SAFETY USE CASE ANALYSIS AND LIKELY BENEFITS OF DMS: EXAMINATION OF DRIVER STATES AND SCENARIOS UNDER THE EURO NCAP 2026 DRIVER ENGAGEMENT PROTOCOL.

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ABSTRACT

Driver drowsiness and distraction are significant risk factors for crashes. To address this EuroNCAP expanded its *Driver Engagement Protocol,* effective 1 January 2026. Manufacturers are encouraged to implement solutions aimed at reducing the incidence of these behaviours. The *Protocol* demands that once these behaviours are detected, drivers are warned and the vehicle intervenes by increasing the sensitivity of forward collision systems and lane keeping systems, and if required to take over the vehicle to bring it to a safe stop. The aim of this paper was to examine the proportion of crashes this *Protocol* could impact and to estimate the likely cost-effectiveness of the driver monitoring system required.

Real-world crash data was used to establish the proportion of serious injury crashes that the risk factors targeted by EuroNCAP were seen. Administrative data, cost of injury values, and the unit cost of fitting driver monitoring systems (DMS) into new vehicles was used to calculate benefit cost ratios (BCRs) for implementation.

Distraction targeted in the EuroNCAP *Protocol* was a common contributing factor to crashes (21.6%; mobile phone use: 3.8%) as was drowsy driving (25.4%; fell asleep: 7.9%), alcohol (11.2%) and drug impairment (12.7%), and sudden medical events (10%). The BCRs demonstrated implementation of the *Protocol* underpinned by DMS would be highly cost effective. Sensitivity analysis across effectiveness levels and implementation costs showed the findings to be robust.

The findings highlight the significant safety potential and cost-effectiveness of DMS in addressing behaviours specified in the EuroNCAP *Driver Engagement Protocol*. Further work is needed before assessing the likely efficacy of the *Protocol* in addressing alcohol and drug intoxication. Limitations include that estimates of the efficacy of the interventions were used. Nonetheless, the analysis demonstrates that significant reductions in road trauma can be achieved by implementation of the *Protocol* with this being highly cost-effective.

Keywords: Driver Monitoring Systems, driver state, inattention, distraction, drowsiness, sudden sickness, cost-effectiveness, Advanced Driver Assistance System, EuroNCAP, Regulation

INTRODUCTION

The road safety context

With 1.19 million people killed and more than 20 million people injured on the world's roads, road crashes continue to be a major public health concern [1]. Underpinned by *Vision Zero* [2], concerted global action has had positive results given that the previous WHO Global Status estimated that 1.35 million people were killed in 2016 [3]. In spite of this result, it remains the case that more than half of these deaths are vulnerable road users (i.e., cyclists, pedestrians, motorcyclists) and 92% occur in low- and middle-income countries [1]. In the European Union, 20,400 people were killed in 2023, 40,901 people were killed in the United States [4] and 1,266 in Australia [5]. In addition to these deaths, thousands more are seriously injured [1].

Research points to the interaction between the safety of vehicles (i.e., crashworthiness; *Safe Vehicles),* road design including speed limit setting (*Safe Roads),* and driver factors (*Safe Drivers)* in determining the level of safety of the road transport system, and hence the number of crashes that occur [6-9].

Improved vehicle safety has been a key priority in addressing the number and severity of road crashes. This has had positive results, with the strength of safety requirements being a key determinant of these improved safety outcomes [10, 11].

Noting the role of vehicle regulations in setting a minimum safety standard for vehicles, the *European New Car Assessment Program* (EuroNCAP) has played a pivotal role in lifting the safety standards of vehicles since 1997 when EuroNCAP was established [12]. With an initial focus on passive safety (i.e., occupant protection), the advent of Advanced Driver Assistance Systems (ADAS) has seen a broader focus in the assessment of vehicles that includes active safety. This combined approach enables threats to safe driving to be addressed, facilitates crash avoidance, ensures improved occupant protection when crashes occur, and enables rapid emergency response [13, 14]. This approach to addressing each crash phase was formalised in EuroNCAPs *Vision 2030* statement [13].

Distraction, drowsiness and acute medical events as key road safety risks

Driver drowsiness and driver distraction, including the use of mobile phones whilst driving, have been consistently shown to be significant contributing factors in crashes, as has driver drowsiness and the occurrence of sudden medical events that render drivers unresponsive.

For instance, using naturalistic data from the 100-car study Klauer et al [15] found that 80% of crashes involved visual inattention with mobile phone use was the most frequent secondary task being undertaken leading up to the crash. Similar results were seen in an Australian Naturalistic Driving Study [16], with drivers engaging in a secondary task every 96 seconds; mobile phone use was common with drivers handling the phone for approximately 30 seconds and whilst rare the average call length whilst handling a phone was 6.6 minutes. Recent analysis of this dataset showed age differences in driver behaviour, with novice drivers (17-18 years) spending over half of their driving time engaged in non-driving tasks (58.4%) compared to 45.3% for experienced drivers (25-62 years); moreover, these novice drivers initiated a non-driving task every 1.8 minutes in contrast to every 3.1 minutes for experienced drivers [17]. Analysis clearly demonstrates the increased crash risk associated with engagement in secondary tasks whilst driving, with the duration of glances away from the road being a potent predictor of crash risk [18-20].

Driver drowsiness has also been shown to be common and to be associated with increased risk [21, 22]. For example, Teft [21] reported a dose-dependent relationship with hours of sleep and crash risk. Relative to driver sleeping 7-9 hours per night, drivers reporting 6 hours of sleep had a 30% increase in the odds of being culpable for a crash, whilst for drivers with 4 hours of sleep this was 2.9 times higher, or a 190% increase in the odds of being culpable for a crash. A similar relationship has been demonstrated with measures of sleepiness and crash risk, including the Karolinska Sleepiness Scale (KSS) [23-25]. Research from the 39 country ESRA consortium shows that drowsy driving is common, with 18.4% of European respondents across 22 countries stating that they had driven when they were so sleepy that they had trouble keeping their eyes open, with this being 18.6% and 20.6% of drivers in the Americas (8 countries) and in Asia-Oceania (6 countries) respectively [26]; of note, talking on a hand-held mobile phone was self-reported by 22.2%, 30.5% and 27.6% of these respondents [26].

Finally, acute medical events that precede crashes are seen to occur with specific medical conditions seen to be associated with increased crash risk [27]. In a 2010 US study that used the National Motor Vehicle Crash Causation Survey (NMVCCS) medical events were seen in 1.3% of crashes; these included seizures, blackouts, or complications associated with diabetes [28]. Among 1,984 road users hospitalised in South Australia between 2014 – 2019, 5.6% of cases were directly caused by a medical condition or acute medical event, including loss of consciousness, seizures, cardiac events, and hypoglycaemic events [29].

These behaviours and crash factors — distraction, mobile phone use, drowsiness, medical events — were also seen to be direct contributing factors in a study of serious injury crashes conducted by the authors of this paper [6, 14, 30]. That data is used in the analysis reported in this paper.

Addressing key contributing factors for crashes: European New Car Assessment Programme (EuroNCAP) *Driver Engagement Protocol*

Recognising the importance of driver drowsiness, distraction (including phone use), and acute medical conditions as contributing factors to serious injury crashes, EuroNCAP have introduced assessment criteria for driver engagement. This requires fitment of driver state monitoring systems (DSM) and in-cabin monitoring systems into the 2026 test *Protocol*s. Under the 2026 EuroNCAP assessment *Protocol*s, the fitment of DMS technology is required for vehicles to attain a 5-star EuroNCAP safety rating [31]. This assessment *Protocol* commenced on 1 January 2026.

