Automated Driving Requires Rethink of Human-Vehicle Interaction

Fully autonomous vehicles are coming — but until autonomous systems are able to account for every situation, every environment and every circumstance, automated driving will continue to be a continuum, with humans an integral part of the driving team.

Progressing along that continuum presents distinct challenges. Today, many OEMs are moving to advanced partial automation at Level 2+ and conditional automation at Level 3, balancing performance and affordability by allowing the driver to disengage from certain driving tasks for periods of time. The flipside of that benefit is that there will be times when the system requires the human to reengage and take control of the vehicle.

Ensuring that the handoff is as seamless as possible should be the automated system's goal as much as it is the human's. What is required is an intelligent approach to interacting with the driver — one that combines an environmental model of both the inside and outside of the vehicle with a driver model built with contextual assistance and semantic understanding, to provide drivers with the tools they need to successfully accept the transition of control.

READY OR NOT

Say you are on a cross-country trip. A gently curving ribbon of interstate winds through miles of prairies ahead of your vehicle. Your teenage son is driving, and you let your attention wander. Maybe you reflect on sights you have seen on your vacation so far; maybe you daydream about adventures still to come. Or perhaps you pick up a book, browse social media on your phone or just doze off for a bit.

Suddenly, your son urgently asks you to take the wheel and drive, because there is a situation coming up and he does not know how to handle it. But your mind was elsewhere — as quickly as possible, you try to assess the situation: Where are we? What lane are we in? What vehicles are around us? What poses a danger and what is the urgency? What traffic signs are relevant?

Obviously, humans cannot safely switch drivers in the middle of a busy highway, but this example illustrates the challenge at certain levels of automated driving. It becomes a particular issue as vehicles move to Level 3 automation, where humans can expect to fully disengage from the act of driving in specific situations. At some points, the automated system may require a human to be fully present and ready to take over.

To address the transition of control, current systems might flash warnings or budget time for the driver to take control. However, a driver's takeover time and takeover performance are influenced by many factors leading up to the transition of control: How involved is the driver in non-driving-related tasks? Is the driver in a distracted state? How complex is the driving situation?

		0 No automation	1 Driver assistance	2 Partial automation		3 Conditional automation		4 High automation	5 Full automation
		Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, such as acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.		Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.		The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option of controlling the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option of controlling the vehicle.
				2	2+	3	3+		
VEHICLE CAPABILITIES	Safe Stop	NO	NO	LIKELY (SLOW DOWN IN LANE)	LIKELY	LIKELY	YES	YES	YES
	Sensing	-	1 - 2	3 - 4	4 - 6	10 - 12	15 - 20	20+	20+
	System Redundancy	NO	NO	NO	NO	NO	NO	YES	YES
	Driver Monitoring	NO	NO	NO	TOUCH/ DRIVER STATE	DRIVER READINESS	DRIVER READINESS	DRIVER READINESS	NO
DRIVER ENGAGEMENT (ON / OFF)	Brain on Task	ON	ON	ON	ON	PARTIAL	OFF	OFF	OFF
	Eyes on Task	ON	ON	ON	ON	PARTIAL	OFF	OFF	OFF
	Hands on Wheel	ON	ON	ON	OFF	OFF	OFF	OFF	OFF
	Feet on Pedals	ON	OFF	OFF	OFF	OFF	OFF	OFF	OFF

OEMs must explore ways to help get human drivers ready to assume control, effectively and rapidly. In the human-machine driving team, it is important for a system to understand its human partner in real time — to understand the driver's cognitive state, behaviors and intentions — and to create a personalized profile of the driver for safe operation with automation.

A BRIDGE TO UNDERSTANDING

The good news is that the industry is developing the tools today to provide vehicles with enough intelligence to learn not only a driver's current physical state but also the best ways to interact with that specific driver leading up to the transition of control. Combining that perspective with knowledge of the environment around the vehicle can allow an automated system to proactively adapt vehicle interfaces to augment the driver's decision making.

