Transport Research Laboratory

Study on lane departure warning and lane change assistant systems

Final report

by C Visvikis, T L Smith, M Pitcher and R Smith

PPR 374

ENTR/05/17.01 Technical assistance and economic analysis in the filed of legislation pertinent to the issue of automotive safety

PROJECT REPORT

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Prepared for:	Project Record:	ENTR/05/17.01 Technical assistance and economic analysis in the filed of legislation pertinent to the issue of automotive safety Study on Lane Departure Warning and Lane Change Assistant Systems
	Client:	European Commission, DG Enterprise and Industry (Ian Knowles)

	Name	Date Approved
Project Manager	William Donaldson	21/11/2008
Technical Referee	Mike McCarthy	24/11/2008

Contents Amendment Record

This report has been issued and amended as follows

Version	Date	Description	Editor	Technical Referee
1	24/11/08	Final Report	Tanya Smith	Mike McCarthy

Contents

List of Figures 4

List of Tables 5

Executive summary 7

Abstract 11

1 Introduction 13

2 Literature survey 15

- 2.1 Lane departure warning 15
- 2.2 Lane change assistance 16

3 Review of technical standards 19

- 3.1 Lane departure warning systems 20
  - 3.1.1 Overview 20
  - 3.1.2 Sensor technology 21
  - 3.1.3 System behaviour 21
  - 3.1.4 System capability 23
  - 3.1.5 Human-machine interface 24
- 3.2 Lane change assistant systems 25
  - 3.2.1 Overview 25
  - 3.2.2 Sensor technology 26
  - 3.2.3 System behaviour 26
  - 3.2.4 System capability 27
  - 3.2.5 Human-machine interface 28

4 Review of systems 31

- 4.1 Lane departure warning 31
  - 4.1.1 Sensor technology 31
  - 4.1.2 System behaviour 32
  - 4.1.3 System capability 32
  - 4.1.4 Human-machine interface 32
- 4.2 Lane change assistance 33
  - 4.2.1 Blind spot monitoring 33
  - 4.2.2 Lane change warning (LCW) 34
- 4.3 Other systems 36
  - 4.3.1 Lane keeping assistance (LKA) 36
- 4.4 The future 37
  - 4.4.1 Lane departure warning sensing 37
  - 4.4.2 Blind spot monitoring 37
  - 4.4.3 Lane change assistance 37
  - 4.4.4 Merge in assistance 37
  - 4.4.5 Lane keeping assistance 37
  - 4.4.6 Road departure warning 37
  - 4.4.7 Complete lateral safety system 38

5 Proposed technical/operational requirements 39

5.1 Lane departure warning 39

5.2 Lane change assistance 40

6 Estimating costs and benefits to society 41

6.1 Introduction 41

6.2 Identifying target populations from accident characteristics 41

6.3 Methodology – GB data 42

6.4 Methodology – German data 44

6.5 Results – estimating EU casualty benefits 44
6.5.1 Target population 44
6.5.2 Effectiveness 46
6.5.3 Estimated casualty benefits 52

6.6 Estimated congestion benefits 53

6.7 Costs 56

7 Cost-benefit analysis 59

7.1 Vehicle stock and new registration data 59

7.2 Technology implementation 60

7.3 Benefits 61

7.4 Costs 62

7.5 Benefit-cost ratios 63

8 Fuel economy benefits 65

8.1 Methodology 65
8.1.1 Drag co-efficient and frontal area 65

8.2 Results 66

8.3 Discussion 68
8.3.1 Passenger cars 69
8.3.2 Goods vehicles 69
8.3.3 Buses, coaches and minibuses 69
8.3.4 Estimated European fuel economy benefits 70

9 Discussion 71

9.1 Introduction 71

9.2 Methodological issues 71

9.3 Costs and benefits 72

9.4 Potential risks relating to LDW and LCA systems 73

9.5 Technical specifications 73

10 Conclusions 75

Acknowledgements 76

References 76

Appendix A Literature survey 78

Appendix B Review of systems 102

Appendix C Outline technical/operational requirements – lane departure warning systems 111

Appendix D Outline technical/operational requirements – lane change assistant systems 115

Appendix E Target populations by accident type 119

Appendix F Fuel economy data 123

List of Figures

Figure 3.1. Functional elements of a lane departure warning system (ISO 17361:2007). 20
Figure 3.2. Functional elements of a lane departure warning system (FMCSA-MCRR-05-005). 21
Figure 3.3. Location of earliest warning line (ISO 17361: 2007). 23
Figure 3.4. Lane change assistant system state diagram (ISO 17387:2008). 26
Figure 3.5. Warning requirements diagram (ISO 17387:2008). 28
Figure 6.1. Process for development of STATS19 queries. 43
Figure 6.2. Estimated VOT saving (£ million) for motorways in GB (2007 price index). 55
Figure 7.1. Proportion of vehicle fleet fitted with LDW or LCA systems based on two implementation scenarios. 61
Figure 8.1. Comparison of fuel consumption between the baseline and modified HGV. 67
Figure 8.2. Comparison of carbon dioxide emissions between the baseline and modified HGV. 67
Figure 8.3. Relative change in fuel consumption (or carbon dioxide) between the “with mirrors” and modified HGV. 68

List of Tables

Table 3-1. Location of earliest warning line. 22
Table 6-1. Target population for LDW. 45
Table 6-2. Target population for LCA. 45
Table 6-3. Example of effectiveness information required. 46
Table 6-4. Effectiveness of LDW systems identified from the literature. 47
Table 6-5. Effectiveness values applied to LDW target populations. 49
Table 6-6. Effectiveness of LCA systems identified from the literature. 50
Table 6-7. Effectiveness values applied to LCA target populations. 51
Table 6-8. Estimated casualty benefit of fitting LDW system. 52
Table 6-9. Estimated casualty benefit of fitting LCA system. 52
Table 6-10. Estimated casualty benefit of fitting combined LDW and LCA system. 53
Table 6-11. Total number of accidents on 70 mile/hr dual carriageways (DfT 2007a, DfT 2006a). 54
Table 6-12. Number of avoidable accidents on 70 mile/hr dual carriageways. 54
Table 6-13. Estimated number of accidents had LDW and LCA been fitted to all vehicles. 55
Table 6-14. Britain's Motorway Network (DfT 2007b, DfT 2006b). 55
Table 6-15. Retail costs of LDW and LCA systems. 56
Table 7-1. Vehicle stock and registration data (EC, 2008). 59
Table 7-2. Vehicle stock and new registration data used in analysis. 60
Table 7-3. Total benefits for M1/N1 vehicles. 61
Table 7-4. Total benefits for N2/N3 vehicles. 62
Table 7-5. Total benefits for M2/M3 vehicles. 62
Table 7-6. Total costs for M1/N1 vehicles. 62
Table 7-7 Total costs for N2/N3 vehicles. 63
Table 7-8. Total costs for M2/M3 vehicles. 63
Table 7-9. Benefit-cost ratios for each vehicle type assuming mandatory fitment in 2013. 63
Table 7-10. Refined benefit-cost ratios based on the average target population for each vehicle type assuming mandatory fitment in 2013. 64
Table 8-1. Drag co-efficients and frontal areas. 66
Table 8-2. Potential fuel economy benefits (EU-27). 70

Executive summary

Lane Departure Warning (LDW) Systems monitor the position of the vehicle with respect to the lane boundary. When the vehicle is in danger of leaving the lane unintentionally, the system delivers a warning to the driver. Lane Change Assistant (LCA) Systems monitor the adjacent lanes; if a lane change manoeuvre is initiated and the system detects a vehicle in the adjacent lane, the system will alert the driver.

The objective of this research was to gather and evaluate information regarding the performance standards of LDW and LCA systems and the likely costs and benefits of meeting these standards with respect to:

- Light vehicles (e.g. categories M1 and N1)
- Heavy goods vehicles (HGV) (e.g. categories N2 and N3)
- Large passenger vehicles (LPV) (e.g. categories M2 and M3)

A literature review of studies on LDW and LCA systems revealed most of the LDW information orginated from the USA where LDW relevant crashes are estimated to account for 10% of all accidents; for LCA the estimate was lower at around 5% of all accidents. In this study, information regarding the circumstances of the accidents was considered and used to help define relevant accident types for the target population. A review of systems identified the sensing technologies used by current LDW and LCA systems and also provided information on advancements in functionality.

The target populations for LDW and LCA systems were identified in national data using accident characteristics and accident contributory factors. These were validated using in-depth data, with upper and lower ranges generated for the target population based on the ability of the national data query to correctly identify relevant accidents (those in which LDW or LCA would influence the accident outcome). After the target population for each accident type was identified, the percentage of casualties influenced was applied to European data and effectiveness information taken from the literature review in order to apply to the target population. Using published system costs and other information, the estimated benefit to cost ratios (including the benefits due to reduced congestion) over the period 2010-2020 were as follows:

Technology	Benefit-cost ratio	M1/N1	N2/N3	M2/M3
LDW	Min	0.13	0.18	0.47
	Max	4.18	6.56	23.97
LCA	Min	0.00	0.02	0.00
	Max	0.15	2.51	0.62
LDW & LCA	Min	0.07	0.58	0.31
	Max	4.08	36.39	24.19

These data show that the return on investment is more likely to be positive for LDW than for LCA systems, and that fitment to larger vehicles is more likely to result in a positive return than for smaller vehicles.

The benefit cost ratio ranges reported here are large. This is a result of the large ranges in estimated target population (those accidents influenced by the systems), the

effectiveness of the systems (0%-60% effective in some cases), and ranges of the cost information. It should also be noted that European casualty valuations were used and that significantly higher valuations are used by other countries. In order to reduce the range of the benefit to cost ratios, more precise data is required on one or more of these areas. In particular, information from European field operational trials has the potential to provide a more robust effectiveness estimates. Once this information is available, the benefits presented in this report can be updated.

The HMI of both the LDW and LCA systems is critical to the efficacy of warning systems. Systems on the market were reviewed and their strategies for conveying information to driver reviewed. Visual warnings were generally found to be least effective (especially in relation to situations were the driver is distracted) and were often combined with two stage warnings, the second stage of which was audible or haptic. These were found to be more effective, with the latter more unobtrusive to other occupants in the vehicle.

Standards on LDW and LCA systems were reviewed to form the basis of technical specifications for the systems and to ensure that the specification of the systems matched the circumstances in which they will be required to act in order to prevent real world accidents. Two standards were identified that were relevant for lane departure warning systems; ISO 17361 Lane Departure Warning Systems (ISO 17361:2007) and The Federal Motor Carrier Safety Administration Concept of Operations and Voluntary Operational Requirements for Lane Departure Warning Systems (FMCSA-MCRR-05-005). For lane change assistant systems; ISO 17387 Lane Change Decision Aid Systems (ISO 17387:2008) was the only identified standard.

Initial technical specifications for LDW and LCA systems have been developed, largely based on the most stringent requirements of ISO 17361:2007 and ISO 17387:2008. However, the initial specification for LDW specifies a latest warning to be given when the vehicle is level with the lane boundary and therefore has more stringent requirements than either ISO 17361:2007 or FMCSA-MCRR-05-005. The rationale for this requirement is so that the system provides a warning with which the driver can avoid the lane departure, thereby realising the estimated target population benefits.

The technical specification also highlights areas which are missing or require further work. It would be desirable for both systems to have performance assessments in a range of environmental conditions, since the literature review indicates that some systems can be influenced by adverse weather. Lane departure warning systems should also be operational irrespective of the lane marking type (within the range of markings used in Europe). A method of assessing this aspect of the performance of lane departure warning systems is missing from current standards. ISO 17361:2007 defines a zone used to assess the repeatability of the lane departure warning system. For the purposes of the technical specifications, it was assumed that this zone would permit a meaningful examination of the system’s repeatability; however, testing would be necessary to verify this. Also, during brief periods when the lane departure warning system cannot determine the position of the vehicle with respect to the lane, it was considered that the system should extrapolate the current position based on previous estimates of lane geometry and vehicle trajectory.

For LCA systems, it would be desirable for a system to detect a lane change irrespective of turn signal use. However, more information is required regarding the capacity of current lane change assistance systems to meet these specifications. Furthermore, it was identified that a LCA system should system should not respond to stationary objects at the side of the road or to vehicles travelling in the opposite carriageway.

It was estimated that if advanced LCA systems were to replace mirrors on all vehicle types, there is potential to reduce annual CO_2 emissions by 40,000 tonnes for EU-27.

The initial technical specifications produced for LDW and LCA systems are based on the published information and consideration of the appropriate safety requirements. If these specifications are developed further, it would be desirable to perform tests to validate the technical specifications. It also may be necessary to carry out further consultation with industry as part of this process.

Abstract

Lane Departure Warning (LDW) Systems monitor the position of the vehicle with respect to the lane boundary. When the vehicle is in danger of leaving the lane unintentionally, the system delivers a warning to the driver. Lane Change Assistant (LCA) Systems monitor the adjacent lanes to assist drivers when changing lane. If the driver of the vehicle fitted with the LCA system initiates a lane change manoeuvre and the system detects a vehicle in the adjacent lane, the system will alert the driver to the presence of the other vehicle.

The objective of this research was to gather and evaluate information regarding the performance standards of LDW and LCA systems and the likely costs and benefits of meeting these standards with respect to:

- Light vehicles (e.g. categories M1 and N1)
- Heavy goods vehicles (HGV) (e.g. categories N2 and N3)
- Large passenger vehicles (LPV) (e.g. categories M2 and M3)

The study considers the potential casualty savings to occupants of both the vehicle to which the equipment is fitted as well as occupants of other vehicles. The potential benefits for vulnerable road users (pedestrians, cyclists and motorcyclists) were also considered. Initial specifications for LDW and LCA assistance systems have been developed based on relevant standards and the safety requirements required to influence the target population of accidents.

1 Introduction

Lane Departure Warning (LDW) Systems monitor the position of the vehicle with respect to the lane boundary. When the vehicle is in danger of leaving the lane unintentionally, for example, when the driver is not paying full attention to the road ahead, the system delivers a warning to the driver. These systems do not provide any intervention to assist the vehicle to remain within the lane boundary. However, some systems supplement the warning with intervention to keep the vehicle within the lane in which it travelling, these Lane Keep Assist (LKA) Systems are not the main focus of this report, but have been included in the literature and systems review for completeness.

Lane Change Assistant (LCA) Systems monitor the adjacent lanes to assist drivers when changing lane. If the driver of the vehicle fitted with the LCA system initiates a lane change manoeuvre and the system detects a vehicle in the adjacent lane, the system will alert the driver to the presence of the other vehicle. These systems do not currently intervene to prevent the lane change from being carried out, although this functionality is expected to be provided by future systems.

The objective of this research was to gather and evaluate information regarding the performance standards of LDW and LCA systems and the likely costs and benefits of meeting these standards with respect to:

- Light vehicles (e.g. categories M1 and N1)
- Heavy goods vehicles (HGV) (e.g. categories N2 and N3)
- Large passenger vehicles (LPV) (e.g. categories M2 and M3)

The study considers the potential casualty savings to occupants of both the vehicle to which the equipment is fitted as well as occupants of other vehicles. The potential benefits for vulnerable road users (pedestrians, cyclists and motorcyclists) was also considered.

Currently LCA systems are designed only to detect other vehicles. Future development of the systems to detect pedestrians and cyclists has the potential to significantly increase the benefits of such systems. The use of enhanced LCA systems could offer the driver integrated information on the positional relationship between their vehicle and other road users. It is also possible that such systems could replace conventional mirror systems yielding savings in fuel consumption and hence CO_2 emissions. These potential benefits were also investigated in this research.

2 Literature survey

A literature survey was carried out to highlight any previous research in the fields of lane departure warning and lane change assistance. The intention was to draw on the findings of the literature when drafting the technical specifications for these systems in Section 5.

The survey can be found in Appendix A; however, a summary is provided in the following sections. Section 2.1 focuses on lane departure warning while Section 2.2 focuses on lane change assistance.

2.1 Lane departure warning

The literature survey described the problem of lane departure in terms of the proportion of police-reported collisions that result from the manoeuvre. In addition, the survey examined the causes and characteristics of these collisions in order to comment on the circumstances in which a lane departure warning system must operate. This was necessary to inform decisions about the outline technical specifications proposed for lane departure warning systems in Section 5.

Most of the research available on the frequency and characteristics of collisions resulting from a lane departure was carried out in the United States. The literature revealed that three broad accident types are important: a vehicle leaving the lane and striking oncoming traffic in the opposite carriageway; a vehicle leaving the lane and striking traffic travelling in the same direction in an adjacent carriageway; a vehicle leaving the lane and the roadway and striking a stationary object and/or rolling over. All three accident types are “lane departure collisions”, although they are not always grouped in this way in the literature, and researchers often analyse them separately. Even when these accident types are combined, lane departure collisions are a relatively small proportion (around 10 percent) of the total number of police-reported collisions in the United States. Assuming that the situation in Europe is similar, the total number of collisions that could be avoided is nevertheless significant.

Two main lane departure accident types emerged from the literature. In the first, the vehicle drifts out of the lane slowly, for a range of reasons that can include driver fatigue, inattention or use of alcohol or drugs. In the second accident type, the driver loses control of the vehicle due to excessive speed (or inappropriate speed in adverse conditions), mechanical failure, or once again, impairment as a result of alcohol or drugs. Information about the circumstances of lane departure conditions suggests that most road departure collisions occur on straight sections of carriageway; however, same direction and opposite direction lane departure collisions are distributed more evenly between straight and curved roads. Investigations of other environmental factors reveal that many lane departure collisions occur during daylight with no adverse weather conditions.

The survey also examined literature on the dynamics of lane keeping and lane departure. This was necessary to provide additional information that was not forthcoming from the collision studies due to the retrospective way that the information was collected. This revealed that time to line crossing is a key indicator of driver performance and a way of characterising the potential for lane departure. The time to line crossing is a calculated measure of the amount of time before a lane departure would occur, given the current speed and position of the vehicle. A warning threshold based on time to line crossing would need to give drivers enough time to prevent a departure while avoiding nuisance or annoying alarms. Studies reported that around one second is an appropriate warning limit that balances these considerations.

It was considered that any technical specifications for lane departure warning systems would need to include the human-machine interface. This is the means by which the system conveys information to the driver. The literature revealed that the nature and performance of this interface can affect the way that a driver responds to a warning following a lane departure. Three warning strategies are realistic for lane departure warning: visual, audio or haptic. These may feature in one- or two-stage warnings. One stage (imminent) warnings are more common because there would typically be insufficient time before departure occurs to allow a graded series of warnings. However, some advanced systems are capable of distinguishing the likelihood of a collision resulting from the departure and can therefore offer only a cautionary warning when the likelihood of lane departure is low.

Visual warnings are not recommended for lane departure warning systems unless they are supplemented with auditory and/or haptic warnings. This is because lane departures often occur due to inattentive drivers who may fail to notice a visual warning. Auditory warnings are an effective means of warning drivers, but they can disturb other passengers. In addition, most auditory warnings do not guide action, which could be important if the vehicle is fitted with multiple driver assistance systems. In contrast, haptic warnings can alert the driver without disturbing others in the vehicle, and can provide information in a more intuitive way. However, studies of the effectiveness of auditory warnings in comparison to haptic warnings were broadly inconclusive.

A further consideration was the effect of lane departure warning on driver behaviour. Lane departure warning systems are fitted to vehicles with the expectation that drivers will take corrective action when they are issued with a warning. However, their fitment may have other affects on drivers and driving. The survey examined the literature for research on these effects in order to inform decisions about the performance aspects of the outline technical specifications for lane departure warning systems.

A consistent finding from the literature was that lane keeping is improved when the vehicle is fitted with a lane departure warning system. It appears that drivers are more aware of the position of their vehicle, possibly in an effort to reduce the number of warnings, or because their safety awareness has been raised. There is no effect on the frequency of (intended) lane changes, but turn signal use increases during these manoeuvres. There is also no effect on vehicle speed; however, there is anecdotal evidence to suggest that some drivers will be more inclined to use their hands for other tasks if their vehicle is fitted with a lane departure warning system.

Lane departure warning systems have shown to be effective in warning drivers and preventing lane departures. The research has extended to drowsy drivers, an important target group for these systems. However, there remains a need for more long-term research on the effects of lane departure warning, particularly when the system is integrated with other functions. In addition, the experimental tests and simulations reviewed may not be fully representative of on the road driving conditions, thereby inducing driver behaviour unrealistic of real-world situations.

The final part of the survey (with respect to lane departure warning) examined the costs and benefits of the technology. Two important studies were found from Europe; however, these assessed lane departure warning systems in combination with lane change assistance systems. It was impossible, therefore, to gauge the costs and benefits of the individual systems. Nevertheless, both studies reported the benefits to be around twice as high as the costs. It should be noted that very different methodologies were used by these two studies, mainly as a result of how the target population was identified, and .this resulted in different estimates of the number of accidents and casualties prevented.

2.2 Lane change assistance

An analysis of the circumstances of lane change collisions was carried out from the findings of the literature. This was necessary to understand the magnitude of the problem, and the causes and characteristics of these collisions. The information was used to inform decisions about the outline technical specifications for lane change assistance systems in Section 5. For example, an understanding of the circumstances of real lane change collisions was useful when considering technical specifications related to the detection area of lane change assistance systems. In addition, knowledge of the environmental conditions when lane change collisions occur was useful when considering performance specifications.

The literature reported that lane change collisions represent a relatively small percentage (5 percent) of the crash population; nevertheless, the number of collisions that could potentially be avoided across Europe is significant. Lane change collisions may occur because the driver was unaware of another vehicle in the adjacent lane. There is little consensus on why drivers fail to note the presence of these vehicles, but poorly executed observation (both direct and indirect visibility), visibility obstructions in the vehicle and driver distraction were proposed in the literature. There are areas of the road that cannot be seen while looking through the rear view or side mirrors (especially if the adjustment of these is poor), but many collisions involve vehicles outside these “blind spots”. The implication for the detection area of a lane change assistant system is that it must cover the full length of the vehicle and extend beyond simple blind spot monitoring to address these collisions. Statistics on the environmental conditions of lane change collisions indicate that most occur during daylight hours or on lit roads with dry roadway conditions.

Accident data on lane change collisions can provide a great deal of useful information, but this is restricted by what can be collected at the scene of the collision or by retrospective investigations and driver interviews. An analysis of real lane change manoeuvres was therefore carried out from the findings of the literature. This analysis was based on field experiments, where drivers were monitored over extended periods, and from driving simulator studies. This was necessary to supplement the collision data and provide more detailed information on driver behaviour and driving performance. It was anticipated that this information would lead to a better understanding of the relationship between the subject vehicle and other vehicles in the adjacent lane. This was useful when considering technical specifications related to for warning timing and the size of the detection area.

The literature revealed that one of the main reasons that drivers change lanes is to pass another vehicle that is travelling at a slower speed. Hence it would appear that drivers perform a lane change to maintain their current speed. The majority of drivers feel comfortable when there is a distance of around 12 m in front and to the rear of their vehicle at the start of their lane change. However, studies reported that drivers were also willing to change lanes when another vehicle was approaching from the rear. In addition, drivers sometimes initiated steering to change lanes when there was an overtaking vehicle present in the adjacent lane. This was done in anticipation of a gap behind the overtaking vehicle and did not result in any collisions. This could have implications for the timing of warnings in a lane change assistant system, if nuisance warnings are to be avoided. The field experiments also revealed that turn signals were used in less than half of intended lane changes. The lane change collision studies did not discuss turn signal use, possible due to the difficulty in establishing this from accident data. However, this is a potentially important finding with implications for lane departure warning systems as well as lane change assistant systems. Finally, field experiments of representative driving situations were used to propose a suitable sensing range to detect adjacent vehicles. This information was also important and could be used to form the basis for future technical specifications.