Sitting within the *Safe Driving* phase — the other phases being *Crash Avoidance, Crash Protection, Post-Crash* [13, 32] — Driver Monitoring contributes 25 of a possible 100 points within the part of the driving phase under EuroNCAPs Vision 2030 rating scheme [13]. Points are awarded based on warning and intervention (forward support FCW, AEB] sensitivity, and lane support sensitivity [LDW, ELK]) across all target behaviours. Intervention termination conditions are either time-based for transient states, end-of-journey or end-of-state for non-transient states, or a driver response where a driver was assessed as being unresponsive.

Transient distractions are targeted, including long and short distractions plus use of a mobile phone. These *visual-based* secondary tasks act to temporarily reduce the drivers capacity to focus on the driving task.

Non-transient driver states are also targeted. EuroNCAP have defined this as:

> '...A state that partially or fully reduces the driver's capability to maintain focus and properly perform the driving task and that cannot be reversed without appropriate recovery time outside of the driving session – includes impairment (build up or get into vehicle that way); microsleep; sleep – unconsciousness due to fatigue; and unresponsive driver'. [31, p.2]

Table 1 details the driver states and associated behaviours targeted in the *Safe Driving Driver Engagement Protocol* [31]. To score points in Driver Monitoring the following general requirements apply:

- The DSM is operational by default at the commencement of each trip and cannot be deactivated, nor can the system be adjusted.
- The DSM continuously monitors driver state.
- Warning and/or intervention are as follows:
  - Distraction, microsleep, sleep and unresponsive driver states –
    - Warn and/or intervene at forward speed of at least 20 km/h.
    - Lane support intervenes at lowest operational speed.
  - Impairment states:
    - Warn and/or intervene at forward speed of at least 50 km/h, noting a learning period of up to 10 minutes when the vehicle is travelling 50 km/h or more is permitted.
- To prevent system overreliance, and where a vehicle is fitted with an *assisted driving system* (standard, option), the Driver Monitoring *and* the Driving Collaboration score must be a minimum of 50%.
- System performance must be reported in accordance with the EuroNCAP technical dossier [33].

The assessment requirements are detailed and complex (see below). High levels of accuracy are required, coupled with low false alarm rates. To meet the assessment criteria forward-facing cameras are required, providing a direct assessment of driver state. Tracking head position and eye movements are essential. Indirect assessments, such as those based in steering angle adjustments, is insufficient to meet the demands of the *Protocol.*

Vehicle response: Issuance of warnings: For points to be scored when any of the driver states described above are detected (Table 1), a warning and/or intervention is required. Warning requirements for transient distraction states consist of a visual plus audible and/or haptic warning must be given when the vehicle is travelling ≥ 20 km/h; these warnings can be suppressed after the first warning where the vehicle response intervention of forward support plus/minus lane support is available. For a pass (hence points) to be awarded, all gaze patterns within each *movement type* must be covered (Table 1).

Likewise, for the non-transient microsleeps, sleep, and the unresponsive driver states, these same warnings apply; the provision of rest stops in the vehicle's navigation system is a permitted warning. Warnings must escalate depending on the scenario. For the non-transient impairment states, no warnings apply.

Vehicle response: Forward Collision Warning / AEB and Lane Support (LDW/ELK): For detected transient and non-transient states, increased sensitivity of the forward support and lane support sensitivity applies, both being *required for non-transient states*. For microsleep and sleep driver states, Assisted Mode is an eligible intervention, this being a combination of Adaptive Cruise Control (ACC) and Lane Centering (LC), and for unresponsive drivers (sudden sickness, extreme fatigue), the vehicles *emergency function* is applicable (also for microsleep, sleep), ending only with a driver response. In such instances, the emergency function controls the vehicle by decelerating to a safe stop (i.e., lane, slower lane, hard shoulder, emergency area) or to a speed of < 10 km/h and maintaining headway and its lane position.

For transient states, the driver returning their gaze for 1s to 2s to the forward driving area depending on the target behaviour. For non-transient states, the system response reverts to normal sensitivity either once the trip ends or the end of that assessed driver state is determined, but only if the DSM includes microsleep and sleep detection.

The vehicle response must be effective at ≥ 20 km/h for detected states, or ≥ 50 km/h for impairment states. Points are awarded based on system response.

Table 1.

EuroNCAP transient and non-transient driver state targets, associated behaviours and interventions [31, 33]

Distraction Type	Glance Target Type	Movement Type	Glance target	Warning, Forward Support, Lane Support (sensitivity)
Driver State: Transient (15 points)				
Long Distraction (5 points) (3-4 s. away from road, preceded by confirmed 4 s. on-road gaze)	Non-Driving Task	Owl	Driver side window; passenger side window; passenger footwell; passenger face; In-vehicle infotainment (IVI) system display	Assessed
		Lizard	IVI display; glovebox	Assessed
		Body Lean	Passenger footwell; rear passenger	Assessed
	Driving Task	Owl	Rear mirror; passenger side mirror; driver side mirror	Assessed
		Lizard	Instrument Cluster; driver side mirror; rear mirror	Assessed
Short Distraction / Visual Attention Time Sharing (VATS) (5 points) (sum of glances, ≥ 10 s in 30 s period)	Driving Task	Owl	Rear mirror; passenger side mirror; driver side mirror	Assessed
		Lizard	Instrument cluster; driver side mirror; rear mirror	Assessed
	Away from road – single target (non-driving)	Owl	IVI display; passenger side window; passenger footwell	Assessed
		Lizard	Driver side window; IVI display; passenger footwell	Assessed
	Away from road – multi target (non-driving)	Lizard	Any	Assessed
Phone Use (5 points) [subset of VATS] (gaze toward phone)	Basic	Owl	Driver side knee, passenger side knee, driver lap; driver side dashboard; OEM charging dock	Assessed
		Lizard	As above + upper wheel rim; centre steering wheel	Assessed
	Advanced	Lizard	Held at on-road; held at instrument cluster; mounted at on-road	Assessed
Driver State: Non-transient (10 points)				
Impairment (4 points)		Drowsiness (2 points)	Assessed as KSS>7, functional from 50 km/h	Assessed
		Non-fatigue (2 points)	Alcohol and/or drug impairment (unrelated to fatigue); assessment commences in first 10 minutes of the trip.	Assessed
Microsleep (2 points)			1-2 s. eye closure	Assessed
Sleep (2 points)			Continuous eye closure	Assessed
Unresponsive driver (2 points) – likely due to onset of sudden sickness or extreme fatigue.			Defined as when gaze does not return to forward view within 3 seconds after distraction warning or when eye closed for ≥ 6 seconds. Note: earlier timings can be used.	Assessed

Notes: definitions - Owl type movement: a shift of visual attention away from the road and forward-facing position that is primarily achieved by head rotation followed by the eyes. Lizard type movement: a movement in which the driver focuses on a task by moving primarily their eyeline away from the road with their head/face remaining in the forward-facing position [31]. KSS: Karolinska Sleepiness Scale, '8' equates to 8, 'sleepy, some effort to keep awake*'* [24].

