seeingmachines

November 2026

Technical Paper

From transport to worlds beyond: Human factors remains a cornerstone for optimising human-machine collaboration

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Acknowledgements

Our achievements are only possible due to the quality people that have and continue to work across all areas of Seeing Machines.

With regard to the human factors focus of this paper, special thanks for the wisdom and healthy debates with fellow human factors experts, past and present: Jonny Kuo, Shiyan Yang, Kyle Wilson, Trey Roady, Megan Mulhall, Georgia Tuckwell, Angus McKerral, Xuanying Zhu and Brook Shiferaw. Thanks also to our extended team, our research partners, who remain core to our journey thus far. Acknowledgments also to JT Griffin for supporting our research translation into policy positions and actions in the United States.

While already acknowledged above as member of our human factors community, extra special thanks to Brook Shiferaw for great support in preparing this paper.

Finally, thanks to Pearl Ansley from marketing for helping make this content shine.

Introduction

"It is not the most intellectual of the species that survives; it is not the strongest that survives; but the species that survives is the one that is able best to adapt and adjust to the changing environment in which it finds itself."

This famous quote represents Leon Megginson's paraphrasing of a core concept in Darwin's *On the Origin of Species*[1]. It applies equally to corporate evolution as companies seek to adapt business models over time to keep at the forefront and competitive in their given market. It also applies to Seeing Machines.

In the early 2010s, Seeing Machines began a significant evolution, recognising the potential for eye-tracking technology to develop into world-class human state monitoring technology.

The first signs of opportunity were emerging in our core market of transport as the automotive industry increasingly focused on driver support systems and hands-free driving features. Driver monitoring was just beginning to gain recognition as a critical safety measure. Several leading automotive manufacturers were beginning to explore the potential to address long-standing contributors to road crashes and injuries including driver distraction and drowsiness.

In 2014, before the introduction of global safety regulations and ahead of Seeing Machines' first successful automotive award with household name General Motors for its Super Cruise® system, we launched our world-leading human factors capability. This marked a pivotal moment for the business, transforming how we viewed the global landscape and, ultimately, shaping the development philosophy behind our technology.

This paper considers the contributions that human factors has made to the interior sensing solutions and highlights how these same philosophies and approaches will guide us into future market opportunities.



Human factors provides the scientific understanding of people that enables Seeing Machines to develop and validate human-centred technology.

Peer-reviewed publication extends the value of that science beyond the product by strengthening the evidence base supporting technology and brand credibility.

It provides scientific evidence to inform practice across the wider industry, regulatory and policy ecosystem.

Realising the benefits to technology development and industry implementation

As a discipline, human factors seeks to optimise human performance by taking into account human abilities and limitations, the tasks people undertake and the environments in which they perform them[2]. In transport this equates to understanding human performance in the context of operating a vehicle within a given road environment and vehicle configuration, and using that knowledge to design vehicle systems, interfaces and operating conditions that support the human operator.

Over the last decade this approach has taken us deep into the world of human factors research and its application, beginning with an in-depth understanding of the problems to solve and the science underpinning operator state. States such as drowsiness and distraction are not simply computer-vision problems, the behaviours observable by a camera are indicators of underlying human states and must be interpreted within appropriate scientific frameworks. Working with universities around the world we have conducted in-depth data collection studies to understand how driver state can be characterised and the associated impairment profiles.

Understanding human state is not simply a computer-vision problem.

Our initial areas of focus included drowsiness and distraction with both being common human experiences. As humans we all get tired, our ability to concentrate fluctuates and our capacity to respond to the world around us is not always consistent. Our attention is also constantly shifting between competing demands, sometimes deliberately and at times without our awareness[3]. Other factors, such as alcohol, certain medications, or illness, can further compromise our cognitive capabilities that are essential for safe operation of a vehicle[4,5]. Through a decade of direct investigation into these very human conditions, in both controlled and naturalistic settings, we have built an internal capability and evidence base providing the data that drives our technology development for real-world solutions[6,7]. These data inform both internal product specifications and industry-level policy centred on the adoption of driver monitoring system (DMS) solutions[3,8]. Furthermore, such continued research engagement with our global network of expert collaborators keeps us at the forefront of innovation in the field.

While a challenge in its own right, understanding human state related to distraction and impairment is only part of the challenge. Human performance emerges through the interaction between people, technology, and the environment in which we operate. In the context of surface transport, the immediate relevant element of the road system is the vehicle functionality. As vehicle systems become more capable, the nature of human performance challenges shifts from purely human abilities and limitations to the interaction between human and machine. For example, the presence of assisted driving functions significantly changes the driving task, impacting driver state and performance[9–11]. In such circumstances, expectancy mismatch, where the human expectations of the machine (vehicle) and its actions do not align, is a key point of failure in the human-machine interaction[12]. Expectancy mismatch can significantly break the human-machine collaboration, and it can take days or weeks to rebuild trust in the automation.