An important aspect of a lane change assistant system is the way it communicates with the driver. The effect of the human-machine interface on driver behaviour was examined from the literature. This was necessary to understand the way that drivers respond to different warning types and whether the location or type of warning is important. This information was useful when considering technical specifications for the human-machine interface of lane change assistance systems.

The literature revealed that two-stage warnings are usually recommended for lane change assistance systems. The first stage is reserved for cautionary warnings where there is a low likelihood of a collision. The second stage is a separate, imminent warning where there is a high likelihood of a collision. Visual, auditory or haptic warnings may be issued; however, visual warnings are recommended for low priority information only because they depend on the driver looking at the warning display. In contrast, auditory warnings can attract the driver's attention irrespective of where they are looking and are therefore suitable for imminent warnings. While there was limited information on the effect of auditory warnings with lane change assistance systems, the findings were generally positive. Similarly, there was limited information on haptic warnings with lane change assistance. Broader research on the effectiveness of haptic warning systems in general could have been influenced by the specific system being evaluated and may not, therefore, provide an accurate indication of the effectiveness of haptic warnings with lane change assistance systems.

Another important consideration is the effect of lane change assistance on driver behaviour. Very few field tests and simulator studies in which a lane change assistance system was fitted to a test vehicle have been reported in the literature. It was anticipated that the findings of such studies would be useful in identifying issues that need to be addressed by future system and performance requirements. Further research in this area is required; nevertheless, it would appear that there are no adverse affects on lane change frequency, mirror usage or over-the-shoulder glances. In fact, there was some evidence that lane change assistance systems improve driving, either to prevent warnings, or because drivers' awareness of lane change safety had been raised.

Finally, the costs and benefits of lane change assistance were examined from the literature. Two important European studies were found; however, as discussed in Section 2.1, these assessed the costs and benefits of lane change assistance in combination with lane departure warning. It was impossible, therefore, to gauge the costs and benefits of the individual systems from these sources.

3 Review of technical standards

Road vehicles are subject to comprehensive regulation. The requirements cover both the construction of the vehicle and its use. The approval of most vehicles is based around the EC Whole Vehicle Type Approval (ECWVTA) System. With this approach, a production sample is tested and if it passes the tests and the production methods pass an inspection, vehicles of the same type are approved for production and sale within Europe. A Framework Directive lists a series of separate Technical Directives and Regulations that the vehicle must be approved to. In order to gain ECWVTA, a vehicle has to meet the requirements of each of the relevant individual Directives. The scheme was introduced (for M1 vehicles) in the 1970s through Directive 70/156/EEC. A recast new Framework Directive, 2007/46/EC, has since been published and extends the scheme to all vehicle categories.

At the present time, there are no EC Directives or UNECE Regulations for lane departure warning and lane change assistant systems. This is also the case for advanced driver assistance systems in general, although their presence in the vehicle, and their function, may overlap with existing Regulations, such as those for steering, braking, interior fittings or field of vision. There is a similar situation in the United States. The National Highway Traffic Safety Administration (NHTSA) has a legislative mandate under Title 49 of the United States Code, Chapter 301, Motor Vehicle Safety, to issue Federal Motor Vehicle Safety Standards and Regulations. However, there are currently no Standards or Regulations for lane departure warning and lane change assistant systems in the United States.

These systems have, for the most part, been relatively slow to reach the market (eSafety forum, 2008). However, the development and use of new technologies is being encouraged in Europe with a view to reaching casualty reduction targets. Furthermore, improving technology, coupled with vehicle manufacturers’ desire to achieve a competitive advantage, has led to the emergence of several lane departure warning and lane change assistant systems.

With no regulatory framework in place for the design and evaluation of lane departure and lane change assistant systems, vehicle manufacturers have been working together with research institutes to develop Standards for these systems. The International Organisation for Standardisation (ISO) has been the main forum for the creation of Standards for lane departure warning and lane change assistant systems. ISO is a non-governmental organisation that draws on the national standards institutes of 157 countries. ISO Standards are voluntary; however, the application of a Standard may be included in a technical file, compiled by a product manufacturer, to demonstrate that they have considered the risks associated with the use of their product. International Standards are usually prepared through the work of a technical committee. Lane departure warning and lane change assistant systems fall within the terms of reference of Technical Committee ISO/TC 204 Intelligent Transport Systems.

There are several instances where existing ISO Standards have formed the basis for proposals to amend European legislation. This section of the report reviews the relevant Standards for lane departure warning and lane change assistant systems. This review examines the key system, function and test requirements. Relevant codes of practice are also included.

3.1 Lane departure warning systems

3.1.1 Overview

Two documents were identified that were relevant for lane departure warning systems; ISO 17361 Lane Departure Warning Systems (ISO 17361:2007) and The Federal Motor Carrier Safety Administration Concept of Operations and Voluntary Operational Requirements for Lane Departure Warning Systems (FMCSA-MCRR-05-005).

ISO 17361:2007 was published in February 2007. The Standard defines the specifications, requirements and test methods for systems intended for passenger cars, commercial vehicles and buses.

FMCSA-MCRR-05-005 was published in July 2005. The requirements cover all aspects of the systems for large trucks greater than 10,000 lbs; however, there are no test methods included to assess their performance.

Both ISO 17361:2007 and FMCSA-MCRR-05-005 define lane departure warning systems as in-vehicle systems that warn the driver when an unintentional lane departure has occurred. They will not take any automatic action to prevent a possible lane departure and the driver remains responsible for the safe operation of the vehicle. ISO 17361:2007 requires that a lane departure warning system includes the following functional elements as shown in Figure 3.1. Optional functions are shown with dashed lines.

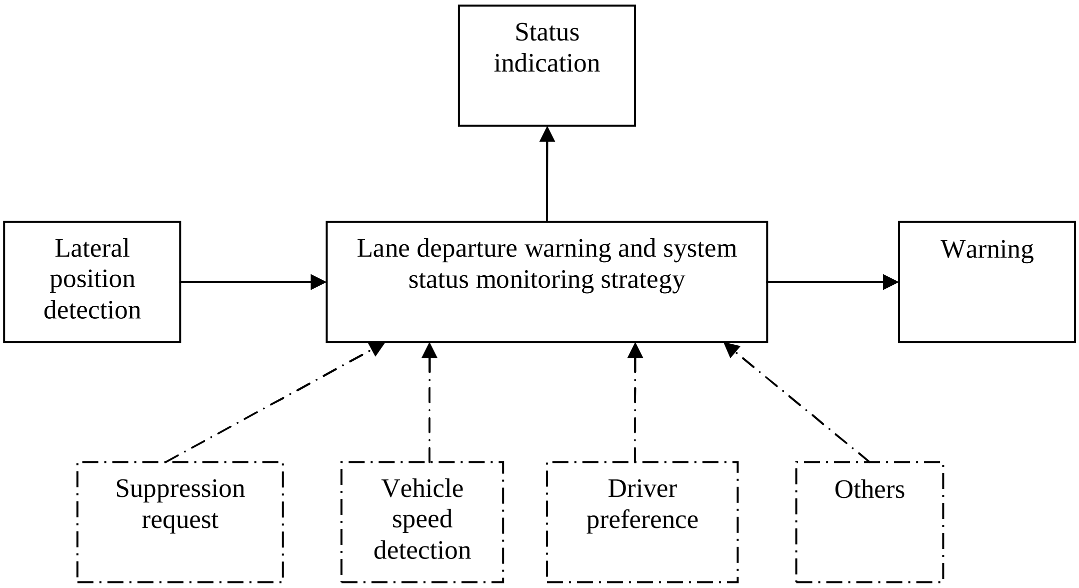

Figure 3.1. Functional elements of a lane departure warning system (ISO 17361:2007).

The terminology used in FMCSA-MCRR-05-005 is different, but it would appear that the main functional elements are the same. However, FMCSA-MCRR-05-005 includes some additional elements that are either voluntary or not required by the ISO Standard. The functional elements of a lane departure warning system in FMCSA-MCRR-05-005 are shown in Figure 3.2.

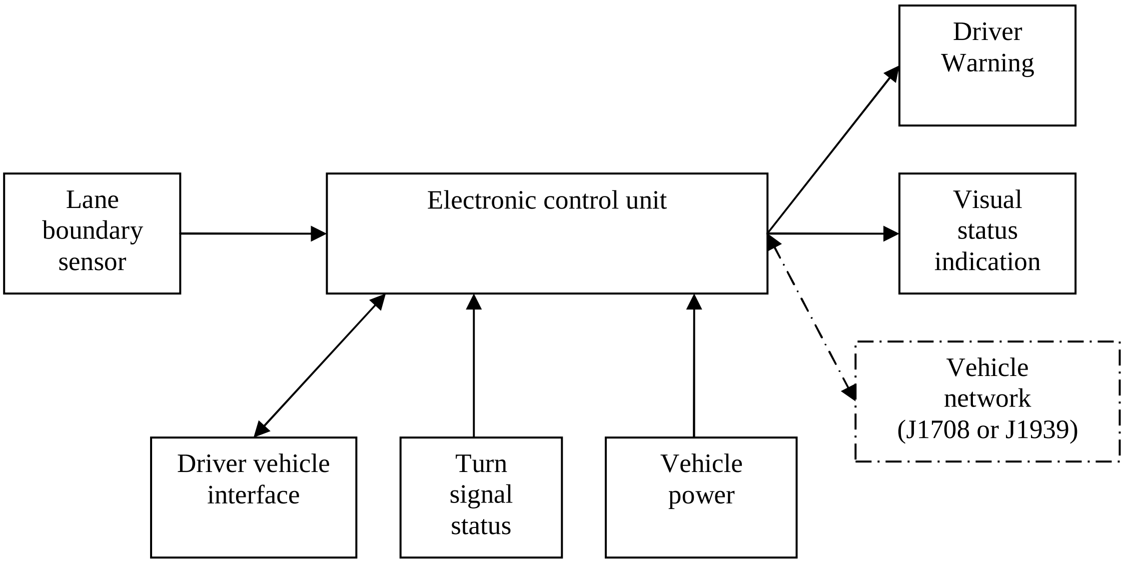

Figure 3.2. Functional elements of a lane departure warning system (FMCSA-MCRR-05-005).

A typical lane departure warning system can be characterised by the sensor technology, the behaviour of the system, the capability of the system and finally, by the human interface. The following sections examine how ISO 17361:2007 and FMCSA-MCRR-05-005 define requirements for these key areas.

3.1.2 Sensor technology

Neither ISO 17361:2007 nor FMCSA-MCRR-05-005 makes any specific requirements about the type of sensor technology used in a lane departure warning system. For instance, the ISO Standard states (in the scope) that a system may utilise optical, electromagnetic, GPS, or other sensor technologies. FMCSA-MCRR-05-005 also permits any type of sensor technology and comments that if a vision-based system is used, the image of lane boundaries may be black or white or colour and may be transferred in either digital or video format.

The existing requirements allow manufacturers to develop their own solutions without restricting the design process. This is an important consideration for any legislative or regulatory activity. Nevertheless, it would be worthwhile to consider whether any further requirements would be appropriate, based on the findings from the literature review.

3.1.3 System behaviour

This section outlines the way that ISO 17361:2007 and FMCSA-MCRR-05-005 characterise the behaviour of lane departure warning systems. There are two key areas to consider. Firstly, there is the speed threshold and road curvature, which are used as a basis for classifying the systems. Secondly, there is the warning threshold, which determines when the warning will be issued.

3.1.3.1 Speed threshold and road curvature

ISO 17361:2007 uses a system of classification to characterise the behaviour of a lane departure warning system. A Class I system must operate when the vehicle speed is greater than or equal to 20 m/s (72 km/h or 45 mile/h) and when the radius of curvature of the road is greater than or equal to 500 m (i.e. “straight” or “near straight” roads). A Class II system must operate when the vehicle speed is greater than or equal to 17 m/s (61 km/h or 38 mile/h) and when the radius of curvature of the road is greater than or equal to 250 m. However, both systems may also operate at lower speeds.

FMCSA-MCRR-05-005 states that a lane departure warning system should function when the vehicle is travelling at or above a speed of 60 km/h (37 mile/h). It also states that a system should issue warnings on straight roads and when one of two curvature test conditions is encountered. These conditions are presented in a table that is referenced from ISO/CD 17361:2003 (an earlier draft version of the ISO standard). The first condition occurs when the radius of curvature of the road is greater than or equal to 250 m and the vehicle speed is less than 72 km/h (45 mile/h) but greater than or equal to 61 km/h (38 mile/h). The second condition occurs when the radius of curvature of the road is greater than or equal to 500 m and the vehicle speed is greater than or equal to 72 km/h (45 mile/h).

It would appear that efforts have been made to harmonise the speed threshold and curvature conditions in FMCSA-MCRR-05-005 with the version of the ISO Standard that was available at the time. Before further comment can be made on these conditions, it will be important to examine the information about accident types collected in the literature review, and the accident analysis parts of this project. This should give an indication of the relevance of these specified conditions in relation to the vehicle speed and road curvature in collisions related to lane departure.

3.1.3.2 Warning threshold

Both ISO 17361:2007 and FMCSA-MCRR-05-005 describe the concept of lane departure warning in terms of warning thresholds and warning threshold placement zones. A warning threshold is the line across which a warning is issued by the system. The threshold is placed within a zone defined by an earliest warning line and a latest warning line. The earliest warning line is inside the lane boundary and the latest warning line is outside the boundary.

ISO 17361:2007 requires that the latest warning line is located 0.3 m outside the lane boundary for passenger cars and 1 m outside the boundary for trucks and buses. The location of the earliest warning line depends on the rate of departure of the vehicle. This is illustrated in Table 3-1 and Figure 3.3. The rate of departure is defined as the approach velocity at a right angle to the lane boundary at the warning issue point.

Table 3-1. Location of earliest warning line.

Rate of departure, V (m/s)	Maximum distance inside the lane boundary (m)
$0 < V \leq 0.5$	0.75
$0.5 < V \leq 1.0$	1.5 x V[a]
$1.0 < V$	1.5

[a] is the time to lane crossing multiplied by the rate of departure

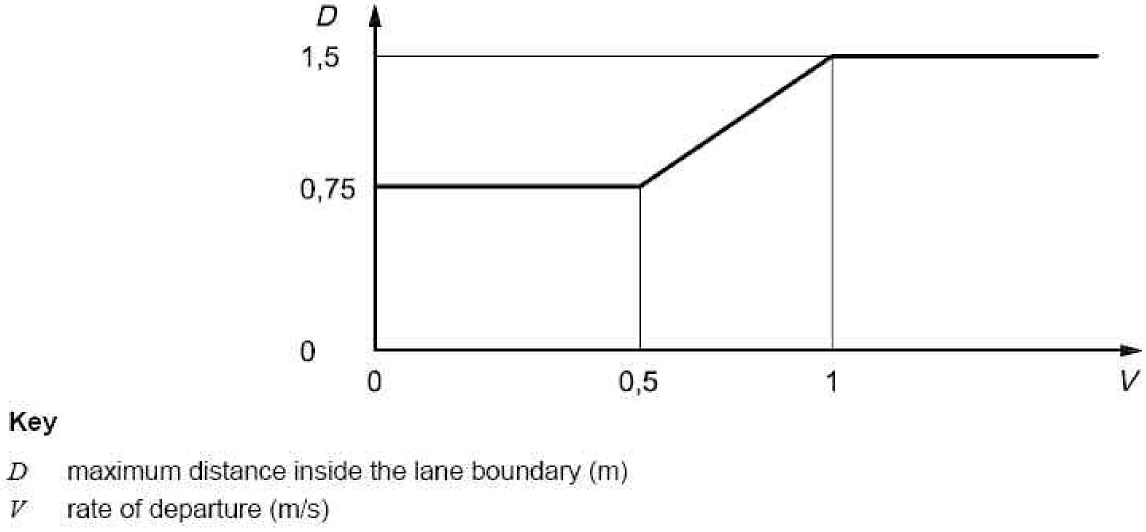

Figure 3.3. Location of earliest warning line (ISO 17361: 2007).

FMCSA-MCRR-05-005 (relevant to large trucks only) states that a lane departure warning system should be able to track lane boundaries and issue warnings within ± 0.1 m from the warning threshold when the rate of departure is less than 0.8 m/s. However, there are no requirements for the location of the threshold with respect to the lane boundary.

3.1.4 System capability

This section outlines the way that ISO 17361:2007 and FMCSA-MCRR-05-005 characterise the capability of lane departure warning systems to detect lane boundaries and issue warnings. There are two key areas to consider: firstly, the types of boundaries that the system can detect, and secondly, the weather and environmental conditions in which the system can operate.

3.1.4.1 Detectable boundaries

A vehicle might encounter a number of different lane boundaries during a typical journey. These can include single or double painted lines and raised pavement markers, with or without reflective material. Additionally, painted lines can be uninterrupted or interrupted (i.e. broken) with different segment lengths. An effective lane departure warning system will need to function irrespective of the lane boundary type. However, this is complicated further by the fact that the boundary geometry differs from country to country.

ISO 17361:2007 does not include specific requirements for the types of boundary that the system should detect; however, there are performance tests for the lane departure warning system. These include a warning generation test on a curve, a repeatability test on a straight course and a test for false alarms. The test environment conditions state that “the visible lane markings of the test location shall be in good condition in accordance with the nationally defined visible lane markings. Also, they shall be marked in accordance with applicable standards for lane-marking design and materials”. An informative annex includes details of the road markings in a selection of countries. It is possible that regional variations in the line marking pattern and width will not affect the capacity of the lane departure warning system to detect the boundary, but this would need to be confirmed from the literature.

FMCSA-MCRR-05-005 states that a lane departure warning system should detect vehicle position relative to the following types of visible lane boundary:

- Solid and dashed painted lines
- Single and double painted lines
- Yellow and white painted lines
- Raised pavement markers
- Lines with and without reflectors/reflective material

There are no performance tests within FMCSA-MCRR-05-005, but there is a requirement for the system to track the boundary and issue a warning 95 percent of the time, when lane boundary markings of the types listed above are encountered. However, there is no information about how this requirement should be evaluated.

3.1.4.2 Weather and environmental conditions

Many lane departure warning systems use a camera and image processing unit to detect the position of the vehicle with respect to the lane boundary. Such a system is likely to be affected by the capacity of the camera to observe the boundary in different weather or environmental conditions. For example, if there is water, snow or ice on the carriageway or if it is foggy. ISO 17361:2007 does not include requirements for the environmental conditions in which the lane departure warning system should operate. In fact, the performance test of the system must be carried out with a horizontal visibility range greater than 1 km.

In contrast, FMCSA-MCRR-05-005 states that a lane departure warning system should detect vehicle position relative to the lane boundary where lane markings are clearly visible in daylight (sunny/cloudy), night time (with and without streetlight illumination) and twilight (sunrise/sunset) conditions. However, there are no performance tests and no information is provided regarding the evaluation of this requirement.

Therefore, both ISO 17361:2007 and FMCSA-MCRR-05-005 have no performance requirements in adverse weather conditions. If the casualty benefit of these systems is to be maximised, the system should function in situations reflective of that experienced by the accident target population.

3.1.5 Human-machine interface

This section outlines the way that ISO 17361:2007 and FMCSA-MCRR-05-005 specify the human-machine interface requirements for lane departure warning systems. There are three key areas to consider: firstly, the way that the warning is presented to the driver, secondly, the way that the status of the system is communicated, and finally, any driver control and adjustment features.

3.1.5.1 Warning presentation

The type of warning issued by the lane departure warning system is critical as it is the means by which the system communicates with the driver when a lane departure has occurred. Since it is the driver that must take action to correct the vehicle, their initial perception of (and reaction to) the warning can affect the amount of departure from the lane.

ISO 17361:2007 and FMCSA-MCRR-05-005 both state that a haptic and/or audible warning should be issued when the vehicle crosses the warning threshold. Visual warnings are permitted only as a supplement to the main warning, for instance, as a visual cue to indicate the direction of departure. The literature review highlighted several studies of the effectiveness of different warning systems. It will be important to take the findings of these studies into account, when discussing the requirements of the existing standards.

3.1.5.2 Status indication

Most drivers will assume that a lane departure warning system is operational throughout their journey. However, there will be instances where the system is disabled or where it is unable to track the lane boundary (for example where the lane boundary is obscured, worn or temporarily not present). It is important, therefore, that the driver is alerted to the status of the lane departure warning system in order to avoid such confusion. The way this information is presented to the driver is also important and could have an adverse effect on their behaviour or lead to unforeseen problems related to distraction.

Both ISO 17361:2007 and FMCSA-MCRR-05-005 require that the system status is indicated to the driver. Additionally, the driver must be informed when a failure is detected on start-up or during operation, or when the system is unable to warn the driver due to temporary conditions.

ISO 17361:2007 states that “the system status indication shall be easy to understand for the driver”, but it does not state how this should be achieved or measured, (except for a general requirement for any symbols used to be standard symbols for the particular message). FMCSA-MCRR-05-005 goes further by describing the type of indicator that should be used. For instance, it states that a visual indicator should be used to indicate that the system is operational and to indicate when it is not tracking the lane boundary. It also states that a visual or audible indicator should be used when the system fails or malfunctions. There is also a requirement for lane departure warning indicators to be discernable in direct sunlight and at night.

3.1.5.3 Driver control and adjustment

Lane departure warning systems can be designed with adjustable warning thresholds that let the driver define when the warnings occur with respect to the lane boundary. Adjustable systems might be welcomed by consumers, but it will be necessary to examine whether there are any adverse effects identified in the literature. Neither ISO 17361:2007 nor FMCSA-MCRR-05-005 require adjustable thresholds; however, the ISO Standard includes an optional function for the warning thresholds to be adjustable within the placement zone.

3.2 Lane change assistant systems

3.2.1 Overview

One document was identified that was relevant for lane change assistant systems; ISO 17387 Lane Change Decision Aid Systems (ISO 17387:2008). It should be noted that lane change assistant and lane change decision aid are different names for the same system. Lane change assistant will be used in this Section, when referring to systems within the scope of ISO 17387:2008, for consistency with the rest of this report.

ISO 17387:2008 was published in April 2008. The Standard defines the specifications, requirements and test methods for systems intended for forward moving cars, vans and straight trucks. It does not address lane change assistant systems for motorcycles or articulated vehicles such as tractor/trailer combinations and articulated buses. Lane change assistant systems are defined in the Standard as systems that warn the driver against collisions that may occur due to a lane change manoeuvre. They will not take any automatic action to prevent a possible collision and the driver remains responsible for the safe operation of the vehicle.

ISO 17387:2008 requires that a lane change assistant system operates according to a state diagram, rather than a series of specific functional elements. The diagram describes two main states: System Inactive and System Active, and is shown in Figure 3.4. There are also a series of states within the Active State as the Figure highlights.

