ADAS IN YOUR POCKET – A REVIEW OF THE FEATURES, FUNCTIONS AND FUTURE OF SMARTPHONE-BASED ADVANCED DRIVER ASSISTANCE SYSTEMS

David Paine

Kylie Webber

Michael Paine

Vehicle Design and Research, Pty Ltd

Australia

Paper Number 23-0245

ABSTRACT

Advanced Driver Assistance Systems (ADAS) are technology systems that rely on a combination of sensors that scan the road environment to detect potentially hazardous situations and assist the driver to either avoid the hazard, or to reduce the severity of outcomes if a crash is unavoidable.
Recent developments in consumer-level smartphone technology have allowed third party software applications to make ADAS functionality accessible to millions of mobile phone users. By utilising the smartphone's hardware such as cameras, positioning sensors and processors, together with software-based object recognition and tracking algorithms, these applications purport to allow users to receive real time road hazard detection and warnings. These smartphone-based ADAS applications are compatible with many popular models of smartphone and offer ADAS functionality that includes Forward Collision Warning (FCW), Lane Departure Warning (LDW) and Intelligent Speed Assist (ISA).

ADAS related applications are identified and reviewed for claimed features and functionality. Applications with the most promising functionality are acquired for more detailed evaluations.

We review the features and functionality of selected ADAS applications using several different smartphone models. We report on the results of on-road performance evaluations that examine the effectiveness and limitations of these. We also explore potential road safety benefits for drivers whose vehicle is not equipped with ADAS, but who have a smartphone available when they drive.

The results confirm that ADAS applications are capable of vehicle detection/tracking, lane marking detection, road sign detection, speed zone detection and related warning functionality, however the performance between apps varied and issues such as false alerts, non-detections and incorrect detections were recorded.

While smartphone-based ADAS can provide reliable, and potentially useful road safety benefits to drivers, these potential benefits depend on a combination of the hardware capability of the smartphone, the sophistication of the application and, to a lesser extent, the correct set up of the smartphone in the vehicle. Furthermore, while smartphone-based ADAS has the potential to improve road safety, especially where OEM-fitted ADAS is not a feasible option, there are inherent limitations posed by current technology. Finally, subject to appropriate provisions in relevant regulations, the barriers to the adoption of smartphone-based ADAS appear low and the main barrier to adoption is that smartphone users are unaware that ADAS applications exist. We foresee that continued developments in smartphone hardware and processing capability, together with software evolution in ADAS applications, will continue to improve the reliability and effectiveness of smartphone-based ADAS in the future.

INTRODUCTION

Advanced Driver Assistance Systems (ADAS) are technology systems that rely on sensors that scan the road environment and monitor vehicle systems to detect potentially hazardous situations and assist the driver to either avoid the hazard, or to reduce the severity of outcomes if a crash is unavoidable. To date ADAS has mostly only been available as a feature on new vehicles, severely limiting widespread adoption across the global vehicle fleet.

Recent developments in consumer-level smartphone technology have allowed third party software applications (apps) to make ADAS functionality accessible to billions of mobile phone users globally. By utilising the smartphone's hardware such as cameras, positioning sensors and processors, together with software-based object recognition and tracking algorithms, ADAS apps purport to allow users to receive real time road hazard detection and warnings. These smartphone-based ADAS apps are compatible with many popular models of smartphone and offer advisory ADAS functionality that includes Forward Collision Warning (FCW), Following Distance Warning (FDW), Lane Departure Warning (LDW) and Intelligent Speed Assist (ISA).

We review the features and functionality of selected, publicly available, ADAS applications using several different smartphone models and report on the results of on-road performance evaluations that examine the effectiveness and limitations of these. We also explore potential road safety benefits for drivers whose vehicle is not equipped with ADAS, but who have a smartphone available when they drive.

This research is part of a multi-stage research project by the authors to examine the performance and potential of smartphone-based ADAS applications and represents the findings from the initial stage of the project.

STATE OF SMARTPHONE ADAS IN AUSTRALIA

There are numerous applications currently available on both Android and iPhone operating systems in Australia that purport to include ADAS features. Apps range in cost from free, to several dollars, with most of the apps evaluated in this research being available for free. App developers include local and overseas developers.

The types of advisory ADAS offered by smartphone applications include ISA (camera or GPS/Map based), FCW, FDW, top speed warning, LDW, traffic sign recognition, red light camera recognition and fatigue detection. In this initial study only features related to ISA, FCW, FDW, top speed warning and LDW were evaluated. Some applications also combined two or more ADAS types (see Table 1). This is particularly common for applications that use the smartphone camera/s for visual detection (e.g., lane markings, other vehicles/pedestrians and roadside signs). Other, non-ADAS features, such as dash cam functionality, navigation or red light/speed camera warnings were also present in some applications, alongside the ADAS features.

IDENTIFICATION AND SELECTION OF ADAS APPLICATIONS FOR EVALUATION

Applications for potential inclusion in the research were identified through searching the Google Play and Apple Store app stores using various search terms (e.g., 'ADAS', 'driver assistance', 'intelligent speed assist, 'forward collision warning', 'lane departure warning' 'crash prevention', 'crash safety', etc). Some apps identified through this search were already known to the authors from previous research [1]. In total 45 apps were identified as potential candidates from the search.

