TECHNOLOGIES FOR THE PREVENTION OF RUN OFF ROAD AND LOW OVERLAP HEAD-ON COLLISIONS

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INTRODUCTION

A substantial number of serious collisions occur when a vehicle:

- Runs off the edge of the road way and collides with roadside furniture such as trees; and
- Crosses the centre line of the road and collides head-on with an oncoming vehicle.

A proportion of these are very likely to be caused by some form of inattention and/or distraction and several new technologies have been introduced into the market with the intention of preventing these crashes. Actions to promote the fitment of "lateral assist" systems are included within the Euro NCAP programme (Euro NCAP, 2014):

- Lane Keep Assist Test and Assesment Procedure for the 2016 rating scheme
- Advanced Lateral Support System Test and Assessment Procedure for 2018 rating scheme.

The aim of this research was to:

- Analyse the frequency and severity of relevant collisions in order to understand the potential impact of lateral control technologies
- Characterise crashes to inform the development of performance criteria that will be relevant to the real world
- Undertake initial research to explore the capability of different technologies
- Investigate the potential of candidate test procedures that could form part of future assessments.

LATERAL ASSIST TECHNOLOGIES

A wide range of lateral assist technologies have been developed and put into production since the beginning of the 21st century. These include blind spot monitoring systems but these have not been considered in-depth in this paper because they are intended to be of benefit in crashes that occur during deliberate lane changes rather than crashes that occur because of unintended departure from the lane or road. The main characteristics of the different types of technology are briefly reviewed below.

Lane Departure Warning

Lane Departure Warning (LDW) systems are now widely available on many production models, including high volume models. When the system detects that the vehicle has left the lane, or is just about to, without the activation of the direction indicator, then it provides a warning to the driver. Warning types have historically varied between different makes and models of vehicle (e.g. directional audible warnings, visual warnings on the multi-function display, steering wheel vibrations and even haptic seat vibrations) however at the time of writing warnings are generally converging to a visual multi-function display warning and/or haptic steering wheel vibration.

Lane Keep Assist

Lane Keep Assist (LKA) works on exactly the same principles as lane departure warning, except that when the system detects that the vehicle has left, or is leaving, the lane, a small heading correction is applied automatically in the form of steering torque or by differential braking in order to at least prevent further departure from the lane and, depending on exact circumstances, to re-direct the vehicle back into its lane. The intervention is deliberately kept relatively low such that it can be easily overcome by the driver, if they are deliberately changing lane and have simply forgotten to use the direction indicator.

Lane Keep Assist is now offered by many manufacturers, including Volvo, Volkswagen, Mercedes, Toyota, Subaru etc. but it tends to be offered on the higher end models.

Lane Centering Assist

Lane Centering Assist uses exactly the same technologies as a lane keeping assist. However, a lane keep assist only reacts to the vehicle passing over a road marking. Thus, in the absence of driver input it is possible that the vehicle would proceed along the road in a zig zag fashion "bouncing" from one lane boundary to the other. A lane centering system will autonomously apply steering inputs to keep the vehicle positioned as centrally in the lane as possible at all times.

This variation of the technology is less common than the systems based on crossing lane boundaries but Honda, Mercedes, Volkswagen and Infiniti have been early adopters of this strategy.

Autonomous Emergency Steer

All of the systems previously described react according to a relatively simple set of criteria, regardless of the extent of collision risk. If the speed is in excess of the threshold (typically 37 to 45 mile/h), a lane marking is detected and may be crossed, and the indicator is not activated, then the warning and/or corrective torque will be applied. Thus, the system will take the same action in normal driving with no other vehicles around, as it will in a critical incident where a head-on collision is imminent. The category of Autonomous Emergency Steer has been created to consider systems with two key differences:

- The activation criteria are combined with an assessment of the risk of collision. For example, if on a country road, in the absence of any other traffic, a driver takes a straight line path through a bend and cuts across the road centre marking, then the system may not activate at all, in other circumstances it may warn the driver but not intervene
- The range of actions available to the system is increased such that a relatively severe correctional steering input can be applied if a lane departure is detected and the sensors detect an imminent risk of collision with an overtaking or oncoming vehicle. While this could be applied via a higher steering torque, the first example of such a system used the electronic stability control system to generate the correcting moment via differential braking, with the added advantage that this also slows the vehicle down.

The aim of this system is to both reduce the chances of the system intruding on normal driving thus boosting driver acceptance and increase its effectiveness in terms of the ability to avoid critical incidents. This type of system has been introduced by Mercedes but, at the time of writing, was not known to have been introduced by other manufacturers.