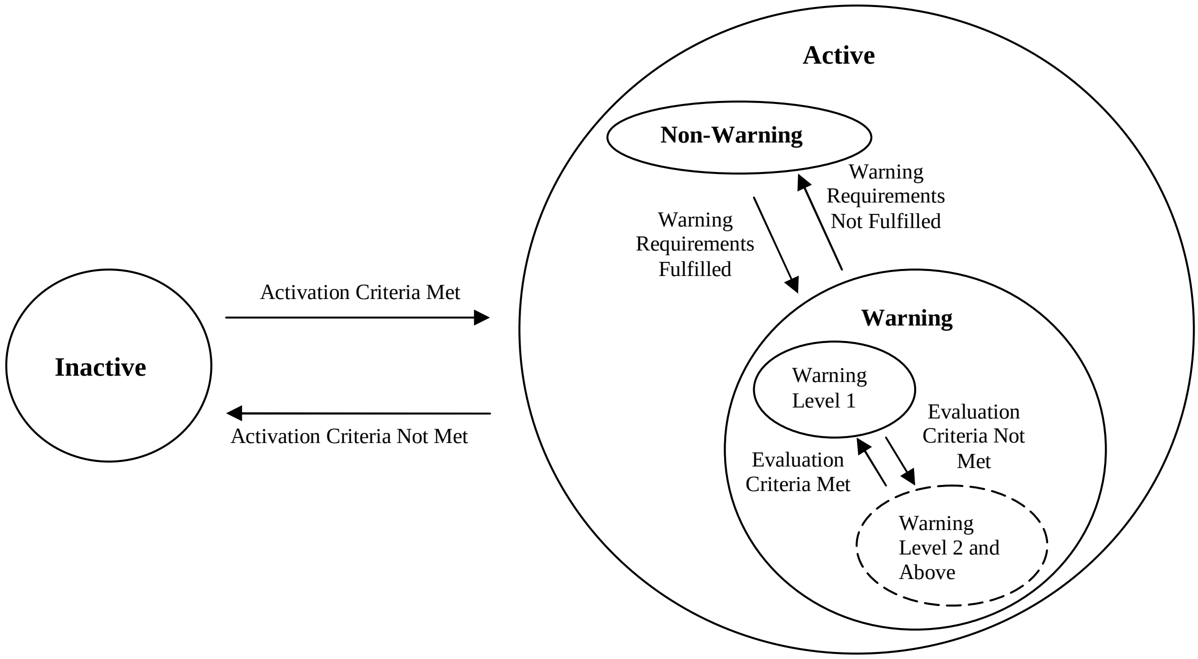

Figure 3.4. Lane change assistant system state diagram (ISO 17387:2008).

A typical lane change assistant system can be characterised by the sensor technology, the behaviour of the system, the capability of the system and finally, by the human interface. The following sections describe how ISO 17387:2008 defines requirements for these key areas.

3.2.2 Sensor technology

There are no requirements or comments relating to the type of sensor technology used in a lane change assistant system in ISO 17387:2008. This allows manufacturers to develop their own solutions without restricting the design process. This is an important consideration for any legislative or regulatory activity. Nevertheless, it would be worthwhile to consider whether any further requirements would be appropriate, based on the findings from the literature.

3.2.3 System behaviour

This section outlines the way that ISO 17387:2008 characterises the behaviour of lane departure warning systems. There are two key areas to consider. Firstly, there is the coverage zone over which the system will detect another vehicle. Secondly, there is the maximum closing speed of the target vehicle.

3.2.3.1 Coverage zone

The coverage zone is the entire area monitored by the lane change assistant system. The system will detect another vehicle when it enters this zone. ISO 17387:2008 describes the coverage zone in terms of a subset of smaller zones, adjacent to, or behind the subject vehicle. The extent of the coverage across this subset of zones is used to classify the behaviour of a lane change assistant system. A Type I system covers the zones adjacent to the subject vehicle and therefore provides blind spot warning only. A Type II system covers the zones to the rear of the subject vehicle and therefore provides closing vehicle warning only. A Type III system provides both blind spot and closing vehicle warning and provides full lane change warning.

3.2.3.2 Target vehicle closing speed

Type I and Type II lane change assistant systems are classified further according to the maximum closing speed of the target vehicle (i.e. the vehicle being tracked by the system) and the minimum radius of curvature of the road. A Type A system will operate up to a target vehicle closing speed of 10 m/s (36 km/h;22 mile/h) with a radius of curvature of at least 125 m. A Type B system will operate up to a target vehicle closing speed of 15 m/s (54 km/h;34 mile/h) with a radius of curvature of at least 250 m. A Type C system will operate up to a target vehicle closing speed of 20 m/s (72 km/h; 45 mile/h) with a radius of curvature of at least 500 m. A lane change assistant system may belong to more than one of these types.

3.2.4 System capability

This section outlines the way that ISO 17387:2008 characterises the capability of lane departure warning systems to detect lane boundaries and issue warnings. There are two key areas to consider: firstly, the warning requirements, and secondly, the weather and environmental conditions in which the system must operate.

3.2.4.1 Warning requirements

There are three types of lane change assistant system, based on the system of classification in ISO 17387:2008. These were described in Section 3.2.3.1. The capability of each type of system is measured against a series of warning requirements in the Standard. The requirements refer to a Figure that shows a vehicle located towards the top and centre of a grid. This Figure is reproduced here in Figure 3.5. The vehicle is the subject vehicle fitted with the lane change assistant system. Each horizontal and vertical line within the grid is labelled with a letter. The lines are used to describe a series of zones that shape the warning requirements. The system will issue a warning to the driver depending on the location of the other vehicle on the grid and on the type of function provided by the system (i.e. blind spot warning, closing vehicle warning or lane change warning). The Standard also includes a series of performance tests for each type of system. The tests include a number of overtaking manoeuvres carried out with a subject vehicle and another vehicle (always represented by a motorcycle) at different speeds.

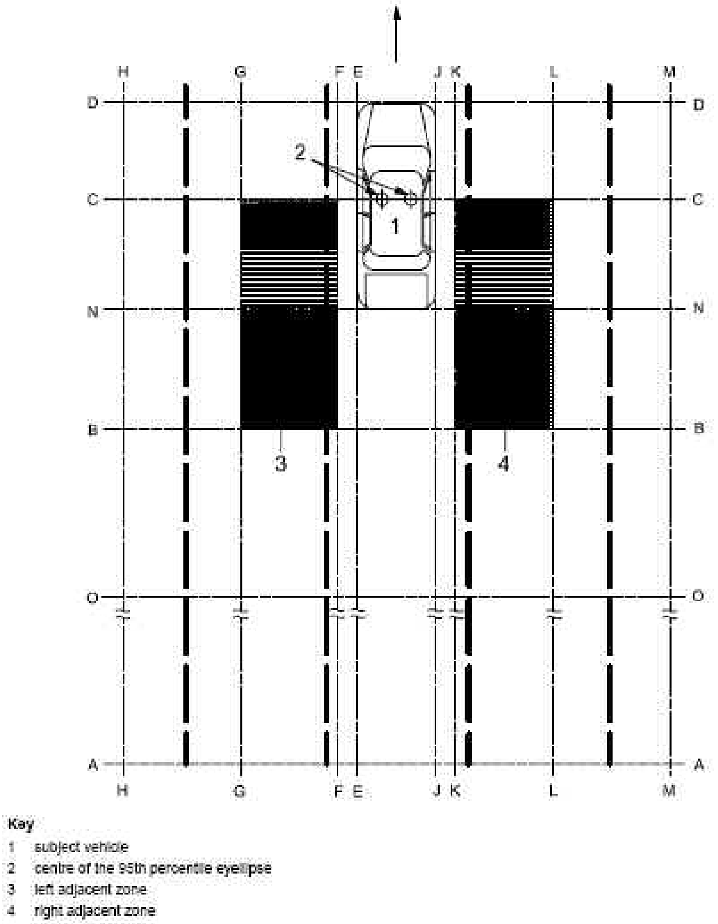

Figure 3.5. Warning requirements diagram (ISO 17387:2008).

3.2.4.2 Weather and environmental conditions

ISO 17387:2008 does not include requirements for the environmental conditions in which the lane change assistant system should operate. However, the performance tests of the system must be carried out on flat, dry asphalt or concrete with an ambient temperature within range of 10 °C ± 30 °C and a horizontal visibility range greater than 1 km.

3.2.5 Human-machine interface

This section outlines the way that ISO 17387:2008 specifies the human-machine interface requirements for lane change assistance systems. There are two key areas to consider: firstly, the way that the warning is presented to the driver and secondly, the way that the status of the system is communicated.

3.2.5.1 Warning presentation

The type of warning issued by the lane change assistant system might influence the amount of time that it takes for the driver to perceive the warning and then react to it. It is, therefore, a very important part of the system. ISO 17387:2008 states that only a visual warning should be used when the system is in the Warning Level 1 state (see Figure 3.4). This reflects the less urgent nature of this state compared with others at subsequent levels. In Warning Level 2 and above (where the urgency has increased) the system may use visual, audible and/or haptic warnings.

The Standard recommends that the warnings are used to indicate the side on which the other vehicle is present. Additionally, the Standard recommends that visual warnings are placed to encourage mirror usage and that any warnings are clearly distinguishable from other signals of the same type within the vehicle.

3.2.5.2 Status indication

A driver might assume that a lane change assistant system is active throughout their journey. However, there could be periods when the system is inactive. For example, if the driver has failed to activate a manual system, or if certain criteria have not been met that would activate an automatic system. Clearly, a driver needs to know when the system is active to avoid any confusion. The way this information is presented to the driver is also important and could have an adverse effect on their behaviour or lead to unforeseen problems related to distraction.

The requirements for status indication within ISO 17387:2008 depend on the way the system is activated. If the system is activated and deactivated manually by the driver, then the driver’s selection should be indicated visually, according the Standard. Additionally, if a switch is used, and the position of the switch is clearly understood by the driver, then the switch can be considered to be the indicator for a manual system. All other systems should indicate visually whether they are in the active or inactive state (see Figure 3.4).

4 Review of systems

There are a number of different systems that are intended to assist the driver to maintain their position within a lane or to assist the driver to change lane. These systems include LDW and LCA systems, but a number of other systems have also been identified.

Information was preliminarily collected from websites of vehicle manufactures, Tier 1 suppliers and automotive news sites. More specific information about the systems was also gathered from vehicle owner's manuals.

The vehicle manufacturers and Tier 1 suppliers were also contacted directly and asked to provide more information about current systems and systems soon to be introduced to the market.

The following section describes the information collected in relation to the technology used, the system capabilities and the interface with the driver. A full list of the systems identified can be found in Appendix B. It should be noted that some Tier 1 suppliers may provide the same technology to different vehicle manufacturers who have the systems customised to their own requirements.

4.1 Lane departure warning

A lane departure warning system is defined as a system that warns the driver when an unintentional lane departure is about to occur. The system will not take any automatic action to prevent a possible lane departure and the driver remains responsible for the safe operation of the vehicle.

There are seven LDW systems for passenger vehicles currently available on the market, two LDW systems are exclusive to North America and two LDW systems are exclusive to Europe. Three of the LDW systems are available in both Europe & North America.

There are three LDW systems for trucks and one coach system available. The truck systems are available across both North America and Europe.

LDW systems are currently only an optional extra for the more excusive vehicle models costing £300-£350 (€384-€448) or can be included in a package, such as with adapted cruise control. Truck systems are mainly available only as aftermarket additional system.

4.1.1 Sensor technology

Several different technologies have been utilised to create LDW systems. There are currently two types of LDW systems that have been introduced to the market; a camera-based system and an infra-red system.

4.1.1.1 Camera systems

The typical camera-based LDW system utilises a forward-looking CCD or CMOS camera mounted behind the windscreen that continuously tracks visible lane markings. This is linked to a computer with image recognition software that may also compute inputs for vehicle information such as speed, yaw rate, and steering angle. Camera-based LDW systems rely on the lines painted on the roadway to calculate the lateral divergence and divergence angle from the lane's centre. It then estimates the future vehicle position through sophisticated algorithms. If the data suggests that the vehicle is leaving its intended path unintentionally, the system alerts the driver.

There is also a camera system that uses a camera at the rear of the vehicle to monitor the lane position. This has the benefit that the same camera is also used for rear-view monitoring during parking manoeuvres.

4.1.1.2 *Infra-red systems*

An infrared-based LDW system uses a series of infra-red light sensors mounted under the front bumper of the vehicle to identify the lane markings on the roadway. Each sensor contains an infra-red light-emitting diode and a detection cell. The sensors detect the variations in the reflections from the infra-red beams emitted by the diode onto the road. When the vehicle moves over a lane marking the system detects a change and alerts the driver if the indicator signal has not been used.

4.1.2 *System behaviour*

Current LDW Systems have three operational performance criteria; operation speed, road curvature and warning threshold.

- LDW systems are typically operational at speeds of 56-72 km/h (35-45 mile/h) for passenger vehicles and 64-80 km/h (40-50 mile/h) for trucks and coaches.
- LDW systems are typically operational on straight roads and curves of a radius of 230m or greater.
- The warning threshold varies depending on the technology; camera systems are able to work to the warning line inside the lane, where as infra-red systems work to the warning line outside the lane.

4.1.3 *System capability*

The advantages of a camera system are that potential hazardous lane drift is identified ahead of time and warns the driver prior to lane departure occurring. The only drawback of camera systems is that they can be limited by the weather and visibility of the road marking. However advances in camera technology and the calculation algorithms have resulted in systems that can compensate for adverse road conditions.

The more advanced camera systems also monitor the edges of a road not just the road marking and therefore work on single lane roads or roads with no or poor road markings. They can also compensate for sudden changes in light such as tunnels and recognise when wiper blades are in operation.

The infra-red systems are able to detect white lines as well as coloured temporary road markings. The infra-red system also has an advantage that it is unaffected by poor visibility conditions and is a lower cost system. However this system can not predict the vehicle path and therefore can only detect lane departures as the event is occurring.

4.1.4 *Human-machine interface*

The majority of LDW systems currently available alert the driver via any combination of the following:-

- Warning tone resembling the sound of a vehicle driving on a physical rumble strip. This can also be oriented to only sound on the side of the vehicle that lane departure is occurring;
- Visual warning on the instrument panel. This can be integrated into the driver’s dashboard or located separately.
- Hepatic feedback via vibrating the steering wheel or driver's seat, which can vibrate on the side of the seat that lane departure is occurring.

A more advanced system for trucks constantly displays the truck’s position relative to the lane. The system also monitors the driver’s ability to stay in lane as well as assessing reaction times if a correction is required and awards an alertness score at the end of the journey.

It is also important that the driver is informed when the system is not functioning correctly or temporarily unavailable. The system may not be available if the road marking could not be identified, due to bad weather etc. and therefore a message or indication in the dash or centre console would inform the driver of this. Similarly the driver would be informed if the system had a fault and was not able to function correctly. The driver may also have the choice to disable the system, in which case the indication on the switch would not be lit.

4.2 Lane change assistance

A lane change assist system (LCA) is defined as a system that warns the driver against collisions that may occur due to a lane change manoeuvre. The system will not take any automatic action to prevent a possible collision and the driver remains responsible for the safe operation of the vehicle.

Lane change assist systems currently on the market can be divided into two groups; blind spot monitoring (monitoring the area immediately around the vehicle) and lane change warning systems (LCW) (monitoring the area around and behind the vehicle).

4.2.1 Blind spot monitoring

These are systems that only monitor the immediate surroundings of the vehicle, typically only the blind spot areas to each side of the vehicle.

There are five blind spot monitoring systems currently available for passenger vehicles as an optional extra system. Three aftermarket systems are also available for commercial vehicles. Two of the systems are exclusive to North America and two of the systems are available in North America and Europe.

Blind spot monitoring systems currently cost around £450 (€576) in Europe and $200-$395 (€127-€250) in North America.

4.2.1.1 Sensor technology

There are currently several different ways to monitor the blind spot area.

Radar sensors

The most commonly used system in the market at the moment is radar based sensors. These are typically mounted in the rear bumper and detect vehicles that are along side or slightly behind the vehicle. If a vehicle is detected the system informs the driver until the vehicle has moved out of range.

Camera sensors

Another technology is a vision based system that uses a camera mounted under the wing mirror to capture images of the lanes either side of the vehicle. These images are then analysed by the system to determine whether there is a vehicle present or not. At night the same cameras can detect headlights to identify the presence of a vehicle. If a vehicle is detected the system informs the driver until the vehicle has moved out of range.

Infra-red sensors

Infra-red sensors can also be used to monitor adjacent lanes for vehicles. The sensors can be integrated into mirrors, bumpers or side fascia and they monitor the adjacent lane temperature to detect whether a vehicle is present. If a sufficient change in temperature occurs the system alerts the driver.

Ultra-sonic sensors

The final technology used for blind spot monitoring is ultra-sonic sensors. This is typically used by trucks which require several sensors due to the length of the vehicle. A series of sensors are placed along the vehicle and also on the rear bumper that produce short ultra-sonic waves which detect if a vehicle is located in adjacent lanes. The system will then inform the driver of adjacent vehicles.

4.2.1.2 System behaviour

Blind spot monitoring systems have two performance criteria; operation speed and detection area.

- The speed to activate the system varies from 10-32 km/h (6-20 mile/h)

The detection area for the blind spot is typically 2.5-3.5m laterally from the vehicle and 3.0-9.5m behind the vehicle

4.2.1.3 System capability

It is important that a blind spot monitoring system is able to determine the difference between moving objects and static objects such as road side barriers.

The camera systems are affected by weather, and poor visibility but advances in camera technology and the calculation algorithms have resulted in systems that can compensate for adverse road conditions.

4.2.1.4 Human-machine interface

Most of the systems have a warning symbol either in the mirror or inside the vehicle next to the mirror. When a vehicle is located in the blind spot the symbol will light up. If the driver uses the indicator signal in anticipation of changing lane, the symbol will flash and an audible warning will sound to alert the driver to the presence of the other vehicle.

For truck systems, a display containing a series of lights will highlight which areas around the truck in which a vehicle may be located.

It is also important that the driver is informed when the system is not functioning correctly or temporarily unavailable. If the sensors become blocked, caused by dirt or snow over the sensors, the driver is informed by either a warning in the mirror or a display in the dash or centre consol. Similarly, if the system has developed a fault, the driver is informed by either a warning in the mirror or a display in the dash or centre consol. The system could also have been disabled by the driver, in which case a display in the dash or centre consol will remind the driver that the system is inactive.

4.2.2 Lane change warning (LCW)

Blind spot area analysis alone may not be sufficient to protect the driver against a poor choice of a lane change manoeuvre. Fast moving approaching vehicles may pose a potential threat for a lane change as well. LCW systems not only monitor the blind spot areas but also further behind the vehicle to each side, to detect approaching vehicles that may cause a problem when changing lanes.

There is only one LCW system currently on the market for passenger vehicles, available in North America and Europe as an optional extra. The LCA system is sold as a technology package option in North America that also includes LDW for $1400 (€886) and the LCA system in Europe is available for £450 (€576).

4.2.2.1 Sensor technology

Again, a camera on the side mirror can be used for monitoring the host vehicle's blind spot area and also detect approaching vehicles and motorcycles from a distance of 50m. The combined analysis of the near and far areas as viewed from the side camera is geared towards indicating to the driver whether or not it is safe to change lane. The blind spot area analysis is based primarily on visual motion analysis. However, fast approaching vehicles generate too small a retinal footprint to be reliably detected by means of visual motion alone. A pattern recognition module is therefore required to assist the visual motion analysis as well as a lane analysis module. The lane analysis is required for determining whether an approaching vehicle is in a neighbouring lane or one lane removed (thereby not posing a threat) or same lane as the host vehicle.

An alternative technology used for LCW systems is radar sensors. Two radar sensors mounted in the rear bumper of the vehicle are used to detect approaching vehicles from behind the vehicle. If a vehicle is either currently in the blind spot or deemed to be a potential hazard, an indication is displayed to inform the driver that it is unsafe to change lanes.

4.2.2.2 System behaviour

LCW systems have two performance criteria; operation speed and detection area.

- The speed to activate the system is typically 60 km/h (38 mile/h)

The detection area for the system is 50-90m behind the vehicle and 3.5m to each side of the vehicle

4.2.2.3 System capability

It is important that an LCA system is able to determine the difference between moving objects and static objects such as road side barriers.

Poor visibility due to adverse weather conditions such as fog or snow, can affect the camera systems. However advances in camera technology and the calculation algorithms software can overcome these limitations. The system is unaffected by traffic density and performs equally well in congested and open motorway conditions.

A typical system would categorise detected vehicles approaching from behind into one of two categories; vehicles that pose no threat, which are marked green and vehicles posing a threat (based on distance and time to contact) which are marked red. The system detects the lane position of the rearward approaching vehicles. Vehicles that are one lane removed are marked by a blue rectangle and do not affect the driver’s indicator operation.

Radar sensor systems are able to determine the detected vehicle’s relative position and whether they would pose a threat to a lane change manoeuvre.

The radar sensor system is unaffected by environmental conditions such as darkness, dirt obstructions and weather conditions. However, it is more expensive technology to utilise for this application.

4.2.2.4 Human-machine interface

The LCA driver display is incorporated into the side mirror. When a vehicle (or any other object) is in the blind spot area a warning symbol appears in the mirror. The system uses a red/green box in the upper right corner of the mirror to indicate to the driver whether it is safe to change lane. Red meaning it is unsafe to change lane and green when it is safe. An additional audible alert can also sound if the vehicle indicator is used while it is deemed unsafe to change lanes.

It is also essential that the system informs the driver when it is not functioning correctly or temporarily unavailable. The driver is informed by either a warning in the mirror or a display in the dash or centre consol if the sensors become blocked, usually due to dirt or snow over the sensors. The driver is informed by either a warning in the mirror or a display in the dash or centre consol if the system has developed a fault. If the system has been disabled by the driver, a display in the dash or centre consol will remind the driver the system is inactive.

4.3 Other systems

4.3.1 Lane keeping assistance (LKA)

An expansion to the LDW system is to provide the driver with assistance to maintain lane position. These systems are generally called lane keeping assist systems. There are currently two different methods of achieving this; steering input assist and corrective braking.

Both these methods use the LDW technologies described earlier, to detect the lane position and provide an alert when lane departure is about to occur. LKA typically works at similar operational speeds as LDW systems, i.e. above 65 km/h (41 mile/h).

4.3.1.1 Steering assistance

The LKA system detects lane markers on the road, and assists the driver's steering to help keep the vehicle between lane markers. When the system detects the vehicle straying from the lane, it alerts the driver visually as well as with an audible alarm, while applying a slight counter-steering torque, trying to prevent the vehicle from moving out of the lane.

There are several different versions currently on the market, which provide slightly different amounts of steering input; however the vehicle manufactures all maintain that the driver still remains in ultimate control of the vehicle.

4.3.1.2 Corrective braking

A camera unit installed behind the windscreen detects lane markers in front of the vehicle and calculates its position relative to the lane markers. Brake actuators control the brake pressure of each wheel individually to generate part of necessary yaw moment.

When the vehicle is endanger of crossing over the lane markers, the system warns the driver by a visual display and an audible buzzer and assists the driver to return the vehicle into the centre of the lane by gently applying the required brake pressure.

4.4 The future

4.4.1 *Lane departure warning sensing*

Currently, the LDW systems that have been introduced to the market recognise and process the existing road markings. However, in the future specialised magnetic markers could be embedded in the road and then be sensed by vehicle based detectors. This has the advantage that the road markings will be standardised and so the system will be always correct, removing any uncertainties due to undetectable markings. Obviously to implement this on a grand scale would be very expensive but in the short term these road markings could be applied to smaller applications such as bus lanes.

Using these markers means the system could be advanced so that the vehicle automatically steers along a road. This technology has already been implemented into several city buses around Europe and the USA. These buses work just like trams in urban areas without the need for rails and the operator only controls the speed of the vehicle. However, the bus has the advantage that, out of town the driver can drive on any road normally.