An environmental model

The key to doing this effectively is by paying attention to the environment around the vehicle. Advanced driver-assistance systems (ADAS) take into account multiple aspects of the environment, such as the weather, traffic conditions, time of day, and whether the vehicle is traveling on a highway or in an urban setting.

Each generation of vehicles adds more sensors — including radars, cameras, lidars and ultrasonic sensors — while increasingly gaining access to map, traffic and weather data over the air. Through sensor fusion, the system can build an excellent environmental model that reflects what is going on around the vehicle and assess situational threats.

The challenge is to match the vehicle's model of the environment with the human's model, since humans have their own senses and their own mental models of system and environment.

HUMANS AND ROBOTS *CAN* GET ALONG

The automotive domain is not the first instance of cooperation between automated systems and humans by any means. Prominent examples include aviation, defense and space exploration. All of these domains require:

- A safety culture
- Resiliency in human-machine coordination during adverse, dynamic and uncertain conditions
- Fluid task handoffs among different people and machines
- User education and training on the capabilities of automated systems

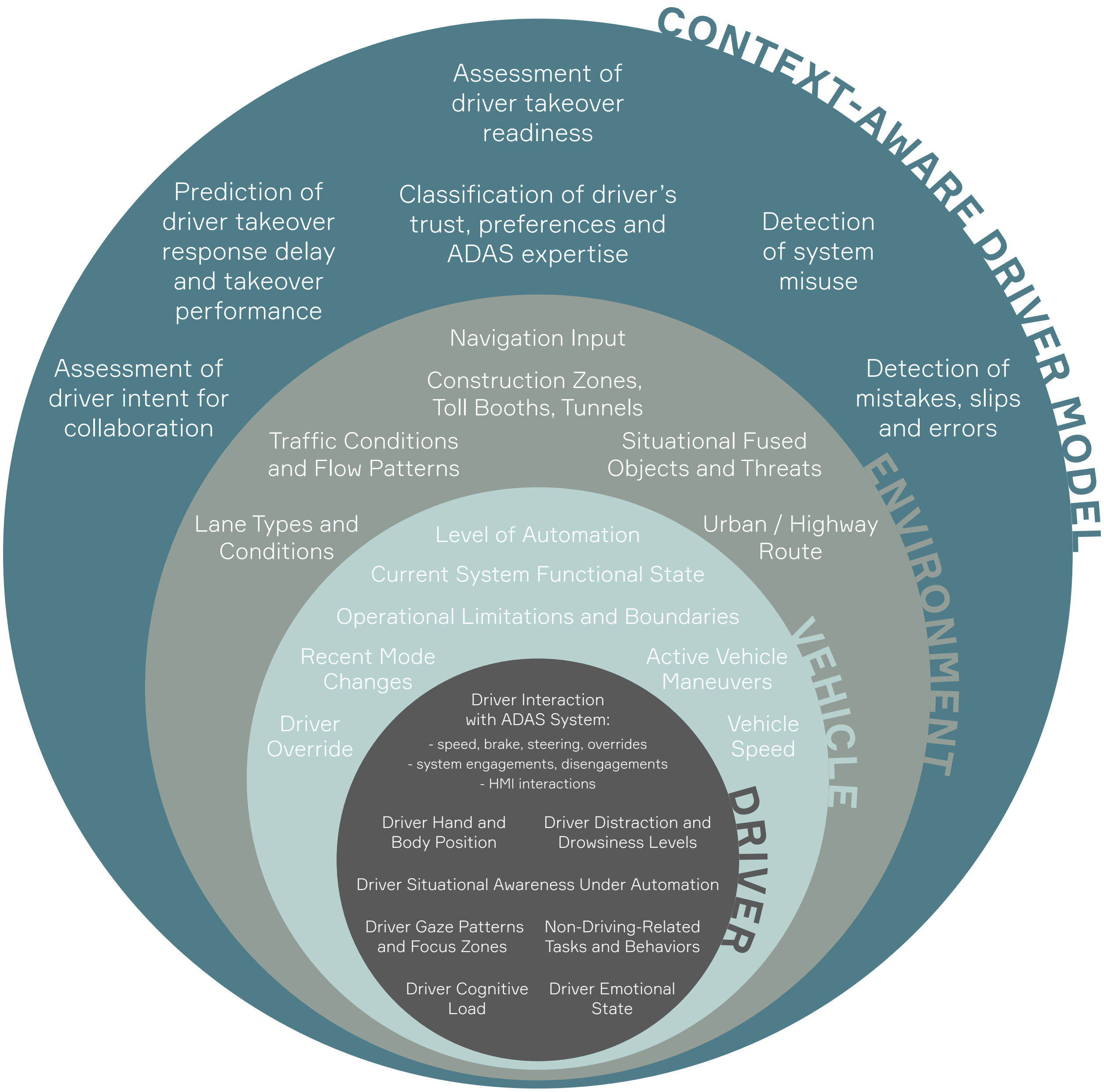
Each of these areas also has adopted a team-based framework consisting of a supervisory role complemented by shared team goals of coordination and assistance. Lessons from these areas should be applied as automated driving emerges.