Features common to different systems

Most lateral assist systems now use forward facing camera sensors to detect lane markings. It is therefore, a fundamental requirement of the system that lane markings are present and clearly visible. Effectiveness would be expected to be high on main highways and motorways where good quality markings are typically present. However, rural roads could be more challenging. For example, in the UK many rural roads may have only a centre line and not a road edge marking. Some systems can detect a road edge even without markings but the accuracy and consistency of detection is thought to be lower, as is the level at which the system will intervene (e.g. warning only rather than corrective heading control).

In addition to this, some drivers have reported that false interventions of both warning and intervention systems. These can commonly occur where the vehicle crosses road features that appear somewhat like lane markings but are not. For example, where road works have taken place and temporary lane markings have been installed and then imperfectly removed.

The time at which warnings and interventions occur can vary considerably. For example, ISO 17361, permits a lane departure warning system to issue the warning at any point from when the vehicle remains 1.5m inside the lane boundary to a point where the vehicle is already 0.3m past the lane boundary. Given typical human reaction times, then the vehicle could be very significantly past the boundary by the time the driver reacts and the range of warning times would, therefore, be expected to substantially influence the overall effectiveness of the system.

CHARACTERISING LANE DEPARTURE CRASHES

The objective of this element of work was to understand the quantity of crashes that lane keeping technologies might have the potential to prevent and to characterise those crashes in order to inform the development of test procedures that would promote the design of systems with the best real-world effects. The analysis was based on:

- Analysis of 12,565 insurance claims from a First Notification of Loss (FNOL) dataset involving collisions occurring in the UK in 2010. The data includes 1st and 3rd party claims and crash categorisation was based on text analytics of collision descriptions.
- Analysis of crash data from the German In-Depth Accident Study (GIDAS).
- Review of published effectiveness studies

Analysis of the crash types found in UK insurance claims showed that in combination, single vehicle collisions and head on collision represented approximately 21% of both damage and personal injury claims (see **Figure 1**).

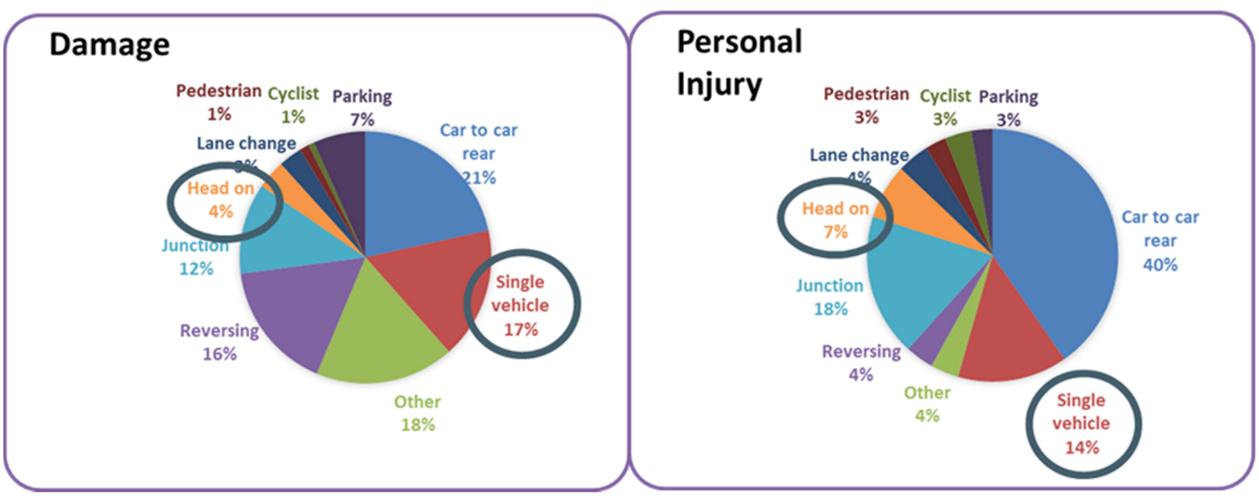

Figure 1: Crash Type Analysis, UK insurance claims 2010

Data provided to Thatcham from the GIDAS database characterised lane/road departure crashes as follows:

- Collision Mechanism
  - 44% straight road, 30% gentle left bend, 22% gentle right bend
  - 46% left departure, 40% right departure, 12% collision with other vehicle
  - Higher speeds typically 60-80km/h+

