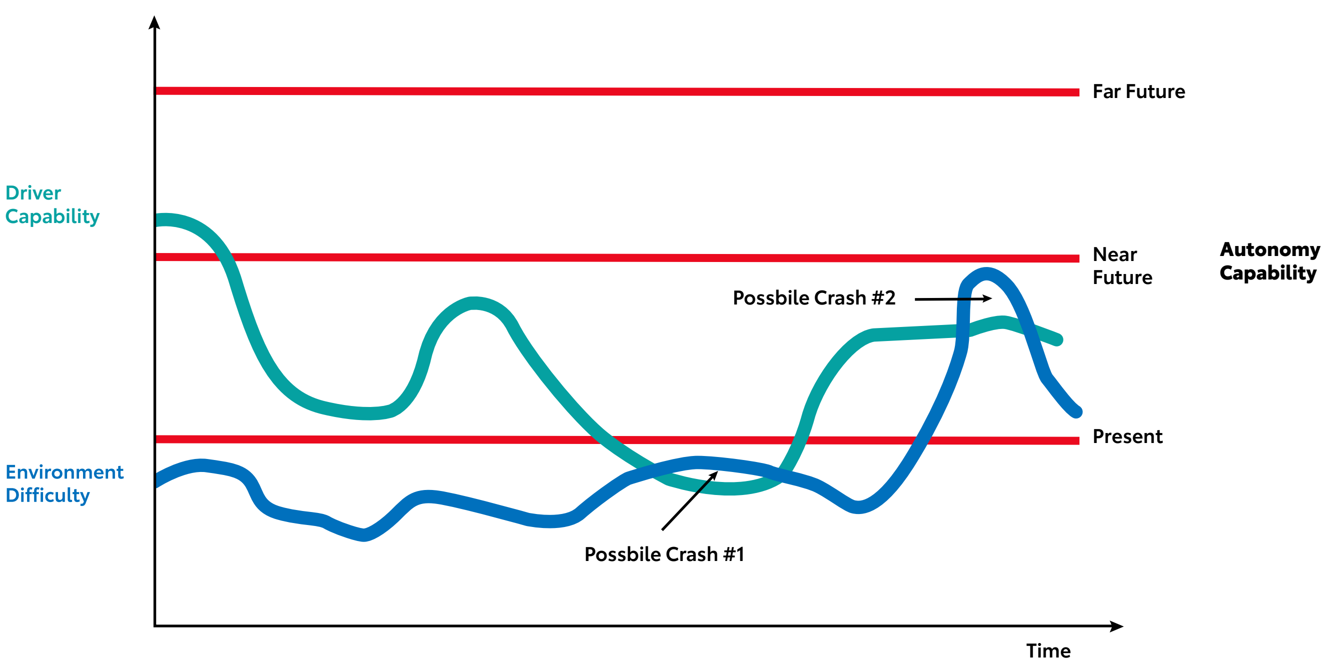
Toyota's research on automated driving technology goes beyond seeking to expand vehicle capabilities. It also considers the capability of human drivers and the difficulty of the driving environment.

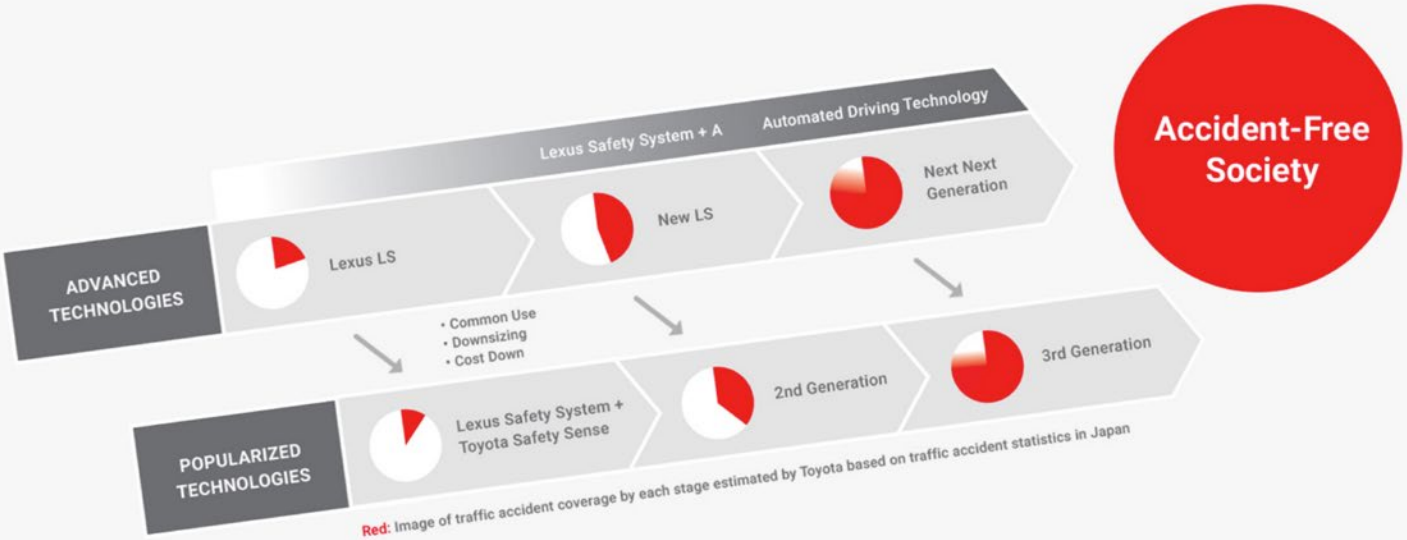
Importantly, driver capability and driving difficulty are not static. They rise and fall over time. Driver capability depends on factors, such as skill, fatigue and distraction level. Driving difficulty shifts based on issues ranging from weather to traffic or construction. Most of the time, driver capability is sufficient to prevent a crash. It is the times when driving difficulty rises above the driver's skill that a crash is likely.

Automated technology offers the potential to contribute at periods of both high and low driving difficulty. With the power of blended envelope control, the vehicle might one day leverage Guardian to help prevent a crash when driving difficulty is higher than the driver's capability to navigate safely. At times of low driving difficulty, Guardian technology will maintain vigilance to help make minor corrections (i.e., lane keep assist) to help keep a vehicle in its lane, for example.

At present, Guardian's technical abilities might be higher than the driver's skill only in some limited circumstances. Over time, as technology improves and the system learns, Guardian capability will grow steadily toward an ideal goal of creating a vehicle that would never be responsible for a crash, regardless of human driver errors. At the same time, Chauffeur capability will advance toward a goal of being able to drive safely in all conditions.

Importantly, driving environments can be extremely complex and difficult, and no automated system – regardless of how capable it may be – is likely to prevent crashes entirely. A fundamental question yet to be addressed is "how safe is safe enough?" The answer will depend on government regulation, liability risks, societal acceptance and what is technically possible. In general, we believe systems providing Chauffeur capability might need to be significantly safer than average human drivers to be accepted by society. By contrast, Guardian capability might be judged against the standard of, on average and as often as possible, "do no harm."





AUTOMATED DRIVING DEPLOYMENT: PERSONALLY-OWNED VEHICLES

In 2003, Toyota introduced its first millimeter wave radar-based Pre-Collision System (PCS). Soon after, Toyota rolled out the system to more-affordable vehicles, such as Prius. Developing advanced technologies first, then finding reasonable ways to bring them to a more popular and affordable range of vehicles, continues to be Toyota's strategy. This two-axis approach allows us to rapidly spread the availability of safety technology, and it also applies to automated driving technologies.