A driver model

One way to bridge the gap is for the system to create a model of the driver, leveraging driver monitoring systems, which use a camera to determine whether the driver is paying attention, distracted or drowsy.

Traditional systems have followed a rules-based approach or assumed that driver behavior is static, but there is much more potential, especially when monitoring multiple variables, such as facial expressions and cognition. For example, systems sometimes issue lanedeparture warnings without regard to whether the driver intends to change lanes or to how attentive the driver is at that moment. But an advanced interior sensing system could observe the driver over time and create a model of how that driver appears or acts in various states and under different driving conditions.

As drivers experience features that move into Level 2+, such as automatic lane-change assistance, they gradually learn system behaviors and handling in various traffic scenarios, including unstable traffic flows, varying traffic densities, merging with gaps and so forth. This initial exploration phase, where drivers are learning about the system's capabilities, plays a critical role in overall trust and acceptance of the technology. They form a mental model of its operation and judge whether the system's actions are conservative or aggressive, annoying or appropriate.



During this time, the driver model can also learn in real time about the driver. In the above example, the driver model can classify a driver's response to and interactions with the system before, during and after automatic lane-change maneuvers.

A driver model allows the system to see drivers in a more complete light. It uses the history of interactions to determine whether the driver tends to trust the automated system too much, or not enough. It finds patterns in situations when the driver is engaged or not. And it deduces which methods are the best ways to communicate with that driver in the future. For example, the system can observe whether a driver prefers to receive more information on exactly what the vehicle is doing and why, or would prefer fewer interruptions.

Contextual assistance

With the environmental model and the driver model in place, the automated system now has a better idea of what the driver will need in order to be successful in the act of driving. For example, the system can perform semantic analysis on a driver's queries, enhanced with machine learning, to better link interrelated concepts and context. The automated system should have contextual assistance functions, whose sole job is to anticipate drivers' needs and get them the information they require, when they require it and in a form that suits them best.

The contextual assistance function can predict how and when the driver will need help. For example, by sensing a driver's confusion, the vehicle can proactively provide information to help build trust, just as human drivers would for their passengers.

There are two ways a driver model can help here:

- **Tailor the human-machine interface so that its communications align with the driver's patterns.** This is especially important during times of uncertainty, such as difficult driving conditions. For example, in a lane-change situation, the system can inform the driver about changes in lane risk estimates and provide forewarnings based on surrounding traffic flow complexity — all of which can help build a driver's trust in the system.

- **Adapt the ADAS response to the personalized driving characteristics of each individual driver.** In the lane-change example, variables such as speed, assertiveness and acceptable gaps between vehicles can be personalized for each driver's comfort level.