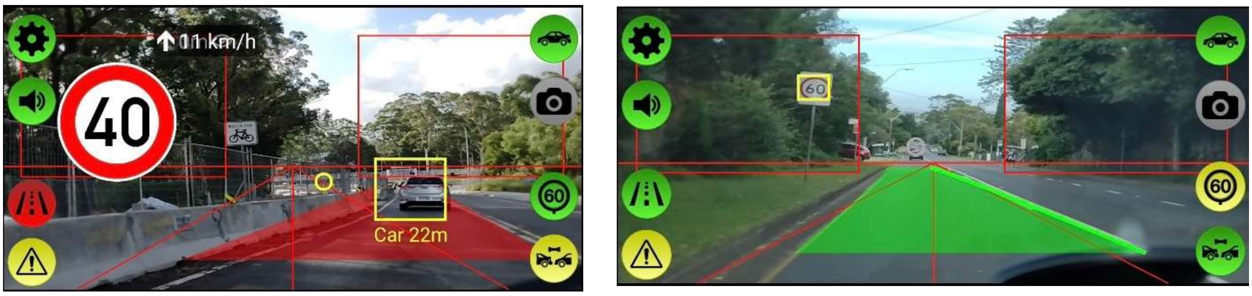
Information provided by developers about the app functionality was then reviewed and those which clearly claimed to have ADAS features/functionality were downloaded (to a compatible smartphone) and the basic functionality of the app was reviewed through limited on-road trials to confirm that the app features worked and to eliminate any apps that were not worth further testing. Some applications that purported to include ADAS functionality either did not provide ADAS features or the app was unusable (including applications that 'crashed' frequently) and these were excluded from the evaluations.

A total of 12 apps were shortlisted for the evaluations. Some apps were available for smartphones with both Android or iPhone operating systems while others were available for one operating system only. Since there is no driving automation offered by the ADAS apps (i.e., no braking or steering intervention) the apps evaluated in this research would be classified as SAE Level 0 on SAE's Levels of Driving Automation™ [2].

Table 1.
ADAS Applications Shortlisted for Evaluation

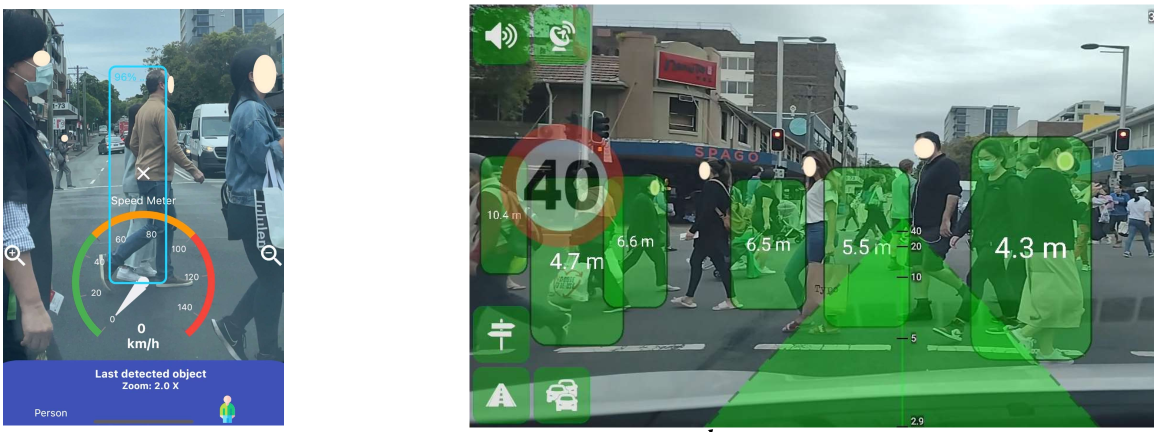
App (Developer)	ADAS features	OS platform
UGV Driver Assistant (INFOCOM LTD)	FCW, FDW, LDW, camera-based speed assist, other sign detection and warning (not evaluated)	Android and iPhone
aCoDriver (EvoTegra GmbH)	FCW, FDW, LDW, camera-based speed assist, lane departure warning	iPhone only
Roadscan AI (Samuel Souza)	FCW, LDW, red light detection (not evaluated), fatigue monitoring (not evaluated)	iPhone only
Speed Adviser (Transport for NSW)	GPS map based advisory ISA	Android and iPhone
Metroview (MetroView Systems)	GPS map based advisory ISA, manual set top speed warning	Android and iPhone
MobileSection (murbit GmbH)	Manual set top speed warning	iPhone only
Speedometer by HUDWAY (HUDWAY LLC)	Manual set top speed warning	iPhone only
Speedometer: GPS Tracker (POKET APPS, OOO)	Manual set top speed warning	iPhone only
Lane Identification Pro (Vembar LLC)	LDW	Android and iPhone
DriverAssistant (TheFrenchSoftware)	FCW, LDW	Android only
Car Assistant (FAA STUDIO)	ISA, other sign detection and warning (not evaluated)	Android only
LaneDetect+ (Hirofumi Cho)	LDW	iPhone only

Example ADAS applications
Each app provided onscreen ADAS information to the user during operation. Figures 1, 2, 4 & 5 below show actual smartphone screen captures taken while in operation during the evaluations. These images show the exact display provided to the driver during operation of the app.



a *b*

Figure 1 a & b. Screenshot from screen capture of aCoDriver App (Android). a) Speed zone reminder (40), LDW, FDW. b) Speed zone detection (60), Lane path OK, centerline detection.



a *b*

Figure 2 a & b. Pedestrian detection a) Roadscan AI (iPhone). b) UGV Driver Assistant (Android).