As illustrated in Table 1, we have also examined how other elements of the driving task, and non-driving related activities, affect performance and how this relates to risk[3,9,13,14]. We have conceptualised how perceived and real risk shape the integration of interior and exterior sensing technologies[15]. We have also explored how a range of environmental factors such as operating time of day and the dynamic driving context, including speed and headway, shape driver alertness and attentional demands[16–18].

Managing these interactions requires careful consideration of how information, intent, and control are exchanged between human and machine. The design of the interface between human and machine therefore has a significant impact on the achievement of both human and system goals. Effective interface design can help foster appropriate trust, support understanding of system capabilities and limitations, and reduce the likelihood of expectancy mismatch[19,20]. Leveraging artificial intelligence (AI) to unlock new forms of human-machine collaboration is particularly promising, an avenue we have pursued in both research and practice[21,22]. Beyond the vehicle itself, these interactions occur within a broader transport ecosystem. Humans and vehicles operate within road networks governed by infrastructure, regulations, and social expectations, while vehicle technology continues to evolve in ways that seek to improve both safety and the overall road user experience[8,23].

Table 1: Summary of the two-way interactions between human state and the broader technology and environment. All material presented here has impacted the design and implementation of our technology and product.

Human → Technology **Deep understanding of human behaviour has informed aspects of our technology design and implementation**	Technology → Human **Understanding how technology and environment influence human behaviour**
• Provided foundational real-world evidence for a statistical relationship between ocular metrics from our technology and subsequent driving impairment[24]. • Characterised how driver's age modulates subjective awareness of drowsiness, physiological drowsiness and crash risk on a test track during sleep deprivation[25,26]. • Characterised real-world distraction, showing that lizard type glance strategies are common and that head-only tracking misses a substantial share of distraction[3,27]. • Modelled peripheral vision on the road, showing that gaze fixation alone is an incomplete measure of what a driver perceives[13]. • Demonstrated that moderate alcohol intake results in objective functional impairment towards the descending phase of the BAC curve[28]. • Demonstrated that automotive-grade DMS can effectively predict alcohol impairment, with models involving ocular features outperforming driving data-only models[29], and ocular metrics correlating with established metrics of vehicle control/driving impairment[30].	• Demonstrated that real-time fatigue alerts result in a 66% reduction in fatigue events, increasing to a 95% reduction when coupled with customer feedback via the Guardian service[7]. • Demonstrated how distraction changes glance behaviour and take-over performance in assisted driving, with eyes-off-road being more detrimental than hands-off-wheel[9]. • Demonstrated that engaging in non-driving tasks changes drivers' workload, responses and glance patterns in different assisted and automated driving environments[10,31,32]. • Demonstrated that understanding ocular metrics and physiology provides a direct link to measuring workload and safety outcomes during assisted driving[33-36]. • Showed that head-up displays for non-driving tasks can improve take-over response and reduce workload[37,38]. • Developed concepts that represent how subjective and objective risk can be captured in interior-exterior fusion applications[15]. • Developed novel LLM-based conversational agent for supporting driver vigilance during passive fatigue[21]. • Developed novel concept of using vestibular cues to reorient driver attention away from a distraction task toward the roadway[19].

We exist to make a positive impact for our customers, and the community and industry more broadly. The increasing global recognition of driver-state monitoring as a critical transport safety measure, being the "seatbelt of our current time", has reinforced the value of this approach[39].

Growing regulatory and policy requirements for DMS across the world, together with the deployment of our systems in more than 10 million vehicles worldwide (at the time of publication), suggests that the decision to establish and continue to invest in human factors capability during the mid-2010s was transformational.

We continue our drive to improve safety for our customers while extending our engagement with policy and regulatory groups to support the sensible widespread implementation of DMS around the world. Our scientific research into human state has been translated into evidence that has shaped Euro NCAP's monitoring requirements, framing capability by detection difficulty and behavioural complexity and illustrating how technology performance translates to safety coverage at an industry level[8,40]. Our research has quantified how often Euro NCAP-defined distraction behaviours occur in naturalistic driving, providing unique insights into the expected alerting rates for DMS design and test protocols and confidence that the intended safety benefits can be achieved[27]. Adherence to the 2026 protocol could cut road injuries by approaching 30% and is highly cost-effective[41].

We have submitted similar research to the NHTSA to support policy advancements in the United States[42], proposing a roadmap for the implementation of in-vehicle solutions for impaired driving[43].

We also seek to leverage our science and real-world experience to shape global and local vehicle safety regulations, particularly engaging in the definitions of the safety states to be covered and the application to vehicle classes including heavy vehicles[23,44,45].