System performance requirement: The EuroNCAP *Driver Engagement Protocol* [31] sets assessment criteria based on test scenarios and true positive rates (average across subjects and glance targets) and false alerts (per hour, average across driving hours). System performance is assessed across a range of conditions including driver height, sex, age, complexion, eyelid aperture, ambient light, eye wear, facial hair, makeup, hand position, facial occlusion (i.e., mask, hat), and secondary behaviours (e.g., eating, talking, laughing, singing, smoking/vaping, eye scratching, sneezing). Assessments are done across test drives ranging from 1800 minutes to 6000 minutes that can include on-road driving and/or validation in a driving simulator [33]. From year 2026, to achieve a 5-star rating validation will need be done on EU public roads with more than 2000 km of driving being required.

Precis: In short, the EuroNCAP *Driver Engagement Protocol* targets distraction with phone use being a special case, and non-transient states of impairment due to drowsiness or alcohol/drugs. Additionally, microsleeps, sleep, and unresponsive driver due to either extreme fatigue or a medical event are targeted behaviours. The above detail is useful as it highlights two things: 1) the wide-ranging assessment criteria for the principal targets of distraction, drowsiness, unresponsive drivers, and alcohol/drug impairment, and 2) that the vehicle's ADAS systems play a key intervention role by acting to facilitate the resumption of safe driving as well as acting in a crash avoidance capacity as needed. This is important as the efficacy of the Driver Monitoring in real-world driving is in part due to the driver's response when the warning(s) is given.

Having discussed the NCAP which is the basis for the analysis presented in this paper, it is useful to understand the broader regulatory environment concerning driver monitoring systems as they relate to driver drowsiness and distraction. It is worth noting that the EuroNCAP *Driver Engagement Protocol* is more expansive than the implemented EU regulations, however the latter apply to all vehicle types and are mandatory.

Regulatory context

Within the EU, mandatory vehicle technology requirements have been put in place to address non-transient driver drowsiness and transient distractions. At a high level, the requirements for the fitment of a Driver Drowsiness and Attention Warning (DDAW) system and the Advanced Driver Distraction Warning (ADDW) were set out in the EU General Safety Regulation, referred to a GSR-2 (EU 2019/2144) [34]. GSR-2 entered into force on 27 November 2019 and became mandatory in all EU Member States on 6 July 2022. The included safety requirements outlined in GSR-2 were to apply to Category M (passenger vehicles, cars buses) and Category N vehicles (light commercials, medium & heavy goods vehicles). Additional regulations, referred to as *Delegated Regulations* specific to DDAW and ADDW that outlined the technical requirements with each technology, and the implementation timeline were then passed.

The purpose of the DDAW system is to assess the driver's alertness and warn the driver as required. The technical requirements for the DDAW are set out in *EU Delegated Regulation 2021/1341* [35]. The *Regulation* applied to new types of Category M and Category N vehicles from July 6, 2022, and to all new vehicles from July 7, 2024.

The DDAW is designed to monitor a drivers level of drowsiness and provide warnings when the driver is assessed to meet a level of drowsiness equivalent to a rating of 8, '*sleepy, some effort to keep awake*' on the Karolinska Sleepiness Scale (KSS) [24]. Manufacturers can elect to provide a warning when the DDAW detects a level of drowsiness equivalent to a rating of 7, '*sleepy, no effort to keep awake*' on the KSS. The DDAW system is to be active at a speed of 70 km/h and then operate from 65 km/h and higher once active. Direct (camera-based) and indirect (steering, other inputs) can be used in this assessment, noting that the performance requirements favour camera-based systems given inputs include directly measured head position and eye movement patterns and responses. Vehicle indicators that improve the accuracy of the drowsiness assessment are encouraged, including for instance a) reduction in steering micro-corrections paired with an increase in large and fast corrections, and b) increased variability of lateral lane position of the vehicle; additional secondary measures (e.g., physiologic) may also be used. Visual warnings (steady or flashing; tell-tale, pop-up message) and an auditory (50–90 dB) warning (that may include speech) must be provided. Warnings are permitted to cascade and intensify with drivers required to acknowledge the warnings with the strategy and means to do so to be determined by manufacturers. Drivers can manually deactivate the warnings — although this is reset upon vehicle ignition — but not the DDAW system itself.

Advanced Driver Distraction Warning (ADDW) was also mandated for Category M and Category N vehicle under GSR-2 [34]. The ADDW is focused on driver attention with the implemented system needing to warn the driver when they are distracted. The technical requirements for the ADDW are set out in *EU Delegated Regulation 2023/2590* [35]; this applies to all vehicles registered for the first time ('new vehicle types') from 7 July 2024 and from 7 July 2026 for all new vehicles.

Interior-facing camera-based AI systems that assess head position, face, and eyes are required as ADDW systems are required to monitor the direction of the drivers gaze, with the trigger behaviour for a distraction episode being when the drivers gaze is downward (directly down / lap, toward left, toward right; i.e., eyes-off-road) and fixed in that direction for a maximum time of 3.5 seconds when the vehicle is travelling at or above 50 km/h, or when the vehicle speed is at or above 20 km/h for a maximum time of 6 seconds. Visual warnings (steady or flashing; tell-tale, pop-up message) plus an auditory (50–90 dB) and/or haptic warning (e.g., seat vibration, seatbelt tightening) must be provided; these are to escalate until the driver's attention is redirected to the driving task (i.e., looks up and re-attends to the roadway). Vehicle manufacturers can elect to implement ADDW trigger speeds to be lower than those specified and can implement additional warning strategies to aid the driver, factoring in prior warnings, road and weather conditions, among others. Compliance test requirements are also set out in the *EU Delegated Regulation 2023/2590* [36].

For completeness, we note that there has been significant work undertaken toward the development of a UN Regulation by the Driver Drowsiness and Distraction Warning Systems (DDADWS) Informal Working Group (IWG) on General Safety Provisions (GRSG) under the WP.29 process [37]. At the time of writing this paper, a Proposal [dated 18 December 2025] to establish a new UN Regulation No. [182] on Driver Drowsiness and Attention Warning system is to be considered for approval at the World Forum for Harmonization of Vehicle Regulations 198th session to be held in Geneva from 10–13 March 2026; this is aligned with the *EU Delegated Regulation 2021/1341* driver drowsiness and attention warning system [38]. Further work is being carried by this IWG.

Further, the People's Republic of China implemented the *Driver Attention Monitoring System (DAMS)* performance requirements and test methods (GB/T 41797-2022), effective from 1 May 2023. Real-time monitoring of eye closure, abnormal head pose (tilt, rapid movement), answering and making phone calls, and monitoring yawning or smoking behaviour. Prompt warning requirements are specified [39].

Effectiveness of warnings and interventions in addressing targeted behaviours

Whilst both the EuroNCAP and the EU regulations require visual warnings plus an auditory and/or haptic warning, the EuroNCAP demands Advanced Driver Assistance System (ADAS) functionality. This combination of warnings and interventions is likely to demonstrate greater efficacy in addressing the target behaviours than warnings alone.

Single modality warnings have low efficacy, with Fitzharris et al [40] suggesting that 20% or fewer drivers would respond appropriately to a simple *Attention Assist* warning. Systems that use escalating warnings across multiple modalities are seen to be a better solution and whilst short escalating warnings are preferred by drivers and seen to be more effective than long escalating warnings [41], quantification of these benefits in real-world driving is challenging.

In a recent study of 373 light commercial vehicle drivers in Ireland over 22 months (~ 1 million trips) [42], warnings reduced distraction events by more than 50% in half of the involved drivers, with lesser reductions seen in other drivers, although the authors stated that there was little effect on mobile phone use and fatigued driving. Reductions were seen safety critical scenarios as opposed to habitual behaviours.