PERFORMANCE EVALUATIONS OF SMARTPHONE-BASED ADAS SYSTEMS AND KEY OBSERVATIONS

In-Vehicle Set Up

The smartphones were affixed to the vehicle using dashboard or windscreen-mounted cradles positioning the smartphone leftwards of the vehicle centreline (passenger side in Australia) towards the bottom edge of the windscreen. For camera-based applications the smartphone was orientated so that the leading edge of the vehicle bonnet and the LHS A pillar were at the edge of the camera field of view. Approximately the same position was used for all applications and all smartphone models, allowing for some variance due to camera field of view (for camera-based apps), smartphone size, and screen orientation (landscape or portrait) for the application.

OEM ADAS features fitted to the vehicle used for evaluation were disengaged during the evaluations to ensure that these did not conflict with the performance of the ADAS apps being evaluated.

Familiarisation with features and functions

An initial ‘test drive’ was undertaken by driving on a variety of roads in various traffic conditions (with a mix of vehicles) to better understand the application functionality including setting/adjusting any relevant settings, determining the set-up position, determining the limits of the app (i.e., vehicle types/sign types that the application did/did not detect) and familiarising with the types of warnings.

Further evaluations were undertaken by driving a variety of public roads (highway, suburban, urban) at various times and in various traffic conditions.

Method of evaluation

Operations of the apps and all recordings during the evaluations were undertaken by the front seat passenger, while the driver controlled the vehicle.

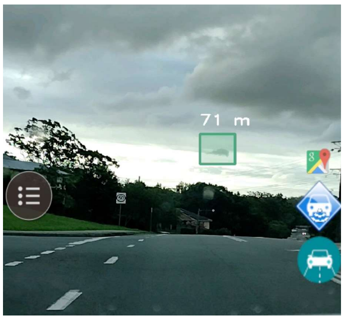
Evaluations were conducted on a variety of public roads, at various times during the day in a mixture of traffic. A mixture of urban, sub-urban and highway roads at all speed limits were included, as were variable speed zones such as time variable school zones, weather dependent zones and where different speed limits apply to different vehicle types.

To test the warning functionality in school zones for ISA apps the smartphone clock was adjusted to be within the time period when the time variable 'school zone' was active. This allowed the zone to be driven at 'normal' (i.e., higher) speeds legally while the smartphone believed that the lower (time dependent) speed zone was in effect.

Screen recording applications were used to capture each apps' behaviour during the evaluations. These captured whatever was displayed on the screen of the smartphone, including visual warnings, and also captured any audio warnings/notifications. The captured footage was reviewed to examine reliability and consistency of app functionality including where false warnings were issued and/or where non-detection conditions occurred.

Figure 3. Australian time dependent School Zone sign. 40km/h limit applies during listed times.

PERFORMANCE OBSERVATIONS



Performance varied greatly between apps providing ADAS features of the same type. Some apps provided consistent performance, reliably reacting to trigger conditions and providing the relevant notification/warning while others either had inconsistent detections (e.g., frequently missed detection conditions), provided false alerts or detected erroneous objects (i.e., misinterpreting signs, clouds and non-road infrastructure as potential hazards).

Figure 4. Screenshot from screen capture of Driver Assistant (Android) showing detection of a 'cloud' as a potential hazard.

Apps that performed well tended to perform well consistently across multiple phone models and different operating systems, whereas apps that did not perform well did so on all models and for all operating systems. Across different phone models and operating systems, the apps generally had the same functionality however it was noted that warnings sometimes differed (e.g., the tone of warning chimes, or the voice used for verbal warnings).

Performance observations for apps that offered Speed Assist features

In general, the applications offering ISA and top speed warnings features performed well with ISA systems identifying most speed zone changes reliably and warnings deploying when the trigger conditions had been reached. Exceptions to this were time-based school zones (common in Australia), and condition dependent speed zones such as weather dependent or vehicle type dependent speed zones. Electronic variable speed signs were also not detected by any app (as is the case with many OEM ISA systems in Australia).

It should be noted, however that both GPS/map-based ISA apps ('Speed Adviser', 'Metroview') provided consistently accurate results for 'fixed' speed zones, detecting almost all speed zone changes at the point of the speed zone change. Both of these apps also correctly detected time dependent school zones but did not detect other variable or temporary speed zones (e.g., condition dependent speed zones, electronic speed signs, temporary roadworks speed zones).

For camera-based ISA apps the 'UGV Driver Assistant' and 'aCoDriver' apps had good performance at detecting most speed signs, although in some cases signs behind other objects (trees, other large vehicles) were not detected. Both these apps detected temporary speed zones that the map-based ISA apps did not, however these also detected speed signs on the back of vehicles (see Figure 6 below) and could not correctly determine the applicable speed limit for school zones, weather dependant speed zones or vehicle dependant speed zones. However, for the 'Car Assistant' app the camera-based speed sign detection performed poorly with very inconsistent results in detection; signs were often missed, and where a speed sign was detected the value detected was often incorrect.