- Road Markings
  - 76% continuous white line, 12% dashed, 9% no marking
  - 72% well visible, 15% worn, 9% no marking
- Lighting & Weather conditions
  - 55% dry, 34% wet, 11% ice/snow
  - 61% daylight, 5% twilight, 34% darkness
  - 97% no fog
- Causation factors
  - Inattention
  - Fatigue
  - Failure to apply sufficient steering

It should be noted that this data is based on Germany. While this may well be representative of Europe in some respects, it may not be in all respects. Anecdotally, it would be expected that the presence, type and condition of road markings would be a feature that varied for road networks in different jurisdictions. Given that many lateral assist systems rely on cameras identifying road markings, this would be expected to have a strong influence on their overall effectiveness.

Concerns over roadmarkings notwithstanding, when combined with the data on the specification and intention of the technologies developed so far, the accident data suggests that there is strong potential for lateral assist systems to be effective. This is consistent with earlier predictive studies such as Visvikis et al (2008), which also showed strong potential (15% to 60% of lane departure crashes). However, the effects actually measured in terms of collision rates of vehicles with and without lane departure warnings have been much more ambiguous.

A US study (IIHS, 2012) found that lane departure warning systems fitted to Buick and Mercedes models were actually having a small adverse effect on claims rate for both collision (1st party) and property damage liability (3rd party) claims, although this was not statistically significant. A Volvo system appeared to be beneficial but the effect could not be separated from the fitment of a comprehensive AEB system for frontal crashes.

A more recent study (IIHS, 2014) has found that in combination a forward collision warning and lane departure warning has proved to be more effective than would have been expected based on earlier studies of both systems fitted to other vehicles. A reduction of 14% in the frequency of property damage liability claims was found, which compared to just 7% for earlier studies of forward collision warning systems. However, the effects of the FCW and LDW technologies could not be separated in the analysis of the Honda system so it remains unknown just how much the lane departure warning system has contributed to this benefit.

No studies have been identified that have yet attempted to measure the acutal claims reduction effect of a lane keeping system or other more advanced lateral assist system. Comparison of the typical results for forward collision warnings compared to autonomous braking systems suggests that the additional physical intervention should be beneficial but, as yet, this remains hypothetical.

CANDIDATE TEST PROCEDURES

Straight roads

The accident data suggests that a large proportion of lane departure crashes occur on straight roads. The type of crash most likely to be influenced by lateral assist systems is that where the driver is distracted, tired or otherwise impaired. The data suggests these crashes are characterised by relatively low lateral velocities (i.e. the vehicle leaves its lane relatively slowly.). Straight roads are thus likely to represent the simplest test procedure, and the circumstance where technology would be most capable. It is, thus considered that a straight road test would be well justified and will be the first scenario evaluated.

Any test procedure will need to define a series of standardised road markings, perhaps regionally adjusted, for which the system must be effective.

Curves

According to the data, an even larger proportion of lane departure crashes occur on gentle curves (c.52%). However, gentle bends could be interpreted as very large radius e.g. 300m plus. On these roads, the required sensor field of view and the rate of road departure (lateral velocity) may not be much greater than for straight roads. Conversely, executing tests may be more difficult because very large test areas could be required. Research tests will therefore focus on establishing whether testing on large radius curves is required by assessing whether it highlights any performance advantages or disadvantages of different lateral assist systems.

Testing on tighter bends represents a smaller proportion of all crashes, though potentially a higher proportion of severe crashes. It also represents a much greater technical challenge with much higher lateral velocities and much greater correctional steering inputs required to maintain the path. Investigation of small radius curves will therefore focus on the potential for systems to prevent this type of crash and the technical feasibility of developing appropriate tests.

Another consideration is how long lateral support should be continued for when negoatiating a curve and what mechanism should be employed to advise the driver of the support and the driving condition in which the vehicle should be left in if/when the support is terminated.

Sensitivity to hazards

One of the key factors distinghuishing between the systems described as lane keep (or lane centring) asssist and autonomous emergency steering is the ability to adapt the type or magnitude of autonomous intervention depending on the risk of collision. Thus, in order to distinghuish between such systems then tests on either straight roads or curves need to be repeated with and without the presence of a collision threat. For obvious safety and cost reasons the simulated collision risk must present minimal actual risk of equipment damage or injury.

