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The micro-scale challenge of simulating vehicle interiors

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Matthew Beecham
Mobility Global
Supply Chain and Technology, Automotive

How in-cabin sensing is transforming vehicle safety, while complex interiors make accurate simulation challenging.

Source: Getty Images/ Bim

From July 2026, the EU's General Safety Regulation makes Advanced Driver Distraction Warning mandatory on all new vehicles, and Euro NCAP's 2026 protocols sharply increase the weighting given to driver and occupant monitoring systems. Almost overnight, sensing what is happening inside the cabin has become one of the most consequential areas of vehicle safety development, and it is accelerating in step with wider shifts in vehicle architecture and human–machine interaction. As Level 2/2+ functions proliferate, regulators and consumer ratings are converging on a simple premise: if the vehicle is going to share control with the driver, it must be able to verify driver attention, readiness to take over, and occupant status with high confidence. At the same time, the technology stack is evolving quickly; multi-modal sensor fusion (RGB/IR, time-of-flight, radar), health-of-system diagnostics, and increasingly AI-driven intent and state estimation are moving in-cabin monitoring from a discrete feature to an integrated safety layer that also supports automated driving roadmaps and software-defined vehicle (SDV) strategies. As with every other part of the modern car, manufacturers want to move as much of that development as possible into simulation, to save time and cost and to start development before any prototype exists. But simulating the interior of a vehicle turns out to be surprisingly challenging. To learn more, we spoke to Matt Daley, Technical Director at rFpro, about why in-cabin sensing is so hard to recreate virtually, the technology needed to overcome it, and how simulation could eventually feed into the assessments themselves.

Matt Daley [Source: rFpro]

Mobility Global: Driver and occupant monitoring has climbed the agenda very quickly. What has changed?

Matt Daley: Two things have happened almost simultaneously, and both carry real commercial weight. Under Euro NCAP's 2026 protocols, the importance of in-cabin monitoring on a vehicle's safety rating has risen dramatically. To put that in perspective, the points available for driver monitoring have gone from a maximum of two to 25, and child presence detection has increased as well. At the same time, Advanced Driver Distraction Warning becomes mandatory for every new vehicle in the EU from July 2026.

So this is no longer a feature that helps at the margins of a star rating. It is central to both the rating and to regulatory compliance. Get it wrong and the cost is a lost star, or worse, a system that fails type approval. For a manufacturer, that means these systems have to work reliably across an enormous range of real-world conditions, and they have to be developed and validated faster and earlier in the program than before. That is exactly the kind of pressure that pushes engineering teams towards simulation.

The industry already simulates a great deal of its external sensing. Why is the inside of the cabin challenging?

On the face of it, you would think simulating vehicle interiors is much simpler than trying to simulate the exterior environment. The space is much smaller, the variables are less, so it’s much more controlled in that respect.

An external sensor is working at a relatively macro level. It is looking out at the world to identify a car, a pedestrian, a speed limit sign or a lane marking. Those are large, distinct objects, and the challenge is essentially one of recognizing them reliably at distance and at speed.

An internal sensor is doing almost the opposite. The environment it is scanning is small and enclosed, but the things it has to detect are tiny and subtle. It is trying to read specific eye movements, head position, eyelid behavior and posture, and from those infer something quite abstract, such as whether the driver is drowsy, distracted or potentially under the influence. So although the space is narrow, the detection task moves to a micro scale. Recreating that convincingly in simulation is a very different and much finer-grained problem.

Can you give a sense of just how fine those cues are?

A good illustration is the difference between what NCAP calls ‘owl’ and ‘lizard’ movements. An owl movement is where the driver turns their whole head to look around or away from the road. A lizard movement is where the head stays still and only the eyes flick away, to check the speedo or nav instructions. A monitoring system has to distinguish between the two, and between a genuine glance away and a momentary, perfectly safe check of a mirror.

To test that in simulation, you cannot just have a static digital human. You need to be able to control facial and limb movement very precisely, reproducing both the obvious gestures and the small, fleeting expressions that these systems are designed to catch. If the virtual human cannot perform those movements accurately, the sensor model has nothing meaningful to learn from.