For apps with a top speed warning (‘Metroview’, ‘Mobile Section’, ‘Speedometer by HUDWAY’, ‘Speedometer: GPS Tracker’) these worked accurately and provided warnings when the set top speed warning threshold was reached, however it was noted that adjusting the top speed setting (where adjustable) for these was impractical for the driver to achieve while driving. It was further noted that several of these apps only allowed a few (or a single) top speed setting options.

Performance observations for apps that offered FCW and/or FDW features
Most apps with FCW and/or FDW consistently and reliably identified other vehicles in the camera’s field of vision, however not all apps detected vulnerable roads users such as pedestrians, cyclists or motorcyclists suggesting that some apps are not keeping pace with the detection capabilities of OEM FCW/FDW systems in Australia.

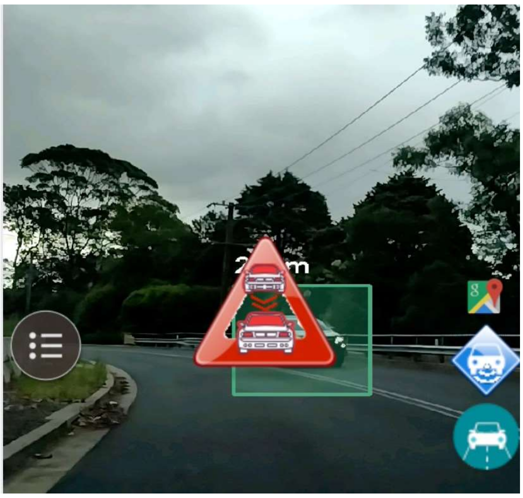


Figure 5. Screenshot from screen capture of Driver Assistant (Android) showing false FCW alert.

For the FCW/FDW apps ‘Roadscan AI’, ‘aCoDriver’ and ‘UGV Driver Assistant’ reliably detected other light vehicles (e.g., cars) and large vehicles (buses and trucks) and also pedestrians but only UGV appeared to identify motorcycles and bicycles as potential hazards.

FDW features showed distance estimates to surrounding vehicles and provided audio/visual warnings when the vehicle in front became too close (approx. 1 second gap). The distance estimates for surrounding vehicles were updated in real time and generally seemed to be accurate (comparative measurement was used to estimate accuracy) however both ‘Roadscan AI’ and ‘UGV Driver Assistant’ tended to struggle with long vehicles (e.g., truck trailer combinations) where the distance measurement would fluctuate along the length of the vehicle.

All FCW/FDW apps had instances of false warnings, either warning of impending collisions with a vehicle/pedestrian that was either too far away, or for oncoming traffic that was not on a collision trajectory. Similarly, some false warnings were provided for objects that were not vehicles/pedestrians and that did not pose a hazard. In particular the frequency of false alerts provided by the ‘Driver Assistance’ app made it impossible to assess its performance and evaluations were discontinued for this app.

Performance observations for apps that offered LDW features
None of the apps offering LDW provided consistent performance. While some apps provided warnings for lane change manoeuvres all apps offering LDW suffered from false alerts and path matching issues where the predicted road path did not match the actual road path. The severity of these issues varied however for some applications these were so frequent that further testing was abandoned. The performance offered by the LDW features were significantly inferior to the performance of modern OEM LDW systems in Australia.

Some apps had adjustable settings for LDW (e.g., lane width, horizon level, etc) and may have been sensitive to set up location and orientation. These will be investigated in further research, however if this is the case then additional guidance would need to be provided to the user to ensure that the systems are correctly set up (including positioning).

Comments about warnings and notifications
A variety of warnings were used including visual and audible. Audible warnings varied from chimes/beeps to spoken warnings. Visual warnings included the appearance of onscreen icons, colour changes for on screen icons or the screen background, flashing of onscreen icons or a combination of these. There was little consistency in warning types (either audible or visual) between the apps. Although performance of the warning type/s was not evaluated it was noted that in many apps the warnings were subtle with warning volumes quite low and/or visual warnings being so small they could be overlooked, or the user might experience difficulty interpreting the nature of the warning. Furthermore, for some applications with multiple ADAS functions, distinguishing between different warning types could be difficult since the same warning types were used for different ADAS functions, or the warning types were only subtly different.

Several apps were capable of muting/pausing other audio (radio, music streaming app) when connected to the vehicle (wirelessly or via USB connection) to eliminate some in-car noise that could obscure safety alerts and to emphasise warnings provided by the app.

Comments about adjusting app settings
Some apps required either or both detection types or warning types to be enabled since the default setting was 'off'. Where apps had variable settings (e.g., FCW distance, lane width, horizon line, top speed, etc), changing these often involved several steps to access a settings screen and it was often not clear which setting was relevant or which value/setting was suitable. In general, the apps also did not provide useful guidance for troubleshooting these types of issues or for selecting the appropriate settings. However, several apps required little, or no, settings adjustment and provided useful functionality with the default settings.

General limitations and issues of evaluated apps
Where electronic variable speed signs were present, or where variable speed zones existed (e.g., school zones, weather dependent speed zones, or speed zones that apply to certain vehicle types only) most apps with ISA functionality struggled. The exceptions were school zone performance for Speed Advisor and Metroview which both performed well in detecting the applicable speed limit at all times.