In addition, the driver model and contextual assistance can help reduce human error. For example, if the driver suddenly deactivates Level 3 automated driving on a highway, the system can consider the context, observe how the driver reacts to the switch, and determine whether the driver has in fact switched it off accidentally. This could become an extremely unsafe situation, as the driver is not aware or prepared to regain control of the vehicle. If that happens, the system could be designed to support the driver by momentarily enabling control assistance during this transition.

BENEFITS OF CONTEXT-AWARE SYSTEMS

Context-aware systems assist drivers in the decision-making process by:

- Assessing the situation holistically, considering driver state, road conditions and ADAS state

- Helping the driver in a manner that would have highest safety benefit, considering the driver's comfort, skills and ability to process the current information

Aptiv is currently working with multiple OEMs on driver modeling efforts and attention criteria management contextualized to specific driving scenarios.

THE HANDOFF

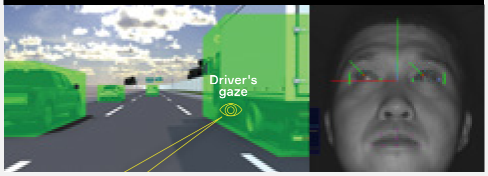
A key challenge in conducting a handoff is rapidly transitioning the driver from a relaxed state to an active and alert state. It does not have to be on a cross-country trip, either. Consider a traffic-jam situation, where drivers could have items in their hands (sipping coffee, checking email) or could be out of position (leaning back or rubbernecking).

This is where the environmental model's situation and threat assessment and the driver model come into play. The system's environmental model allows it to know which elements require attention and which do not. For example, a driver's attention might immediately go to two large trucks nearby, but perhaps the car moving into the driver's lane is of more concern. The system could use the driver model to highlight that car in a helpful way, such as putting visual markers around the vehicle on the heads-up display, using information on the infotainment system or communicating through audio.

The emerging approach to ensure handoffs go smoothly is to explore cooperative interactions, where maneuvers and uncertainties are tackled together by the driver and the vehicle. Active-safety systems may be unsure what actions to take in certain environmental or traffic conditions. A vehicle could form an "agreement to watch over me" with the driver at certain points in the drive, where the vehicle informs the driver of upcoming uncertainty — due to a construction zone, say — and assesses the driver's intent to collaborate. The driver would actively confirm the collaboration, and then watch closely as the system performs maneuvers in lanes near the construction zone. This close collaboration makes the human and the machine a team to improve safety.

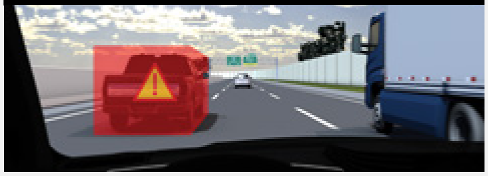
Redirecting and Refocusing

What the system sees



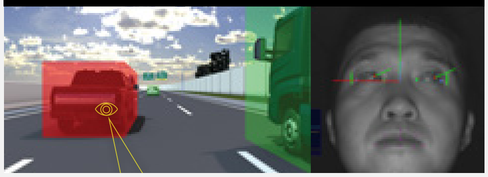
The situation: The system is tracking the surrounding vehicles and assessing threats, while simultaneously tracking the driver's gaze and their situational awareness patterns.

What the driver sees



Evaluating awareness: As the system prepares to transfer control to the driver, it determines he is not aware of the higher threat on the left and highlights it in a heads-up display.

What the system sees



Reoriented: Highlighting the vehicle moving into the lane has drawn the driver's attention to the element in the environment that is most concerning at the moment control is transferred.