4.4.2 *Blind spot monitoring*

An advance in blind spot monitoring is a system that is able to produce a ‘bird’s eye’ view of the vehicle and its surroundings. This is achieved by four cameras around the vehicle capturing the surroundings from each side of the vehicle. These images are synthesized by an image processing technique into one view from above the vehicle displaying all around the vehicle.

4.4.3 *Lane change assistance*

Vehicle manufacturers are developing vehicles that can communicate with each other. Using the LCA radar sensors, GPS and radio communications, vehicles will be able to know where each other are. This would allow vehicles to change lane safely, avoiding accidents.

4.4.4 *Merge in assistance*

Merge in assistance is a system designed to support the driver when joining motorways or freeways by providing information about the length of the merge lane and warning about other vehicles located to the sides in adjacent lanes.

4.4.5 *Lane keeping assistance*

Advanced LKA systems use sensors to analyse crosswinds, curves or ridges in the road, in addition to detecting lane edges. This information is then used to calculate the optimal steering behaviour and define tolerance limits. If these are exceeded the system applies force to the steering wheel to suggest corrections, which the driver can accept or overrule.

4.4.6 *Road departure warning*

Road departure warning is a system that is in development. It expands on the features of lane departure warning into lateral drift warning as well as incorporating curve speed warning (CSW). RDW uses several different sensor technologies; forward looking camera, short range lateral radar sensors and high definition maps and GPS.

The lateral drift warning uses the camera to measure the vehicle position and lateral velocity relative to the lane compared to the lane width. This data is combined with the radar data to estimate manoeuvring room and assess the threat of lateral drift departure.

The CSW uses the camera to process road geometry and conduct a map matching function, compute the vehicle’s most likely path and compute the instantaneous curvature. A CSW assessment is then conducted based on current speed, path and deceleration to decide whether to warn the driver that the vehicle is travelling too fast for the road.

4.4.7 Complete lateral safety system

Although both LDW systems and LCA systems have only recently been introduced to the market, technology manufactures are now developing ways to incorporating them together with LKA and CSW to create a total lateral safety system. However, to reduce manufacturing cost these lateral systems would also be combined with forward and rear systems. This would mean that the vehicle would use the same sensors for multiple systems and that one switch could activate several systems, enabling the vehicle to follow the speed of the vehicle in front and stay in lane with minimal driver input as well as being able to avoid or prepare for collisions

5 Proposed technical / operational requirements

Outline technical specifications were developed for lane departure warning and lane change assistance systems. These can be found in Appendix C and Appendix D respectively. The specifications drew on the findings of the literature survey (Section 2) and on the reviews of standards (Section 3) and systems (Section 4).

At the present time, there are no EC Directives or UNECE Regulations on lane departure warning or lane change assistance; however, the EC may wish to introduce requirements in the future. Any such requirements would be developed in collaboration with an expert working group comprising regulators, industry representatives and research establishments. The outline technical specifications presented here are intended to serve as a starting point for these discussions. For the purposes of this study, separate specifications were developed for lane departure warning and lane change assistance. Nevertheless, a new regulation might refer to a single system with two (or possibly more) functions.

The technical specifications comprise both equipment and performance specifications. A great deal of information was available about lane departure warning and lane change assistance. Nonetheless, a number of issues emerged during the development of the specifications where there were gaps in the knowledge. The following sections summarise these issues for each system.

5.1 Lane departure warning

The general functional specifications for lane departure warning systems in Appendix C set out the conditions under which a system shall warn the driver. These were derived from ISO 17361:2007. The Standard classifies lane departure warning systems according to the radius of curvature of the road and the vehicle speed (see Section 3.1.3.1). Two types of system are defined in the Standard, based on these two criteria; however, systems are permitted to warn drivers under both sets of conditions.

ISO 17361:2007 offers no justification for allowing two classification types for lane departure warning systems (for example, according to vehicle class). While this approach was acceptable for the Standard, TRL considered that it would be preferable, at least at this initial stage, to adopt a single set of conditions for the technical specifications. The values proposed in Appendix C represent the requirements for a Class II system according to the Standard. These are more stringent than those for a Class I system. There was no information in the literature or from the review of systems regarding the capacity of current systems to achieve these requirements. In the future, it may be necessary to review the limits when this information is available.

The performance specifications in Appendix C were drawn from ISO 17361:2007. The Standard describes three tests: a warning generation test; a repeatability test; a false alarm test. The warning generation test is carried out on a flat, dry asphalt or concrete surface. However, it would be desirable for a lane departure warning system to be operational in a range of weather and environmental conditions. The literature revealed that some systems can be influenced by these conditions. A method of assessing this aspect of the performance of lane departure warning systems is missing from current standards.

In addition, the warning generation test is carried out on visible lane boundaries that are marked “in accordance with applicable standards for lane marking design and materials”. The characteristics of the lane markings are not defined further. A vehicle may encounter a range of lane markings and patterns. It would be desirable for a lane departure warning systems to be operational irrespective of the lane marking type (within the range of markings used in Europe). A method of assessing this aspect of the performance of lane departure warning systems is missing from current standards.

ISO 17361:2007 defines a zone used to assess the repeatability of the lane departure warning system. For the purposes of the technical specifications in Appendix C, it was assumed that this zone would permit a meaningful examination of the system's repeatability; however, testing would be necessary to comment further on its suitability.

Finally, during brief periods when the lane departure warning system cannot determine the position of the vehicle with respect to the lane, it was considered that the system should extrapolate the current position based on previous estimates of lane geometry and vehicle trajectory. However a method of assessing this aspect of the performance of lane departure warning systems is missing from current standards.

5.2 Lane change assistance

The general functional specifications for lane change assistance systems in Appendix D set out the conditions under which a system shall warn the driver. These were derived from ISO 17387:2008. The Standard classifies lane change assistance systems according to the maximum target vehicle closing speed and the minimum roadway radius of curvature (see Section 3.2.3.2). Three types of system are defined in the Standard based on these two criteria; however, a system may belong to more than one type. For example, a highly capable system may meet or exceed the minimum requirements defined individually for the three types.

The Standard suggests there is a relationship between the maximum closing speed and the road curvature. Systems capable of achieving the most stringent closing speed are permitted to achieve the least stringent road curvature, and vice versa. The values proposed in Appendix D represent the most stringent requirements for each individual criterion. There was no information in the literature or from the review of systems regarding the capacity of current systems to achieve these requirements.

A lane change assistance system should warn the driver only when they intend to change lanes. This is important to prevent needless or distracting warnings during normal driving. Different methods have been proposed to resolve this issue. For example, some lane change assistance systems operate only when the turn signal is used. With such an approach, the system responds when there is a clear indication of the driver's intent. However, drivers do not always use their turn signal when changing lanes, or if it is used, it is turned on relatively late in the manoeuvre. This implies that a system linked to turn signal use will not be operational during some lane change manoeuvres, and potentially when it is needed. It is possible to predict the driver's intent using other means, but this has proven challenging.

For the purposes of these specifications, it would be desirable to state that a lane change assistance system shall operate only when a lane change manoeuvre is intended. It would also be desirable to state that a system shall detect a lane change irrespective of turn signal use. However, more information is required regarding the capacity of current lane change assistance systems to meet these specifications.

The performance specifications in Appendix D were drawn from ISO 17387:2008. The Standard describes a series of test scenarios and a false alarm test. However, two situations were not addressed. Firstly, a lane change assistance system should not respond to stationary objects at the side of the road. A method of assessing this aspect of the performance of lane change assistance systems is missing form current standards. Secondly, a lane change assistance system should not respond to vehicles travelling in the opposite carriageway. A method of assessing this aspect of the performance of lane change assistance systems is also missing form current standards.

6 Estimating costs and benefits to society

6.1 Introduction

The use of advanced driver assistance systems has the potential to reduce the number of road traffic accidents across Europe. A reduction in the number of accidents can also lead to a reduction in the amount of congestion. The following section describes the estimated benefits to society in terms of the reduction in the number of casualties and the associated congestion.

The casualty benefits were estimated using data from a range of sources. These included the European Statistical Pocketbook 2007 (DG-TREN, 2008), national statistics from Great Britain and Germany and the in-depth data sources, On-The-Spot and GIDAS from Great Britain and Germany respectively.

The data analysis was combined with information collected during the literature review and review of standards and systems to estimate the casualty benefits for the EU.

6.2 Identifying target populations from accident characteristics

The target population is a group of accidents that are considered relevant to the technology being assessed. For a system to be 100% effective, all accidents within the target population should be prevented. Data for EU-25 is high level (total number of accidents and total number of fatalities), therefore, expressing the target population as a proportion of all accidents in the sample would be the most direct and appropriate method to estimate the target population for Europe.

Once the target population has been defined, the effectiveness of the system was applied to estimate the potential casualty reduction benefits. The effectiveness was taken from the literature review and the information available about the systems/proposed technical requirements.

In order to identify the target population, the accident types which could be influenced by LDW and LCA systems were considered. A number of accident types relevant to LDW and LCA systems were defined based on characteristics identifiable in the accident data:

- LDW – the primary characteristic of these accident groups was driver inattention;
    - A) Head-on collisions – the vehicle of interest (VOI) drifts out of the lane in which they are travelling and collides with an on-coming vehicle;
    - B) Leaving roadway collisions – the VOI drifts out of the travel lane. These accidents are often single vehicle and may involve impacts with roadside furniture. However sometimes other vehicles may be involved because they have been required to react to the lane departure of the VOI;
    - C) Side-swipe collisions – when the VOI departs the lane in which they are travelling on a road with multiple lanes, the side of the VOI could collide with the side of a vehicle that is travelling in an adjacent lane. There is also a possibility of an impact between the front of one vehicle and the rear of the other;
- LCA – the primary characteristic of these accident groups are the incorrect identification of another vehicle that is approaching from behind either because of an error of judgement or because of a vehicle blind spot;
    - D) Side-swipe collisions – the VOI is travelling on a road with multiple lanes and changes lane. The side of the VOI collides with the side of a vehicle that is travelling in an adjacent lane. There is also a possibility of an impact between the front of one vehicle and the rear of the other. This

group of accidents can include those where the VOI is merging from a slip road or where the two vehicles are traversing a roundabout;

- E) Manoeuvring collisions – the VOI is stationary in the traffic lane waiting to turn across the oncoming carriageway and a line of traffic has formed behind the VOI. Another vehicle has decided to overtake the stationary traffic and collides with the VOI as it commences or completes its manoeuvre. The VOI could also be turning to the nearside and the other vehicle is undertaking, or the VOI may be making a U-turn;
- F) Leaving parking space – the VOI is pulling out from a parking space at the nearside of the road and collides with another vehicle that is travelling in the traffic lane.
- G) HGV turning collisions – this is a specific group of accidents that involve an HGV turning to the nearside and colliding with another vehicle that has travelled up the nearside of the HGV. Some of these accidents may overlap with group E accidents.

6.3 Methodology – GB data

The analysis of accidents in Great Britain has been carried out using the STATS19 database. STATS19 is the system for collating personal injury road accident data recorded by police officers in Great Britain. The data comprised details of attendant circumstances held on the accident record, together with vehicle and casualty data (DfT, 2006a).

The design of the STATS19 queries was based on criteria such as:

- Road types
- Location of first impact on both vehicles
- Combinations of vehicle manoeuvres
- Driver contributory factors such as driver impairments or errors while making a manoeuvre

It is possible that queries based on these criteria may select accidents that are not relevant to LDW or LCA systems and so it would be beneficial to check that the queries were returning relevant accidents. However, the STATS19 database does not contain a description of the accidents, which would be the most direct method to assess the queries.

To ensure that the design of the queries were appropriate, the On-The-Spot (OTS) Database was used. The OTS study is funded by the Department for Transport and the Highways Agency. It aims to establish an in-depth database that can be used to improve the understanding of the causes and consequences of road traffic accidents. Full details of the methodology of OTS are given in Cuerden *et al.* (2008). The procedure followed to review and develop the STATS19 queries is shown in Figure 6.1.

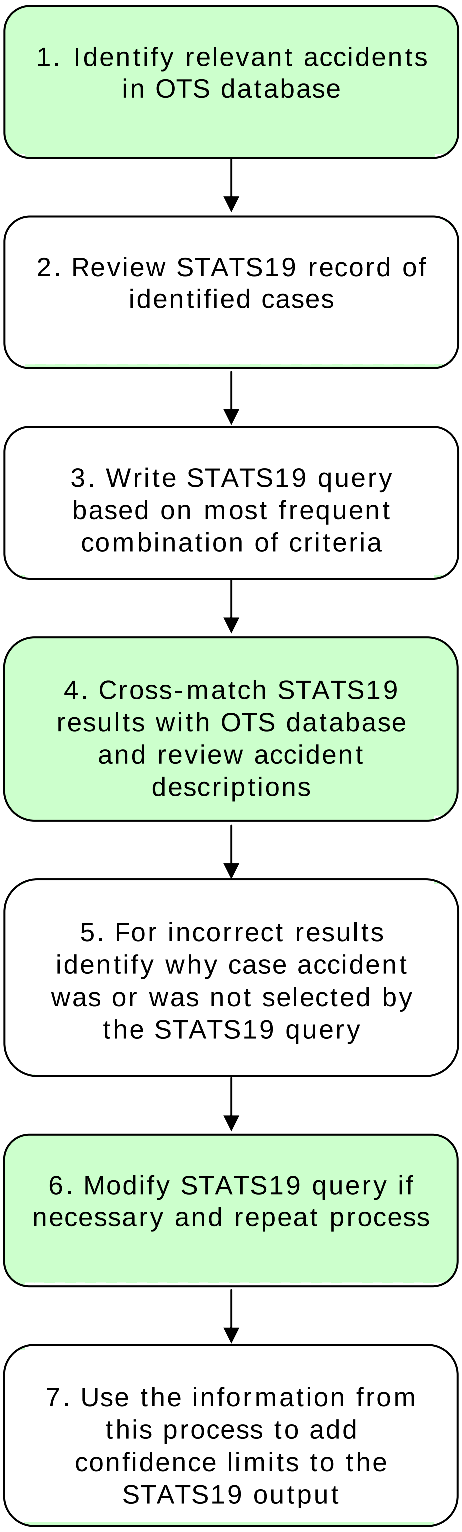

Figure 6.1. Process for development of STATS19 queries.

The following paragraphs describe each of the steps defined in Figure 6.1. The process was followed for each of the seven defined accident types.

- Step 1 – Accidents of the seven types described previously were identified in the OTS database using a combination of contributory factors and the accident type (chosen from a matrix of 72 accident types).
- Step 2 - Where an accident had been identified in the OTS database, the corresponding STATS19 record was reviewed.
- Step 3 – The STATS19 query for each of the seven accident types was written by looking at how the selected OTS cases had been entered into the STATS19 database.
- Step 4 – Once the STATS19 query had been run, the list of records (from the two OTS relevant police areas) selected were cross referenced against the OTS database using the STATS19 reference number, police force and date and time of the accident.
- Step 5 – When cross-referencing between the two databases, there were some accidents that were in the OTS database and were appropriate for the study, but were not selected by the STATS19 query. One of the main reasons for this was the coding of contributory factors.
- Step 6 – In some cases the query was amended based on the results from Step 5 and the query was re-run.
- Step 7 – when cross-referenced to the OTS database, the output from the STATS19 query did not identify all the relevant OTS cases and also selected some that were not relevant (based on description of accident in OTS). However, it was not considered feasible to refine the STATS19 query any further because the limitations of the database had been reached. Therefore the information related to the correct and incorrect identification of OTS accidents was used to form upper and lower estimates of the target population of LDW and LCA systems in GB.

6.4 Methodology – German data

German national statistics and analysis of the GIDAS database was provided by the Technical University of Dresden (TUD). The queries developed for the accident groups defined previously were supplied to TUD. TUD matched the queries using the GIDAS database, which then allowed the target population for each casualty group to be defined as a proportion of all accidents in GIDAS. Assuming that GIDAS is representative of Germany, the GIDAS results were scaled up to estimate the numbers of fatal and serious casualties in each casualty group using the total number of accidents in Germany.

6.5 Results – estimating EU casualty benefits

6.5.1 Target population

The target population was estimated for GB and Germany based on the methodology described above. The target population was separated by the vehicle type to which the system is to be fitted and also by the type of road user that could be protected (i.e. occupant of the vehicle to which the system is fitted, occupant of an opponent vehicle, or a vulnerable road user). For the purpose of this analysis vulnerable road users (VRU) include pedestrians, pedal cyclists and motorcyclists. For each type of accident (A-G) the target population for each accident severity was expressed as a proportion of all accidents. The target population for one specific member state is not necessarily representative of EU-27. However, the information required to define the target population is not available for EU-27 and deriving target populations for all member states is outside the scope of this study. Therefore it is assumed that the target population for EU-27 is likely to be within the range of values identified for GB and Germany.

In 2006 there was a total of 1,278,400 road accidents involving personal injury in Europe. Using this number and the lower and upper proportional values, the target population was defined in terms of numbers of casualties for each type of accident. The target populations for each casualty group were combined in relation to relevance for LDW or LCA systems and are shown in Table 6-1 and Table 6-2.

Table 6-1. Target population for LDW.

Equipped vehicle type	Casualty severity	Target population – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	903	5,949	67	612	64	620	1,034	7,181
	Serious	5,773	31,539	1,026	7,530	249	3,197	7,048	42,266
	Slight	21,867	64,838	7,028	19,549	459	1,361	29,354	85,748
M2/M3	Fatal	7	189	0	7	0	5	7	201
	Serious	51	1,045	0	21	0	0	51	1,066
	Slight	338	1,000	27	82	8	23	373	1,105
N2/N3	Fatal	23	111	0	65	0	5	23	181
	Serious	135	615	19	213	3	315	157	1,143
	Slight	404	1,413	184	693	9	42	597	2,148

Table 6-2. Target population for LCA.

Equipped vehicle type	Casualty severity	Target population – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	52	11	189	45	230	56	471
	Serious	199	2,196	146	1,323	711	3,877	1,056	7,396
	Slight	3,472	15,424	5,242	23,982	5,629	20,638	14,343	60,044
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	11	0	15	0	51	0	77
	Slight	90	393	86	419	98	399	274	1,211
N2/N3	Fatal	0	23	0	45	11	114	11	182
	Serious	0	11	99	788	25	568	124	1,367
	Slight	84	489	2,518	14,895	163	648	2,765	16,032

6.5.2 Effectiveness

The effectiveness of a LDW or LCA system can be affected by a number of factors such as curvature of the road, driver response and weather conditions. If a system could be designed to overcome all potential factors then it could be considered 100% effective and the benefits expected would be the same as the target population (as shown in Table 6-1 and Table 6-2). In reality, it is unlikely that systems will be able to account for all factors in a potential accident situation. An example of the information required to complete the analysis of casualty benefits for LDW systems is shown in Table 6-3. It may be most appropriate to differentiate between the accident types within the target population for the system. However, a suitable alternative would be to have the equivalent information for the whole target population for LDW (or LCA).

Table 6-3. Example of effectiveness information required.

	Target population A			Target population B			Target population C		
	M1/N1	M2/M3	N2/N3	M1/N1	M2/M3	N2/N3	M1/N1	M2/M3	N2/N3
Fatal	✓	✓	✓	✓	✓	✓	✓	✓	✓
Serious	✓	✓	✓	✓	✓	✓	✓	✓	✓
Slight	✓	✓	✓	✓	✓	✓	✓	✓	✓

Information about the effectiveness of systems such as LDW and LCA is available from a number of sources. However, the effectiveness of the system can be expressed in a number of different ways, e.g. as a percentage of a specific group of accidents, as a percentage of all casualties by severity or as a percentage reduction in all collisions. Very few studies provide effectiveness of the systems for the different types of vehicle, most of the information identified is related to passenger cars.

Additionally, some of the assumptions made in the analyses that were identified are different to those that have been made by this analysis so far. For example, here the target population includes all lane departures where there was some form of inattention, Accidents where alcohol and excessive speed were factors have not been ruled out at this stage since it was considered that these factors would influence the effectiveness of the system rather the target population. However some of the analysis reported in the literature has exclude accidents involving alcohol impairment or excessive speed from their analysis.

The following sections review the estimated levels of effectiveness for both LDW and LCA systems to allow the most appropriate level of effectiveness to be applied during the analysis that follows.

6.5.2.1 Effectiveness of LDW systems

Table 6-4 summarises the information available about the effectiveness of LDW systems.

Table 6-4. Effectiveness of LDW systems identified from the literature.

System	Effectiveness	Source
LDW	10% reduction in passenger car road departure crashes 30% reduction in heavy truck road departure crashes	In the USA, Pomerleau *et al.* (1999) estimated effectiveness through mathematical modelling. Target population excluded 75% of the accidents where alcohol intoxication was involved. Effectiveness estimate includes excluding accidents where the system is not functioning due to adverse environmental conditions, missing lane boundaries and low speed.
LDW	12% of fatalities 9% of severe 5% slight	Bosch (2005) in COWI (2006) estimated casualty savings in Germany.
LDW	Avoidance 25% head on collisions 25% left roadway collisions 25% side collisions Mitigation 25% head on collisions 15% left roadway collisions	Abele *et al.* (2005) estimated effectiveness based on changes to reaction time. Information related to head-on and left roadway collisions is clear, however the effectiveness of LDW for mitigating injuries in side collisions is not clear. Also report only considers side collisions where the vehicles are travelling in the same direction (LDW could influence side collisions where the vehicles are travelling in opposite directions.
LDW	24% reduction in singular accidents	Schermers (2000) cited in Malone *et al.* 2006. US study.
LDW	20% for cars	Alkim *et al.* (2007) based on FOT pilot using 19 Volkswagen Passats for 4 month period in one region of the Netherlands. Assumed representative of the Netherlands as a whole.
LDW & LCA	Avoidance 25% (15-35%)* fatalities 25% (15-35%)* severe injuries 25% (15-35%)* slight injuries Mitigation 15% (10-20%)* fatal to severe 15% (10-20%)* severe to slight	COWI (2006) effectiveness based on literature which included Abele *et al.* (2005)

* ranges used for sensitivity analysis

The study reported by Abele *et al.* (2005) reviews the socio-economic impact for a wide range of safety systems and therefore the analysis is based on published accident data. The effectiveness determined by Abele *et al.* (2005) appears to be independent of the type of vehicle to which the system is fitted and is based on the additional time that the driver will have to react to the lane departure. It is not clear how this reaction time is defined; is it before the collision or before the lane crossing. In a proportion of lane departures, there is no reaction from the driver, and providing a warning at the time of lane crossing could provide more than 0.5s for the driver to react before an impact, in some cases an additional 0.5s may not be sufficient. The effectiveness for avoiding the accident is the same for the three types of collision mentioned. However, the data for conversion from shift in reaction time to collision probability is for oncoming traffic collisions, collisions at intersections and rear end collisions. The shift in reaction time for left roadway and side collisions has been assumed to have the same effect as for the oncoming traffic collisions, which appears to be the worst case. Additionally the data used to convert the change in reaction time to the probability of a collision is relatively old (1979).

The effectiveness is expressed as a percentage of the target populations defined as head-on, left roadway and side collision. These accident groups are different to the target populations defined for this research. Head on collisions are not always caused by a lane departure, for example a car that is overtaking could collide head on with another vehicle. The lane departure could occur under conditions where the LDW system is inoperative, or the lane departure could be due to a medical emergency in which case the driver may not be able to respond to the warning. The effectiveness that is defined for a less refined target population, if applied to the more refined population could lead to an under-estimate of the potential benefits. Also the side collisions only include those where the two vehicles were travelling in the same direction, whereas the target population for this study also includes side collisions between oncoming vehicles. Under-estimating the target population will result in an over-estimate of the proportional effectiveness. Information is presented to change the effectiveness to be presented as a proportion of all accidents, however this data is taken from a US study.