Map-based ISA systems are unable to adapt to temporary changes to physical signs such as where signage is temporarily changed, such as for road work speed zones. Although map-based ISA systems can become inaccurate if changes to speed zones are not updated in the digital map, leading to the system communicating out-of-date speed limits to the driver, this was not an issue that was observed in any of the apps evaluated as part of this research.

It was noted that for apps which relied on the smartphone camera that partial obstruction (e.g., by trees, vehicles or other roadside infrastructure) affected detection of roadside signs, particular speed signs at changes of speed zone. This is a known issue for systems that rely upon cameras for detection [3].

Camera-based apps also incorrectly identified signage on some vehicles that relate to the maximum speed of the vehicle or conditional speed limits that are intermittently active. In Australia, some buses that are operated as route service buses for school children are equipped with a speed indication sign (40km/h) and flashing lights. The 40km/h speed limit is only in effect when the flashing lights are in operation (e.g., when setting down/picking up schoolchildren) however the sign is always visible.

Figure 6. Screenshot from screen capture of UGV Driver Assistant (Android) detection of 40km/h sign on rear of bus (40km/h zone not active).

Buses are not the only vehicle type that may display a speed indication sign in Australia, with other examples including trucks that are top speed limited (e.g., to 100km/h) and some delivery vehicles that have an effective top speed (e.g., postal service delivery 'trikes') and it is likely that camera-based ISA apps would also incorrectly identify these speed indication signs as roadside speed limit signs.

Figure 7. Speed indication sign on a vehicle. Postal service delivery trike (top speed 45km/h).

DISCUSSION OF RESULTS OF EVALUATIONS AND KEY OBSERVATIONS

Our analysis of the evaluations confirms that smartphone-based ADAS applications are capable of vehicle detection/tracking, lane marking detection, speed sign detection/speed zone detection and related warning functionality to provide advisory ISA, FCW, FDW, LDW and top speed warning functions. We found that performance varied between different apps offering the same types of ADAS and even between the same apps on different operating systems.

Importantly, from our observations we conclude that the ADAS offered in the apps evaluated includes examples that offer reliable detection of relevant trigger conditions and deployment of an associated warning for ISA, FCW, FDW and top speed warning functions.

LDW functions were not as reliable and although our observations confirmed that the applications offering LDW features were often able to determine the lane boundaries, they also often detected erroneous lane boundaries and provided incorrect feedback to the user.

Potential benefits of smartphone based ADAS systems

While estimates of advisory ADAS effectiveness vary (depending on prevailing environmental conditions, road infrastructure design, or driver behaviour [3] [4]), what has been demonstrated in multiple studies is that advisory ADAS can provide an overall road safety benefit when they are used [1] [3] [5] [6]. Aside of crash risk reductions for the driver, there are also benefits to other road users (those who may also be involved in a crash) and economic benefits to the driver (reduction in speeding fines, reduced fuel costs) [6] [7] [8].

Table 2.

Estimated effectiveness for selected ADAS

Type of ADAS	**% Reduction in relevant crashes**
Camera-based Forward Collision Alert[1]	21% of rear-end crashes
Following Distance Warning[2]	10% of rear-end crashes
Lane Departure Warning[1]	10% of lane-departure crashes
Intelligent Speed Assist (Advisory ISA)[3]	20% of all serious crashes in Australia

Notes:

1. Based on 127,377 GM cars involved in Police-reported crashes in the USA. [9]

2. Based on estimates for Australia. [10]

3. Based on ISA trials in Australia. [1]

While OEM-fitted ADAS systems (AEB, LKA, speed-limiting ISA, ACC) that are optimised for specific vehicles are undoubtedly more effective than aftermarket advisory ADAS (i.e., of the kind provided by smartphone based ADAS apps) there are many vehicles worldwide that are not fitted with ADAS of any kind. Drivers of these vehicles are likely to benefit from using an advisory ADAS system. As we have described above, smartphone ADAS apps could realise this potential by providing advisory ADAS including ISA, FCW/FDW, LDW and top speed warning, and could deliver these features in a single application - although from this study we found that LDW functionality may require further development.

Smartphone ADAS apps avoid the component and installation cost barrier that has constrained uptake of some aftermarket ADAS systems using proprietary hardware (for example the Mobileye and IRoad systems), with the additional bonus that smartphone ADAS apps are easily moved between different vehicles as they are not hardwired into the vehicle.

The low cost and straightforward, non-specialised, non-permanent set up of a windscreen or dash mounted smartphone cradle means that smartphone-based ADAS apps are more accessible to drivers who cannot otherwise afford access to ADAS systems that require more specialised installation, or who use car sharing for access to a vehicle that they do not own (and are unable to modify).

Another advantage of ADAS apps is that they can utilise established distribution methods (i.e., app stores) to quickly, easily and cheaply deploy ADAS apps to end users, reducing constraints on uptake and making for efficient implementation of any local, regional or global initiatives to increase the use of ADAS apps.

Of the approximately 1 billion cars in use worldwide it is estimated that only 10% of these (100 million) are fitted with some form of ADAS [11]. While this is an excellent achievement in terms of road safety progress, it still remains that the other 90% of the global car fleet (900 million vehicles) lack any form of ADAS.