The results can be seen most clearly in Toyota Safety Sense and Lexus Safety System+. As research and development progresses, future generations of both systems will continue to expand to widen the range of safety systems and automated technologies available to the general public. For example, in 2018, Toyota began to roll out the second generation of Toyota Safety Sense and Lexus Safety System+ on vehicles benefiting from a major model change. In this second generation, we added new capabilities to enhance safety, including the ability to detect pedestrians in low-light conditions, the ability to detect bicycles, and an expanded road sign recognition system covering more regions and countries than before.

This approach of beginning with personally-owned vehicles is a proven and valuable method for technology development, as it speeds the introduction of advanced systems that can help improve safety, reduce accidents and ease traffic. Today, thanks to rapid component and information technology developments, we can often reach mass-vehicle deployment of new safety systems much faster than before.

Toyota is committed in the near term to bringing vehicles with automated driving capabilities to market. **Teammate**, targeted for commercial availability in 2021, is expected to initially enable driver-supervised automated driving (SAE Level 2) on highways. The system will evaluate traffic conditions, make decisions and take action during highway driving. Potential capabilities include changing lanes (with driver approval), maintaining a safe distance from preceding vehicles and exiting highways.

AUTOMATED DRIVING DEPLOYMENT: MOBILITY AS A SERVICE

USING MAAS TO ACCELERATE AUTOMATED DRIVING DEVELOPMENT

Through its own programs and in partnership with various companies in the mobility services space, Toyota plans to leverage a range of MaaS platforms to support and accelerate the development and deployment of automated driving technology.

MaaS addresses one of the key challenges in developing automated driving systems – the need for significant driving data to improve core technologies. Initial component costs mean personally-owned vehicles with systems for automated driving are likely to be expensive and sell in small numbers. This, combined with the low usage rates of private vehicles, limits how much data they will collectively generate in order to help improve the system. In a MaaS application, costs can be amortized across a fleet and higher utilization rates will increase data gathered. As a result, the system's capabilities can be extended more quickly, benefiting both MaaS and personal vehicle applications.

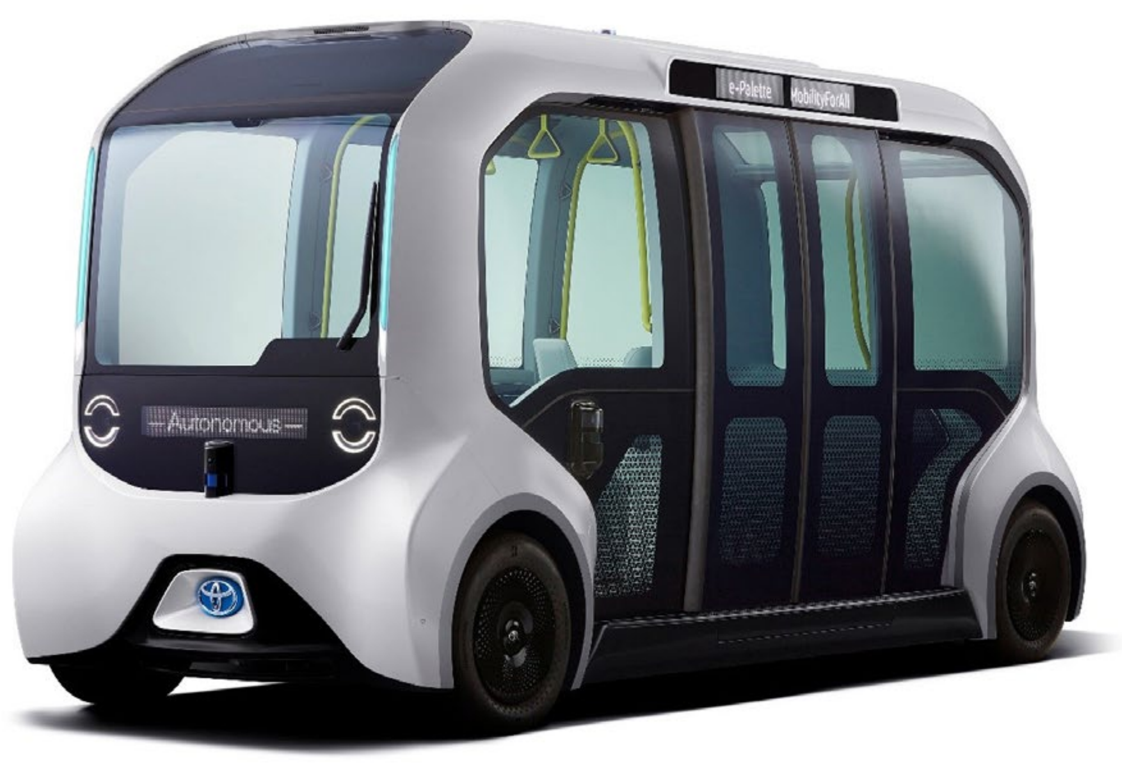
In addition, MaaS provides a unique opportunity to deploy vehicles equipped with SAE Level 4 automated systems sooner. Fleets do not need the same flexibility as personally-owned vehicles and can be limited to simplified operating domains, such daylight hours, good weather and/or known fixed routes.

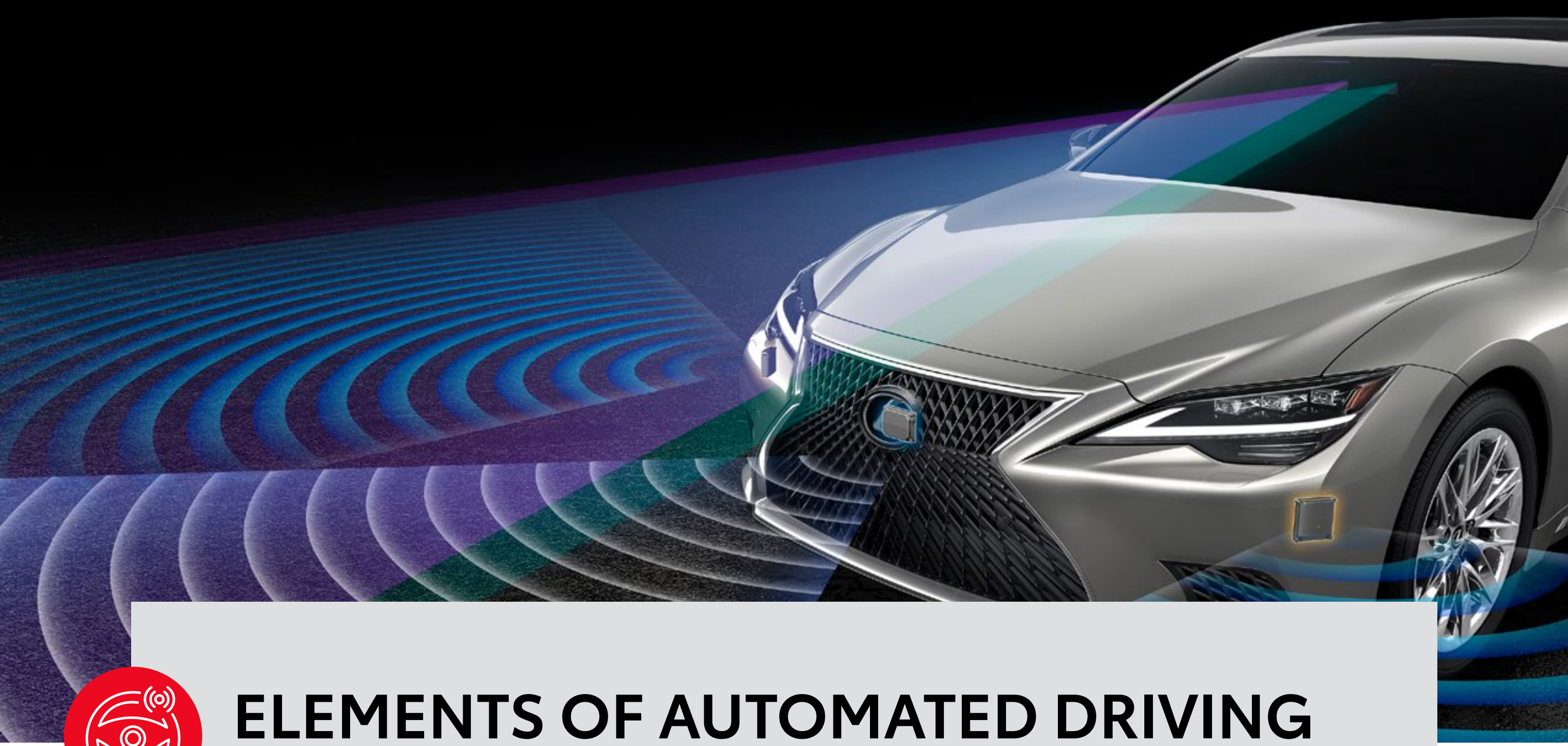
Toyota believes the deployment of a high level of automation to support MaaS can help lower costs per passenger mile to create new waves of consumer demand and a virtuous cycle of affordable mobility, safety and convenience. It can also help improve automated driving technology and support greater societal acceptance and consumer adoption. Taken together, the system will bring forward key benefits of automated driving much faster than through private ownership alone.