Pomerleau *et al.* (1999) estimated effectiveness through mathematical modelling. The effectiveness is expressed as a proportion of the target population for two different vehicle types. To account for accidents where the driver was intoxicated, 75% of the accidents where alcohol intoxication was involved were excluded from the target population, assuming that some intoxicated drivers would be able to respond to the warning. The effectiveness estimate excludes accidents where the system is not functioning due to adverse environmental conditions, missing lane boundaries and low speed. This assessment of the effectiveness is probably the most comprehensive and there is sufficient information to re-instate the accidents that included intoxication. However, it is based on data from the USA where there are differences in road infrastructure, climate and driver behaviour which could influence the effectiveness of the system. Pomerleau *et al.* (1999) showed that there can be a different effectiveness depending on the type of vehicle, however they only considered run off road accidents. For the other relevant accident types, the difference between effectiveness between two types of vehicle may be different. For example, in head on collisions the effectiveness for trucks could be lower than for cars, particularly if the behaviour of the opponent in head-on collision is the main contributory factor.

The effectiveness quoted from Bosch (2005) does not differentiate between how effective the system is for different types of vehicle. The effectiveness increases with increasing severity of the casualty. This could be appropriate because single vehicle roadway departures and head on collisions tend to have a higher severity than other accident types such as rear end shunts. Also if the LDW system has a minimum operating speed, then it would be less effective accidents occurring at lower speeds which are more likely to be lower severity.

Taking the Pomerleau *et al.* (1999) effectiveness and compensating for the way in which the effect of alcohol intoxication was accounted for provides an estimated effectiveness of 7.5% for passenger cars and 22.5% for trucks for roadway departure crashes. Abele *et al.* (2005) estimated the same effectiveness across the other types of accident, but did not differentiate between the type of vehicle and as mentioned the effect of the vehicle type may differ between accident types. It could therefore be assumed that the effectiveness for head on collisions and side collisions could be somewhere between 7.5% and 22.5% for both passenger cars and trucks. Additionally, assuming that these values of effectiveness are an average for all severities, the severity distribution from Bosch (2005) could be applied. There is minimal information available for minibuses and buses/coaches (M2/M3) and so it would be necessary to assume that the effectiveness is the same as that for large goods vehicles (N2/N3).

Using the information from the literature and taking the approach described in the paragraph above, the following effectiveness values for avoiding accidents were applied to the target populations (Table 6-5). The effectiveness for the mitigation of injuries has not been included because it was not possible to identify how the effectiveness of the system for mitigation had been derived. Additionally, most of the studies only considered the effectiveness of the system for avoiding accidents, which is the primary objective of these systems.

Table 6-5. Effectiveness values applied to LDW target populations.

	Target population A			Target population B			Target population C		
	M1/N1	M2/M3	N2/N3	M1/N1	M2/M3	N2/N3	M1/N1	M2/M3	N2/N3
Fatal	16%-48%			16%	48%	48%	16%-48%		
Serious	12%-36%			12%	36%	36%	12%-36%		
Slight	7%-20%			7%	20%	20%	7%-20%		

Although the data from the Dutch pilot study has not been used to generate these effectiveness values, the effectives from Alkim *et al.* (2007) is within the ranges for M1/N1 vehicles for type A and type C accidents. It is also similar, although slightly higher than the values used for type B accidents. There is no distinction between accident type or severity in the paper.

6.5.2.2 *Effectiveness of LCA systems*

Table 6-6 summarises the information identified in relation to the effectiveness of LCA systems.

Table 6-6. Effectiveness of LCA systems identified from the literature.

System	Effectiveness	Source
LDW & LCA	Avoidance 25% (15-35%)* fatalities 25% (15-35%)* severe injuries 25% (15-35%)* slight injuries Mitigation 15% (10-20%)* fatal to severe 15% (10-20%)* severe to slight	COWI (2006) effectiveness based on literature which included Abele *et al.* (2005)
LCA	43%±20% of right lane changes for comprehensive system (USA) 32%±22% of right lane changes for proximity sensing system only (USA)	Talmadge *et al.* (2000) estimated effectiveness using drivers errors as a surrogate for collisions during road tests
LCA	9% fatalities** 9% severe injuries** 9% of slight injuries**	Bosch (2005) in COWI (2006) estimated casualty savings in Germany.
LCA	60% avoidance and 10% mitigation of side collisions	Abele *et al.* (2005) estimated effectiveness of the systems based on the reduced reaction time.
LCA	15% to 40% reduction in side collisions	Malone *et al.* (2006) reported a review of literature and comparison with expert opinions from a workshop that was carried out under the ADASE2 project. A simulator study (Wang *et al.* 2003 cited in Malone *et al.* 2006) reduction in accidents of 15% whereas other literature reviews and mathematical modelling quoted 40% reduction in side collisions

* ranges used for sensitivity analysis

**COWI present only number of casualties saved for LCA. However number and proportion of casualties saved by LDW are presented and therefore the proportion of casualties prevented by LCA is estimated.

Similar issues to those identified for the effectiveness of LDW systems exist for LCA systems. None of the literature identified stated different levels of effectiveness for the different vehicle types being considered. None of the literature differentiates between the different types of collision that could be prevented by an LCA system and tend to refer only to “side collisions”.

Minimal information is provided in relation to the definition of side collisions, however Abele *et al.* (2005) only include accidents where the vehicles are travelling in the same direction and Talmadge *et al.* (2000) only include accidents where the vehicle was changing lane to the right. All the values for effectiveness fall within the range 15%-60%, so although there are some differences between how the collisions are defined it is likely that the effectiveness for the target population defined in this study (some front to rear impacts are included) will fall within this range.

Bosch (2005 cited in COWI, 2006) is the only information identified that defines the effectiveness by injury severity and for LCA there is no difference by severity. Therefore the same effectiveness will be applied to each level of injury.

Malone *et al.* (2006) state that the expert workshop carried out under ADASE 2 did not identify any observations where LCA could be effective for collisions other than side collisions. Therefore the minimum benefit for the other types of accident identified should be 0%. It is assumed that the upper limit for the effectiveness is the upper limit for side collisions (60%) since it is feasible that it will not be more effective for these types of collision then for those for which it is intended.

The inclusion of the turning group of accidents (G) was mainly intended to assess the potential benefits of systems that include blind spot monitoring on HGVs. However a number of accidents were also identified where the vehicle of interest was not an HGV. The effectiveness for these accidents could be assumed to be the same as for the N2/N3 vehicles, and the lower frequency of the accidents involving other vehicles will influence the overall benefit.

Table 6-7 shows the effectiveness values that were applied to the LCA target population derived from the discussion above.

Table 6-7. Effectiveness values applied to LCA target populations.

	Target population D			Target population F, G, H		
	M1/N1	M2/M3	N2/N3	M1/N1	M2/M3	N2/N3
Fatal	15%-60%			0%-60%		
Serious	15%-60%			0%-60%		
Slight	15%-60%			0%-60%		

6.5.2.3 *Improving the effectiveness estimates*

Field operational trials (FOT) of the systems are one of the most reliable indicators of the effectiveness of the systems. FOT results identified in the literature review were from the USA and a pilot study from the Netherlands. Differences in the infrastructure, driving behaviour and vehicle designs could mean that the effectiveness in the USA is not the same as in Europe. European FOT that will consider LDW and LCA systems are currently in the pipeline (EC 7th Framework). There is also a planned pilot study for N2/N3 vehicles in the Netherlands that will assess LDW. Once the results from these trials are available, the benefit assessment could be updated by applying the FOT results to the accident data presented in this report provided that relevant systems are included in the trials.

6.5.3 *Estimated casualty benefits*

The estimated casualty benefits for fitting LDW and LCA systems are shown in Table 6-8 and Table 6-9.

Table 6-10 shows the casualty benefit from fitting a combined LDW/LCA system. These are the benefits expected average annual benefit based on 2005/2006 accident data assuming that all vehicles in the fleet had been fitted with the technology.

Table 6-8. Estimated casualty benefit of fitting LDW system.

Equipped vehicle type	Casualty severity	Estimated benefit – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	144	2,856	11	294	10	298	166	3,447
	Serious	693	12,249	123	3,391	30	1,468	846	17,108
	Slight	1,531	15,232	492	6,718	32	359	2,055	22,309
M2/M3	Fatal	1	91	0	3	0	3	1	96
	Serious	6	399	0	9	0	0	6	408
	Slight	24	222	2	27	1	6	26	255
N2/N3	Fatal	4	53	0	31	0	3	4	87
	Serious	16	233	2	88	0	147	19	468
	Slight	28	300	13	181	1	9	42	490

Table 6-9. Estimated casualty benefit of fitting LCA system.

Equipped vehicle type	Casualty severity	Estimated benefit – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	31	2	113	1	138	3	283
	Serious	15	1,318	13	794	14	2,326	42	4,438
	Slight	207	9,254	322	14,389	88	12,383	618	36,026
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	7	0	9	0	31	0	46
	Slight	6	236	7	251	3	239	16	727
N2/N3	Fatal	0	14	0	27	0	69	0	109
	Serious	0	7	14	473	0	341	14	820
	Slight	12	294	365	8,937	4	389	380	9,619

Table 6-10. Estimated casualty benefit of fitting combined LDW and LCA system.

Equipped vehicle type	Casualty severity	Estimated benefit – number of casualties							
		Equipped vehicle		Other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	144	2,887	12	407	11	436	169	3,730
	Serious	708	13,567	136	4,184	44	3,795	888	21,546
	Slight	1,738	24,486	814	21,107	120	12,742	2,673	58,335
M2/M3	Fatal	1	91	0	3	0	3	1	97
	Serious	6	406	0	18	0	31	6	454
	Slight	30	458	9	278	4	246	42	982
N2/N3	Fatal	4	67	0	58	0	71	4	196
	Serious	16	239	16	561	0	488	33	1,289
	Slight	40	594	378	9,118	5	398	422	10,109

The data so far, shows that the greatest casualty benefits can be achieve by fitting LDW rather than LCA to M1/N1 vehicles. This is not surprising because of the proportion of M1/N1 vehicles that are on the roads. This will be examined further in section 7.

For all three classes of vehicle, LDW appears to offer greatest benefit to the occupant of the vehicle to which it is fitted. However LCA appears to offer the greatest benefit to the opponents of the vehicle to which the system is fitted, including the vulnerable road users.

The annual average casualty benefit in monetary terms was calculated using casualty prevention values for fatal, serious and slight casualties. The prevention values selected had been previously used by Abele *et al.* (2005) and COWI (2006):

- Fatality - €1,000,000
- Serious - €135,000
- Slight - €15,000

The estimated total casualty benefits and casualty valuations are used in the cost-benefit analysis presented in section 7.

6.6 Estimated congestion benefits

LDW and LCA are expected to prevent accidents in specific circumstances. The immediate benefit of this is a potential reduction in casualties. However, it is increasingly recognised that accidents contribute substantially to congestion and delays on the road network.

This section of the report provides an estimate of the potential benefits of avoiding accidents in terms of reducing congestion. The analysis considers the value of time (VOT) benefits in terms of reduced delay to all road users caused by preventing accidents so that running lanes can be kept clear.

The VOT benefits are estimated using the INCA (INcident Cost benefit Assessment) tool developed for the UK Department for Transport (DfT). This tool can estimate monetary benefits caused by changes to current levels of accident rate and duration.

Inputs to INCA include the percentage change in overall rate and change in average duration of all accidents caused by introducing some measure (compared with doing nothing). The tool is built on previous research into incident related congestion which has examined the frequency of accidents and for how long they inhibit traffic flow in relation to their effect on delay and congestion. Details of traffic levels and total road length are also required so that annual benefits to users of Great Britain's motorway network can be estimated. It is limited to the motorway network because relevant data for all purpose inter-urban or urban roads is scarce. The INCA tool is designed for analysis of congestion on UK roads and therefore t is only possible to look at the effect of LDW and LCA systems on congestion for the UK. However this estimate can be compared to congestion costs for Europe that were reported in the literature.

A simple overall average approach has been adopted, and the effect on journey time variability reduction and detailed traffic diversion opportunities has not been considered.

The accident figures used are those for recorded injury accidents because data for non injury accidents is scarce. It is assumed that the change in accident rate will be the same for injury and non-injury accidents.

It has also been assumed that the average duration (the length of time the accident inhibits traffic flow) of avoidable accidents is the same as the average duration of all accidents, i.e. reducing the number of accidents will not change the overall average duration.

The total accident population is required to calculate the effect on overall accident rate. The total accident population for Great Britain is reported annually in Road Casualties Great Britain (RCGB); however, the total for motorways is not given. The most relevant figure is that for dual carriageways with a 70 mile/hr speed limit. The figures are shown in Table 6-11.

Table 6-11. Total number of accidents on 70 mile/hr dual carriageways (DfT 2007a, DfT 2006a).

Year	Total
2005	13,117
2006	13,426

Accidents that are potentially avoidable using LDW and LCA were previously identified in the analysis of casualty benefits. This is the maximum number of accidents that might be avoided. In practice, the systems will only prevent a proportion of these accidents, defined by the effectiveness (discussed later in this section). The accidents in the target population were filtered further to obtain the number of accidents that occurred on dual carriageways with a 70 mile/hr speed limit. These figures are shown in Table 6-12, split by the type of system. Only leaving carriageway (type B) for LDW, and side-swipe (type D) and leaving parking space (type F) accidents for LCA, occurred on 70 mile/hr dual carriageways.

Table 6-12. Number of avoidable accidents on 70 mile/hr dual carriageways.

Year	LDW System	LCA System	Total
2005	1339	801	2140
2006	1349	794	2143

Assuming LDW and LCA was fitted to all vehicles and that all avoidable accidents were actually avoided, the number of accidents occurring as a percentage of the total would be as shown in Table 6-13.

Table 6-13. Estimated number of accidents had LDW and LCA been fitted to all vehicles.

Year	% of total
2005	83.7%
2006	84.0%

It is assumed that this effect on accident reduction does not vary between motorway and non-motorway dual carriageways.

INCA also requires the Average Annual Daily Total (AADT) flow for the average section of motorway which can be calculated using road length and total vehicle kilometres, which is also published annually in Transport Statistics Great Britain (TSGB). These values are given in Table 6-14 .

Table 6-14. Britain’s Motorway Network (DfT 2007b, DfT 2006b).

Year	Length (km)	Vehicle Kilometres ($\times 10^9$)	AADT (vehicles)
2005	3520	97.0	75498
2006	3556	99.2	76428

Using these values, the potential savings for Britain’s motorway network for 2005 and 2006 are estimated to be £ 7.2 million and £ 7.7 million respectively. Figure 6.2 also gives the figures by system type.

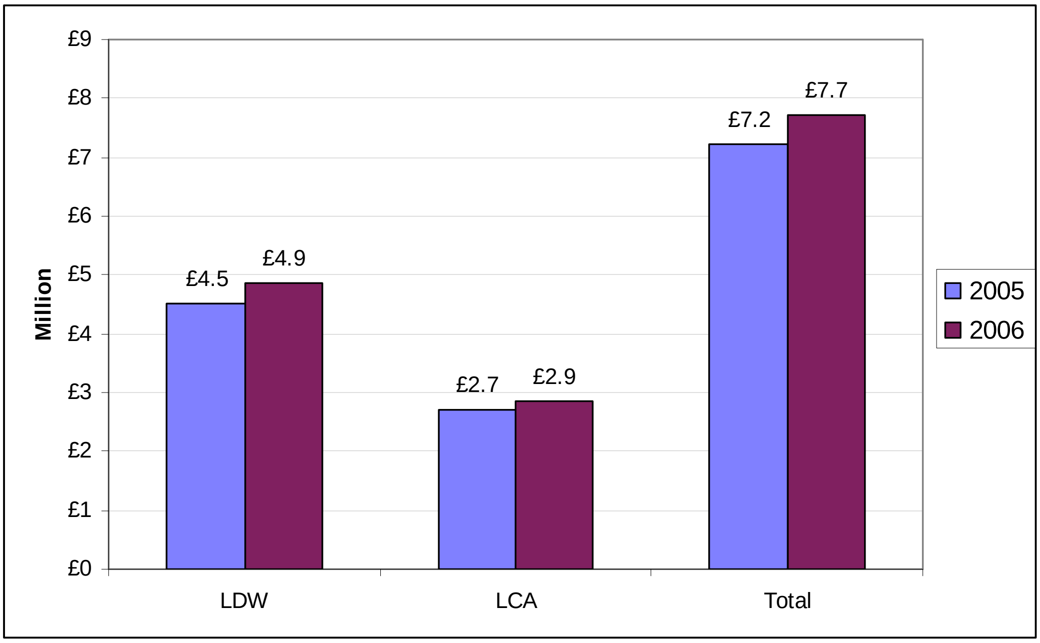

Figure 6.2. Estimated VOT saving (£ million) for motorways in GB (2007 price index).

The benefit of avoiding the average single accident would be £2,660 and £2,838 for 2005 and 2006 respectively. Using an exchange rate of €1.3 per GB pound, this is equivalent to €3,458 and €3,689 respectively. These values are of the same order of magnitude to the value €5,000 used by Abele *et al.* (2005) for non-fatal injury accidents. The difference may be as a result of the INCA estimate only includes time costs and not costs associated with increased fuel consumption and emissions, which the €5,000 value does. Also, the INCA tool does not allow the differentiation between fatal and non-fatal injury accidents and so the value of €15,000 used by Abele *et al.* (2005) for fatal accidents cannot be used in the INCA analysis. The valuations from Abele *et al.* (2005) have been used in the cost-benefit analysis reported in section 7. Based on the number of casualties per accident in GB, 1.36, (DfT, 2007a) the number of casualties for EU-27 from section 6.5.3 was converted to a number of accidents so that the total congestion cost could be calculated.

6.7 Costs

The casualty reduction and congestion benefits described in previous sections were combined and assessed against the cost of implementing the technologies in a cost-benefit analysis. The potential fuel efficiency benefits were not included because these were generated as part of a “What if” analysis that considered the potential benefits of removing vehicle mirrors.

Information about the retail cost of LDW and LCA systems was available from a number of published sources. This information is summarised in Table 6-15.

Table 6-15. Retail costs of LDW and LCA systems.

System	Retail prices	Unit cost used in analysis
LDW	€384 - €448 from various manufacturers information €300 Abele *et al* (2005) for 2010 €200 Abele *et al.* (2005) for 2020 €200 COWI used €400 for combined system	€200 - €448
LCA	€576 from manufacturers literature	€200 - €576
Combined LDW/LCA	€886 in USA €600 Abele *et al.* (2005) for 2010 €400 Abele *et al.* (2005) for 2020 €400 COWI (2006)	€400 - €1000

The maximum and minimum prices identified for LDW and LCA systems were used. However, for the combined system, there was less information available for European systems. The two European studies used similar values, however if only these were used, then the upper limit was similar to the upper limit for LCA on its own. The retail price of the combined system in the USA was €886, however information about blind spot monitoring systems showed that the prices quoted for the USA can be substantially lower than those for Europe, €127-€250 compared with €576. Therefore the USA price was increased to make some allowance for the potential effect of this difference between the markets.

No additional information relating to the costs of systems was identified, either through the literature review or through consultation with industry. Therefore, the benefit-cost ratio has been calculated using these retail costs. Retail costs include the expense incurred by the manufacturer during system development and any profit element. The cost of the system, both to the manufacturer and the retail cost, is also linked to the size of the production order. Therefore a system fitted as an option is likely to have a higher retail price. Should such a system become mandatory (and therefore be fitted in larger numbers), both the manufacturer’s and retail cost would be expected to reduce. It should be noted that the effect of reduced unit costs with increased fitment has not been considered in the cost benefit assessment (i.e. the current cost has been used). This, although arguably conservative, is the most reliable cost value available at present.

Although vehicle manufacturers can make some profit on systems that are mandatory, there is likely to be a higher margin when the system is fitted as an option. It is therefore possible that the actual cost of current systems to the manufacturer is a relatively small proportion of the retail cost used in this analysis. However, no data was collected during the consultation phase to allow full consideration of this issue.

Retail costs have been used in this cost benefit estimate because they represent the costs to the end user (the consumer). This is consistent with the assessment of the benefits, which are valued in terms of the end user; the benefit to society.

The cost information identified does not indicate significant savings when LDW and LCA systems are combined. This is likely to be attributed to the fact that LDW uses forward looking sensors and LCA uses rearward looking sensors. The user interfaces of the two systems can also be different, with LCA positioning the warning near the mirrors. However, there could be substantial cost savings by combining LDW (or LCA) with other systems that utilise similar sensors or user interfaces, for example forward collision warning or pedestrian sensing technology could share its sensors with LDW systems.

7 Cost-benefit analysis

The following section compares the benefits and costs described in section 6 to determine benefit-cost ratios (BCR) for the fitment of LDW and LCA systems to the following groups of vehicles:

- Light vehicles (e.g. categories M1 and N1)
- Heavy goods vehicles (HGV) (e.g. categories N2 and N3)
- Large passenger vehicles (LPV) (e.g. categories M2 and M3)

The fitment of a combined LDW and LCA is also included in the analysis.

7.1 Vehicle stock and new registration data

In order to perform a cost-benefit analysis, it is necessary to know the number of vehicles in the overall fleet and the number of new registrations. Table 7-1 summarises the data that is available for EU-27 for 2006 (EC, 2008).

Table 7-1. Vehicle stock and registration data (EC, 2008).

Vehicle type	Stock	New registrations	Comment
Passenger cars	229,954,000	15,557,000	-
Goods vehicles <3.5t	32,249,000	2,025,425	Stock combined with heavy goods vehicles
Goods vehicles >3.5t		354,596	Stock combined with light goods vehicles New registrations EU-15
Buses	797,920	44,361	New registrations EU-15

The data available was not consistent with the grouping of the vehicle types and the complete data were not all available for the EU-27. Therefore a number of assumptions were made and the required values were estimated. It was assumed that:

- The ratio of new registrations for heavy goods vehicles and buses between EU-15 and E-27 were the same. This was used to estimate the new registrations for heavy goods vehicles and buses in EU-27;
- The proportion of goods vehicles in GB that were <3.5t is the same as EU-27. The number of vehicles that are classed as light goods and the number of goods vehicle over 3.5t were identified from Transport Statistics Great Britain (DfT, 2007b) and the ratio applied to estimate stock of light and heavy goods vehicles for EU-27.

The data used in the analysis is shown in Table 7-2.

Table 7-2. Vehicle stock and new registration data used in analysis.

Vehicle type	Stock	New registrations
M1/N1	258,363,100	17,582,424
N2/N3	4,014,356	354,596
M2/M3	797,920	48,087

For the purpose of this analysis it was also assumed that there was no growth in new registrations and the range for the unit cost remained the same throughout the period.

7.2 Technology implementation

The implementation of a technology is often influenced by the potential of regulatory action. LDW and LCA systems are currently being fitted to some vehicles. However, there is currently a proposal that all large vehicles N2/N3 and M2/M3 must be fitted with LDW from 2013. Any systems that are fitted to M1/N1 vehicles will be required to meet a technical specification, although fitment will not be mandatory. To demonstrate the effect of mandating the technology two scenarios have been considered:

1. Do nothing – do not specify any requirements for LDW and LCA systems. The systems will continue to be fitted to some of the vehicle fleet.
2. Mandate the systems – require that all new vehicles are to be fitted with the systems.