Smartphone ownership rates vary globally between advanced and developing economies, and between different socioeconomic groups within these economies. While not every smartphone user is guaranteed to be the driver of a vehicle lacking ADAS, we speculate that many millions across the globe are.

Given the estimated 900 million cars in use which are not fitted with ADAS, and the number of smartphone owners who are likely to be driving these vehicles, smartphone-based ADAS apps can provide a cost-effective, accessible means of improving equitable access to ADAS for potentially millions of road users globally.

Barriers to the uptake of ADAS apps

Barriers to adoption of ADAS apps by users Despite generally positive user ratings (based on app store ratings) the download volumes for ADAS apps have been fairly low. For example, despite being launched in 2014 the 'Speed Adviser' app, developed by Transport for NSW (an Australian state government body) has only been downloaded 77,000 times (as of December 2022) across both Android and iPhone platforms [12]. Similarly, the aCoDriver app on Android has only had around 50,000 downloads since its launch in 2013. User acceptance is probably not a significant barrier since ADAS systems have become commonplace in new vehicles and are largely accepted by drivers. Cost is also unlikely a barrier since most of these apps are available for free, or only cost a few dollars. Equipment compatibility is probably not a factor as we demonstrated that the applications work across different models of phones and operating systems. Access to equipment is also less of a barrier for many potential users as smartphone ownership is considerable (and growing) globally, in both advanced and emerging economies and furthermore (as noted above) apps are available through established online distribution mechanisms (i.e., app stores) that provide users with quick, easy and low-cost access. Therefore, a key reason for drivers not up taking these free road safety tools is likely a lack of awareness, as ADAS apps have received little media attention and are not marketed widely.

Regulatory Barriers An additional barrier to the uptake of ADAS apps in some regions are restrictions placed on the use of mobile phones for some drivers (e.g., novice drivers). Some Australian States ban drivers from touching a smartphone screen for any purpose, while driving. While these restrictions are more aimed at preventing distraction due to phone use for texting, social media use or website browsing, etc., it also may prevent some drivers from being able to use smartphone-based ADAS apps while driving. For example, the Speed Adviser app, developed by Transport for NSW (a department of the regional government) may not be used by novice drivers (those on Learner or Provisional licences). Regional authorities should consider strategies to support the legitimate use of smartphone-based ADAS to improve road safety while maintaining restrictions intended to prevent distractions to the driver from phone use while driving.

Infrastructure Barriers To function properly some ADAS systems require that the road infrastructure is designed (and maintained) to support the system. For example, LDW systems require clear lane markings, camera-based ISA systems require unobstructed roadside speed signs, and map-based ISA systems require up-to-date digital maps of speed zones. In some cases, ADAS systems may benefit from optimisation of road infrastructure (e.g., standardisation of sign types, or lane marking dimensions). Good design and maintenance of road infrastructure also benefits other road users (not just users of ADAS). Although there are potentially significant costs associated with this, these should already be budgeted for by responsible road authorities. Where speed zone map data is required this can be outsourced to third parties, as has been done in OEM ISA systems built into the vehicle navigations systems.

Comments on overcoming common limitations/issues observed during evaluations

One notable observation during our evaluations is that while the map-based and camera-based ISA apps each performed reasonably well, there are areas of performance where each has inherent advantages and disadvantages – and those areas of disadvantage for one type of app are generally covered by the performance strengths of the other. For example, where camera-based ISA systems missed signs that were behind objects, or that were faded, map-based ISA apps detected these zones well. Conversely, map-based ISA systems failed to recognise temporary speed zones (e.g., roadworks zones) whereas camera-based apps detected these. One way to enhance ADAS apps with ISA features could be to develop applications that utilise both camera detection and map-based speed zones to detect speed zones even more comprehensively.

We observed that FCW and FDW features in particular seemed susceptible to false positives. Anderson et al (2012) [3] found that FCW systems with wider fields of view may be more susceptible to false positives. A review of the applications evaluated that displayed an onscreen overlay of the camera view showed that all of these had very wide fields of view, often extending well beyond the road to include road adjacent areas and portions of sky. Anderson et al (2012) [3] proposed narrowing the field of view as a potential solution to this issue and the apps evaluated in this study may benefit from this.

One likely barrier to the uptake of smartphone ADAS apps is a lack of awareness and we postulate that these potentially beneficial road safety tools require more promotion to reach their intended end users, however it's important that only apps that demonstrate consistent, beneficial performance are promoted. As such a method of evaluating, and perhaps rating ADAS apps could be worthwhile to ensure that end users can make informed choices in the selection of an ADAS app based on its comparative performance. Consumer rating programs such as the various NCAP programs (new vehicles), CREP (child car seats) and SHARP (motorcycle helmets) have proved to be effective in increasing consumer awareness of varying performance in road safety technology and also for driving improvements in design. It seems likely that a rating program for smartphone ADAS would assist consumers in selecting the best performing applications and may also help drive further improvements in ADAS app design.

While there are some issues with the systems evaluated there appear to be obvious avenues to address these through improved app design, by combining technology types and through future advancements in technology - for example ADAS apps will benefit from further improvements in processor speed, camera optics and GPS chipset accuracy. Clear, reliable warnings are an essential component of an advisory ADAS system and improvements in this area are likely to increase the benefits of ADAS apps. Improvements in HMI design for warnings such as increasing the visibility, contrast and persistence of warnings would also address some of the issues we noted with inadequate warnings, however more research is needed in this area. The latest research into HMI design may inform apps developers on the most effective warning types, which will further improve the effectiveness of ADAS apps and ensure these apps are a benefit rather than a distraction.

