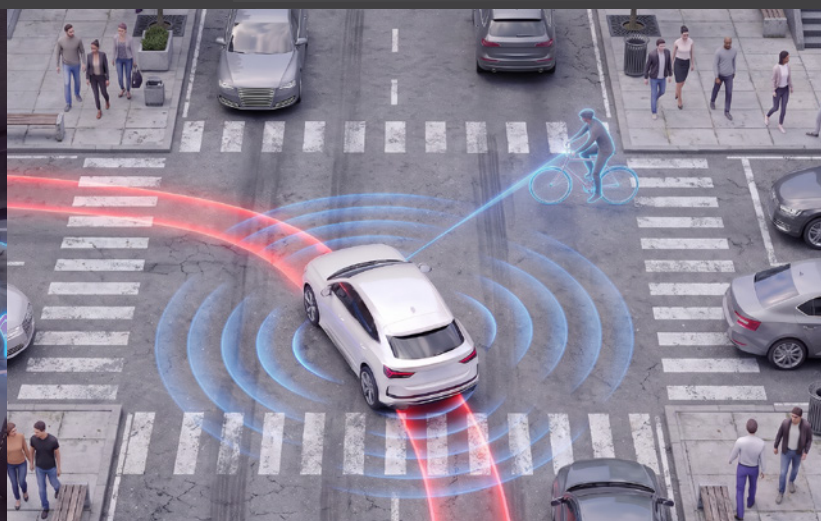




How Interior-Exterior Fusion Can Improve ADAS Safety

ADAS continuously processes data from cameras, radars and other sensors to create a detailed and ever-changing model of the external driving environment — one made up of vehicles, lane boundaries, traffic controls, vulnerable road users and more. But recognizing what happens outside the vehicle is only part of the safety equation. While a vehicle can detect hazards, it typically cannot determine whether the driver noticed them as well.

Driver and cabin monitoring systems look inside the vehicle cabin. Using interior cameras and related technologies, driver monitoring systems and cabin monitoring systems know where the driver is looking, whether their attention is on the road and whether the driver is exhibiting signs of distraction or fatigue.

Interior-exterior fusion brings together those two perspectives that, until now, have remained largely separate. By combining what the vehicle knows about the road with what it knows about driver attention and readiness to respond, automakers can build automated driving systems that make educated decisions.

FROM SENSOR FUSION TO SHARED AWARENESS

Imagine a driver preparing to make a right turn. The driver looks left, watches the traffic, judges gaps between vehicles and plans the turn. Meanwhile, a cyclist approaches from the right.

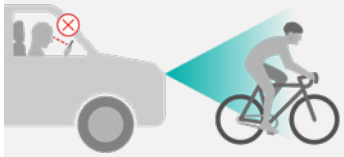
The vehicle's radars and cameras detect the bicycle immediately. The driver might — or they might not.

Drivers can miss hazards for many reasons, including distraction, fatigue, looking in the wrong place at the wrong time — or even "alert fatigue" from too many false warnings. Understanding the driver's state gives ADAS valuable context, enabling interventions that could help prevent crashes and save lives.

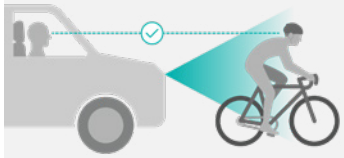
Traditional sensor fusion combines information from multiple external sources into a single model of the environment surrounding the vehicle.

WHEN THE VEHICLE AND DRIVER SEE DIFFERENT THINGS

The value of shared awareness becomes clearer when comparing how different systems might respond to the same situation.

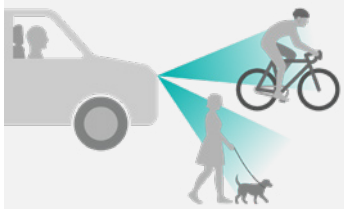


Scenario 1: The vehicle sees the hazard. The driver does not.
The vehicle detects a cyclist approaching an intersection, but the driver never looks in the cyclist's direction. Traditional ADAS evaluates the environmental risk and may issue warnings. A shared-awareness system can recognize that the driver appears to be unaware of the cyclist. That information may justify earlier intervention, stronger warnings or a different communication strategy.



Scenario 2: The vehicle sees the hazard. The driver sees it too.
The vehicle detects the cyclist from the previous scenario. In this case, the driver has already looked toward the cyclist and is slowing appropriately. Traditional ADAS may generate the same warnings as before because the environmental situation appears to be the same.

But a shared-awareness system could potentially recognize that the driver has already identified and responded to the risk. It could either reduce the number of warnings issued or determine whether intervention is even needed.



Scenario 3: Many hazards are competing for attention. Drivers in a complex urban environment may encounter several risks simultaneously: a pedestrian entering a crosswalk, a cyclist moving alongside traffic, a changing traffic signal and vehicles approaching from multiple directions.

Traditional ADAS evaluates environmental risks. Shared awareness adds another layer of context by helping to identify which risks the driver may not have perceived. The challenge is no longer simply detecting hazards. It is understanding where the mismatch exists between what the driver knows and what the vehicle knows.

Interior-exterior fusion combines information about the environment with information about the driver, extending "What is happening around the vehicle?" to "Does the driver know what the vehicle knows about what is happening?"

Traditional ADAS primarily understands the environment. Driver monitoring systems primarily understand the driver. The concept of shared awareness emerges when those two perspectives are evaluated together. The additional context allows the system to evaluate both the environmental risk and the gap between vehicle awareness and driver awareness.