In relation to drowsiness, research involving a sample of heavy vehicle drivers within commercial fleets reported a 66% reduction fatigue events due to the provision of in-cabin warnings alone, with this increasing to a 95% reduction with real-time feedback added [43].

A highly controlled field trial of 21 drivers conducted in Australia reported significant reductions in the occurrence of fatigue events associated with warning alarms (-55%) as well as reductions in hard braking (-48%) and other benefits [44]. This study assessed drivers with alarms on and off for a period of 4 weeks, with 2,734 unique drives with an average duration of 38 minutes examined. The authors also highlighted that 52% of drivers had an improved recognition of fatigue, 90% better equipped to handle fatigue, 81% felt the alarms were not annoying, and all drivers reported that the alarms did not interfere with their work. Improvements in KSS scores were also seen.

Studies have demonstrated the efficacy of ADAS systems including AEB linked with FCW [45] and ELK linked with LDW, and the safety benefits of ACC [46] There is robust evidence of the efficacy of these technologies, with Tan et al. providing a review of key studies [47]

For example, Cicchino [45] reported a 56% reduction in front-to-rear injury crashes due to FCW and AEB combined, with FCW alone providing only a 20% reduction and AEB alone providing a 45% reduction in injury crashes. In a separate analysis, Cicchino [48] reported a 30% reduction in pedestrian-involved crashes due to AEB, although no effects were seen at night, for turning vehicles, and at speeds greater than 50 mph. Focussed on crashes of all severities and including data from multiple countries, Fildes et al [49] reported a 38% reduction in rear-end crashes associated with AEB. Using SHRP-2 data, Seacrist et al [50] reported an 80% benefit reduction in front-to-rear impact crashes due to AEB. For Lane Keep Assist, Riexinger et al [51] reported a 50% reduction in road departure crashes whilst Flannagan et al [52] reported a 30% reduction in lane departure crashes.

To the authors knowledge there is no information available on the efficacy of emergency function where the vehicle assumes control for reasons of safety in the event of an unresponsive driver, nor the Assisted Mode technology that combined ACC with Lane Centering implemented to address microsleep and sleep episodes. While real-world evaluations of these technologies would be invaluable, conducting such studies is likely to be complex given the nature of the target behaviours involved and their relatively rare occurrence.

As it is not possible to determine the combined efficacy of the warnings and intervention approaches specified in the EuroNCAP *Driver Engagement Protocol*, based on the research examining the efficacy of warnings alone and technology interventions, some estimates of the likely benefit of the multi-faceted warning plus intervention approach can be made. Field trials are however necessary and ought to be an urgent priority so that the real-world benefits can be fully understood.

The present study

With the release of EuroNCAPs *Driver Engagement Protocol* in March 2025 for implementation in January 2026, this paper seeks to quantify the proportion of serious injury (including fatality) passenger vehicle (M1) and light commercial vehicle (N1) crashes to which Driver Monitoring is applicable, with specific emphasis on driver drowsiness, distraction, and mobile phone use. In doing so, we seek to estimate the likely cost-effectiveness of implementation of driver monitoring technology in passenger vehicles.

METHODS

Risk factor Data

Data from the Monash University Enhanced Crash Investigation Study (ECIS) program were used to establish the proportion of hospitalisation (injury) crashes where distraction, mobile phone use, drowsiness, acute medical events, and impairment due to alcohol and drug intoxication were direct contributing factors to the crash.

The ECIS program was an in-depth crash investigation study of 393 serious injury crashes. Crashes included were those where a driver of a passenger vehicle was injured and admitted to one of two adult trauma centres in Melbourne, Australia (i.e., The Alfred Hospital; The Royal Melbourne Hospital). Injured drivers, or their Next-of-Kin for the most seriously injured drivers, were required to give informed consent for participation in the study. The study was approved by The Alfred Hospital Research Ethics Committee (HREC, Project: 249-14), The Royal Melbourne Hospital HREC (Project: 249-14), and the Monash University HREC (CF14/2329-2014001254).

In total, 400 injured drivers were enrolled to the study (67% consent rate). Enrolled drivers were aged 18 – 93 years, 55% were male, and 37% of crashes occurred in non-metropolitan, regional areas of Victoria. These drivers were involved in 393 crashes, with two drivers injured in 7 crashes enrolled to the study. In total, these crashes involved 923 people, 18 of which died (in 17 crashes) and 547 people were hospitalised.

Comprehensive details of the crash were obtained. This included interviews with the involved driver, medical records, police reports, inspection of the vehicle, inspection of the scene and full crash reconstruction. Injuries were coded using the Abbreviated Injury Scale [25], with ‘serious injury’ being defined as a driver having sustained an AIS 3 or higher injury, referred to as MAIS 3+; injured drivers are referred to as MAIS 1+ injured drivers [53]. The reader is referred to ECIS Reports 1,2,3, and 4 for detail [6,14,30,44].

Contributing factors were assessed using a case-by-case Safe System Failure Analysis (SSFA) approach. As part of this currently available and future technology countermeasures, including DMS linked to ADAS, were identified [14, 44].

For this analysis, data was weighted to hospitalised populations of persons injured in crashes. Sample frequency weights were based on 6,654 TAC hospitalised claimants using MAIS 1, MAIS 2, MAIS 3+, crash location (urb/rural), road geometry (intersection /midblock), number of vehicles involved (single, multiple) and speed zone (below 80 km/h, ≥80 km/h SAV/MVA. This weighting was as done to ensure that the sample statistics were representative of the broader crash population for passenger (M1) and light commercial vehicles (N1).

Population-based crash data

Police reported crashes for the State of Victoria, Australia, were used in the analysis. Publicly available data for the 2023-2024 calendar year was used. Data is validated with ‘serious injury’ relating to injured persons admitted to hospital following a crash [54]. The data was used to 1) enumerate the relevant crash problem, and 2) to determine the age of vehicles involved in crashes; these represent inputs to future crash estimates and vehicle turnover rates, the latter being needed to model penetration of new technologies into the fleet which includes vehicles meeting the 2026 EuroNCAP *Driver Engagement Protocol*. Estimates will be based on the year commencing 2026. A 25-year implementation period will be modelled as past work indicates it takes 25 years for 99% of the passenger car and light commercial fleet to be fully replenished in Victoria, Australia [59].

In the 2023 – 2024 period, there were 9,548 crashes that resulted in at least one road user being admitted to hospital following a crash. These crashes resulted in 579 persons killed, 10,409 persons admitted to hospital, 2391 sustaining minor injuries, and 8,590 were not injured. The combined number of persons killed and injured was 10,988 in these two calendar years (ratio to crashes: 1.15). The ratio of persons hospitalised to the number of crashes was 1.09:1. There were 16,440 vehicles involved in these crashes (ratio: 0.63 serious injury per vehicle involved) (FSI/vehicle ratio: 0.668). These crashes involved at least one category M1 or N1 vehicle.

Using mean values, per annum numbers are as follows: hospitalisation crashes = 4729; killed road users = 263; persons sustaining serious injury / admitted to hospital = 5,204; persons sustaining minor injury = 1,195, persons involved but not injured: 4,295; fatality + serious injury = 5,494. The annual number of persons admitted to hospital is the key metric here.

Population (persons) data

To establish current and future population estimates, population data from the Australian Bureau of Statistics for the State of Victoria was used [55, 56]. For future population projects, the medium series was used.