LIMITATIONS OF THIS STUDY

The evaluations do not cover the full range of potential scenarios possible (future research will investigate more scenarios and the results of this research will be published separately).

Due to geographical constraints only ADAS apps available in Australia could be evaluated so ADAS apps available in other regions have not been evaluated. Similarly, the smartphone models used for the performance evaluations were models available on the Australian market, however these were popular models widely available globally and this is not considered to impact the outcomes of the performance evaluation.

The evaluated device/application combinations were limited to several selected examples and do not cover the full range of potential device/app combinations. Similarly, only limited app/operating system version combinations were evaluated and these do not cover the full range of potential app/operating system version combinations. While the models of smartphone used for the evaluations varied somewhat in technical characteristics (e.g., operating system, processor speed, lens type, etc.) they are not representative of the most basic or the most advanced smartphones that exist in the market.

The performance evaluations were conducted on public roads in Australia in regional and metropolitan areas in the States/Territories of New South Wales, Victoria and the Australian Capital territory (ACT). As such the ADAS apps were evaluated against Australian road infrastructure such as speed limit signs and lane markings.

Some applications may have been optimised for overseas road infrastructure (despite being available in Australia).

Only scenarios that arose during normal driving conditions were included. No scenarios where potential collision could have occurred were considered. Pedestrian detection was only undertaken during a stationary position at traffic lights with a pedestrian crossing, with pedestrians passing across the field of new (perpendicular to direction of travel).

No evaluations of differences in effectiveness of warning type, loudness or effect on driver behaviour were undertaken (although warning types were recorded).

For some applications, especially those utilising cameras, a more optimum position may have been possible which may have improved performance of the app - however in early trials the apps did not appear overly sensitive to positioning, provided the camera was centred with respect to the lane ahead of the vehicle and its view was not obstructed.

Lane departure warning manoeuvres were only undertaken where dashed line separation markings were present so other types of lane markings, or unmarked road edge detection, were not evaluated.

It is stressed that these were preliminary evaluations under the limitations described above and that the results for particular apps are not necessarily representative of their performance under more detailed evaluation. The outcomes should be regarded as indicative only.

CONCLUSIONS

Smartphone-based ADAS apps are an extremely low-cost road safety tool that have been mostly overlooked by drivers and the road safety community for many years.

While smartphone-based ADAS can provide reliable, and potentially useful road safety benefits to drivers, the potential benefits depend on a combination of the hardware capability of the smartphone, the sophistication of the application and to a lesser extent the correct set up of the smartphone in the vehicle. We found examples of apps that provided seemingly effective FCW/FDW and speed assist functionality in particular, but also found that LDW performance was uniformly poor in the apps evaluated.

Although the ADAS functionality offered by smartphone apps lags behind that offered by in-vehicle, OEM-fitted ADAS systems, there appear to be potentially significant benefits for drivers of vehicles that lack OEM-fitted ADAS, or where their vehicle lacks either ISA, FCW/FDW or a manual set, top speed warning. Our research identifies that while some ADAS apps appear to provide useful features, some do not, so more work is required to develop and promote worthwhile ADAS apps to end users.

Developers of ADAS apps need to ensure that their apps function well and provide beneficial, relevant features to drivers by taking advantage not only of the latest developments in smartphone technology, but also by applying existing road safety research findings. App developers would benefit from examining previous research into advisory ADAS, and the latest research into HMI design to ensure that the lessons learned through decades of ADAS development for new vehicles are applied to smartphone ADAS apps. It is also likely that subsequent improvements in warnings to drivers would enhance the effectiveness of ADAS apps to ensure that the warnings are more easily and correctly interpreted by drivers and that driver distraction is minimised.

Furthermore, while smartphone-based ADAS has the potential to improve road safety, especially where OEM-fitted ADAS is not a feasible option, there are inherent limitations posed by current technology. These may be overcome through future improvements in technology (smartphone processor or camera capabilities), through improvements in HMI design, or by combining different types of technology (for example by combining map based and optical recognition for ISA applications to improve the detection of all speed zones). We foresee that continued developments in smartphone hardware and processing capability, together with software evolution in ADAS applications, will continue to improve the reliability and effectiveness of smartphone-based ADAS in the future.

Road authorities should ensure that the road infrastructure supports ADAS functionality through good infrastructure design and maintenance. They should also ensure that other road safety initiatives, especially those aimed at reducing driver distraction through phone use, do not impose onerous conditions on drivers who legitimately wish to use ADAS apps for their safety benefits.

Subject to appropriate provisions in relevant regulations, the barriers to the adoption of smartphone-based ADAS appear low and the main barrier to adoption is that smartphone users are unaware that ADAS applications exist. These apps could be better promoted by road safety advocates/champions, to bring them to the attention and (hopefully) use of millions of drivers worldwide whose vehicles are not currently ADAS-equipped. However, advocates must be careful only to promote those apps that provide real benefits and that function well. In order to ensure this, a method of evaluating and rating the available apps may assist in identifying the most beneficial apps to promote. Consumer rating programs may be an effective way to promote and encourage the best performing ADAS apps and may also help drive further improvements in ADAS app design.