AUTONOMOUS MOBILITY AS A SERVICE ("AUTONO-MAAS")

To fully realize the potential synergies of automated technology and MaaS networks, Toyota is pursuing a range of technology and vehicle platforms.

- e-Palette, first announced at the 2018 Consumer Electronics Show, is a purpose-built mobility commerce platform designed to support Autono-MaaS business applications. The open, flexible platform will be easily adapted to support a range of uses, including ride-sharing, delivery and retail. Currently under development in coordination with partners, including Amazon, DiDi, Mazda, Pizza Hut and Uber, e-Palette will be controlled by SAE Level 4 Automated technology or, if desired, by a user's proprietary system for automated driving. In either case, e-Palette will include Toyota's Guardian technology, which will act as a safety net. Toyota plans to deploy mobility solutions like the e-Palette at the Tokyo 2020 Olympic and Paralympic Games, which now take place in 2021.
- Toyota also plans to deploy automated driving technology on the mobility networks operated by third parties. In August 2018, we announced a new collaboration with Uber Technologies designed to advance and bring to market autonomous ride-sharing as a mobility service at scale. As part of the agreement, Toyota is developing an Autono-MaaS fleet based on the Sienna Minivan platform, which will be equipped with Uber's Autonomous Driving System and use Toyota's Guardian as a safety support system. Pilot-scale deployments are intended to begin on the Uber ride-sharing network in 2021.





ELEMENTS OF AUTOMATED DRIVING

FUNDAMENTALS OF AUTOMATED TECHNOLOGY

In general, driving automation operates via interactions between fundamental systems. Various combinations of these systems enable vehicles to understand the driving environment, make intelligent decisions and, in the case of higher automation levels, navigate safely to a destination. These fundamental systems are described as follows:

- Localization and Mapping determines where the vehicle is within its environment. This requires building a specialized map of the surrounding environment, either from scratch or by drawing from a baseline of prior knowledge that is well-understood and trusted to be mostly correct, and then localizing the vehicle within that map. This system helps a vehicle correctly interpret the data its sensors gather.
- Perception combines information from the Localization and Mapping system with data from vehicle sensors – including cameras, LiDAR, RADAR, Global Navigation Satellite Systems (GNSS) and inertial navigation units (INU), among other inputs – to collect and interpret information about the vehicle's current situation and its relationship to its environment. This includes the location and movement of the full range of obstacles, both static and dynamic, including infrastructure, vehicles, pedestrians, bicycles and more. The amount and complexity of data for analysis makes this one of the most challenging steps in automated driving.
- Prediction helps the vehicle estimate where other vehicles, pedestrians, bicycles, etc. are likely to be in the future. Often there are multiple possible predictions (known as hypotheses). Currently, humans do a much better job of prediction than any machine. This area will continue to challenge the development of automated driving.
- Planning determines one or more safe courses of travel for the vehicle, including decisions such as which lane to travel, where to position the vehicle relative to other dynamic objects and how much space to afford obstacles. Importantly, the Planning system makes decisions about how to safely guide the vehicle under uncertain conditions,

such as when other vehicles on the road may be blocked from view or if they behave in unexpected ways. Multiple hypotheses may lead to multiple possible plans, with the ultimate choice depending on the actions of other vehicles, pedestrians and more.

- Control executes the planned driving trajectories set by the planning system, which are updated constantly based on new information. This is accomplished using actuators that direct vehicle driving functions.
- Coordination communicates with other vehicles, the road infrastructure and cloud databases.
- External Human Machine Interaction (e-HMI) manages the communication of information between the vehicle and humans in the traffic environment. Importantly, while communication between driver and vehicle is obviously important, particularly in managing the transfer of vehicle operation, so too is communication between the vehicle and humans outside the vehicle, such as drivers of other vehicles, first responders and pedestrians.