Vehicle registration data

The number of registered passenger cars and light commercial vehicles was obtained from the Australian Bureau of Transportation Economics (BITRE) [57]. This data was used to establish vehicle ownership rates per 100,000 persons. This data was used to project the future number of vehicles in the fleet together with the population projection data.

Vehicles per person (registration and population data)

Across the 2023 to 2024 calendar years, there was an average of 5,456,523 million persons in Victoria aged 18 years and older. In this same period there was an average of 4,116,748 passenger vehicles and 886,830 light commercial vehicles registered in Victoria (total, 5,003,578 vehicles). Including all other vehicle types, there were 5,499,499 vehicles registered in Victoria in that period.

Limiting this to passenger vehicles and light commercial vehicles only, the ratio of vehicles to persons is 0.912.

Serious injury rate per registered vehicle

For future projections, we observe that the serious injury rate per registered vehicle is 0.001040056 (i.e., 5,204 persons hospitalised / 5,003578 category M and N vehicles registered)

Cost of injury

Cost of injury values used as follows:

- Based on earlier regulatory work [59, 60] and using the Reserve Bank of Australia (RBA) inflation calculator [61], the cost of a serious injury is AUD $1,104,483; for 2026 this is taken to be AUD $1,143,139 (USD $762,832; €649,458). Minor injury is valued at AUD $40,487 (2025) and AUD $41,094 (USD $27,422; €23,347) in 2026 dollars. Cost of injury values are willingness-to-pay estimates and include all aspects of emergency care, costs to the individual, and to society.

It is noted that Australia's preferred inflation band is 2% - 3% per annum, with 12-month inflation at end December 2025 being 3.8% [62]. It is assumed that inflation will continue at 3.5%, on average, over the forward estimates.

Driver Monitoring system cost

The estimated range for DMS system cost is USD $55-75 across the 2025-2031 time period [63, 64]. This is based on projected market volumes and costs from market analysts for DMS, with DMS defined as vision (camera) based. This represents the total system cost for fitment to the vehicle. Integration with other ADAS systems is estimated to be USD $3 per unit and a $1 USD regulatory compliance per vehicle cost is added (total USD $ 59 – 79 per vehicle). Converted to $AUD, these total costs (including integration and compliance unit cost) are AUD $88.10 - AUD $ 117.95. For the purposes of the BCR analysis and forward projections these are taken to be 2026 (+3.5% inflation) costs, these being: AUD $91.18 – AUD $122.12. An average system implementation cost is AUD $106.65.

Applying these values to the current M1 (passenger vehicle) and N1 (light commercial) vehicle fleet, if all vehicles were fitted with the Driver Monitoring system as specified, the total fitment and implementation cost would be AUD $ 533.631.594 (range: AUD $ 456,226,242 - $611,036,945) in 2025 values.

Benefit-cost analysis

A simple full fleet implementation BCR analysis was conducted; this gives an indication of immediate benefits if all vehicles in the current fleet had the Driver Monitoring Technology.

A 30-year implementation BCR analysis was also conducted, this being the time it takes for the entire vehicle fleet to turn over, and hence for new vehicles fitted with the Driver Monitoring technology to fully penetrate the fleet. It is only once this occurs that full benefits realisation is achieved. Benefits and Costs accrue over time, and the pool of applicable crashes expands annually with the increased number of vehicles with the technology fitted. This approach follows past work completed for vehicle regulations [59] and adopts the principles of the Australian Government Office of Best Practice Regulation [65]. For the purposes of the analysis and future projections a 7% discount rate is used.

EuroNCAP *Driver Engagement Protocol* effectiveness warning and intervention effectiveness

The efficacy of warnings alone provided to drivers to address distraction and drowsiness ranged from 50-66%. Depending on the crash type and specific technology, effectiveness estimates range from 30% to 80% reductions in targeted crash types.

As there are no field trials of the combined warnings plus the FCW/AEB and LDW/ELK interventions – nor of *Emergency Function* or *Assisted Mode (ACC+LC)*, it is challenging to determine an effectiveness estimate.

Having said this and based on available evidence in relation to warning systems and the ADAS systems, a **70%** effectiveness value is used across all targeted behaviours. This higher effectiveness value assumes the driver will intervene in most cases to mitigate the identified risk and correct their behaviour and the vehicle ADAS will ensure their safety a) in the time they take to do so, and b) act to mitigate the consequences of any crash should it occur to a point the crash severity would be reduced from a hospitalisation crash to a minor injury (non-hospitalisation) or property damage only crash. A sensitivity analysis using 50% and 80% is also used.

For the purposes of the analysis, it is assumed that all new vehicles entering the fleet will meet the full requirements of the *Driver Engagement Protocol* from 2026.

We note that warnings do not apply for alcohol or drug affected drivers with only the ADAS interventions being applicable. Due to the lack of data on how well driver monitoring systems capture these behaviours these behaviours are not modelled in the analysis reported here. Of note, in the in-depth crash investigation data, the intoxicating effects of alcohol (11.2%) and illicit drugs (12.7%) were clear contributing factors for a subset of crashes; their exclusion here means that the results would be under-estimates assuming DMS implementation can capture these behaviours accurately.

Additionally, the analysis does not consider sudden sickness due to acute medical conditions, again, due to a lack of information regarding the efficacy of the *Emergency Function* and the *Assist Mode* in either crash prevention or injury mitigation.

RESULTS

Analysis of in-depth serious injury crash data (ECIS)

Table 2 presents the proportion of hospitalisation crashes in the ECIS in-depth crash investigation dataset where distraction, driver drowsiness, sudden medical events, and impairment due to the acute effects of alcohol and illicit drugs were a direct contributing factor to the crash. Unweighted and weighted data is presented; the latter being based on all hospitalised drivers in the study period. As more than one contributing factor could be determined for each crash, percent values where any of the contributing factors applied is presented. This is done in order to ensure benefits, if any, due to driver monitoring and the associated interventions are not double counted.

The definition of distraction used includes within vehicle distractions (e.g., looking rearwards, pets/animals, organising bags, etc...) distraction due to eating/drinking, passenger interactions, distraction due to the in-vehicle entertainment system and heating/air-conditioning functions, mobile phone use (direct handling), handling of other technologies. Distractions outside of the vehicle, including wayfinding excluded, as were distractions / inattention due to inward thoughts; these were excluded as the driver may still have been looking onto the forward roadway.

Using the definitions and data restrictions above, 42.5% (unweighted; weighted: 39.3%) of the hospitalised crashes involved either driver distraction or driver drowsiness. Individual contributing factors are also shown. The prevalence of these contributing factors is higher in the most seriously injured MAIS 3+ injury crashes. We also note that there are differences in the prevalence of these contributing factors across lane departure crashes, intersection crashes, and rear-impact crashes, however as the overall impact of the *Driver Engagement Protocol* is assessed here, these are not presented here.

Limiting the analysis to driver distraction (including mobile phone use) and drowsy driving (including falling asleep), the proportion of all hospitalisation crashes targeted by the *Driver Engagement Protocol* is 39.2%. As a matter of interest, this proportion lifts to 54% of all hospitalisation crashes when all targeted risk factors are included.

Table 2.