Fundamentally, our approach has been human-centred while recognising that people operate within broader technical, environmental, and social systems. It is this human factors and systems perspective that has helped enable our successful transition from eye tracking to state monitoring. This perspective has enabled us to translate scientific understanding of human behaviour into practical solutions for safety-critical, real-world environments, while also contributing to the field through applied research, peer reviewed publications and policy engagement.

The human and systems focus has, and will continue, to underpin how we think about designing solutions that add positive value to the human experience and outcome.

It is critical to recognise that there are many elements of Seeing Machines' technology that contribute to our world-leading position. Our patent portfolio for example reflects our longstanding and deep IP centred on fundamental elements of eye tracking and driver monitoring, and notably, the application of optical science to support successful technology deployment in highly variable real-world environments.

Same humans, new machines: Applying our technology to robotics

Today we see new opportunities to evolve. The advancements in AI are enabling new autonomous and robotic capabilities that afford transformational new ways in which humans and machines can collaborate.

Compared to human-machine collaboration where the human is operating a vehicle, the scope of human-machine collaboration in applications such as robotics are limitless. Within the road transport system there are countless ways that system elements can interact to influence human performance and goal achievement. The human factors challenges and opportunities within the robotics field are even greater.

A robotics system has much broader scope, encompassing a wider range of possible teamwork dynamics with an exponentially greater performance envelope. Further, the system is much more variable from its embodiment to the broad scope of environments, behaviours, actions and possible outcomes involved. Noteworthy is that our ability to influence the design of the system in robotics appears greater than for transport.

The human factors capability, expertise, and evidence base accumulated over the past decade provides a natural foundation for Seeing Machines to expand into developing human-centred solutions for robotics.

While new applications such as robotics are emerging, the human factors approach to understanding human state and designing for positive human-machine collaboration remain the same. The underlying challenge remains remarkably consistent: understanding how people and increasingly capable machines interact with one another, and how those interactions shape performance, safety and experience within the broader system. Humans must still perceive, interpret, predict, trust, coordinate with and adapt to the machines around them. Equally, the success of the overall system depends not only on the capabilities of the technology itself, but on how effectively people and machines work together to achieve shared goals.

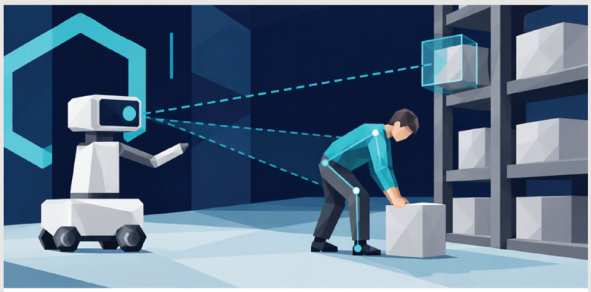
Figure 1 provides an illustration of where our existing human factors research can be directly applied to new robotic applications. In many respects, the importance of human factors and systems perspective may be even greater for robotics.

Robotics represents a new frontier and, as with any period of technological change, we must continue to evolve and adapt. Part of this evolution involves expanding the range of human behaviours and states we can observe, study and understand. Our recently introduced Human Mesh Recovery capability provides an important step in this direction, extending our ability to examine whole-body movement, posture and physical behaviour[46]. This opens new opportunities for human factors research into how people interact with their surroundings, respond to changing conditions and coordinate their actions with robotic systems. Such insights can, in turn, inform the design and evaluation of more effective human-centred robotic solutions.

The machines are more varied, the use cases more diverse, the environments less constrained, and the opportunities to create a positive impact significantly greater. Yet, in many ways, the more things change, the more they remain the same.

Our philosophy has always been to place people at the centre of the systems we design. Whether supporting drivers interacting with vehicles or workers collaborating with robots, the objective remains consistent: applying an understanding of human behaviour and performance to create safer, more effective and more positive outcomes.





SAME PEOPLE,

NEW MACHINES

Understanding the human in the vehicle

Human states and behaviour studied

- Drowsiness, microsleeps and time-of-day effects
- What a person has and has not perceived
- Alcohol and cannabis impairment
- Peripheral vision, attention and take-over readiness
- Trust and expectancy mismatch with assisted driving

Outcome: production driver monitoring, peer-reviewed evidence, and input into global policy and regulatory requirements

Helping robots understand the human world

Enabling capabilities for robots

- Where a person's attention is directed
- What a person has, and has not, perceived
- How people and objects are likely to move next
- Whole-body posture and movement (Human Mesh Recovery)
- The roles, routines and expectations of the setting

Outcome: competence enablement, turning robotic capability into safety, productivity and positive experience across the wider system

THE FOUNDATION

Human factors science that carries across domains

- Defining safety-relevant human states
- Generating valid behavioural ground truth
- Interpreting behaviour in its sociotechnical context
- Sensing people robustly, in real time, on embedded hardware
- Validating against meaningful safety and performance outcomes
- Designing effective human–machine interaction

Figure 1: Over a decade of human factors science on the vehicle occupant (left) is the foundation for giving robots an understanding of people within the spaces and context they come to share (right).