KEY TOOLS FOR AUTOMATED DRIVING

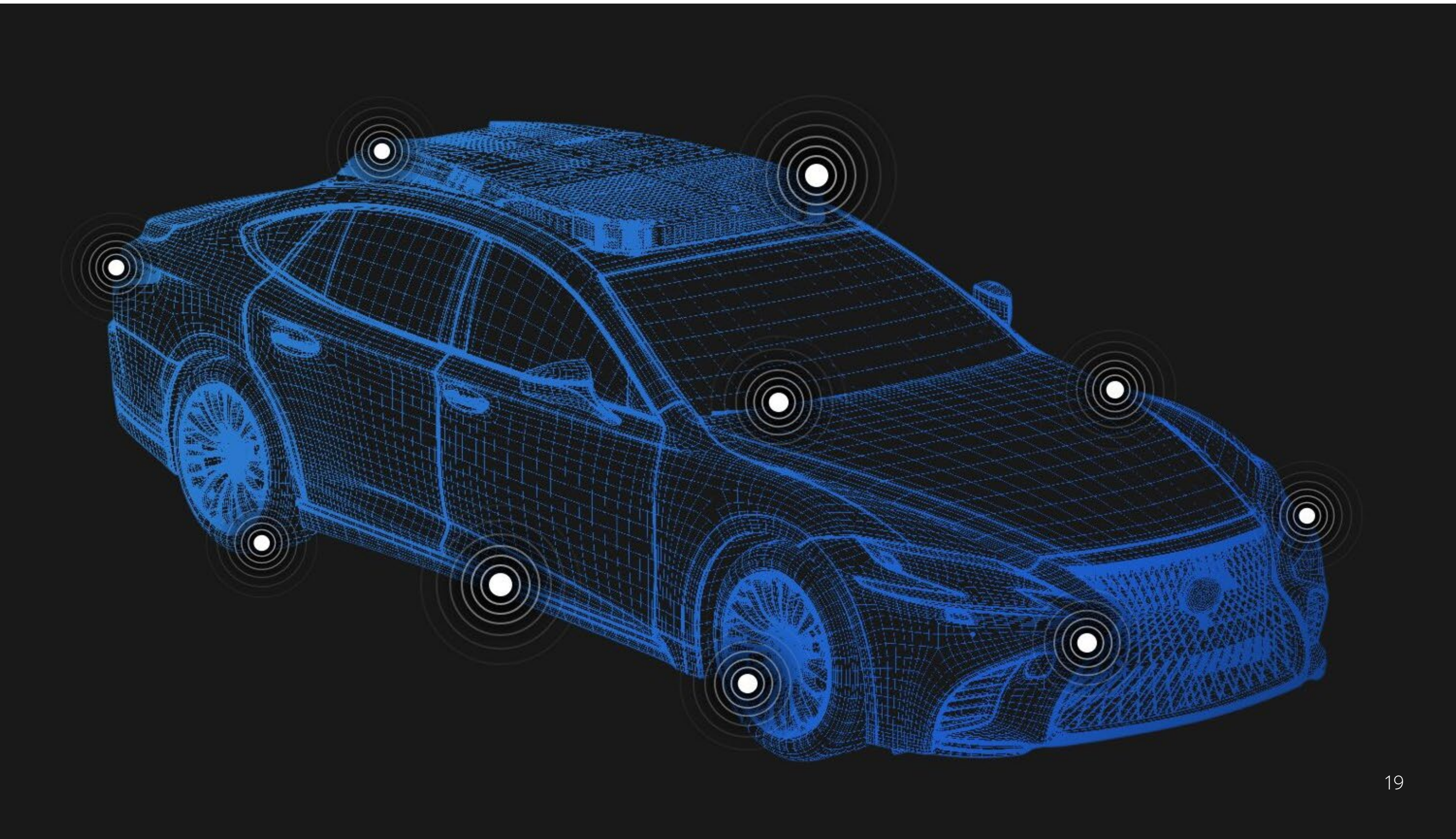
An overlapping set of core technologies and tools help make the fundamentals of automated driving possible. The core technologies and tools are described as follows:

- Classical controls, including proportional-integral-derivative controllers and non-linear gain scheduling, are used for low-level controller tasks like set-point tracking and regulation within actuators, such as steering actuator or throttle actuator.
- Modern controls include state-space representations, robust control, nonlinear control and adaptive control. These mostly explicit mathematical equations solve apriori (offline) for the control value.
- Optimizations, such as model predictive control (MPC) or receding horizon control (RHC), are used to generate path trajectories, which lower-level controllers subsequently track. Optimizations rely on numerical methods to solve/converge in real-time for the control value.
- Artificial Intelligence (AI) is a broad term for technology that processes information and makes decisions to achieve a certain goal. This may be accomplished via a rule-based system, such as if a vehicle perceives a stop sign and follows a programmed command to stop, or via machine learning, in which a system might process large volumes of information
- Computer Vision is the process of gathering information from sensors and using it to perceive the surrounding environment. This process leverages AI to draw knowledge from the data, identifying and differentiating individual elements, such as cars, pedestrians, trees and roads.
- Predictive Algorithms are used to anticipate the likely behavior of other objects in the road environment, such as the expected future position of another vehicle on the road based on its current trajectory and proximity to other vehicles.
- Decision Algorithms choose the vehicle's proper path based on the predicted behavior of others on the road. Importantly, decision algorithms must operate despite uncertainty, which varies based on conditions, including visibility and traffic congestion.
- Maps are baseline representations of the core elements of the physical world the vehicle occupies. These can be generated ahead of time, such as high-definition maps, to be used by a vehicle when it enters an environment, or generated in real time (on-the-fly) using algorithms, such as Simultaneous Localization and Mapping (SLAM).
- Sensors gather data from the driving environment or from the vehicle itself. These include systems that gather data about the world, such as cameras, sonar, LiDAR and RADAR; those that track location, such as GNSS; and those that monitor the movement of the vehicle itself, such as inertial measurement units or wheel speed and angle monitors.

- Actuators are used to control the physical operation of the vehicle, opening or closing the throttle, turning the wheels or engaging the brakes. Importantly, while computers rapidly perform much of automated driving, actuators are limited by physical constraints, including vehicle dynamics and the speed of the actuator itself. Thus, automated drive systems must account for the lag between issuing commands and the vehicle's physical response.

- Simulation is used to test the performance of automated driving software in a virtual environment. Data gathered from real-world testing is used to recreate a variety of traffic scenarios digitally, which are then used to test and measure system response and to promote proper operation. Automated driving software can be tested in both the car and simulator at the same time, while engineers shift back and forth seamlessly to allow for continuous integration testing. Driving systems can also be operated in multiple simulation instances at the same time, allowing for the relatively-rapid creation of billions of miles of training and test data.

- V2X Communication consists of a direct information exchange between vehicles with roadside traffic management systems and with pedestrians via dedicated short-range communication (DSRC) and/or via cellular networks. These vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) communications share information about road signals, signs, road conditions and other vehicles or pedestrians that may be difficult to see. They can also alert drivers of approaching vehicles, pedestrians, red lights, and slow or stationary vehicles. Vehicle-to-network (V2N) supports map data generation and map data updates, as well as various kinds of information delivery and remote control. Together, V2X communications provide an additional means for automation to gain knowledge about surrounding traffic. The obtained information is combined with data from on-board sensors to enable the vehicle to make better decisions for vehicle control, traffic safety, efficiency and driver interaction.



CHALLENGES FACING AUTOMATED DRIVING DEVELOPMENT

The industry faces various challenges to realize and popularize automated driving. These include legal/regulatory developments, social-system reform and the time needed for societal acceptance, with the detailed situation varying between countries and regions.

Automated driving technology also depends on other industries that provide key technologies that together make up the automated driving ecosystem. Key subjects, listed below, typically reflect geographical or cultural differences, globally and regionally. Therefore, one key and unique success factor for automated driving is the level of collaboration and cooperation with various stakeholders who are not always actors in the traditional auto industry. Realizing and popularizing automated driving will call for appreciating their expectations. Industry collaboration in non-competitive areas that act as a foundation of systems for automated driving and vehicles, such as infrastructure or social systems, is an effective way forward.

For example, in Japan, SIP (Cross ministerial Strategic Innovation Promotion Program) under the Japan Cabinet Office, identifies areas of collaborative work and promotes research and development among relevant stakeholders. SIP collaboration scope includes dynamic mapping and cybersecurity.