EuroNCAP Driver Monitoring targeted risk factors as contributing factors to serious injury crashes [6]

Contributing factor	**Unweighted**		**Weighted**	
	All (AIS 1+) (n = 393)	**AIS 3+ (n= 204)**	**All (AIS 1+) (n= 6,401)**	**AIS 3+ (n = 1,507)**
Distraction	21.6%	22.1%	20.6%	23.7%
Distraction – including phone use	17.8%	17.2%	17.6%	18.1%
Phone use	3.8%	4.9%	3.0%	5.6%
Drowsiness	25.4%	27.5%	22.5%	26.2%
Drowsy only	17.6%	18.6%	16.3%	18.3%
Drowsy – fell asleep	7.9%	8.8%	6.2%	7.9%
Medical event / sudden sickness – unresponsive	14.5%	15.7%	12.9%	14.9%
Alcohol (BAC)	11.2%	14.2%	9.3%	15.0%
Illicit drug (all types)	12.7%	16.2%	10.0%	15.3%
At least one targeted behaviour	57.8%	61.8%	54.0%	61.1%
Distraction + Drowsy only	42.5%	45.1%	39.3%	46.2%

Table 3.

Per annum cost of serious injury crashes associated with contributing factors

Contributing factor	**Unweighted**		**Weighted**	
	Proportion of crashes	**Injury cost (AUD $, bn)**	**Proportion of crashes**	**Injury cost (AUD $, bn)**
Distraction	21.6%	1.354	20.6%	1.291
Distraction – including phone use	17.8%	1.115	17.6%	1.103
Phone use	3.8%	0.238	3.0%	0.187
Drowsiness	25.4%	1.591	22.5%	1.409
Drowsy only	17.6%	1.103	16.3%	1.021
Drowsy – fell asleep	7.9%	0.495	6.2%	0.388
Medical event / sudden sickness – unresponsive	14.5%	0.908	12.9%	0.808
Alcohol (BAC)	11.2%	0.702	9.3%	0.583
Illicit drug (all types)	12.7%	0.796	10.0%	0.627
At least one targeted behaviour	57.8%	3.621	54.0%	3.383
Distraction + Drowsy only	42.5%	2.663	39.3%	2.462

Financial cost of serious injury crashes.

Based on the cost of injury estimates and using an average of the number of people admitted to hospital due to crashes (5,204), the overall cost of these crashes was AUD $5,747,729,532 (i.e. AUD $5.7 billion). Table 3 presents the cost of road trauma associated with the proportion of crashes where the contributing factors shown in Table 2 are present. These values indicate that cost of serious injury associated with driver distraction and drowsiness is AUD $2.462 billion per year (contributing factors weighted).

Simple BCR analysis: Distraction plus drowsiness

Using the data inputs below, Table 4 shows the estimated benefits in mitigating distraction and drowsy driving related serious injury crashes, with the BCR of 2.82 (2.02-3.32) being positive for a per vehicle implementation cost of AUD $106.65. The range of BCR values with lower and higher fleet implementation costs is shown.

- Number of serious injury crashes: 4,729 per annum.
- The proportion of crashes to which the *Driver Engagement Protocol* applies is given in Table 2. For distraction and drowsy driving crashes, this is taken to be 39.3% (i.e., applicable/sensitive crashes).
- Number of persons admitted to hospital per crash: 1.09:1 (ratio).
- Cost of injury values: Serious injury is $1,104,483; for minor injury this is $40,487 (2025 value).
- Mitigation or avoidance: it is assumed that the severity of crashes is mitigated, hence the cost of minor injury applies. This takes a conservative approach to BCR calculation.
- Efficacy of the EuroNCAP *Protocol* in addressing targeted behaviours: 70% (sensitivity: 50% to 80%).
- For the purposes of the BCR analysis and forward projections these are taken to be 2026 (+3.5% inflation) costs, these being: AUD $91.18 – AUD $122.12. An average system implementation cost is AUD $106.65. Implementation to M1 (passenger vehicle) and N1 (light commercial) vehicle fleets. Using the average cost, if all vehicles were fitted with the Driver Monitoring system as specified, the total fitment and implementation cost would be AUD $ 533.631.594 (range: AUD $ 456,226,242 - $611,036,945) in 2025 values. This is based on 5,003,578 Category M and Category N vehicle registrations.

Table 4.

Number of crashes, injury cost benefit, cost of Driver Monitoring Fitment, an BCR estimate

Base crashes	**% Risk factor targeted**	**Sensitive crashes / applicable**	**Efficacy**	**Crashes Mitigated**	**Involved persons no longer seriously injured (ratio)**	**Cost injury saving (AUD $ billion.) (+ minor injury)**	**Fitment cost into fleet (AUD $ billion.)**	**BCR**
Point estimate of Driver monitoring implementation cost (AUD $106.65 per vehicle)								
4,729	39.3%	1,858	0.7	1,301	1,418	$1.50880	$0.533631	2.82
4,729	39.3%	1,858	0.5	929	1,013	$1.07771	$0.533631	2.02
4,729	39.3%	1,858	0.8	1,486	1,621	$1.72434	$0.533631	3.23
Point estimate of Driver monitoring implementation cost (AUD $91.18 per vehicle)								
4,729	39.3%	1,858	0.7	1,301	1,418	$1.50880	$0.45623	3.31
4,729	39.3%	1,858	0.5	929	1,013	$1.07771	$0.45623	2.36
4,729	39.3%	1,858	0.8	1,486	1,621	$1.72434	$0.45623	3.78
Point estimate of Driver monitoring implementation cost (AUD $122.12 per vehicle)								
4,729	39.3%	1,858	0.7	1,301	1,418	$1.50880	$0.61104	2.47
4,729	39.3%	1,858	0.5	929	1,013	$1.07771	$0.61104	1.76
4,729	39.3%	1,858	0.8	1,486	1,621	$1.72434	$0.61104	2.82

Simple BCR analysis: Distraction only crashes

Table 5 presents the estimated benefits for distraction only crashes. Distraction behaviour akin to those targeted by the EuroNCAP *Driver Engagement Protocol* was seen in 20.6% of serious injury crashes (weighted data). Using the stated assumptions and the based number of serious injury crashes involving category M (passenger vehicle) and category N (light commercial vehicles), implementation remained cost effective (BCR: 1.48, range: 1.06-1.69) at a 70% effectiveness value (efficacy range: 50%, 80%) in mitigating or preventing the crash by the system warning the driver when distraction behaviour is identified **and** optimising ADAS vehicle systems.

Table 5.

Number of distraction crashes, injury cost benefit, cost of Driver Monitoring Fitment, an BCR estimate

Base crashes	**% Risk factor targeted**	**Sensitive crashes / applicable**	**Efficacy**	**Crashes Mitigated**	**Involved persons no longer seriously injured (ratio)**	**Cost injury saving (AUD $ billion.) (+ minor injury)**	**Fitment cost into fleet (AUD $ billion.)**	**BCR**
Point estimate of Driver monitoring implementation cost (AUD $106.65 per vehicle)								
4,729	20.6%	974	0.7	682	743	$0.82926	$0.533631	1.48
4,729	20.6%	974	0.5	531	531	$0.59233	$0.533631	1.06
4,729	20.6%	974	0.8	849	849	$0.94773	$0.533631	1.69

Simple BCR analysis: Drowsiness only crashes

Similar to above, Table 6 includes serious injury crashes where drowsiness was direct contributing factor for the crash (22.5%, weighted data). BCRs remained cost-effective with an estimated 745 serious injury crashes mitigated or avoided. Note: for the BCR analysis these are factored cost-wise as mitigated crashes in that they still occur, but it is assumed that those seriously injured sustain minor injuries due to reduced impact speed [66].