This analysis covers the period 2010 to 2020 and 2013 is used as the year in which fitment of the systems will be mandatory (in line with current proposals). The implementation scenarios were the same for LDW and LCA systems.

Abele *et al.* (2005) assumed that in 2010, that 0.6% of the vehicle fleet would be fitted with LDW and LCA, increasing to 7% by 2020. In the absence of any further information regarding technology implementation this has been for the “do nothing” scenario and also the baseline for the 2013 mandatory fitment scenario. The same implementation strategies have been used for the separate LDW and LCA systems as well as the combined LDW and LCA system. It has been assumed that if the technology is made mandatory in 2013 that there will be a linear increase from 8.8% of new vehicles in 2010 to 100% in 2013. Figure 7.1 shows how the technology will penetrate the vehicle fleet based on these implementation strategies.

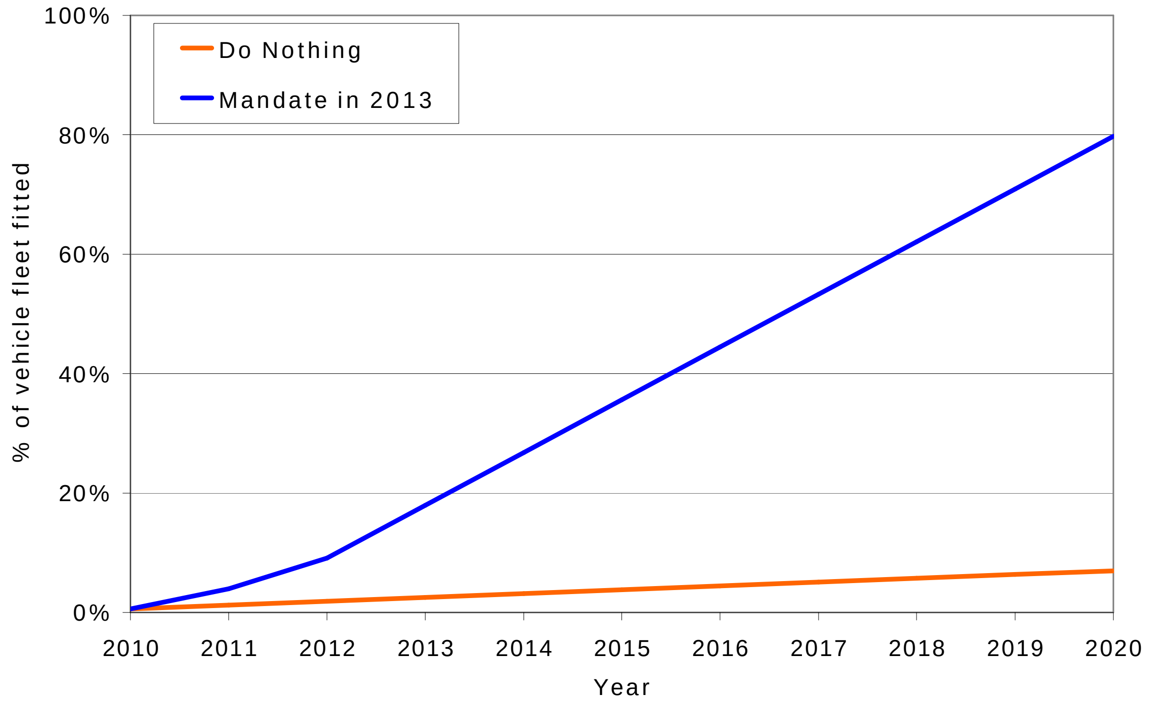

Figure 7.1. Proportion of vehicle fleet fitted with LDW or LCA systems based on two implementation scenarios.

7.3 Benefits

The total benefits expected for the period 2010-2020 are shown in Table 7-3 to Table 7-5.

Table 7-3. Total benefits for M1/N1 vehicles.

Technology	Total benefit	Do nothing	Mandate in 2013
LDW	Min	€1,296M	€9,757
	Max	€18,115M	€136,382M
LCA	Min	€8M	€63M
	Max	€658M	€4,955M
LDW & LCA	Min	€1,576M	€11,865M
	Max	€35,335M	€266,0305M

Table 7-4. Total benefits for N2/N3 vehicles.

Technology	Total benefit	Do nothing	Mandate in 2013
LDW	Min	€27M	€263M
	Max	€442M	€4,278M
LCA	Min	€4M	€37M
	Max	€169M	€1,4M
LDW & LCA	Min	€193M	€1,876M
	Max	€4,890M	€42,428M

Table 7-5. Total benefits for M2/M3 vehicles.

Technology	Total benefit	Do nothing	Mandate in 2013
LDW	Min	€14M	€95M
	Max	€321M	€2,150M
LCA	Min	€0M	€1M
	Max	€8M	€56M
LDW & LCA	Min	€21M	€141M
	Max	€648M	€4,340M

7.4 Costs

The total costs incurred for the period 2010-2020 are shown in Table 7-6 to Table 7-8.

Table 7-6. Total costs for M1/N1 vehicles.

Technology	Total cost	Do nothing	Mandate in 2013
LDW	Min	€3,617M	€31,912M
	Max	€8,102M	€71,483M
LCA	Min	€3,617M	€31,912M
	Max	€10,417M	€91,907M
LDW & LCA	Min	€7,234M	€63,824M
	Max	€18,085M	€159,561M

Table 7-7 Total costs for N2/N3 vehicles.

Technology	Total cost	Do nothing	Mandate in 2013
LDW	Min	€56M	€641M
	Max	€126M	€1,435M
LCA	Min	€56M	€640M
	Max	€161M	€1,845M
LDW & LCA	Min	€112M	€1,281M
	Max	€281M	€3,203M

Table 7-8. Total costs for M2/M3 vehicles.

Technology	Total cost	Do nothing	Mandate in 2013
LDW	Min	€11M	€14M
	Max	€25M	€321M
LCA	Min	€11M	€88M
	Max	€32M	€252M
LDW & LCA	Min	€22M	€175M
	Max	€56M	€438M

7.5 Benefit-cost ratios

Based on the assumptions and data described above, the estimated benefits and costs for the period 2010-2020 and the associated BCR were calculated for fitment to each of the groups of vehicles defined previously. The tables that follow show the BCR for the implementation of LDW and LCA for the different vehicle categories. The figures quoted are defined using the costs and benefits for making the technology mandatory and are over and above those that would have occurred in the “do nothing” scenario.

Table 7-9. Benefit-cost ratios for each vehicle type assuming mandatory fitment in 2013.

Technology	Benefit-cost ratio	M1/N1	N2/N3	M2/M3
LDW	Min	0.13	0.18	0.47
	Max	4.18	6.56	23.97
LCA	Min	0.00	0.02	0.00
	Max	0.15	2.51	0.62
LDW & LCA	Min	0.07	0.58	0.31
	Max	4.08	36.39	24.19

Comparison of the BCR across the different vehicle types shows that in general, fitting LDW or LCA systems to larger vehicles are more likely provide a positive return on the investment than fitting the systems to smaller vehicles (M1/N1). Fitting LDW to any vehicle type is more likely to result in a positive return than fitting an LCA system. However LCA systems may result in a positive return if fitted to N2/N3 vehicles.

The analysis considered both a range in the target population and a range of system effectiveness, resulting in a large range of benefit-cost ratios. Although the uncertainty in the effectiveness was considered to be the most significant value affecting the overall cost benefit outcome, an attempt was made to refine the benefit-cost ratios by using a revised target population value.

This revised target population was achieved by considering the target population in terms of the percentage of all accidents. For GB data the average (mean) value of the minimum and maximum target population was calculated to provide a single estimate for the percentage of all accidents which comprised the GB target population. This was then compared to the target population (percentage of all accidents) from the German data and the average (mean) value used in the subsequent analysis. The range in the effectiveness of the systems was not changed because of the level of uncertainty in the data that had been identified.

Using the average target population, the total benefits for LDW were between 756 and 2269 fatalities and 3,437 and 10,310 serious casualties. For LCA the total benefits were estimated at 223 to 220 fatalities and 293 to 2,835 serious casualties. The revised benefit cost ratios are shown in Table 7-10.

Table 7-10. Refined benefit-cost ratios based on the average target population for each vehicle type assuming mandatory fitment in 2013.

Technology	Benefit-cost ratio	M1/N1	N2/N3	M2/M3
LDW	Min	0.35	0.53	1.94
	Max	2.29	3.48	12.81
LCA	Min	0.00	0.07	0.01
	Max	0.09	1.30	0.32
LDW & LCA	Min	0.20	1.96	1.24
	Max	2.36	20.77	13.48

These revised benefit-cost ratios re-enforce the conclusions that can be drawn from the initial analysis described above.

8 Fuel economy benefits

Advanced LCA systems have the potential to reduce the need for external mirrors. Removing mirrors (particularly on HGVs and buses) can reduce the frontal area of the vehicle and therefore reduce the associated drag force. This section of the report describes the estimation of the potential fuel economy benefits that could be achieved by removing mirrors.

8.1 Methodology

The potential fuel economy benefits have been investigated using the PHEM (Passenger car and Heavy-duty Emission Model) model developed by the EC project ARTEMIS. PHEM is a computer model that uses drive cycle and vehicle characteristics such as engine power and vehicle weight to provide information on fuel consumption and emissions. The analysis was carried out for four different types of vehicle:

- 34 to 40t HGV
- 3 axle coach
- medium sized diesel van
- medium sized petrol car

The vehicles selected for this analysis were already specified within PHEM. All vehicles were compliant with Euro-4 emissions requirements and were half laden.

In order to investigate the effect of removing mirrors, the frontal area and drag-co-efficient for each vehicle type were changed within the model. The existing specification was used as the baseline and it was assumed that mirrors were not included. The changes to vehicle specifications were based on data available from published sources. The modified vehicle specification was the one that included mirrors

8.1.1 Drag co-efficient and frontal area

For an initial estimation of the potential fuel economy/CO_2 benefits of removing mirrors, generic values for drag coefficients and frontal areas from published literature have been used.

The majority of the literature identified considered improved aerodynamics of vehicles in terms of the overall geometry and profile of the vehicles. Some information was identified that would allow the effect of mirrors on frontal area and drag co-efficient to be estimated for HGVs and passenger cars. Only baseline information was available for vans and buses/coaches, therefore the data from the passenger cars and HGVs were used, assuming that:

- mirrors for vans would be similar to those for passenger cars
- mirrors for coaches would be similar to HGV mirrors.

For the analysis of the passenger car and van drive cycles, information was taken from Flegl and Bez (1983), which stated that a single outer rear view mirror may increase the frontal area of a passenger car by between 1 and 2%. For this analysis an increase in frontal area of 1.5% was assumed and this was used to calculate the frontal area of one mirror using the baseline frontal area (A_b). This then allowed the frontal area of the vehicle with two mirrors to be estimated (A_m). Wong (2001) reported that for passenger cars 0.01 is the component of aerodynamic resistance from one external mirror where the total drag co-efficient was 0.435. This allowed the proportion of drag from two mirrors to be estimated and hence the baseline drag co-efficient (C_{db}) as a proportion of drag co-efficient of the vehicle with mirrors (C_{dm}), therefore allowing C_{dm} to be estimated.

For the analysis of the HGV and the coach drive cycles, information was taken from Creswell and Hertz (1992). This paper reported values of drag coefficient (C_d) and drag area (C_dA) for an American “faired” mirror, from which the frontal area of one mirror can be calculated. Of the three types of mirror assessed in this paper, the “faired” mirror was considered most comparable to mirrors used in Europe. This paper also stated that 5.3% of the total drag force of a commercial vehicle comes from a pair of fully faired mirrors and this was used to calculate the C_{db} as a proportion of C_{dm} and therefore allowing an estimate of C_{dm} to be made.

The baseline and modified (with mirrors) values that have been used are summarised in Table 8-1.

Table 8-1. Drag co-efficients and frontal areas.

	Baseline (without mirrors)		Modified (with mirrors)	
	Drag co-efficient (C_{db})	Frontal Area (A_b)	Drag co-efficient (C_{dm})	Frontal Area (A_m)
Car	0.30	2.55	0.31	2.63
Van	0.40	4.11	0.42	4.23
HGV	0.50	9.00	0.52	9.26
Coach	0.45	7.40	0.47	7.66

8.2 Results

PHEM estimates fuel consumption (FC) and the emissions of carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NO_X) and particulate matter (PM) based on the instantaneous engine power demand and engine speed during a driving cycle specified by the user.

Carbon dioxide emissions and fuel consumption are of most interest for this research. Although carbon dioxide (CO_2) was not calculated directly, it was derived from the standard carbon balance equation, as specified in the Commission Directive 93/116/EC. This equates the carbon content of the fuel to the sum of the fractional contributions of each carbon-containing exhaust pollutant (CO, HC and CO_2).

Figure 8.1 and Figure 8.2 show examples of comparisons between the baseline and modified vehicle, in this case, for the HGV.

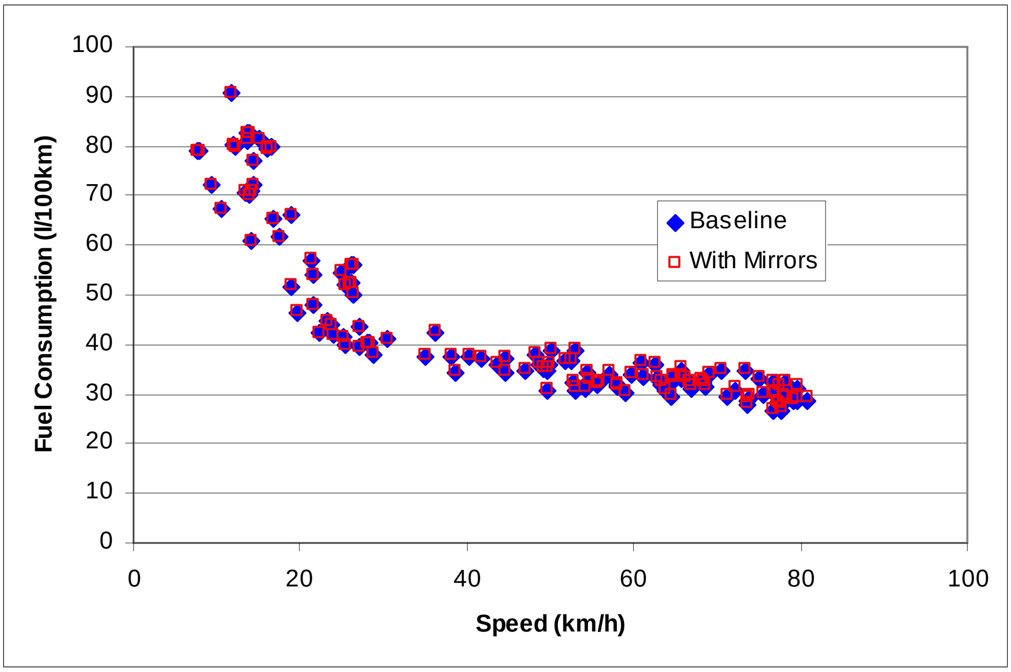

Figure 8.1. Comparison of fuel consumption between the baseline and modified HGV.

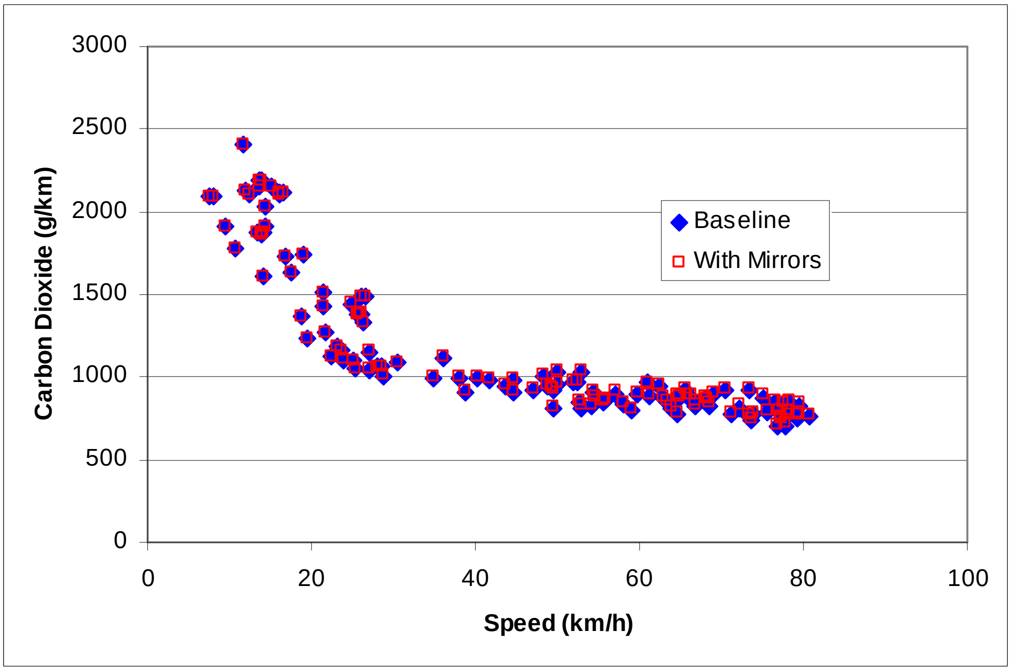

Figure 8.2. Comparison of carbon dioxide emissions between the baseline and modified HGV.

For both metrics, the results from the modified vehicle overlay the baseline data. Also, the strong relationship between fuel consumption and carbon dioxide emissions produce comparable trends with respect to speed.

Figure 8.3 shows the relative change in fuel consumption (or carbon dioxide) between the baseline and the modified vehicle.

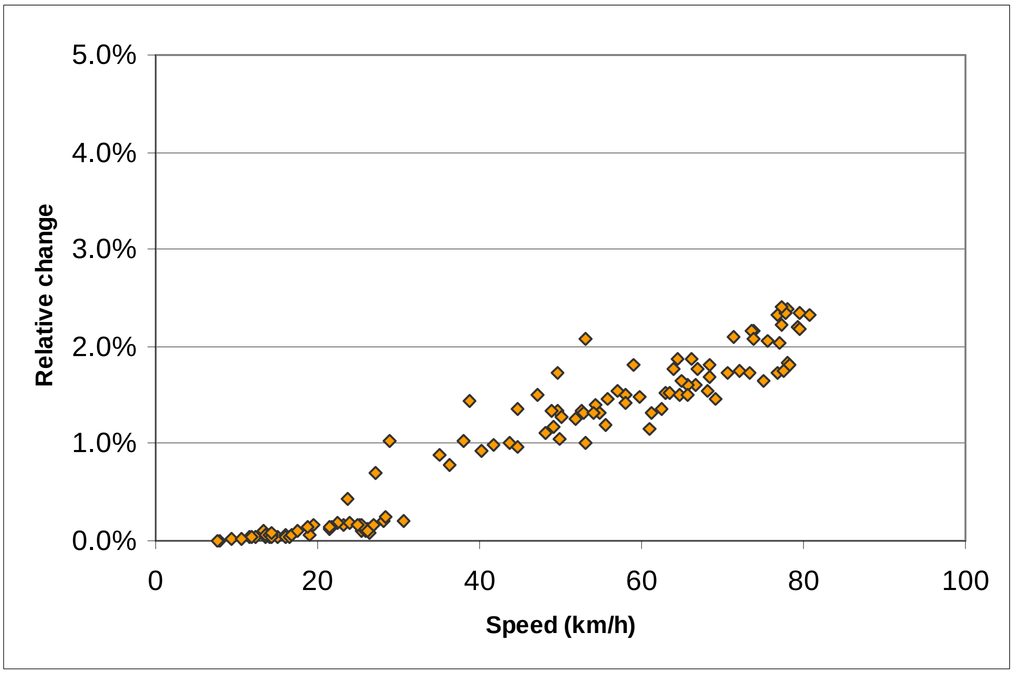

Figure 8.3. Relative change in fuel consumption (or carbon dioxide) between the "with mirrors" and modified HGV.

Not surprisingly, the addition of mirrors has an increasing effect with increasing speed, particularly above 20km/h. For the HGV there is an increase in fuel consumption (and carbon dioxide emissions) of up to 2.5%.

The equivalent of Figure 8.3 for the other vehicle types is shown in Appendix E.

8.3 Discussion

This discussion is intended as an indication of how the proportional difference in fuel consumption can influence the annual fuel and CO_2 savings in Europe. For each type of vehicle considered, the annual average distance travelled by a European vehicle of that type has been estimated using traffic data (vehicle kms) and vehicle stock (number of vehicles) (EuroSTAT, 2008). Data from 2001 was used because this was the year where the data was available for a greater number of member states. The proportional fuel saving has been taken from the PHEM data for a typical driving cycle for that vehicle. This data has then been used to estimate the annual average saving in fuel for the European vehicle fleet.

To identify an appropriate driving cycle, the average in-use speed for each vehicle was required. It was not possible to identify this information for Europe, so data from GB was used. The vehicle speed data was differentiated by road type and vehicle type, however the proportion of the distance travelled on each type of road was also required. The data that provided distance travelled by type of road was grouped differently to the vehicle speed data and therefore the following assumptions were made in order to estimate the overall average travel speed:

- Urban major roads = urban roads with 40 mile/hr speed limit
- Urban minor roads = minor roads with 30 mile/hr speed limit
- Rural major roads = non-urban dual carriageways
- Rural minor roads = non-urban single carriageways
- Motorways = non-urban motorways.

8.3.1 Passenger cars

Data from ten member states[1] was available for this task. The average annual distance travelled by passenger cars was 14,318km. The average in-use speed based on GB data was 83km/h.

For an average European passenger car travelling 14,318km at an average speed of 83km/h, this is equivalent to a reduction in fuel consumption of 26 litres per year and 62kg of CO_2 per vehicle per year.

8.3.2 Goods vehicles

Data was available from 11 member states[2]. The data for the annual distance travelled for goods vehicle did not differentiate between smaller goods vehicles (vans) and larger goods vehicles (HGVs). The goods vehicle results from PHEM are for a van and an articulated HGV. An average distance travelled by “goods vehicles” of 17,071km was estimated from the data available. Data from GB (DfT, 2003) and Denmark (StatBank, 2008) was available to differentiate between vans and HGVs. Analysis of the data showed that the annual average distance travelled by vans was 0.767 times that of “goods vehicles” in GB and 0.862 times that of “goods vehicles” in Denmark. It is therefore assumed that for Europe the annual average distance travelled by vans is 0.815 times that of the “goods vehicles”. For HGVs, the multiplication factor was 2.392 in GB and 2.060 in Denmark, therefore a factor of 2.226 was applied for Europe. The annual average distance travelled fro vans and HGVs was estimated to be:

- Vans, 13,913km
- HGVs, 38,000km

The average in-use speed based on GB data was 81km/h for vans and 80km/h for HGVs.

For an average European van travelling 13,913km at an average speed of 81km/h, this is equivalent to a saving of 32 litres of fuel and 83kg of CO_2 per vehicle per year.

For an average European HGV travelling 38,000km at an average speed of 80km/h, this is equivalent to a saving of 31 litres of fuel and 685kg of CO_2 per vehicle per year.

8.3.3 Buses, coaches and minibuses

In most data sources, minibuses are not identified separately from other large passenger vehicles, and in many cases it is not clear where they are included. Therefore the following analysis is based only on the data for buses and coaches.