As we look for road safety strategies that provide more equitable access to road safety technology across the world, it appears that there may be a low cost, swiftly deployable option for the millions of drivers globally who do not have access to an ADAS equipped vehicle, but who do have access to a smartphone when they drive.

REFERENCES

[1] Paine, D., Paine, M., Wall, J., & Faulks, I. (2013). "Development of an assessment protocol for after-market speed limit advisory devices". Paper number 13-00393. 23rd International Technical Conference on the Enhanced Safety of Vehicles (ESV), Seoul.

[2] SAE International, (2021). *Surface Vehicle Recommended Practice: (R) Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*. J3016™.

[3] Anderson. R., Doecke, S., Mackenzie, J., Ponte, G., Paine, M., & Paine, D. (2012). "Potential benefits of forward collision avoidance technology." CASR106 Adelaide, SA: Centre for Automotive Safety Research.

[4] Peiris, S., Berecki-Gisolf, J., Newstead, S., Chen, B. & Fildes, B., (2021). Development of a Methodology for Estimating the Availability of ADAS-Dependent Road Infrastructure. *Sustainability*, 13(17):9512.

[5] Wang, L., Zhong, H., Ma, W., Abdel-Aty, M., & Park, J., (2020). "How many crashes can connected vehicle and automated vehicle technologies prevent: A meta-analysis". *Accident Analysis & Prevention*, 136, March 2020, 105299. https://doi.org/10.1016/j.aap.2019.105299.

[6] Regan M., Triggs T., Young K., Tomasevic N., Mitsopoulos E., Stephan K., & Tingvall C. (2006). "On-Road Evaluation of Intelligent Speed Adaptation, Following Distance Warning and Seatbelt Reminder Systems: Final Results of the TAC SafeCar Project". Monash University Accident Research Center.

[7] Faulks, I.J., Paine, M., Paine, D., & Irwin, J.D., (2010), "Update on the road safety benefits of intelligent vehicle technologies—Research in 2008-2009". 2010 Australasian Road Safety Research, Policing and Education Conference. Canberra, ACT.

[8] Golias, J., Yannis, G., & Antoniou C. (2002). "Classification of driver-assistance systems according to their impact on road safety and traffic efficiency". *Transport Reviews*, 22(2), p179-196.

[9] Leslie, A.J., Kiefer, R.J., Meitzner, M.R., & Flannagan, C., (2019). "Analysis of the Field Effectiveness of General Motors Production Active Safety and Advanced Headlighting Systems". University of Michigan Transportation Research Institute.

[10] Paine, M., Healy, D., Faulks, I., (2008). "In-vehicle safety technologies - picking future winners!" 2008 Australasian Road Safety Research, Policing and Education Conference. Paper 204.

[11] Raban, S. (2022). "Advanced driver assistance systems market to exceed US$75bn globally by 2030, says SM Research". https://www.iot-now.com/2022/11/03/125096-advanced-driver-assistance-systems-market-to-exceed-us75bn-globally-by-2030-says-sm-research/#:~:text=ADAS%20is%20a%20new%20technology,had%20ADAS%20installed%20in%20them

[12] Australia. Transport for NSW. (2022) *Speed Advisor*. https://roadsafety.transport.nsw.gov.au/speeding/speedadviser/index.html

[13] Creef, K., Wall, J., Boland, P., Vecovski, V., Prendergast, M., Stow, Jacqueline, Fernandes, R., Beck, J., Doecke, S., & Wolley, J. (2011, November 30). "Road Safety Benefits of Intelligent Speed Adaptation for Australia". [Paper presentation]. Proceedings of the Australasian Road Safety Research, Policing & Education Conference, Perth, WA.

[14] Doecke, S.D., & Woolley, J.E. (2010). "Cost benefit analysis of Intelligent Speed Adaptation". CASR093 Adelaide, SA: Centre for Automotive Safety Research.

[15] Doecke, S. D., Anderson R. W. G., Woolley J. E., & Truong J. (2011, November). "Advisory intelligent speed adaptation in government fleet vehicles". Proceedings of the Australasian Road Safety Research, Policing and Education Conference, Perth, WA.

[16] Doecke, S. D., Kloeden, C. N., & Woolley, J. E. (2011) "NSW intelligent speed adaptation (ISA) trial: modelling the effects of Advisory ISA on the Australian driving population". Centre for Automotive Safety Research (CASR). Adelaide.

[17] Paine, M., Paine, D., & Faulks I. (2009). "Speed Limiting Trials in Australia". Paper Number 09-0378. 21st International Technical Conference on the Enhanced Safety of Vehicles (ESV), Stuttgart.

[18] Masello, L., Castignani, German, Sheehan, Barry, & Murphy, Finbarr, (2022). "On the road safety benefits of advanced driver assistance systems in different driving contexts". *Transportation Research Interdisciplinary Perspectives*, 15:100670.

[19] Searson, D., Ponte, G., Hutchinson, T. P., Anderson, R., & Lydon, M., (2015). "Emerging vehicle safety technologies and their potential benefits: discussion of expert opinions". Proceedings of the 2015 Australasian Road Safety Conference.