What about the cabin environment itself, is that a challenge to simulate?

Yes, and in ways that are not obvious until you start. Different sensors perceive the same cabin very differently. A camera sees surfaces and textures, while radar passes through some materials and reflects off others. Radar will, for example, detect the metal framework inside a seat that is completely invisible to a camera and to the human eye. So to be accurate, the virtual cabin has to model structures that you would never normally think to include, because one of the sensors can see them.

On top of that, real cabins are cluttered and unpredictable. Occupant monitoring has to cope with rucksacks, laptops, child seats, pets and all the personal belongings people bring into a car. Even something as mundane as opening or closing a window matters, because it changes how light and radar energy travel through the space. None of that is a consideration for external sensing, but inside the cabin these everyday variables have a real effect on whether a system performs.

How much of the external sensor modeling carries over to the cabin, and what has to be built specifically for the interior?

The underlying physics is no different inside the car than outside it. Light and radar behave exactly the same way, so there is a good deal of our existing technology that carries over to in-cabin systems.

What changes is the content you point the sensors at and the conditions you have to recreate. In-cabin systems lean heavily on infrared cameras that illuminate the scene with their own infrared source, so you have to model the energy the camera emits and trace how it interacts with every surface it touches. Skin, the seats, the trim, the glass, they all have their own infrared and radar properties. Those surfaces are all close, so the level of detail required is high. Skin reflectivity, for instance, varies across a single face; the nose, chin and cheek do not behave identically under infrared.

So there are distinct differences and nuances between simulating the outside and inside world. On top of this, commonly at OEMs, there are different teams working on the in-cabin sensing systems and those working on ADAS, for example. So that interior-specific work is what we have packaged into our new AV elevate IN CABIN solution.

If the industry moves towards simulating in-cabin sensors, could it eventually feed into the NCAP assessments themselves?

Physical testing is often slow, expensive and limited in scope. You can only stage so many combinations of occupant, lighting condition and behavior on a real vehicle. Not to mention that some of the most important scenarios, where the driver is impaired or drowsy, are difficult and unsafe to reproduce on demand. Simulation removes those constraints. You can run thousands of variations, repeatably and safely, long before a physical prototype exists.

As for Euro NCAP, there's already a strong precedent set there. Earlier this year Euro NCAP stated accepting validated virtual testing data as a scored part of its crash-avoidance assessment. The same principle of simulating at scale, and then verifying a subset physically, is exactly what in-cabin development needs. For now, the monitoring systems themselves are still assessed physically with human subjects, but Euro NCAP's Vision 2030 roadmap points clearly towards more virtual testing and tougher performance requirements later this decade.

So virtual testing is the next logical step. Over time, as the correlation between simulation and physical results becomes as well established for the interior as it has for the exterior, I'd expect recognized, validated simulation to take on a formal role here too. Our AV elevate IN CABIN package ships with the base Euro NCAP scenarios predefined, so teams can begin testing against the latest protocols straight away.

How is the future of in-cabin systems shaping up?

Compliance is definitely the immediate driver. As with ADAS though, in-cabin systems will be the stepping-stone technology to an autonomous future. Understanding who is in the cabin, where the occupants are and what they are doing, knowing they are safe before starting the drive, are all going to be essential for automated driving.

But it isn’t just safety that benefits from these systems. If you know precisely where occupants are and how they are positioned, you can optimize noise-cancelling audio, for example or lighting to improve the passenger’s comfort.

As vehicles become more software-defined and more autonomous, the cabin effectively becomes a sensing environment in its own right, every bit as important as the world outside the car. The manufacturers and suppliers that build genuine confidence in simulating that environment now will be the ones best placed to exploit it later.

CONTACTS

The Americas
+1 877 863 1306

Europe, Middle East & Africa
+44 20 7176 1234

Asia-Pacific
+852 2533 3565

www.mobilityglobal.com