The development of a suitable collision target for this type of testing has been the subject of much international discussion. There is an emerging concensus that the likely solution would be to define a harmonised world soft-car target which was an accurate 3D representation of a common world car in terms of radar, lidar, and visual signatures. Such a target also needs to be fully impactable at high relative speeds (100km/h+) without damaging the test vehicle. The target itself either needs to be a low cost, test consumable or it needs to be very durable such that it can be quickly re-built after impact, ready for the next test. The target could then sit on top of any low profile platform based delivery system that complied with an agreed set of performance criteria (e.g. radar signature, speed, acceleration capability etc.). Currently, a range of solutions have been proposed by various stakeholders, as illustrated in **Figure 2**, below.

Figure 2: Candidate car target and propulsion systems for testing lateral assist systems (ABD top left, 4A top right, DSD bottom left & Perrone bottom right)

INITIAL TEST RESULTS

Thatcham's initial test programme has focussed on assessing the capability of the Mercedes E Class, which is fitted with a system that corresponds with the earlier definition of Autonomous Emergency Steer (AES). The vehicle was equipped with path following robotic driving control to ensure repeatable testing. The test scenarios initially considered are based largely on the existing NHTSA standards for Lane Departure Warning confirmation on straight roads. The aim is to assess not only how the car responds to the different circumstances defined (e.g. solid lines, dashed lines, different lateral velocities etc) but also how the test procedure requires developing to allow more sophisticated systems to be fairly assessed.

For lane departure warning, the test procedure prescribes that the vehicle must simply pass through two geometrically defined "gates" that will create a lateral velocity within an acceptable range on approach to the lane boundary. The steering is applied manually and maintained as the vehicle crosses the lane boundary and the proximity to the lane boundary when the warning is isued is measured. The test procedure recommends this is achieved using a human driven open-loop steering input. The NHTSA procedure also offers a recommendation to assess lane keeping systems over a range of lateral velocities for reference purposes only where fitted, however no defined method is provided. On review of these procedures, Thatcham investigated two concerns:

- Repeatability, it was considered that the range of lateral velocities achieved in testing could possibly affect the performance of the vehicle
- If the test was controlled by robotic driving aids to improve accuracy and repeatability, a method would need to be defined to avoid the steering robot over-riding the lane keeping heading correction during the test.

Within the test procedure permitted by the NHTSA confirmation test there are a range of possible variables. If the lane boundary is to be approached at a constant lateral velocity, then the vehicle will initially travel in a straight line, be steered towards the lane boundary and then the path would be straightened. In this process, the initial steer input could be applied slowly (large radius curve) or fast (small radius curve). A range of different radii of initial turn-in were tested for the same resultant lateral velocity. Larger radii of turn required the vehicle to be initially positioned further away from the lane boundary to be crossed. Path controlled robotic steering was used to provide accurate inputs. In all cases, the steering was staightened and released by a distance 0.3m from the lane boundary and any heading control effect after that point was applied by the vehicle autonomously.