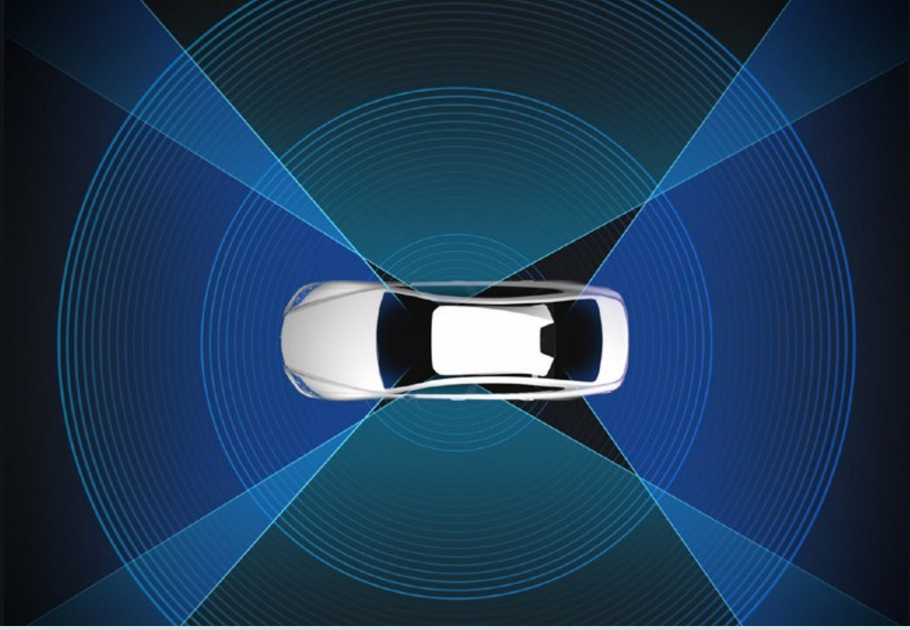
For some technologies, regional or global harmonization and collaboration across borders would be required to establish a common shared foundation. With such a foundation, we can accelerate our technology development toward improving our customers' safety and toward enhancing freedom and mobility efficiency.

LEGAL / REGULATORY FRAMEWORK CHALLENGES

- Infrastructure (Traffic Design and Management, Road Construction)
- Cybersecurity
- Data Privacy
- Safety Assurance (Design, Construction, Performance, Validation)
- Social System (Vehicle Registration, Licensing, Driving Education and Training, Traffic Rules, Insurance, Law Enforcement, Crash Investigation, Safety and Emission Inspections, etc.)

SOCIAL CHALLENGES

- Regional Differences (Custom & Behavior, Tacit Driving Manner and Rules, Ethical Perceptions)
- Social Acceptance (Safety Concerns)
- Sustainable solutions (Smart Cities, Urban Planning)



TOYOTA'S AUTOMATED DRIVING PROGRAMS, PARTNERSHIPS, AND INVESTMENTS

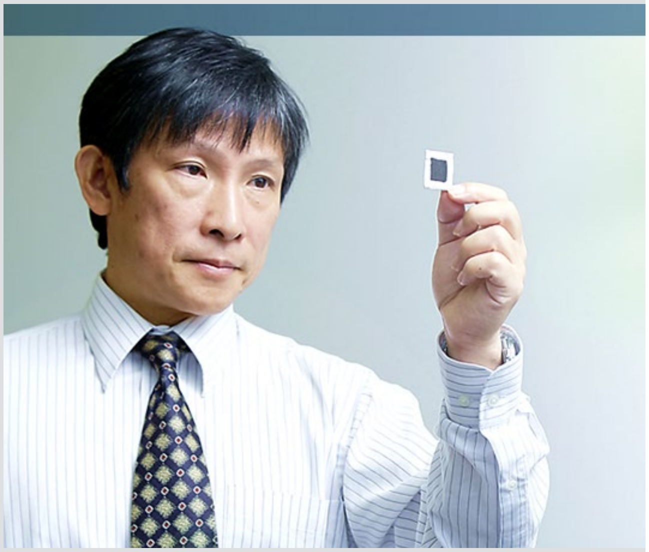
TOYOTA COMPANIES WORKING ON AUTOMATED TECHNOLOGY

JAPAN

- Toyota Motor Corporation: TMC's Advanced R&D and Engineering Company leads the company's efforts to develop automated driving technologies at the global level, pulling together the resources and work of all the other entities listed here, in addition to organizing the research, development and testing of these technologies by all relevant functions at Toyota Motor Corporation.

- Toyota Research Institute – Advanced Development (TRI-AD): Launched in March 2018, TRI-AD is a company Toyota, Aisin and Denso organized that works in collaboration with the U.S.-based Toyota Research Institute (TRI). The company's mission is to leverage the cutting-edge research in AI for automated driving created by TRI into real products that can have a substantial positive impact on mobility for the world.

- Toyota Central Research & Development Laboratories: TCRDL contributes to the present and future businesses of the Toyota Group by conducting research in a variety of fields. At the same time, it surveys global technology trends and explores new fields of science to propose a vision of the future that will lead to new businesses and contribute to the advancement of science, technology and industry.



NORTH AMERICA

- Toyota Research Institute (TRI): Toyota Research Institute is a wholly-owned subsidiary of Toyota Motor North America under the direction of Dr. Gill Pratt. The company, established in 2015, aims to strengthen Toyota's research structure and has four initial mandates: 1) enhance the safety of automobiles, 2) increase access to cars to those who cannot otherwise drive, 3) translate Toyota's expertise in creating products for outdoor mobility into products for indoor mobility and 4) accelerate scientific discovery by applying techniques from AI and machine learning.
- Toyota Motor North America Research and Development (TMNA R&D): Founded in 1977 in Ann Arbor, Michigan, and formerly a division of Toyota Motor Engineering & Manufacturing North America, Inc. (TEMA), TMNA R&D provides everything from engineering design and prototype building to testing and evaluation of vehicles, parts and materials for Toyota's North American vehicles. It includes research divisions studying Next Generation Mobility and Society Research, Cloud Infrastructure Architecture, Intelligent Computing, Network, and System & Software. It is also the home of Toyota's newly established North American purchasing and supplier center. With facilities in Michigan, California and Arizona, TMNA R&D also handles emissions certification, technical research, regulatory affairs and more.
- Toyota Collaborative Safety Research Center (CSRC): CSRC partners with leading universities, hospitals, research institutions and federal agencies, with a focus on safety research projects aimed at developing and bringing to market new and advanced safety technologies. Research areas include active/passive integration, human experience, driver state detection and big data/safety analytics, with results shared publicly with other companies and academia.
- Toyota Connected: TOYOTA Connected leads Toyota's global development of mobility services for consumers, businesses and government, powered by vehicle data science, machine learning and contextual data services. It pioneers the development of Toyota's Mobility Services Platform (MSPF), a global, cloud-based digital ecosystem that provides the tools necessary to bring to market mobility services.
- Toyota AI Ventures: Toyota AI Ventures is a Silicon Valley-based venture capital subsidiary of Toyota Research Institute that invests in promising startups from around the world. The fund focuses on companies developing solutions in AI, robotics, autonomous mobility, data and cloud technology that share its mission of improving the quality of human life through AI.

EUROPE

- Toyota Research on Automated Cars in Europe (TRACE): Toyota Motor Europe's Advanced Research team in Brussels collaborates with experts across Europe in the field of computer vision for automation. It is organized loosely around a lab structure named TRACE (Toyota Research on Automated Cars in Europe).

Current partners include KU Leuven, University of Cambridge, CTU Prague, Max Planck Institute Saarbrücken and ETH in Zürich. Each partner contributes with unique research algorithms, and all elements are integrated into the experimental vehicles under the responsibility of KU Leuven.

Current activities include state-of-the-art deep learning algorithms for object detection, robust and precise tracking, and full scene segmentation and classification. Monocular and stereo-camera algorithms provide long-range depth measurements. The objective is real time-free space estimation for path planning and vehicle control.