GETTING THERE FROM HERE

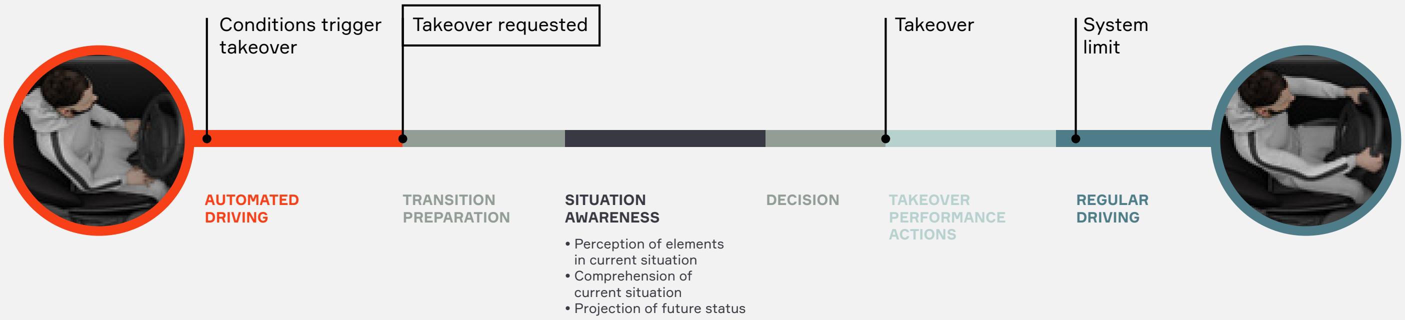
In the end, the approach to working with drivers may be similar to working with technicians in a nuclear plant or pilots in a modern airplane. Power plants and airplanes are also safety-critical systems, but the operators are not in control at all times. Instead, they are trained to know the state of crucial aspects of the system and to watch for anomalies or threats.

Humans, it turns out, are good at finding anomalies and making classifications or generalizations, while computers are better at looking at large amounts of data, parsing it and performing many complex operations at once. A good contextual assistant could match the way humans think — processing data and highlighting anomalies for the driver. Moreover, the contextual assistant would be instrumental in helping to train drivers to work with the vehicle, so that they become strong operators of ADAS.

Developers must not lose sight of the fact that human drivers continue to be essential to vehicle operation at Levels 2 and 3, and developers should design systems that give drivers the support they need to operate their vehicles safely. Every person has a different way of learning and interacting with systems, which means that cookie-cutter approaches will not always suffice.

Building sophisticated models of the driver and the environment are essential to building a safe and collaborative driver-vehicle relationship – and when drivers see that the system really understands them and what is going on around the vehicle, they are more likely to trust it and use it.

Phases of Driver Takeover



PREPARING THE DRIVER FOR TAKEOVER

The driver's awareness of the surrounding environment — vehicles, traffic and road conditions — is critical in ensuring a safe transition of control. Aptiv has developed an initial situational-awareness estimation model of the driver, which looks at where the driver is glancing and evaluates how relevant those glances are to the surrounding vehicles and the total environment.

The model combines environment-sensing and driver-sensing data to deduce the quality of drivers' situational awareness as they attempt to regain control. When drivers show low situational awareness as they get ready for transition, the vehicle could inform them to direct their gaze in a given direction for reorientation — and the system could also highlight specific objects that are potential threats.

ABOUT THE AUTHOR

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Nandita Mangal leads development on the human-machine interaction (HMI) platform for advanced driver-assistance systems at Aptiv. Her work focuses on creating systems that are “safe by design” and centered around human-vehicle interactions inside the cabin. She has extensive experience in product design and interaction research for L2/L3 ADAS as well as L4/L5 systems. She has led design research for Aptiv on autonomous shared mobility, conducting large on-road AV studies in Las Vegas for the launch of Aptiv’s fleet of robotaxis in partnership with Lyft. Nandita holds 13 U.S. patents and was inducted into the Aptiv Innovation Hall of Fame in 2021 for her contributions. Prior to joining Aptiv, she led design for ground combat vehicles and field robots in affiliation with the Army Research Lab and Department of Defense.

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