Table 6.

Number of distraction crashes, injury cost benefit, cost of Driver Monitoring Fitment, an BCR estimate

Base crashes	**% Risk factor targeted**	**Sensitive crashes / applicable**	**Efficacy**	**Crashes Mitigated**	**Involved persons no longer seriously injured (ratio)**	**Cost injury saving (AUD $ billion.) (+ minor injury)**	**Fitment cost into fleet (AUD $ billion.)**	**BCR**
Point estimate of Driver monitoring implementation cost (AUD $106.65 per vehicle)								
4,729	22.5%	1,064	0.7	745	812	$0.86381	$0.533631	1.62
4,729	22.5%	1,064	0.5	532	580	$0.61701	$0.533631	1.16
4,729	55.5%	1,064	0.8	851	928	$0.98722	$0.533631	1.85

Long run implementation: BCR analysis (complete fleet turnover of 30 years)

A full BCR implementation analysis was conducted given the 30-year turnover period for the fleet. The analysis considers new vehicle sales, expansion of the fleet with population growth, vehicle scrappage due to crashes. Estimates of future serious injury crashes are made given historical trends. It is assumed that all new vehicles will meet the *Driver Engagement Protocol* for the distraction and drowsy driving target behaviours, and effectiveness values are stated based on evaluation studies cited in the *Introduction.* Full benefits realisation takes time, and the pool of applicable serious injury crashes increases year-on-year until complete saturation of the fleet with the Driver Monitoring technology; this is true of all newly implemented vehicle countermeasures. It is important then to account for the progressive aggregation of benefits whilst applying implementation costs to all new vehicles entering the fleet.

Table 7 and Figure 1 present the benefit-cost-ratios (BCRs) for different per vehicle implementation costs for the target 39.3% of serious injury crashes where driver distraction and/or drowsiness was a direct contributing factor for the crash. These values apply to Category M (passenger vehicle) and Category N (light commercial) vehicles.

Given the stated scenarios and assumptions, the technology demanded by the EuroNCAP *Driver Engagement Protocol* will deliver significant road safety benefits is seen to be highly cost-effective. For the preferred unit cost of AUD $116.65 [USD $60.85; €51.80] and a 70% efficacy in addressing the target behaviours and mitigating crashes, the BCR was 21.8:1, highlighting significant savings to the community in terms of trauma reductions. Over a 30-year period it is estimated that 39,954 serious injury crashes will be prevented and/or mitigated. From a BCR perspective, it is assumed that these will be converted into minor injury crashes, however it is likely that most will be prevented altogether due to the intervention of the driver and the vehicle. The monetary savings are significant, estimated to be AUD $13 billion [USD $8.74 billion; €7.44 billion] over the 30-year implementation period, with the total cost outlay being AUD $ 0.59 billion [USD $0.39 billion; €0.33 billion].

The benefits and costs with other device implementation costs are shown.

Table 7.

BCR and associated crash and dollar values for specified Driver Monitoring unit cost (7% discount rate, 30-year period) for distraction and driver drowsiness (39.3% all serious injury crashes) at different effectiveness levels

Effectiveness (70%, 50%, 80%) Discount rate: 7%	**Implementation cost per vehicle (AUD $, 2026) [USD $; €]**		
	AUD $91.18 [USD $77.85; €66.27]	**AUD $116.65 [USD $60.85; €51.80]**	**AUD $ 122.12 [USD $81.50; €69.38]**
70% effectiveness			
BCR	27.9	**21.8**	20.85
Total estimated serious injured (30 years)	210,047	**210,047**	210,047
Number serious injury mitigated over 30 years	39,954	**39,954**	39,954
Discounted benefits % AUD $ billion)	$13.00253	**$13.00253**	$13.00253
Discounted implementation cost % AUD $ billion)	$0.46567	**$0.59574**	0.62368
Net benefits (AUD $, billion)	$12.5369	**$12.4068**	$12.3789
50% effectiveness			
BCR	19.94	**15.59**	14.89
Total estimated serious injured (30 years)	210,047	**210,047**	210,047
Number serious injury mitigated over 30 years	28,539	**28,539**	28,539
Discounted benefits % AUD $ billion)	$9.28752	**$9.28752**	$9.28752
Discounted implementation cost % AUD $ billion)	$0.46567	**$0.59574**	0.62368
Net benefits (AUD $, billion)	$8,8219	**$8,6918**	$8.6638
80% effectiveness			
BCR	31.91	**29.94**	23.83
Total estimated serious injured (30 years)	210,047	**210,047**	210,047
Number serious injury mitigated over 30 years	45,662	**45,662**	45,662
Discounted benefits % AUD $ billion)	$14,86004	**$14,86004**	$14,86004
Discounted implementation cost % AUD $ billion)	$0.46567	**$0.59574**	0.62368
Net benefits (AUD $, billion)	$14.3944	**$14.2643**	$14.2364

Figure 1 provides BCR values for a range of Driver Monitoring per vehicle implementation costs. A high implementation cost was added, this being double the upper band cost used in the analysis. This chart provides further insight into potential benefits in addressing distraction and drowsiness crashes through the EuroNCAP *Driver Engagement Protocol*. This gives confidence in the implementation of the technology as even at a low level of effectiveness and higher implementation cost, the BCR remains positive. For instance, at 10% effectiveness level and an implementation cost of AUD $244 (USD$ 163.00; € 138.76) the BCR was 1.49:1.

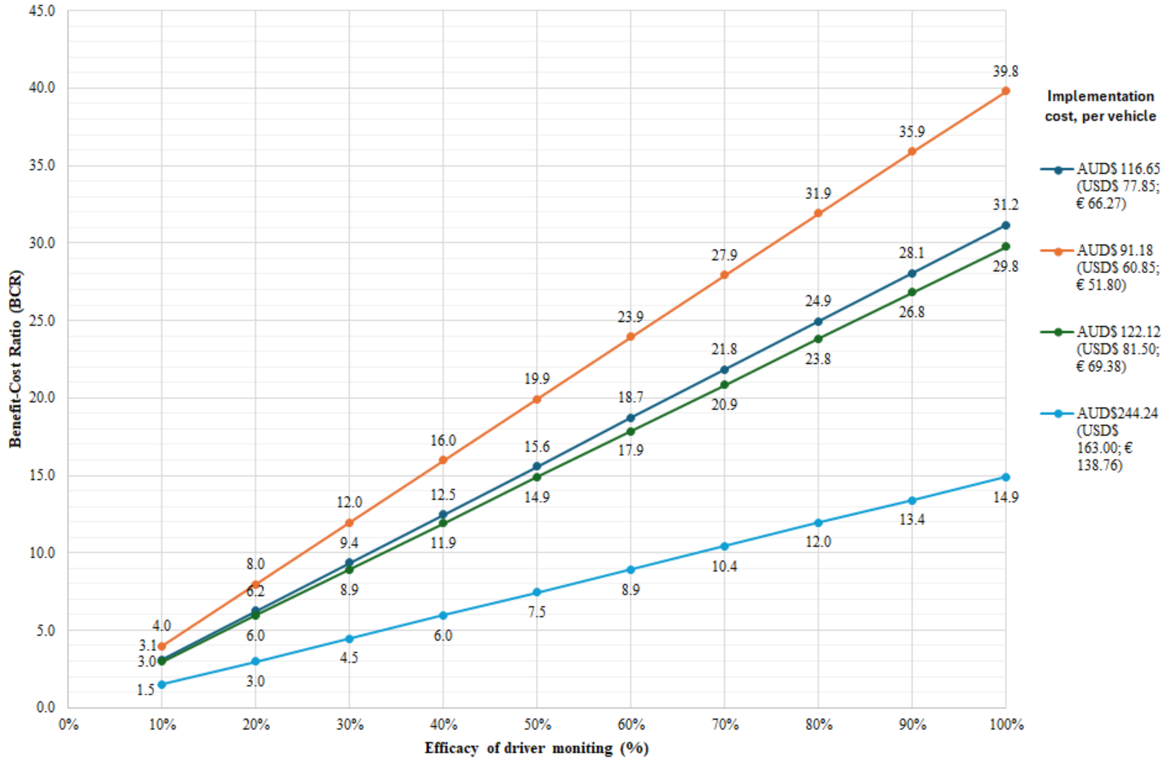

Figure 1.