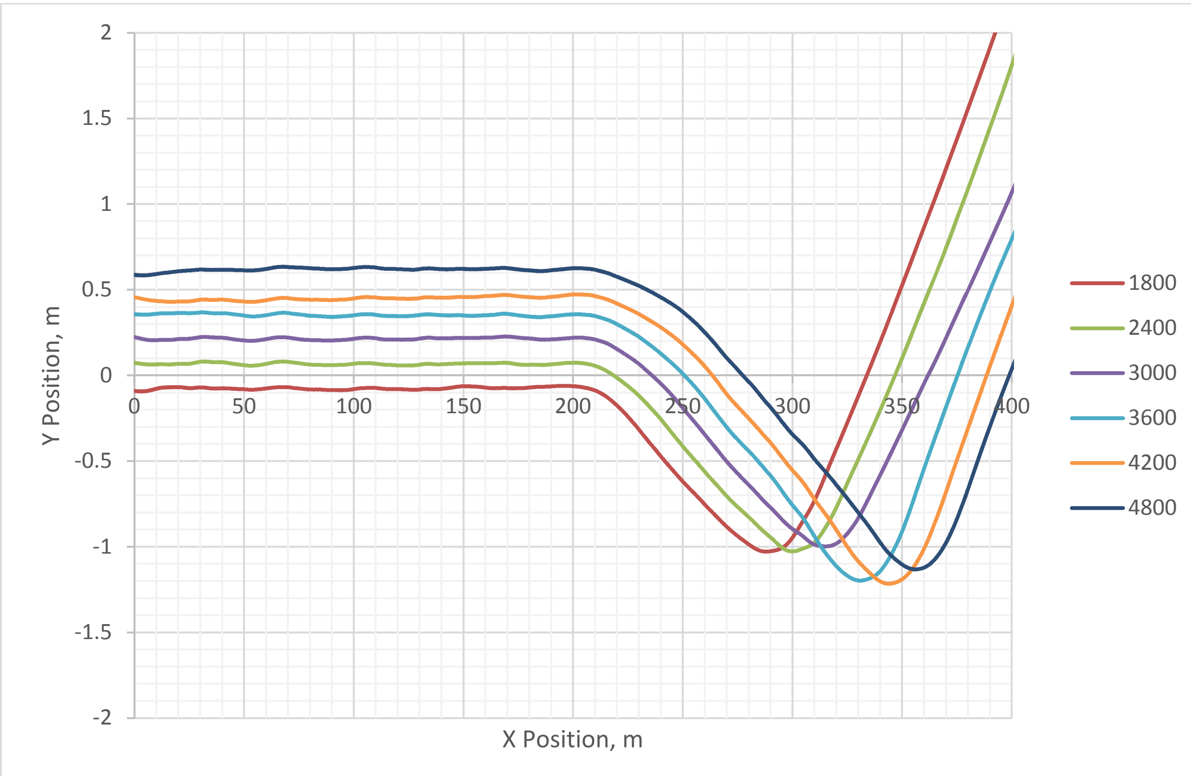

Figure 3. Effect of initial turn radius on lane keep assist function and change in vehicle heading

In this figure, the lane is centred on a y-position of zero and each trace represents the x-y position of the centre of gravity of the test vehicle. Thus, the lane boundaries would be at ± 1.75m and the edges of the vehicle will be at approximately ± 0.9m of the trace. Each trace represents the path of a test with a different radius of the initial curve. It can be seen that this variable has relatively little effect on the extent to which the edge of the vehicle crosses the lane boundary at y= – 1.75m (approximately 0.3m) or on the heading of the vehicle after the lane keep system has intervened.

It is worth noting that the lane markings during this test were such that the boundary at +1.75m was a dashed white line and the one at -1.75m was a solid white line. This graph also, therefore confirms that the Mercedes system adapts it's response according to the circumstances. Where it detected the solid white line (which in the centre of a UK road prohibits overtaking) the system intervened to correct the path. When it crossed the dashed white line it provided the driver with a lane departure waraning but did not actively steer the vehicle to correct the path. A Volvo V40 with lane keep assist tested in the same manner corrected the heading in response to both lane boundaries, such that the path of the vehicle zig-zagged from one lane boundary to the other and back again.

Subsequently, the effect of variation in the lateral velocity with which the lane boundary was approached was investigated, within a range of 0.1 to 0.6 m/s, all with the same initial radius of turn. The results are shown in **Figure 4**.