Data was available from 13 member states[3] to estimate the annual average distance travelled for a European bus/coach. The estimate annual average distance travelled was 34,571km.

The average in-use speed based on GB data was 67km/h.

For an average European bus/coach travelling 34,571km at an average speed of 67km/h, this is equivalent to a reduction in fuel consumption of 141 litres per year and 372kg of CO_2 per vehicle per year.

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[1] Belgium, Czech Republic, Estonia, Ireland, Latvia, Slovenia, Finland, Sweden, UK, Iceland

[2] Belgium, Czech Republic, Estonia, Latvia, Lithuania, Poland, Slovenia, Slovakia, Finland, Sweden and Iceland

[3] Belgium, Czech Republic, Estonia, Ireland, Latvia, Lithuania, Luxembourg, Poland, Slovenia, Slovakia, Finland, UK and Iceland

8.3.4 Estimated European fuel economy benefits

For the total number of vehicles in EU-27, the potential benefits of removing mirrors are as shown in Table 8-2.

Table 8-2. Potential fuel economy benefits (EU-27).

Vehicle Type	Reduction in CO_2 per vehicle per year (kg)	Number of vehicles (2006)	Total benefit (tonnes of CO_2)
Car	62	229,954,000	14,257
Vans	83	284,091,000	23,580
HGV	685	4,014,356	2,750
Bus/Coach/Minibus	372	797,920	297

9 Discussion

9.1 Introduction

Since this research started, the European Commission have made a proposal for a General Safety Regulation (EC, 2008) that will cover advanced technologies such as LDW and LCA systems. The proposal includes requirements for LDW systems, requiring larger vehicles to be fitted with the systems from 2013. In addition, the systems will be required to meet specific technical requirements. This research project has reviewed current standards and technology in order to provide an outline technical specification for LDW systems and LCA systems that can be used within the General Safety Regulation.

The two systems considered by this research have the potential to reduce the number of casualties in two main groups of accidents:

- Accidents where a vehicle drifts out of their travel lane unintentionally; and
- Accidents where a vehicle collides with another vehicle when changing lane.

9.2 Methodological issues

The cost-benefit analysis reported here consists of two main phases, defining the target population for the system, and then defining the effectiveness of the systems for that target population. There are a number of issues that were identified when defining both the target population and the effectiveness. These issues are discussed below.

A number of studies were identified that had carried out cost-benefit analyses, both for Europe and for USA. In principle, there was agreement about the types of accident that could be avoided by fitting LDW and LCA systems. The accident groups defined were at a high level, i.e. head on collisions, leaving roadway collisions and side collisions. Causation factors were not considered when defining the target population and therefore the effectiveness value applied should consider what caused the accidents.

The analysis of Great Britain data showed that identifying relevant accidents (the target population) was not straightforward. Accident types were carefully collated using the circumstances of the accident and also accident contributory factors. However, in some cases the data contained inconsistencies or, upon validation with the in-depth accident data, accidents apparently matching the criteria were found to be not relevant. Therefore, the validation stage of the methodology was used to estimate the upper and lower bounds of the national estimate made from STATS19. Therefore, despite the detailed methodology used to define the target population and the level of in-depth data available, there are limitations with the accuracy of the target population which cannot be further refined without improved accident data. It should also be noted that other studies who estimated target populations for these systems did so using either very high level accident criteria (i.e. all head-on collisions) or were based on a small sample of accidents. In both cases the target population was not validated in any way; neither in relation to whether the accidents considered really were accidents which would be addressed by the systems, or whether they were representative of the national situation.

This research did not set out to define the effectiveness of the safety systems. Therefore the effectiveness of the systems was based on the information in the literature. The effectiveness is usually reported as the percentage of a sample of accidents. This can be the target population or a sub-set of the target population (excluding accidents that were caused by vehicle failure for example). There were two main sources of information identified:

- Field operational trials carried out in the USA; and

- Estimates based on the increased reaction time available by providing the warning.

The cost-benefit analysis reported here used the information available from the literature to define a range of effectiveness values to apply to the target population. One of the limitations of this approach is that the sample to which the effectiveness is applied can be defined differently between studies. In many cases, the assumptions that have been made are not traceable from the information provided in the report, resulting in uncertainty over the appropriateness of the information available. However, some of the uncertainty in the potential effectiveness could be overcome by defining the target population in more detail, reducing the reliance of the overall benefit estimate on the effectiveness criteria used. However, although the causation factors such as driver behaviour and other information about what the vehicles were doing before the impact were used to identify the accidents, there still remained some uncertainty about the accidents within the target population and so, upper and lower limits were specified.

The principle aim of these systems is to avoid accidents; however there is some potential for the systems to help mitigate injuries. Some of the research that was reviewed included the effectiveness of the systems in relation to injury mitigation. However, it was unclear how these were derived and therefore the potential benefits from injury mitigation were not included in the cost-benefit analysis.

9.3 Costs and benefits

A range of benefit-cost ratios were produced for the different systems and vehicle types. The final output from the analysis was strongly influenced by uncertainty in both the costs and benefits of the systems. As mentioned previously, the analysis attempted to refine the target population more than previous studies. The outcome was a range of potential accidents that could be affected by the systems. However in some cases the uncertainty in the effectiveness (e.g. 0%-60% for LCA) was more likely to affect the overall outcome. Revised benefit-cost ratios were calculated based on an average target population. The revised ratios confirm the conclusions drawn from the initial analysis.

The target population data estimated here could be taken forward and combined with the outcome from the planned FOT to determine a more refined estimate of the benefits. Some studies underway or those imminent within Europe may yield valuable data which can be used to more accurately estimate the effectiveness of the systems and allow a more accurate estimate of the potential benefits to be made. Additional cost information would also allow refinement of the BCR.

It should also be noted that the casualty valuations used for fatal, serious and slight casualties are significantly lower than for some EU countries and are relatively old (it has been noted that these values are cited in Directive 1999/62/EC). Using higher casualty valuations would lead to larger predicted monetary benefits and more favourable benefit to cost ratios. For example, the 2006 GB valuations for fatal, serious and slight casualties are €1,936,285, €217,568 and €16,770 respectively (based on exchange rate of 1.3€ per GB pound) (DfT, 2007).

Despite the limitations of the study, the overall casualty benefits are in line with previous studies such as Abele *et al.* (2005) and COWI (2006).

9.4 Potential risks relating to LDW and LCA systems

Although these systems are intended to assist the driver and to help reduce the risk of an accident, there are also potential risks associated with such systems. There are two key areas in relation to risk:

- Unintended consequences – These could relate to the subject vehicle and the driver’s behaviour – i.e. feeling that they can rely on a lane departure warning system while deliberately performing distracting tasks. There is no evidence in the literature that suggests that lane departure warning or lane change assistance results in an undesirable driver response and some fairly large studies have been carried out; nevertheless, these studies are relatively few in number and have not focussed on unintended consequences specifically. There may also be unintended consequences of lane departure warning and lane change assistance for the other traffic. However, more work is required because there was no research identified that had considered this aspect. Particular areas to investigate are the effect of multiple advanced driver assistance systems and the effects on drivers and driving. The cost-benefit analysis considers a combined system, but much of the research that evaluated the systems considered each system individually. The effect of other systems might mean that a proportion of the accidents assumed in this study to be addressed by LDW and LCA systems might have already been partially addressed by other systems, such as driver drowsiness monitoring, speed warning, or ESC.
- Driver acceptance - Firstly, the systems need to be highly intuitive to ensure that drivers understand how to use them and what the warnings mean. They also need to keep false alarms to an absolute minimum. However, it may also be the case that some drivers will be reluctant to rely on the vehicle system for this kind of support and may resist it. Although driver acceptance is often rated highly in the literature, this can be influenced by the way volunteers are recruited and by the design of the experiment. An important point is that drivers may have their own perception of risk that might differ from the lane departure warning or lane change assistance system. For example, curve cutting or moving towards the intended lane while an overtaking vehicle is still adjacent in order to squeeze into a gap.

9.5 Technical specifications

Initial outline technical specifications have been produced for LDW and LCA systems. However, these are an initial attempt based on the published information that was available. If these outline requirements are developed further, it would be desirable to perform some tests to validate the technical specifications produced.

Although the research included consultation with industry, there was minimal response. Therefore it may be necessary to carry out further consultation as the technical specifications are developed.

10 Conclusions

- A number of LDW and LCA systems are currently on the market.
    - Most of the LDW systems utilise forward looking camera systems.
    - Some systems, in particular those using infra-red sensors, do not issue a warning until the lane boundary is crossed
    - LCA systems can be grouped into two types, blind spot monitoring and lane change warning.
- A number of systems that build upon the principles of LDW or LCA were also identified. Lane Keeping Assist (LKA) is one of these and is already offered by some vehicle manufacturers.
- A review of existing standards has highlighted areas where there are currently no requirements. These include:
    - LDW - Operational performance in a range of weather conditions;
    - LDW - Definition of detectable lane markings
    - LDW - Extrapolation of vehicle position based on previous estimates
    - LCA - Potential for issuing warnings when lane change is intended, not just when indicated
    - LCA – Assessment of the ability not to respond to stationary objects and vehicles in oncoming carriageway.
- Three accident types were identified that could be influenced by an LDW system and four for an LCA system. These accident types were used to define the target population of accidents which would be influenced by the systems.
- Effectiveness values were reviewed from existing literature and applied to the target population to define the potential casualty benefits. The large range of effectiveness values in the literature meant that ranges for the estimated benefit was large.
- More precise information relating to effectiveness information and system cost is required to reduce the range of the benefit estimates. Information relating to the effectiveness of the systems may be forthcoming from imminent field operational trials.
- Improved accident data would also help to reduce the range identified for the target population.
- The casualty groups identified for the two systems are mutually exclusive and so these benefits are additive for a combined LDW/LCA system.
- The return on investment is more likely to be positive for LDW than for LCA systems. Fitment to larger vehicles is more likely to result in a positive return than for smaller vehicles.
- If advanced LCA systems were to replace mirrors on all vehicle types, there is potential to reduce CO_2 emissions by 40,000 tonnes for EU-27.
- Initial outline technical specifications have been produced for LDW and LCA systems. However, these specifications will require further development and consultation before they can be used in regulatory activities.

Acknowledgements

The work described in this report was carried out in the Vehicle Engineering Department of the Transport Research Laboratory. The authors are grateful to Mike McCarthy who carried out the technical review and auditing of this report.

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Appendix A Literature survey

A.1 Introduction

Methods of lane departure warning and lane change assistance have been researched increasingly in recent years. In the future, the research is likely to focus on ways of integrating a range of functions or services into a combined advanced driver assistance system; however at present, studies tend to focus on a single function. For example, studies of lane departure warning do not usually address lane change assistance and vice versa.

A great deal of the literature on lane departure warning describes the technology behind specific systems. For example, Chen *et al.* (1995) proposed a system that was based around a downward looking camera that tracked the lane markings. However, the current trend is towards forward looking camera systems that can track the lane markings and other road features (Motoyama *et al.*, 2000; An *et al.*, 2006). While the performance of these systems is generally quite promising, it can be influenced by the environmental conditions in which the vehicle is being used (Hadi *et al.*, 2007). Sensor based systems capable of detecting magnetic markers placed in the lane boundaries have been developed with the harshest conditions in mind (Qi *et al.*, 2006). However, these are relatively expensive to implement because magnets need to be embedded in the carriageway. Other systems have been proposed that use GPS and an accurate digital map of the road network (Bodor *et al.*, 1996). Another innovation is the use of laser or millimetre wave radar. The warning algorithms used to assess the risk of a lane departure taking place have also been the subject of research (Lee *et al.*, 1999). These algorithms process the data from the camera/sensor to determine the vehicle’s position and trajectory, the road geometry, and the driver’s intentions.

Lane change assistance systems have been reported in the literature to a much lesser degree than lane departure warning systems. Nevertheless, a number of different technologies are proposed. These include rearward looking camera systems to detect vehicles that are adjacent to, or to the rear of, the subject vehicle (Chung *et al.*, 2006; Liu *et al.*, 2007). Other systems are based around infra red sensors (Sivak *et al.*, 2007) or radar (Reed, 1998). While some systems use a combination of these technologies, such as that described by Rüder *et al.* (2002), which employs both vision and radar sensors.

Significant engineering developments have been made in the field of lane departure warning and lane change assistance. These have been reported extensively in the literature; nevertheless, these developments were not the main focus for this review. Instead, the focus was on research that could be used to inform decisions about appropriate specifications or requirements for lane departure warning and lane change assistance systems.

A.2 Lane departure warning

This section highlights the key findings from the literature on lane departure warning. It describes the problem of lane departure in terms of the proportion of police reported collisions that occur following the manoeuvre, and examines the causes and characteristics of these collisions. This information was needed to comment on the circumstances in which a lane departure warning system must operate. The section also considers the dynamics of the manoeuvre and discusses the cognitive processes that drivers use to stay in their lane. This was necessary to support the information about the operating circumstances of lane departure warning systems.

The section then focuses on driver behaviour. The first consideration is the effect of the human machine interface. Information was needed on the way that drivers respond to warnings following a lane departure and whether the type and location of the warning is important. The second consideration is the effect of lane departure warning on driver behaviour. The key questions are whether the presence of a warning system changes their behaviour in terms of the number of lane departures and whether they accept the warning and respond to it appropriately. An understanding of these and other issues around behaviour was necessary to comment of the way that the performance of a lane departure warning system should be assessed.

Finally, methods used to evaluate the costs and benefits of lane departure warning were explored from the literature. Some comment was also included on the findings of these studies. This information was needed to support the cost benefit analysis in this project.

A.2.1 Analysis of lane departure collisions

For the purposes of this review, a lane departure is defined as an unintentional manoeuvre across the lane boundary. Although most drivers detect that their vehicle is leaving the lane and take corrective action, a number of other factors may combine to cause a collision. Most of the research available on the frequency of collisions resulting from a lane departure was carried out in the United States. While the situation in Europe is likely to be similar, consideration should also be given to potential differences between American and European roads (and driving) and to the effect that these differences might have. Even so, European researchers often use data from the United States when discussing the situation in Europe (Abele *et al.*, 2005; COWI, 2006).

While there have been several studies of pre crash scenarios in the United States, it is very difficult to derive a single or discrete figure for the frequency of lane departure collisions. This is because different scenarios can result from a lane departure and researchers often analyse them separately. In fact, there are three ways that a collision might occur following a lane departure: the vehicle leaves the lane and strikes oncoming traffic in the opposite carriageway; the vehicle leaves the lane strikes traffic travelling in the same direction in an adjacent carriageway; the vehicle leaves the lane and the roadway and strikes a stationary object and/or rolls over. All three scenarios can be considered lane departure collisions, although they are not always grouped in that way in the literature.

Analyses of the General Estimates System in the United States suggest that around 3 percent of collisions reported to the Police involve vehicles travelling in the opposite direction (Najm *et al.*, 2003; McKeever, 1998). These comprise head on collisions and sideswipes. The vehicle usually leaves the correct lane just before the impact (Najm *et al.*, 2003). This suggests that the majority of these collisions occur due to the vehicle drifting into the path of the oncoming vehicle. It is important to make this distinction because if the vehicle was travelling in the wrong lane for some time, it might indicate that the driver was travelling the wrong way on a one way street or was impaired by alcohol (Najm *et al.*, 2003). It is also important to exclude cases where loss of control or vehicle failure was a factor since a lane departure warning system would not assist the driver in these circumstances.

Lane departure collisions involving vehicles travelling in the same direction are sometimes included in analyses of lane change collisions. Although a lane change is a deliberate manoeuvre (and a lane departure is unintended), it is considered that the crash dynamics can be similar (Choven *et al.*, 1994; Sen *et al.*, 2003). Nevertheless, when the data are separated, it reveals that around 1 percent of collisions reported to the Police involve a vehicle that leaves the lane and strikes adjacent traffic travelling in the same direction (Najm *et al.*, 2003; Sen *et al.*, 2003). This was based on analyses of the General Estimates System in the United States.

The most frequent lane departure collisions in the United States are those that occur when the vehicle leaves the lane and the road. The majority of these collisions are single vehicle events (Najm *et al.*, 2002). They represent around 6 percent of all Police-reported collisions using the General Estimates System when loss of control, vehicle failure and avoidance manoeuvres are excluded (Najm *et al.*, 2003). These collisions are particularly important because around half of all fatal and a third of all severe-injury motor vehicle collisions are attributed to single vehicle events (Sandin and Ljung, 2007). Road departure collisions tend to be severe because the vehicle can strike a rigid object such as a tree or a pole and/or roll over.

The General Estimates System in the United States is based on collisions reported to the Police. It is likely that specific reporting practices are followed that lead to undercounting of collisions and injuries. This situation also exists in Europe (ICF Consulting, 2003). Several studies have examined this issue and the findings were summarised by ICF. This highlighted that the average undercounting for serious injuries could be in the order of 30 percent, while the corresponding figure for slight injuries was 60 percent. Unfortunately, no information was available on the undercounting of lane departure collisions specifically; nevertheless, the implication is that there could be a significant level of undercounting which means that the benefits of lane departure warning might be underestimated.

There are a number of reasons why a vehicle might deviate from the correct lane. However, it is useful to consider two main scenarios: in the first scenario, the vehicle drifts of the lane for no apparent reason, and in the second scenario, the driver loses control of the vehicle. Vehicles that drift out of the lane tend to do so slowly (Sandin and Ljung, 2007). In most of the cases that result in a collision, no attempt at recovery is made. Alcohol, drugs, fatigue/drowsiness and inattention can all play a role in these collisions (Najm *et al.*, 2003). However, inattention is generally under-represented in the collision databases because it is difficult for the Police to detect (Campbell *et al.*, 2003).

Loss of control is more likely to lead to a single-vehicle, off-roadway collision rather than an opposite direction or same direction lane departure collision (Najm *et al.*, 2003). Control loss was hitherto excluded from this review because a lane departure warning system would not assist the driver in maintaining control of the vehicle. For example, speeding is often linked to control loss (Campbell *et al.*, 2003; Sandin and Ljung, 2007). This can include instances where the driver is exceeding the speed limit as well as cases where the vehicle is travelling at or below the speed limit, but the speed is inappropriate for the current weather and road conditions (Hendricks *et al.*, 2001). In these circumstances, the driver has not considered his/her speed adequately and is therefore unable to handle a particular situation such as a curve in the road. While a lane departure warning system would alert the driver to the danger, it would more than likely be too late to regain control of the vehicle. Other advanced driver assistance systems such as curve speed warning systems might help to prevent collisions that result from this situation.

Most off-roadway lane departure collisions occur on a straight section of carriageway; however, same direction and opposite direction lane departure collisions are distributed more evenly between straight and curved carriageways (Najm *et al.*, 2003). Unfortunately, no information was found on the radius of the curved carriageways. The pre crash speed was also unreported in the literature, although some analyses were made using the speed limit where the collision occurred. For example, Najm *et al.*, (2003) reported the speed limit distribution for a series of off-roadway lane departure collision scenarios on non-freeway roads. This revealed that the most common speed limit for the straight carriageway departures (25 mile/h) was much lower than the most common limit for curved carriageway departures (55 mile/h). Similarly, Sen *et al.* (2003) found that more same direction lane departure collisions occurred on roads where the speed limit was less than 35 mile/h rather than on roads with other limits. Clearly, it must be noted that the carriageway speed limit does not give a reliable indication of the speed at which the vehicles were travelling. Investigations of other environmental factors have revealed that many lane departure collisions occur during daylight with no adverse weather conditions (Najm *et al.*, 2003; Sen *et al.*, 2003).

A.2.2 Analysis of lane departures

When driving, it is necessary to monitor the position of the vehicle constantly with respect to the lane markings. A lane departure occurs when the driver fails in this task and the vehicle crosses the lane boundary. Collision databases record several causes of lane departure including driver fatigue, inattention (in various forms), loss of control and vehicle failure. However, these analyses are based largely on retrospective assumptions about each collision.

Keeping a vehicle within the lane places both visual and cognitive demands on the driver. The visual demands are related to observing the roadway ahead and the cognitive demands are related to assessing the scene for changes. Another important consideration is the driver's perception of danger. Drivers do not always associate a lane boundary crossing with immediate danger, as illustrated during deliberate curve cutting manoeuvres (Pohl *et al.*, 2007).

Several studies report the importance of the time to line crossing as an indicator of driver performance and as a way of characterising lane departure (Godthelp *et al.*, 1984; Lin and Ulsoy, 1996). Time to line crossing is an expression used to describe the time available to a driver before the vehicle reaches one of the lane boundaries (Godthelp *et al.*, 1984). There are different computational methods proposed in the literature to determine the time to line crossing with varying degrees of complexity (Mammar *et al.*, 2006). However, evidence suggests that drivers use their own perception of the time to line crossing as a cue to control the position of their vehicle (van Winsum *et al.*, 2000). For example, Godthelp (1998) showed that drivers make a corrective steering action at a constant time to line crossing irrespective of vehicle speed. Furthermore, van Winsum and Godthelp (1996) showed that drivers choose a speed in curves such that the minimum time to line crossing is constant over different curve radii.

Information about the way that drivers make use of the time available to them when driving is essential to the development of effective warning systems (Martin *et al.*, 2003). This is because an appropriate warning time must be determined that gives the driver enough time to take corrective action without being a nuisance. Suzuki *et al.*, (1998) found that drivers need over 0.9 s to avoid a lane departure successfully. Further work led to the suggestion that 1.0 s would be an appropriate warning timing to keep driver annoyance to acceptable levels (Suzuki *et al.*, 2000).

A.2.3 The effect of human-machine interface design on driver behaviour

The human machine interface is a critical part of a lane departure warning system. This is the means by which the system communicates a warning to the driver. It may also convey other information relating to the status of the system. Only three warning strategies are realistic for lane departure warning: visual, audio, or haptic. Nevertheless, a significant amount of human factors research has been carried out in this area. This has focused on the way that drivers respond to different warning strategies when alerted to a lane departure.

The urgency of the warning is another aspect of the strategy to consider. The time available to warn the driver may be insufficient to allow a graded series of warnings to express the urgency of the situation (Pomerleau *et al.*, 1999). Most systems therefore offer one stage warnings only. However, it is possible to distinguish lane departures with a high likelihood of a collision from lane departures with a low likelihood of a collision. Systems that determine imminent versus cautionary warning levels for lane departure usually have additional advanced driver assistance functions (SAE, 2007).

Visual warnings are not recommended for lane departure warning systems unless they are supplemented with auditory and/or haptic warnings (Campbell *et al.*, 2007; SAE 2007). This is because lane departures often occur due to inattentive drivers. It is unlikely, therefore, that those drivers' eyes would be focused on a visual display

(Roßmeier *et al.*, 2005). Visual information is an important part of a human machine interface, but in the case of a lane departure warning system, it should be reserved for status updates (Olsen, 2004), or to give feedback about the type of warning being issued (Le Blanc *et al.*, 2006).

Research shows that auditory lane departure warnings are effective (Roßmeier *et al.*, 2005; Le Blanc *et al.*, 2006). It has been suggested that auditory warnings attract the driver's attention without guiding their action (Suzuki and Jansson, 2003). The implication was that drivers would take time to work out the reason for the warning before responding. However, another study found that the steering reaction times of drowsy drivers following an auditory lane departure warning were too fast for this to be the case (Roßmeier *et al.*, 2005). Basically, there was insufficient time for the drivers to have interpreted the correct course of action simply by looking at the road following the warning. It seems likely that the drivers in this study learnt the meaning of the auditory warning and how to respond appropriately and quickly. Sayer *et al.* (2005) drew similar conclusions about auditory lane departure warnings.