BCR values for four different implementation costs and full range of Driver Monitoring efficacy in addressing driver drowsiness and distraction seen in 39.3% of serious injury hospitalisation crashes (weighted) using a 7% discount rate over a 30-year implementation period)

DISCUSSION

Driver drowsiness and driver distraction are widely recognized key risk factors for crashes. Indeed, the data presented here shows that these two factors were direct contributing factors in 40% of hospitalisation crashes. This is consistent with research elsewhere. Past research has also demonstrated that the provision of multi-modal warnings that target driver distraction, including mobile phone use, and driver drowsiness are effective countermeasures, as are crash mitigation/avoidance ADAS technologies. Driver monitoring technology represents a significant opportunity to assess driver behaviours in real-time, bringing with it new safety countermeasure opportunities. Indeed, Fitzharris et al [14] highlighted the opportunity to integrate real-time driver monitoring technology with vehicle ADAS and chassis control systems to prevent and/or mitigate serious injury crashes across a range of scenarios.

Being at the forefront of safety innovation, EuroNCAP have implemented their *Driving Monitoring Protocol*, effective 1 January 2026, targeting key behavioural and driver risk factors that are prominent in serious injury and fatality crashes. It is expected that manufacturers will seek to develop and implement the warning and intervention systems that improve the safety of consumers and all road users.

Whilst the EuroNCAP *Driver Engagement Protocol* is expansive in that it seeks to address distraction, drowsiness, impairment due to alcohol and drugs, as well as unresponsive drivers due to acute medical emergencies, the analysis reported here focussed only on the likely benefits of the *Protocol* in addressing driver distraction and driver drowsiness. With significant reductions in the number of drivers and road users seriously injured as a result of these two key behaviours being addressed, the findings of the analysis reported here are very positive. Using two different BCR calculation approaches, the first being immediate fleet penetration and the second being a 30-year-full fleet penetration scenario, the financial savings relative to the implementation costs are significant. Stress testing of the BCRs using the full range of effectiveness values and low to very high implementation costs shows the benefits to be robust.

A key issue is the effectiveness of the Driver Monitoring technology in issuing warnings quickly and effectively, in addition to drivers responding appropriately. The assumption here is that both will, with warnings issued and responses implemented in a timely manner so as to mitigate the crash risk and promote a return to *Safe Driving* [30, 32]. That the EuroNCAP *Protocol* increases the sensitivity of the FCW/AEB and LDW/ELK ADAS technologies is important, this providing an important safeguard in the event of non-response of drivers [67]. Nonetheless, these technologies are not 100% effective 100% of the time in preventing crashes but do demonstrate an important crash mitigation effect when the time-to-collision is inadequate (i.e., too short) [66].

Despite the effectiveness of both escalating multi-modal warnings in generating a driver response and the effectiveness of ADAS crash avoidance technologies, it is likely that a subset of drivers will either ignore or be incapable of responding appropriately. It can be suggested that the number of crashes – and hence seriously injured persons – mitigated could as easily be prevented, however we assume for the sake of the BCRs these crashes will continue to occur but would not require hospitalization; the effect is however marginal on the overall benefit.

The analysis presented here demonstrates the magnitude of gains to be made by addressing driver distraction and driver drowsiness. The analysis focussed exclusively on serious injury hospitalisation crashes where driver distraction and drowsiness were direct contributing factors, excluding crashes where acute medical events occurred as well as crashes where drivers were impaired due to alcohol or drugs. These risk factors were excluded as not yet known how well the interventions outlined in the *Driver Engagement Protocol* will address these behaviours. The analysis also did not include fatality crashes, minor injury, and property-damage only crashes. It is likely then that the findings reported here are conservative. With more data on these crash types, risk factors, and some evidence of the efficacy of driver monitoring systems – and hence the *Driver Engagement Protocol* – addressing these risk factors, potential benefits could be estimated in the future. Field studies to assess the real-world benefit of the *Driver Engagement Protocol* is recommended.

Limitations

There are a number of assumptions and limitations that need to be considered when interpreting the findings presented in this paper. Whilst the in-depth crash investigation data was extensive the sample size was relatively small; hence, the estimates of risk factors in terms of the proportion of crashes where present reflect the sample. Whilst the application of the sampling weights overcomes sample bias, it remains the case that the proportion of serious injury crashes where the risk factors are present best reflects the State of Victoria, Australia. In the attribution of contributing factors, each crash was examined in extensive detail and while these are robust, they may be subject to error. For a full exposition of the limitations of the ECIS program and impacts on interpretation, the reader is referred to available reports [61 14, 30, 44]. Crash sample differences may lead to different BCR estimates.

A number of other assumptions were made in the analysis, including the effectiveness of the warnings and vehicle-based intervention in preventing and mitigating crashes. In addition, the estimates of the penetration of vehicles meeting the EuroNCAP Driver Monitoring requirements were made. It was also assumed that future vehicle ownership would reflect the recent past; given the reliance on the vehicle for travel in Australia this estimate is on face value robust. We note that cost of injury and cost of meeting the EuroNCAP *Protocol* are current estimates, these being based on the best available information at the time the analysis was conducted.

CONCLUSIONS

The analysis in this paper indicates that by manufacturers meeting the requirements of EuroNCAPs *Driver Engagement Protocol* significant reductions in road trauma will be achieved. Moreover, based on the estimates reported here, the implementation of the safety systems specified by EuroNCAPs is highly cost-effective. Further work that disaggregates these benefits into targeted behaviours and specific crash types may be of value, particularly as validated on-road estimates of the efficacy of the warning plus ADAS interventions in addressing target behaviours become available. Noting the limitations of the study, research that evaluates the real-world impact on driving acceptance, behaviour and safety delivered by the implementation of driver monitoring systems linked to ADAS systems is recommended. Doing so will aid in the refinement of vehicle safety systems, extract maximum safety benefits, and point to new opportunities to reduce road trauma globally.

DISCLAIMER

Dr Mike Lenné is an employee of Seeing Machines and holds the role of Chief Safety Officer. Seeing Machines is an Australian-based company that develops and markets Driver Monitoring Systems into passenger and commercial vehicle settings. Dr Lenné provided background information used in the Introduction section of this paper; provided DMS cost estimates used in the BCR analysis and associated References; and was a Co-Investigator on the in-depth crash data study (2013-2022) used in this study. The economic assessment of DMS was conducted by the first author (Fitzharris), independent of Lenné; cost estimates were provided before the commencement of the analysis and writing of the paper.

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