This issue aligns with industry discussions about driver engagement and vehicle safety. Euro NCAP is emphasizing driver monitoring, driver engagement, and the relationship between driver state and assisted-driving performance. Recently released protocols are being used to evaluate how effectively vehicles monitor driver behavior and maintain engagement with the driving task.

Most crashes do not occur because information is unavailable. Drivers routinely operate in information-rich environments. Accidents happen because somebody missed something. What is important is determining which information matters most at a particular moment and whether the driver recognizes it.

WHAT CHANGES WHEN DRIVER STATE BECOMES A SAFETY INPUT

For decades, improving ADAS largely meant improving perception — and it succeeded. Better cameras, radars, sensor fusion systems and machine learning models made vehicles progressively better. Today, many ADAS technologies can accurately detect vulnerable road users, estimate trajectories, assess collision risk and identify developing conflicts.

As environmental perception improves, the limiting factor increasingly becomes driver awareness. The vehicle may correctly identify a risk, but safety outcomes still depend in part on whether the driver recognizes the same threat and responds appropriately. The distinction is particularly important in dense urban environments, where drivers must divide their attention among traffic signals, navigation prompts, surrounding vehicles and vulnerable road users, and activity inside the vehicle cabin.

With interior-exterior fusion, the system can alter its own behavior. Driver state becomes a new input into safety decision-making. If a system detects that the driver is inattentive, it can warn the driver of hazards earlier, engage driver assistance features more assertively or change how the human-machine interface (HMI) interacts with the driver.

Shared awareness evaluates and monitors whether the driver appears to be aware of a specific developing risk — a distinction that creates opportunities for more context-aware safety interventions. A brief glance and sustained observation do not necessarily indicate the same level of awareness. Accumulating gaze information over time provides additional evidence about whether the driver appears to perceive a developing hazard, such as a child's toy rolling into the street.

Interior-exterior fusion can correlate accumulated driver gaze behavior (what they have looked at in the surrounding environment) to determine whether the driver looked toward a hazard and for how long. Calibration between interior and exterior perception system data yields better decisions.

Vehicle-following distance offers an example. Today, adaptive cruise control (ACC) evaluates traffic conditions as part of its determination of the optimal spacing between vehicles. Interior-exterior fusion adds the possibility of incorporating driver condition into that evaluation, raising possibilities such as earlier intervention thresholds or larger safety margins that account for the driver's reduced readiness to respond.

Interior-exterior fusion offers benefits even when ADAS is not active, without regard for self-driving features. The vehicle can continue to evaluate environmental conditions and driver state even when ACC, lane centering or other driver assistance features are not engaged. If the system knows that a driver is distracted, that information can contribute to decisions about warning thresholds, intersection alerts or vulnerable-road-user notifications. For example, it may warn a vehicle occupant not to open the car door because a cyclist is coming.

If the system notes that the driver is fatigued, it can increase monitoring sensitivity or change its warning strategies — and optionally do so without notifying the driver of the setting adjustment. The same guidance might apply to adjusting forward-collision warning thresholds and increasing lane-departure sensitivity.

Additional options for passive behaviors could include adding earlier intersection warnings or making audio adjustments to help the driver locate hazards.

IMPROVING DRIVER ACCEPTANCE

Interior-exterior fusion may improve more than safety performance. One current ADAS challenge is achieving balance between useful intervention and unnecessary alerts. Warnings that seem irrelevant or poorly timed reduce driver trust and adoption.

A vehicle that accurately estimates the hazards a driver has already recognized may be able to make its warnings more selective and more relevant. In some situations, the best intervention may be an earlier warning. In others, the system may comprehend that the driver already understands the hazard and is responding appropriately.

Until now, neither the external systems nor the driver monitoring systems could deliver those capabilities independently. Their fusion can result in more context-aware interventions, fewer nuisance alerts when the driver has already recognized a hazard, and earlier or different intervention when the driver has not.

The goal is not necessarily more warnings. It is better-informed warnings.

APTIV PROVIDES THE INFORMATION. OEMS DECIDE HOW TO USE IT

Interior-exterior fusion is not an HMI strategy. It does not determine whether or when an automaker should use visual indicators, audible alerts, haptic feedback, modified ADAS behavior or some combination of approaches. Those HMI decisions remain with the OEM.

Should the detection of a fatigued driver generate a flashing coffee-cup dashboard icon, directional chimes, haptic feedback in the steering wheel or increased audio volume? Should it use a cockpit voice assistant to engage the driver in a conversation to increase their alertness level? That is an OEM choice. So are decisions about adapting alert timing, nature or intensity rather than merely issuing a warning. In many cases these factors affect the brand experience, and therefore OEMs know best how to address consumer expectations.

Manufacturers already differ in their design for warning strategies and how they communicate with drivers. Interior-exterior fusion provides additional information — and, with access to the technology options, automakers can determine how the information should influence vehicle behavior.

Aptiv can also support those decisions. Different warning strategies, intervention approaches and driver engagement models can produce different outcomes for safety, driver acceptance and overall user experience. Interior-exterior fusion provides the information; OEMs determine how best to apply it within their individual programs.

MOVING FORWARD

Cyclists, pedestrians and slowing traffic are not new problems. What is changing is the information available to a vehicle's systems. Rather than evaluating hazards solely in terms of location, trajectory and severity, systems can also account for whether the driver appears to be aware of those hazards and prepared to respond. That information becomes another input into the decisions automakers make about vehicle safety.