Key takeaway

Human factors delivers the peer-reviewed evidence base to: develop technology that collaborates effectively with people; provide confidence to customers, partners and investors; and translate into regulatory and policy positions around the world.

Human factors research is a strategic scientific capability within Seeing Machines. Its contribution extends beyond supporting the technical development of driver and occupant monitoring systems. As illustrated in Table 1 (and Figure 2, layer 1), it provides the scientific framework for defining safety-relevant human states, generating valid behavioural ground truth, interpreting behaviour in context, validating technology against meaningful safety and efficiency outcomes, and designing effective human-machine interaction.

This scientific capability also has broader strategic value. Peer-reviewed publications are key to converting research into publicly accessible evidence that connect technology and product performance with credibility and ecosystem influence. It provides a mechanism for subjecting methods, measures and findings to independent scientific scrutiny. In turn, this supports the credibility of Seeing Machines' technology and its Human-Centred AI philosophy with customers, industry stakeholders and investors (Figure 2, layer 2). It also creates a scientific evidence base that informs wider industry, standards, regulatory and policy discussions (Figure 2, layer 3).

From the building blocks of our core technology to the outer layers shaping end user experience, our design philosophy has always been human-centred. Driven by human factors principles, the human focus is by definition considered within a sociotechnical systems lens - a lens that acknowledges the large number of elements that interact within a system and that contribute to the success of the design solution.

This approach is further evidenced by our core competencies that enable safe and robust sensing of humans, accurate spatial representations, context-aware state estimations and reasoning architectures that enhance both safety and experience. These capabilities are further strengthened by innovations that enable them to operate efficiently and reliably in real time on embedded hardware.

This philosophy has shaped our evolution over the past decade and will continue to guide us as we expand into the world of robotics and beyond. More detailed concepts will be discussed in forthcoming technical papers in our robotics technical paper series.

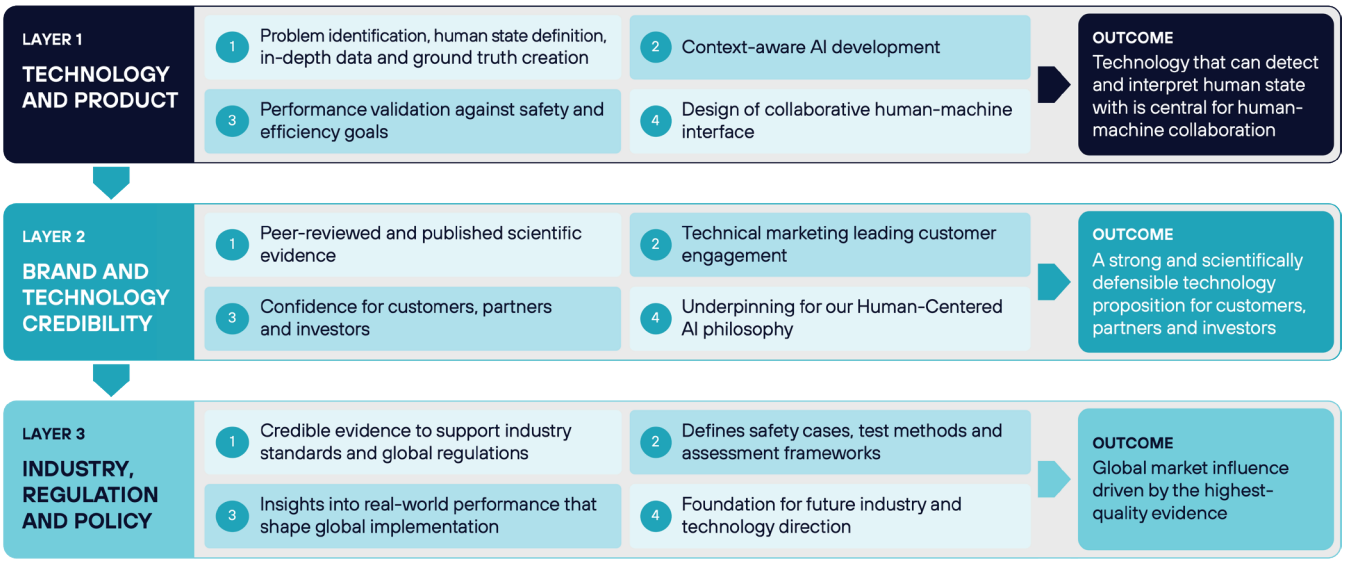


Figure 2: Summary of our strategic implementation of human factors and its contribution to technology, credibility and global influence.

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