TOYOTA COLLABORATIONS FOR AUTOMATED TECHNOLOGY DEVELOPMENT

TOYOTA RESEARCH INSTITUTE

- Massachusetts Institute of Technology: The CSAIL-Toyota Joint Research Center projects range from autonomy to self-awareness. Research is aimed at furthering the development of automated driving technologies.
- Stanford University: Stanford's SAIL laboratory is engaged in research projects that include human-computer and human-robot interactions. The focus is on developing innovative and impactful approaches, algorithms, and data. The approach includes research in perception, learning, reasoning and interaction.
- University of Michigan: TRI's Ann Arbor research facility with University of Michigan focuses on research into enhanced driving safety, partner robotics and indoor mobility, automated driving, and student learning and diversity.

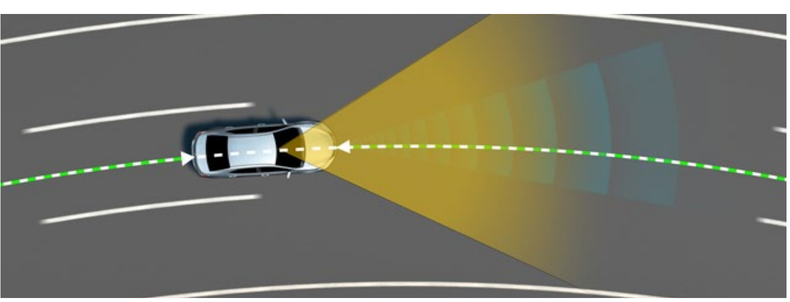
COLLABORATIVE SAFETY RESEARCH CENTER (CSRC)

- Children's Hospital of Philadelphia, University of Virginia, Ohio State University: A project attempting to quantify key occupant responses (kinematics, kinetics and muscle activity) to evasive swerving and emergency braking using both adult and child subjects on a test track.
- Virginia Tech: A research study attempting to estimate the Residual Safety Problem after Integrated Safety Systems (ISS) is deployed in 2025. ISS consists of all active (auto braking for vehicle, pedestrian, bicyclist, lane keeping, etc.) and passive safety systems (advanced airbag, curtain shield airbag, roof strength, pedestrian protection active hood, etc.).
- University of Michigan Transportation Research Institute: An investigation into kinematics of minimally aware adult occupants exposed to Automatic Emergency Braking (AEB) and evasive maneuvers on a test track.
- University of Iowa: Research attempting to measure the response characteristics and estimated benefit with respect to reduction in injury/fatalities of adaptive headlamp system that highlights detected pedestrians and bicyclists using both driver and pedestrian/bicycle simulator study.
- TASI – Indiana University, Purdue University at Indianapolis: A project attempting to develop test scenarios and methods for the evaluation of vehicle road departure warning and assist and control systems on a test track.
- Massachusetts Institute of Technology Age Lab: A project attempting to develop a deep-learning-based, full-scene recognition of vehicle environment from a vision sensor. Examples are vehicles, pedestrians, bicyclists, traffic signs, buildings, curbs, etc.
- University of Wisconsin: A project attempting to provide a theoretical and mathematical framework of how drivers communicate with each other in an intersection.
- University of California at San Diego: A project attempting to provide a computational prediction model for a transfer of control between the automation and the human driver. The model has factors originated from human motor and perceptual behaviors, scenarios and environments.
- University of Iowa – National Advanced Driving Simulator: A project attempting to provide a meaningful and useful dataset of driver behaviors when encountering situations where transfer of control between automation and the human is required.

TOYOTA SUPPORTING STANDARDS OF AUTOMATED VEHICLE SYSTEM TESTING

Beyond our research programs, Toyota is also working to improve the safety of automated technology testing, development and deployment industry wide through Automated Vehicle Safety Consortium (AVSC) and the SAE standards development process. The AVSC works to create a principles-based safety framework to guide the development of common standards for fleet-managed vehicles equipped with SAE Level 4 and 5 automation and to harmonize the range of programs underway at organizations and standards bodies around the world. In addition, the well-established SAE standards development process has already resulted in publication of multiple documents.

- The Automated Vehicle Safety Consortium™ (AVSC) is an industry program of SAE Industry Technologies Consortia (SAE ITC®) building on principles that will inform and help lead to industrywide standards for advancing automated driving systems. The members of this consortium have long been focused on the development of safe, reliable and high-quality vehicles, and they are committed to applying these same principles to SAE Level 4 and Level 5 automated vehicles so communities, government entities and the public can be confident these vehicles will be deployed safely.
- SAE Industry Technologies Consortia (SAE ITC®) is an affiliate of SAE International. The SAE ITC team specializes in establishing and managing consortia by providing proven processes, tools and resources. ITC enables public, private, academic and government organizations to connect and collaborate in neutral, pre-competitive forums thus empowering the global setting and implementation of strategic business improvements in highly engineered industries. (www.sae-itc.com)



TOYOTA COLLABORATIONS TO EDUCATE THE PUBLIC ABOUT AUTOMATED VEHICLES

Partnership for Automated Vehicle Education (PAVE):

Toyota believes in the importance of education to driving safety. It is a key component of our Integrated Safety Management Concept, through which we work to promote safety at different stages of driving, including parking, active safety, pre-collision safety, passive safety and rescue. The emergence of automated technology presents new important consumer education needs, because these vehicles would fundamentally alter the vehicle's existing relationship with its driver, its passengers, and other road users, such as drivers of other vehicles, cyclists and pedestrians.

To support education programs more directly, Toyota has joined with a coalition of industry, nonprofit and academic institutions to launch Partners for Automated Vehicle Education (PAVE). It represents the spectrum of stakeholders who believe in the potential of automated technology and includes advocates for the blind, seniors and other groups seeking new mobility options. Industry members include traditional automakers, parts makers and technology companies. PAVE also includes insurers seeking to reduce the human and financial costs of road crashes and an advisory group of leading academic institutions supporting PAVE's activities.

The group has one goal – to inform and educate the public and policymakers on the facts regarding automated technology. The organization is purely educational and does not advocate for a particular technology or for specific public policies. Its members believe that to fully realize the benefits of automated technology, policymakers and the public need factual information about the present and future state of technology and its potential benefits.

Toyota is excited to support the educational activities that PAVE will launch, including a website and social media channels providing facts about the potential and reality of automated technology; hands-on public demonstration events, so Americans can see, feel, and experience automated technologies; policymaker workshops to help federal, state and local officials make informed decisions; and training materials for auto dealers to help their customers understand and make use of the technology in vehicles today.

TOYOTA INVESTMENTS IN AUTOMATED DRIVING AND RELATED TECHNOLOGY COMPANIES

Toyota invests in a broad range of companies through direct investment, investment funds established in partnership with financial institutions, and Toyota AI Ventures. Portfolio companies include:

- Apex.AI aims to develop reliable, safe, and certified software for autonomous mobility systems. Its initial products are Apex.OS, a robust software framework built on the Robot Operating System (ROS), and Apex.Autonomy, a set of software building blocks that enables developers to create a custom autonomy stack.
- Blackmore develops compact, robust Frequency-Modulated Continuous-Wave (FMCW) LiDAR sensors and supporting analytic tools and software. Blackmore's technology is designed for use in a variety of intense, mission-critical automotive, geospatial and industrial environments where cost and performance specifications limit more traditional sensors.
- Boxbot works to address the last-mile problem in logistics through automation. Through a combination of proprietary delivery software, automated local hubs and tech-enabled fleets, Boxbot makes package deliveries much easier to receive and less expensive to manage.
- Connected Signals is a connected vehicle data analytics company that seeks to provide predictive, real-time, traffic signal information using existing infrastructure. This data, derived using sophisticated proprietary models, supports applications that improve safety, increase fuel efficiency, reduce carbon emissions and improve traffic flow.
- Elementary Robotics builds affordable, intelligent robot assistants designed to help people at home and work.
- Embodied develops companion robots that aim to revolutionize care and wellness to enhance quality of life for individuals and families.
- Intuition Robotics develops social companion technologies designed to redefine the experience between humans and machines. The company's cognitive AI platform and new interaction modalities enable devices to learn about users, adapt to them and proactively engage with them.
- Joby Aviation is an electric mobility company that is building a fully-electric vertical take-off and landing passenger aircraft optimized to deliver air-transportation-as-a-service. The company's 5-seat aircraft is designed to fly at least 150 miles on a charge, to be faster than existing rotorcraft and to be significantly quieter than conventional aircraft.
- May Mobility brings communities closer together with fleets of self-driving vehicles designed to make short-distance travel safe, personal and effortless. May Mobility's fully-managed, right-sized microtransit service helps people engage more fully in the places where they live and work.
- Metawave seeks to revolutionize the future of wireless communications and automotive radar sensing. Leveraging adaptive metamaterials and AI, Metawave is building high-performance radars capable of 4D point-cloud imaging, non-line of sight object detection and vehicle-to-vehicle communication to make cars smarter and more connected.
- Nauto combines leading-edge vehicle hardware with an AI platform to make any car a smart car, helping alert professional drivers to potential hazards outside the vehicle or distraction inside and offering fleet managers insight and feedback to help drivers improve.
- Parallel Domain provides 3D environment generation software for automated vehicle simulation. The automated platform generates high-fidelity living worlds with no manual labor and offers clients configurable, detailed and scalable simulation environments designed to accelerate the time to safety for vehicles with automation.

- Perceptive Automata works to solve one of the hardest problems of automated driving – enabling vehicles to predict and understand human behavior. It develops autonomous systems to anticipate human reactions so they can navigate safely and smoothly around pedestrians, cyclists and other drivers.
- Realtime Robotics develops a proprietary special-purpose processor designed to allow robotic systems to react rapidly to their environments and compute how and where to move as their situation changes.
- Sea Machines Robotics pioneers autonomous control and advanced perception systems for the maritime industry. The company builds autonomous vessel software and systems designed to increase the safety, efficiency and performance of ships, workboats and commercial vessels.
- SLAMcore develops visual tracking and mapping algorithms, more commonly referred to as Simultaneous Localization and Mapping (SLAM), for ground-based and flying robots. SLAMcore's Spatial AI solutions are designed to translate sensor information into spatial intelligence to close the loop between perception and action for autonomous machines.
- Third Wave Automation combines the latest in deep-learning research with modern robotics and software practices to bring autonomy to the supply chain and logistics industries. Its mission is to provide solutions that deploy safely and immediately improve warehouse throughput and efficiency.

TOYOTA'S DEVELOPMENT PROCESS AT TOYOTA RESEARCH INSTITUTE (AS OF MARCH 2020):

System Safety

Toyota designs its core automated technology and the protocols used in its testing to reinforce safety. Collectively, this approach is built on a strong safety culture that incorporates best practices for functional safety into our research activities, which are in turn overseen by multiple layers of institutional controls as research is transformed, refined and prepared for production.

Safety Driver

Currently, Toyota uses a trained Safety Driver in the U.S. to oversee and control the operations of the automated technology during closed course and public road testing.

Though test vehicles operate in tightly controlled design domains, the traffic environment is complex and unpredictable. As a result, Safety Drivers are not merely a backstop in case of an unexpected disengagement or a stopgap on the road to full automation. Rather, they are a key component of the development vehicle's overall safety case that can perceive and prevent unsafe driving behavior in situations that push the boundaries of the technology.

New Safety Drivers must complete an extensive training program, which includes multiple levels of qualification to allow for the various types of vehicles in the Toyota research fleet and for both manual and automated operation. In total, trainees spend one month in Toyota's test facilities in California or Michigan to go through initial training, including observation time shadowing instructors, fault injection training on closed courses, in-class lectures, in-car training on closed courses and public roads, and closed-course emergency drills. Trainees also complete two days of advanced defensive driver training at Toyota's Arizona Proving Grounds. TRI follows, as appropriate, the AVSC's best practice document entitled: AVSC Best Practice for in-vehicle fallback test driver (safety operator) selection, training, and oversight procedures for vehicles with automation under test.

System Architecture

As part of our functional safety approach, we designed the software and systems that control Toyota's automated technology to reinforce safety. Vehicles are controlled by the driving system, which makes decisions about vehicle behavior on the road. In turn, the driving system is governed by a separate safety system that is run via a separate code base on separate hardware. This safety system imposes limits on the driving system, such as steering, braking and acceleration boundaries. This keeps vehicle behavior within safe limits such that the driving conditions would likely remain within the Safety Driver's capability of safely taking control of the vehicle if needed.

Vehicle Cybersecurity

With vehicles becoming more connected, Toyota strives to address ever-changing cybersecurity risks. And as a result, we continue our efforts to strengthen and further improve the security of our vehicles. This includes collaborating with other industry members to further strengthen automotive cybersecurity with respect to vehicle technologies. Among other steps, Toyota was a founding member of the Auto-ISAC focused on sharing cybersecurity threat information within the auto industry and the development of automotive cybersecurity best practices.

With respect to the development and testing of automated technology, Toyota protects the vehicles, and the servers they talk to, from general network access via a multilayer security architecture. Vehicle software and servers are manually updated on a routine basis, helping ensure the use of the latest software releases including functional improvements, bug-fixes and underlying software security updates. Testing data is logged locally, then transferred, stored and protected by a multi-layer security architecture.

In addition, redundancy is built into the automated technology itself. Test vehicles use several different methods to establish constant, real-time situational awareness of the driving environment inside and outside the vehicle. The control system is designed to evaluate all of the available data and not rely solely on one input. Acceleration, braking and steering controls are segmented from the rest of the automated system through a separate software compute box to lower the risk of crucial functions being compromised. This means errors in the driving PC are redundantly checked for soundness by the control unit, so there is less likelihood of unduly influencing system performance. In addition, the systems possess diagnostic capabilities to assess whether both external and built-in sensors are operational and detect failures or other interruptions of service.

Federal, State, and Local Laws

Toyota complies with applicable federal, state and local laws when testing automated technology, including test driving in both manual and automated operation. We are also actively engaged through industry organizations and with other stakeholders to support the development of appropriate regulatory standards that inspire innovation and protect everyone who shares the road.

TECHNOLOGY ON TOYOTA VEHICLES

Some of the following features are available only in specific markets or may be limited in their capabilities on a market-by-market basis.