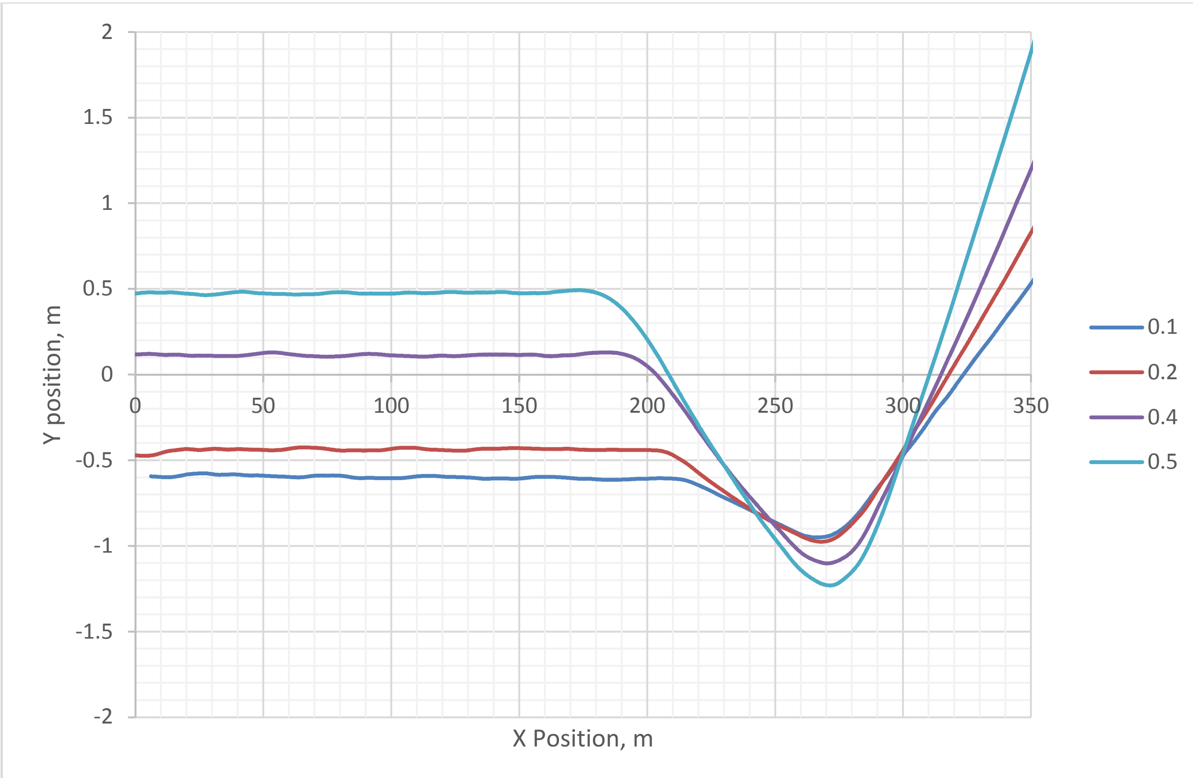

Figure 4: Effect of lateral velocity on lane keep assist function and change in vehicle heading.

It can be seen that higher lateral velocities could only be achieved by initially positioning the vehicle at the far side of the lane boundary to be crossed. However, in this case, it can also be seen that higher lateral velocities tended to result in the vehicle crossing the lane boundary by a greater margin before the active steering assist could correct the path. It also resulted in the correction of heading being applied with a greater yaw velocity, which in turn translated to the vehicle approaching the opposite lane boundary with a higher yaw velocity. The exact actions of the test inputs and vehicle response can be seen in the results of a single test at a lateral velocity of 0.6m/s.

Figure 5. Example of detailed results from a single test at a lateral velocity of 0.6m/s

DISCUSSION

It is clear that lane departures that result in run-off-road or head on collisions represent a substantial safety problems and that lateral assist systems have strong potential to prevent a substantial proportion of them. However, it is considerably less clear as to whether such systems are actually being effective in-service with some evidence suggesting that lane departure warning systems have little effect, or even an adverse effect. If forward collision warning and AEB are considered as a valid analogy, then it seems very likely that that lane keeping systems and autonomous emergency steering should be considerably more effective than a simple lane departure warning. However, further research is required to quantify the actual benefits of such systems as the available sample size increases with greater market penetration of the systems.

The capability of the lateral assist technology available is also evolving rapidly. The first lane keep assist systems only became widely available in the last few years but already the first examples of the next generation of AES is available from Mercedes. Thus performance ranges from a simple audible warning every time any kind of lane marking is crossed, to a system that varies its action in response to different situations and can provide a more abrupt correction in the heading when the threat of a collision is detected as a result of lane departure.

Test procedures already exist for the simpler systems but preliminary research has suggested that these require further development for assessing more advanced systems in a repeatable manner suitably for consumer testing. One essential requirement of a successful test programme will be the development of a lane departure test that occurs in the presence of an imminent collision threat with an oncoming vehicle. A range of different vehicle target and mobile platform systems is in existence to allow such testing. However, creating a harmonised 3-D vehicle target for use throughout the world would offer considerable benefits to both test authorities and industry and could also be used in a wide range of different test scenarios, including the existing car-to-car rear tests.

Actual testing of vehicles and the consequent refinement of test procedures remain at an early stage. However, the initial results are encouraging. They suggest that the vehicle performance offered is considerable and that accurate, representative and repeatable test procedures can be developed.

CONCLUSIONS

1. Head on and single vehicle crashes represent approximately 21% of all UK motor insurance claims and a much greater proportion of fatal collisions. There is, therefore, a substantial problem to solve.
2. Lateral Assist Systems, including lane departure warning, lane keep assist, lane centering and autonomnous emergency steering, have been developed and are on the Euro NCAP roadmap for implementation within their rating scheme.
3. While the evidence regarding the effectiveness of lane departure warning systems is ambiguous, it is expected that systems that intervene on behalf of the driver would prove more effective. AES systems would be expected to both increase effectiveness and driver acceptance of the systems in normal driving.
4. Testing the more advanced lateral assist systems also requires more sophisticated test procedures. Development of these procedures is at an early stage but shows promising results.

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