TOYOTA SAFETY SENSE AND LEXUS SAFETY SYSTEM + FEATURES

- Pre-collision System – Vehicle and Pedestrian Detection: Available on Toyota Safety Sense™ and Lexus Safety System+, Pre-Collision System - Vehicle and Pedestrian Detection uses an in-vehicle camera and radar to help detect a vehicle or a pedestrian in front of you and can help to mitigate or avoid a potential collision. If the system determines a frontal collision is likely, it prompts the driver to take action using audio and visual alerts. If the driver notices the potential collision and applies the brakes, the system may apply additional force using Brake Assist. If the driver doesn't brake in time, the system may automatically apply the brakes to reduce speed to help minimize the likelihood of a frontal collision or reduce its severity. New vehicles equipped with TSS 2.0/TSS 2.5/TSS 2.5+/LSS+ 2.0/LSS+ 2.5 also have bicyclist detection and enhanced low-light pedestrian detection capabilities.
- Pre-Collision System with active steering assist: Available on Lexus Safety System+ A, Pre-Collision System with active steering assist has the potential to help reduce the severity of or prevent collisions with a preceding pedestrian that may not be avoided through automatic emergency braking alone. The system is designed to detect certain situations where there is a high probability of a collision with a pedestrian in the vehicle's lane of travel or with a continuous structure, such as a guardrail. If the system is able to recognize the lane markers on both sides of the vehicle and determines avoiding or mitigating a collision through brake control alone may not be likely, but that it might be avoided or mitigated with steering assist, the system assists in collision mitigation or prevention by providing a limited amount of automatic steering assist within the lane in addition to activating an alert and applying the brakes.
- Front Lateral Side Pre-Collision System: Available on Lexus Safety System+ A, Front Lateral Side Pre-Collision System enhances the capability of the standard Pre-Collision system with lateral side radar designed to detect vehicles approaching diagonally

in front of the Lexus. If the system determines a collision may occur, it warns the driver to perform evasive maneuvers. Additionally, if the system determines there is a high probability for a collision, Brake Assist is applied, which can help the driver avoid a collision or mitigate the impact force to occupants and the vehicle.

- Lane Departure Alert: Lane Departure Alert helps you stay in your lane. Using a forward-looking camera, the system is designed to detect visible painted lane markings on the road and alert you if you are inadvertently moving out of your lane. The system will alert you with an audible beeping sound and an indicator light on the instrument panel will flash so you can then take corrective action.

- Lane Departure Alert with Steering Assist Function: The Lane Departure Alert helps you stay in your lane. Using a specialized camera, the system is designed to detect visible painted lane markings on the road and alert you if you are inadvertently moving out of your lane. The system will alert you with an audible beeping sound and indicator light on the instrument panel will flash so you can then take corrective action. The Lane Departure Alert with Steering Assist system brings added functionality. Should the system determine the driver is not taking corrective steering action, the Steering Assist function will initiate and provide gentle corrective steering when necessary to help keep the vehicle in the lane.

- LSS+ Lane Keeping Assist (LKA): When the Radar Cruise Control is activated and the system senses the vehicle deviating from its lane, LKA helps the car stay on course near the center of the lane by continuously applying a small amount of counter-steering force to keep the vehicle in the center of the lane.

- TSS Lane Tracing Assist: When Full-Speed Range Dynamic Radar Cruise Control (DRCC) is enabled and lane markers are visible, Lane Tracing Assist (LTA) uses the lines on the road and preceding vehicles to help keep the vehicle centered while also displaying the vehicle's position on the vehicle's Multi-Information Display (MID) screen. The system was designed to reduce driver strain and increase convenience and benefit drivers most during traffic jams—but it can be turned off using the MID. (TSS 2.0/LSS+ 2.0 only)

- Automatic High Beam: Automatic High Beams is designed to help drivers see more of what's ahead at nighttime while limiting glare to other drivers. When enabled, this feature uses a forward-looking camera to help detect the headlights of oncoming vehicles and taillights of vehicles in front of you, then automatically switches between high and low beams to enhance forward visibility. By using high beams more frequently, AHB may help drivers to detect vehicles and obstacles earlier.

- Dynamic Radar Cruise Control (DRCC): While staying within a preset speed range, the system maintains a pre-set distance between vehicles to help make long highway drives less tiring. For vehicles equipped with Full Speed Range DRCC capability, the system operates at all speeds. This enables low-speed following, matching speed and, under certain circumstances, stopping before colliding with preceding vehicles on highways.

- Front Cross-Traffic Alert: Available on Lexus Safety System+ A, Front Cross-Traffic Alert is designed to warn the driver of the presence of crossing vehicles at intersections, thereby potentially reducing the severity of or preventing some intersection collisions. FCTA uses the front lateral side radar sensors to detect and alert the driver of approaching vehicles that may cross the vehicle's path. If the approaching vehicle or bicycle continues its trajectory, the system is designed to quickly alert the driver in two stages via the available HUD and Panoramic View Monitor before the vehicle/bicycle enters the path of the Lexus.

- Road Sign Assist: Using a forward-facing intelligent camera, Road Sign Assist (RSA) is designed to detect speed limit signs, stop signs, do not enter signs and yield signs and display them on the vehicle's Multi-Information Display. (TSS 2.0/LSS+ 2.0 only)

ADDITIONAL FEATURES ON MANY TOYOTA AND LEXUS VEHICLES

- Panoramic View Monitor: High-resolution cameras mounted on the front, sides and rear of the vehicle are designed to give drivers a "bird's-eye view" of the near environment. Moving View and See-Through View options create a composite image of the vehicle's surroundings as on-screen guides help assist with parking and tight maneuvering.

- Parking Assist Sonar: Parking Assist Sonar uses ultrasonic sensors integrated into the bumpers designed to detect surrounding objects. Using audible tones and an indicator on the multimedia display, the system can notify you of a detected object's location and proximity to help with routine tasks, such as parallel parking.

- Intelligent Clearance Sonar (ICS): Intelligent Clearance Sonar scans for stationary objects, such as walls or parked cars. Should the system anticipate a collision, it will emit an audible alert, reduce engine or motor output, and may automatically apply the brakes.

- Intelligent Parking Assist (IPA): Intelligent Parking Assist uses ultrasonic sensors to detect surrounding objects and identify parking spaces. The driver stops the car before the open parking space and by pushing a single button, the system guides drivers to the right position for reverse parking and assists drivers in backing into the space.

- Blind Spot Monitor (BSM): BSM is a system that aims to reduce accidents by alerting the driver to other vehicles in the vehicle's blind spot diagonally behind the driver's seat and visual display in the side mirrors and while changing lanes by using rear side radars.

- Rear Cross Traffic Alert (RCTA): RCTA is designed to provide audible and visual indicators, alerting the driver when a vehicle approaches while backing out of a driveway or parking space.

- Rear Cross Traffic Auto Brake (RCTAB): RCTAB is designed to detect a vehicle using a rear camera. And in the case of a possible collision, it helps to minimize damages by using alerts and brake control.

- Intelligent Adaptive Front-Lighting System (AFS): Intelligent AFS is designed to redirect low-beam headlamp units in accordance with the steering angle and vehicle speed at night to improve visibility during cornering.

- Approaching Vehicle Audible System (AVAS): EV-operated (Electric Vehicle) hybrid cars run quietly. When the vehicle is driven at up to 25km/h or reversing, the system emits an alert sound to help notify pedestrians

- Safety Connect: Safety Connect consists of the following four features:

  - Automatic Collision Notification – Toyota's 24/7 response center is automatically notified in the event of an airbag deployment or severe rear-end collision. The 24/7 response center agent will attempt to speak with the vehicle's occupants and then notify local emergency services to request dispatch of emergency services to the vehicle's location.

  - Emergency Assistance Button – Engaging the Emergency Assistance button in your vehicle can connect you with a 24/7 response center agent who can request dispatch of necessary emergency services to your vehicle's location in case of a medical or other emergency on the road.

  - Enhanced Roadside Assistance – pressing the Emergency Assistance Button connects to 24/7 Roadside Assistance.

  - Stolen Vehicle Locator – in a vehicle-theft situation, it notifies our response center so agents can assist authorities in locating your vehicle using GPS technology.

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