Another approach to help drivers interpret an auditory warning is to use a sound that recreates a familiar noise in the vehicle. In the case of a lane departure warning system, the sound of a rumble strip might lead to a more intuitive system (Ziegler *et al.*, 1995). Such auditory icons have produced faster reaction times in abstract reaction tests (Graham 1999; Belz *et al.*, 1999). Further research is needed to determine whether drivers find these sounds distracting in real driving conditions.

Haptic warnings can also be an effective means of alerting the driver to a lane departure (Suzuki and Jansson, 2003). The advantage of a haptic warning is that it will alert the driver without disturbing other passengers. In addition, there may be other advantages in terms of the amount of time it takes people to respond to the warning. Ho *et al.* (2005) found that participants in an experiment responded more quickly to haptic warnings than to either visual or auditory warnings. However, the experiment comprised a simple reaction test, although an attempt was made to recreate the feel of driving using a recorded video. Suzuki and Jansson (2003) found that haptic warnings and auditory warnings produced similar reaction times when drivers in a simulator were made aware of the meaning of the warnings before the experiment. Other studies report similarly inconclusive findings when haptic lane departure warning systems are compared with auditory systems.

Haptic warnings can be delivered through the seat or through the steering wheel. A haptic lane departure warning system could provide information in an intuitive way, while releasing already heavily-loaded visual or auditory channels. One example is a system that reproduces the sensation of driving over a rumble strip (Kochlar and Tijerina, 2006).This approach should be considered because some haptic systems have been misinterpreted by drivers (SAE, 2007). For example, drivers in one (simulator) study responded incorrectly to a haptic lane departure warning system by opposing the pulsed steering torque (Suzuki and Jansson, 2003). However, drivers responded correctly to a similar system in another study (Navarro *et al.*, 2007).

A.2.4 The effect of lane departure warning on driver behaviour

Lane departure warning systems are fitted to vehicles with the expectation that drivers will take corrective action when they are presented with an alert. While this may be the case, it is also important to consider the wider effects on driving. For example, drivers might change their behaviour in some way when they are using a vehicle equipped with a lane departure warning system. Another concern is whether drivers will accept the system and respond to the warning in an appropriate way.

A consistent finding from the literature is that lane keeping is improved when the vehicle is fitted with a lane departure warning system (Tijerina *et al.*, 1996; Portouli *et al.*, 2006; Alkim *et al.*, 2007; Wilson *et al.*, 2007). In one study, drivers were presented with inaccurate warnings only, but still generated fewer warnings than a control group (Rudin Brown and Noy, 200?). It seems that the presence of a lane departure warning system encourages the driver to be more aware of the position of the vehicle, possibly in an effort to reduce the number of warnings that are issued.

The presence of a lane departure warning system has no effect on the frequency of lane changes (Portouli *et al.*, 2006; Alkim *et al.*, 2007). However, turn signal use increases during these manoeuvres (Portouli *et al.*, 2006; Alkim *et al.*, 2007; Wilson *et al.*, 2007). This is further evidence that drivers improve their driving to prevent warnings. In fact, the participants in one study reported that this continued when they drove their own vehicle after the test (Wilson *et al.*, 2007).

These changes do not extend to the vehicle speed. Average speed remains the same irrespective of the presence of a lane departure warning system (Portouli *et al.*, 2006; Alkim *et al.*, 2007). It appears that drivers do not need to drive more slowly to maintain the correct lane position and hence prevent warnings. It also suggests that drivers do not drive faster because they feel safer with the system fitted. This is an important finding, because theories around behavioural adaptation suggest that drivers aim to maintain an acceptable level of risk through the way that they operate the vehicle. If a safety intervention is introduced, such as a lane departure warning system, drivers might change their behaviour in some negative way to keep this level of risk the same. While there is currently no evidence that drivers will increase their speed when their vehicle is equipped with a lane departure warning system, the participants in one study indicated that they were more inclined to use their hands for secondary tasks (smoking, drinking, eating, calling) when the lane departure warning system was switched on (Alkim *et al.*, 2007). Furthermore, the number of participants that felt this way increased after three months. This is a form of misuse of a lane departure warning system and is one possible unintended consequence of the system.

The effectiveness of a lane departure warning system will depend to some extent on drivers' capacity to understand the system and whether they find it easy to use or perceive some benefit from it. Several studies report that driver acceptance of lane departure warning is generally high (Portouli *et al.*, 2006; Wilson, 2007). However, such findings are likely to be influenced by the particular system used in each study. For example, the performance of the system in different environmental conditions could affect drivers' acceptance of the system in the longer term. Hadi *et al.* (2007) found that the performance of their lane departure warning system was affected significantly by heavy rain conditions at night. Similar system performance changes due to environmental factors were reported by McLandres *et al.* (2003). Neither Hadi nor McLandres examined drivers' acceptance of their systems.

Most lane departure warning systems are disabled until certain criteria are met. These criteria can relate to the vehicle speed, turn signal use or some other condition(s). Drivers' awareness of this feature and their broader understanding of the way the system operates could affect their trust in the system and the degree to which they rely on it. Following trials with a road departure warning system, Le Blanc *et al.* (2006) found that only a small percentage of drivers reported the strongest agreement levels with the statement "I relied on the system". However, similar levels of reliance were reported for a different system, which was disabled in fewer situations. Unsafe assumptions about the system in a new or unfamiliar vehicle could be avoided by standardising the conditions under which lane departure warning systems are enabled (Campbell *et al.*, 2007).

Driver inattention due to drowsiness or distraction has been suggested to explain a proportion of the collisions that occur following a lane departure (Najm *et al.*, 2003). Lane departure warning systems are thought to offer a solution to this problem. However, many of the studies reported in the literature are carried out with unimpaired volunteers. While these studies are useful ways of establishing the effect of lane departure warning on driver behaviour, it is also necessary to examine whether drowsy or distracted drivers will respond to the system. Relatively few studies have examined these issues; nevertheless, the findings are generally positive. For example, a lane departure warning system was found to reduce strongly the number and severity of lane departure events; even in the case of a micro sleep episode (Rimini-Doering *et al.*, 2005). While studies such as this are encouraging, further work is needed to examine whether there are any other consequences of lane departure warning on drowsy drivers. One consideration is whether drowsy drivers would accept that they need to rest after receiving a number of warnings, or whether they would continue to drive, effectively relying on the lane departure warning system to keep them safe.

The results of a study of lane keeping following a distracting event were not statistically significant, but trends suggested that the lane departure warning system reduced response times, departure amount and acceleration, and led to more controlled steering manoeuvres (Tijerina *et al.*, 1996). While the issues around driver behaviour have been addressed to some extent in the literature, there remains a need for more long-term research. Often, studies are carried out using driving simulators or real vehicles on test tracks. However, Barickman *et al.* (2007) showed that objective tests do not characterise real world driving adequately.

A.2.5 The costs and benefits of lane departure warning

Lane departure warning systems are proposed as a means of reducing the number of collisions and hence the number of people killed or injured. If they are fitted to vehicles and are effective in this respect, it would lead to reduced costs for society (i.e. there would be a monetary benefit). However, there would also be a cost associated with their fitment. In fact, there would be a number of elements to this cost including the development of the system, its evaluation and testing and the material cost of the additional parts in the vehicle. It is likely that the additional cost will be passed on to the consumer, although this may be offset by a reduction in the cost of insurance. The cost of some performance tests may be passed on to the consumer or they may be covered by another stakeholder.

The market presence of lane departure warning systems is relatively low. The Road Map Working Group of the eSafety Forum estimated that between 0 and 5 percent of vehicles were equipped with a lane departure warning system in 2005 (eSafety Forum, 2008). If no extra measures were made to accelerate the fitment of these systems, the Forum estimated that the level of deployment would rise to between 5 and 20 percent by 2010 and to between 50 and 80 percent by 2020. However, more pessimistic figures were proposed by Abele *et al.* (2005), who estimated that just 0.6 percent of vehicles will be equipped by 2010 with the rate increasing to 7 percent by 2020. Abele *et al.* (2005) considered the market penetration of lane departure warning systems combined with lane change assistance systems. Such rates are very difficult to predict and can depend on a range of factors. For instance, if drivers perceive a safety benefit from a new feature, demand can increase rapidly. This can depend on the encouragement they receive; if tax incentives, customer awareness programmes and insurance incentives were introduced for advanced driver assistance systems, and with other support actions at a European level, the eSafety forum estimates that between 20 and 50 percent of vehicles could be equipped by 2010 with between 50 to 80 percent by 2020.

Cost-benefit analyses are often used to assess whether the benefits of an intervention justify the costs. Two important studies have been completed recently in Europe to asses the costs and benefits of introducing lane departure warning systems. The first study, known as SEiSS (Socio-Economic impact of intelligent Safety Systems), was described by Abele *et al.* (2005) while the second study was described by COWI (2006). Both studies assessed lane departure warning systems in combination with lane change assistance systems, hence it is impossible to gauge the cost-benefit of the individual systems. Nevertheless, in each case, the benefits were around twice as high as the costs (Abele *et al.*, 2005; COWI, 2006). However, very different methodologies were used, which resulted in different estimates of the number of accidents prevented and the number of injuries prevented. For example, Abele *et al.* (2005) based their analysis on relatively low rates of deployment (0.6 percent in 2010 and 7 percent in 2020). The rates were based on the current trends and did not consider changes in the market resulting from efforts to encourage the systems. Based on their analysis, Abele *et al.* estimated that the combined system could prevent 1,442 accidents in 2010 and 13,889 accidents in 2020. In contrast, COWI (2006) considered two scenarios: do nothing and do something. In the do nothing scenario, it was assumed that the market deployment of lane change assistance and lane departure warning systems would reach 10 percent by 2025. In the do something scenario it was assumed that the deployment would be 100 percent. In fact, there were some inconsistencies in the way the analysis was reported by COWI. For example, estimates of the effectiveness of the system were reported for 2010 and 2020, but not 2025. Nevertheless, the study reported that 3,941 fatalities would be prevented in 2010 and 5,491 in 2020 in the do something scenario. The corresponding figures for severe injuries were 19,495 and 30,791.

A third European study, known as eIMPACT, was scheduled to be completed shortly after this review. eIMPACT included a comprehensive framework for socio-economic impact assessment based on the findings of the SEiSS study. Lane departure warning was included in the project within a lane keeping support application. Although the results of study were unavailable at the time of this review, Assing *et al.* (2006) described the methodology in detail.

While no further information from Europe was available, a study from the United States concluded that the potential benefits of lane departure warning systems appeared to be substantial for run-off-road collisions (Pomerleau *et al.*, 1999). The method used by Pomerleau *et al.* made a series of assumptions about the proportion of collisions that would be prevented by a lane departure warning system and took into account the possible causes of the collisions and the environmental conditions. This led to an estimate for the proportion of run-off-road collisions in passenger vehicles that could be prevented by a lane departure warning system with specific settings and limitations. A similar estimate was derived for heavy trucks. Further analysis revealed that a lane departure warning system could save an estimated $195 per passenger vehicle and $1,335 per truck over their operational life time. The authors concluded that manufacturers should be able to reach these cost targets if production quantities were sufficiently large.

A.3 Lane change assistance

This section highlights the key findings from the literature on lane change assistance. It outlines the proportion of police reported lane change collisions, and examines their causes and characteristics. This information was needed to comment on the circumstances in which a lane change assistance system must operate. The section also considers the way drivers carry out lane change manoeuvres, with particular emphasis on their processes within the vehicle and on the relationship between their vehicle and others in the adjacent lane. This was necessary to support the information about the operating circumstances.

The section then focuses on driver behaviour. The first consideration is the effect of the human machine interface. Information was needed on the way that drivers respond to warnings about a lane change and whether the type and location of the warning is important. The second consideration is the effect of lane change assistance on driver behaviour. The key questions are whether the presence of a warning system changes their behaviour in terms of the number of lane changes they make and whether they accept the warning and respond to it appropriately. An understanding of these and other issues around behaviour was necessary to comment of the way that the performance of a lane change assistance system should be assessed.

Finally, methods used to evaluate the costs and benefits of lane change assistance were explored from the literature. Some comment was also included on the findings of these studies. This information was needed to support the cost benefit analysis in this project.

A.3.1 Analysis of lane change collisions

Lane change assistance systems warn the driver when it is unsafe to change lanes. They have the potential, therefore, to reduce the number of collisions that occur during such manoeuvres. There are three main collision scenarios that can result from an unsafe lane change: the vehicle enters the new lane and experiences a side swipe collision with an approaching vehicle already in the lane; the vehicle enters the lane and experiences a rear impact with an approaching vehicle; the vehicle enters the lane and experiences a front impact with an overtaking vehicle that has braked. Other scenarios that are sometimes grouped with lane change collisions include: a vehicle leaving a parking space at the side of the carriageway; a vehicle turning across the path of another.

Most of the research on lane change collisions was carried out in the United States, where these collisions account for around 5 percent of all Police-reported crashes using the General Estimates System (Svenson *et al.*, 2005). Comparable statistics for Europe are not currently available from the literature; however, it is considered that a similar situation exists (Abele *et al.*, 2005; COWI, 2006). Clearly, this represents a relatively small percentage of the crash population; nevertheless, the number of crashes across Europe that could potentially be avoided is significant. Given that countermeasures are available (in the form of lane change assistance systems) there is the potential to make incremental improvements in vehicle safety (Chovan *et al.*, 1994). However, this is providing that these systems are effective. Another consideration is the potential for undercounting of collisions that were not reported to the Police. This was discussed for lane departure warning in Section 1.2.1 and the implications for lane change collisions are likely to be similar.

Most lane change crashes result from the driver being unaware of another vehicle in the adjacent lane. Evidence for this is based on driver statements that they “did not see the other vehicle” (Wang and Knipling, 1994) and on whether collision avoidance manoeuvres were made prior to the collision (Chovan *et al.*, 1994). There are also instances reported in the literature where the driver reported seeing the other vehicle before starting the lane change manoeuvre, but an unanticipated circumstance intervened, such as a misinterpretation of the other driver’s behaviour (Chovan *et al.*, 1994).

There are several reasons why a driver might not see another vehicle in the adjacent lane. For instance, it is well known that certain areas of the road cannot be seen when looking through the rear view or side mirrors. These areas are known as “blind spots” and can conceal another vehicle in the adjacent lane. However, many collisions involve vehicles outside these blind spots (Chovan *et al.*, 1994). This implies that the detection area of a lane change assistant system must extend beyond the blind-spots of the vehicle to be an effective countermeasure for these collisions.

Another reason why a driver might not see a vehicle in the adjacent lane is if their vision is obstructed by the driver side A , B , or C pillars. Wang and Knipling (1994) reported that vision obstructions were noted rarely from a sample of angle/sideswipe lane change crashes; however, Sivak *et al.*, (2007) carried out a more detailed study of this issue and found that lane change crashes tended to increase with both wider A-pillars and with A pillars located farther away from straight ahead. This was important for situations in which the subject vehicle was closing in on another vehicle in the intended lane of travel. This implies that the detection area of a lane change assistant system must cover the full length of the subject vehicle and include areas within the driver’s field of vision.

In another study, Sen *et al.* (2003) considered distraction to be a significant driver contributing factor in lane change crashes. A lane change assistant system would be expected to reduce the effects of distraction by focussing the driver’s attention on the driving task. Sen noted that alcohol/drugs and speeding/reckless driving were insignificant for most cases; however, this appears to be inconsistent with the findings of Campbell *et al.* (2003). A lane change assistant system would not mitigate the effects of alcohol or drugs, or speeding or reckless driving. Any analysis of the potential benefits of lane change assistant systems should therefore take into account the prevalence of these important contributory factors.

Most lane change collisions in the United States occur on a straight section of the carriageway (Sen *et al.*, 2003). This is probably because drivers are more likely to make the manoeuvre on a straight road than on a curved road. Additionally, the collisions tend to occur on level carriageways with no gradient (Wang and Knipling, 1994; Sen *et al.*, 2003). The pre-crash speed was usually unknown, but when information was available from a sample of angle/sideswipe crashes, it showed that the opponent vehicle was usually travelling within 5 mile/h of the subject vehicle (Wang and Knipling, 1994). The speed limit was more often available and revealed that nearly three-quarters of collisions occurred on carriageways with a speed limit less than or equal to 45 mile/h (Sen *et al.*, 2003). However, it should be noted that the carriageway speed limit does not give a reliable indication of the speed at which the vehicles were travelling. Investigations of other environmental factors have revealed that most collisions occur during daylight or on lit carriageways with no adverse weather conditions (Wang and Knipling, 1994; Sen *et al.*, 2003). Information on the most common lane change collision scenarios illustrate the circumstances in which a lane change assistant system must operate. This information could be used to inform decisions about appropriate requirements for lane change assistant systems in the future. This would help to ensure that the systems are designed to reduce the numbers of the most prevalent collisions.

A.3.2 Analysis of lane change manoeuvres

One of the main reasons that drivers change lanes is to pass a slower vehicle and hence maintain their current speed (Lee *et al.*, 2004). Each driver must assess the situation and decide whether it is safe to carry out the manoeuvre. However, the previous section highlighted that mistakes are sometimes made that lead to collisions.

Changing lanes places a number of additional demands on drivers compared with normal driving. These demands are associated with the need to monitor the area around the vehicle. The decision to proceed with a lane change or not is influenced by the gap available in the adjacent lane and on the speed of any closing vehicles. Lee *et al.* (2004) observed that most drivers were content to proceed with a lane change when there was a gap of at least 12 m in front of or to the rear of their vehicle at the start of the manoeuvre. Lee *et al.* also observed that most drivers were content when the relative velocity with respect to another vehicle was less than 22 km/h (14 mile/h). However, there is a relationship between the gap length and relative velocity with some drivers willing to change lanes when an approaching vehicle is nearby, if they perceive the relative velocity of the vehicle to be low. Similarly, some drivers will abort a lane change when an approaching vehicle is very far away, if they perceive the relative velocity to be very high. In addition, drivers sometimes initiate steering to change lanes when an overtaking vehicle is present in the adjacent lane (Smith *et al.*, 2003). This is done in anticipation of a gap behind the overtaking vehicle. These examples demonstrate that the gap length and relative velocity are not good measures of the risk of carrying out a lane change manoeuvre (Lee *et al.*, 2004). Instead, the time to collision (i.e. the headway distance divided by the relative velocity) is a better measure of the risk (Talmadge *et al.*, 1997; Lee *et al.*, 2004).

Lee *et al.* (2004) determined that drivers were willing to perform a lane change manoeuvre when the minimum time to collision with respect to a vehicle ahead, or approaching from the rear, was between four and six seconds. In a similar study, Wakasugi (2005) observed that drivers proceeded with the lane change when the time to collision was at least six seconds, whereas drivers aborted the manoeuvre when the time to collision was less than 10 seconds. This was considered a reasonable starting point for the warning threshold of a lane change assistant system, but it was noted that a threshold placed towards 10 seconds would give precedence to safety, while a threshold placed towards 6 seconds would minimise unwanted warnings. In addition, it was recognised that a lower threshold might be required if a driver aborts a manoeuvre and returns to their lane very quickly following a warning. Wakasugi used a driving simulator to investigate these issues further and from the subsequent analysis proposed the following warning timings for a lane change assistant system:

- 10 seconds and over: Unnecessary (The system must not give a warning)
- 6 to 10 seconds: Adjustable range (The system may give a warning)
- 2 to 6 seconds: Recommended (The system should give a warning)
- Under 2 seconds: Imperative (The system shall give a warning)

The sensing range required was also examined from these results with 20 m considered for the minimum requirement, 50 m for lane changing decision support and 80 m for maximum safety, when the upper relative velocity limit is assumed to be 30 km/h (Wakasugi, 2005).

Vehicles are currently fitted with mirrors and turn signals to assist drivers when performing manoeuvres. Studies of drivers eye movements show that drivers spend most of their gaze time before changing lanes looking at their current lane (Salvucci and Liu, 2002; Lee *et al.*, 2004). As the manoeuvre begins, drivers direct their gaze to the mirrors (Salvucci and Liu, 2002). The rear view mirror is used more often than the side mirrors (Lee *et al.*, 2004). During the manoeuvre, drivers then direct their gaze to the destination lane (Salvucci and Liu, 2002). The implication from these findings is that any visual indicators for the lane change assistant would be better placed in the rear view mirrors or straight ahead. While there are differences in the window size and field of vision between sports utility vehicles and sedans, drivers of these vehicles looked at the same locations with the same probability (Lee *et al.*, 2004).

Drivers do not always use their turn signal when changing lanes. Levels of use reported in the literature can vary; however, the most reliable studies are those carried out in normal driving without members of the research team present in the vehicle. Studies of this kind from the United Stated reveal than the turn signal is used in less than half of all lane change manoeuvres (Lee *et al.*, 2004). However, the turn signal is more likely to be used when moving into the adjacent lane to pass a vehicle rather than when returning to the original lane when completing an overtaking manoeuvre (Lee *et al.*, 2004). Some drivers activate the turn signal only after the lane change manoeuvre has been started. For example, a driving simulator study reported by Salvucci and Liu (2002) revealed than while the turn signal was in use at the start of around 50 percent of manoeuvres, this increased to 90 percent by around 1.5 – 2 seconds into the manoeuvre. This suggests two patterns of behaviour among drivers: those who use the turn signal to display their intent and those who use the turn signal to indicate that the manoeuvre is being carried out. Some lane change assistance systems are activated by the turn signal. The findings of these studies indicate that a lane change system that is activated in this way may not be of use in more than half of all lane change manoeuvres. Steering, lateral acceleration and velocity measures have not proven very meaningful as predictors or indicators of lane change behaviour (Lee *et al.*, 2004). However, the yaw rate may be a useful way of discriminating different vehicle manoeuvres (Miller and Srinivasan, 2005), and is one way that a continuously active lane change assistant system might detect when a manoeuvre is being carried out. Another approach is to use complex mind-tracking architecture to map a driver's observable actions to their unobservable intentions (Salvucci, 2004). While this relies on rigorous and validated models of driver behaviour, Salvucci (2004) achieved an accuracy of 85 percent with a false alarm rate of 4 percent.

Various reasons have been proposed in the literature to explain why drivers don't see other vehicles. These explanations are based principally on retrospective analyses of accidents and on driver interviews. With either approach, it is impossible observe directly the extreme cases of driving behaviour that can sometimes lead to collisions. When observation studies are carried out, they reveal that drowsiness is a more prevalent factor than is reported in accident databases (Dingus *et al.*, 2006; Klauer *et al.*, 2006). In addition, distraction is found to be a key factor with the driver looking away at the key moment prior to the collision (Dingus *et al.*, 2006). However, the understanding of distraction and its causes needs to be expanded to include the situation whereby the driver is paying attention to the driving task, but not on a critical aspect of the task at a key defining moment (Neale *et al.*, 2005).

A.3.3 The effect of human-machine interface design on driver behaviour

A lane change assistance system is likely to be useful only if the driver understands the information that is displayed and accepts it as being reliable (Talmadge *et al.*, 2000). A driver needs to know whether the system is active or not, whether there are faults or malfunctions and crucially the driver needs to recognise any warnings and their meaning. The means by which a lane change assistant system communicates with the driver is usually referred to as the human machine interface.

A lane change assistance system may be developed with one or two stage warnings. A one stage system usually provides an imminent warning where there is a high likelihood of a collision. A two stage system usually provides a cautionary warning where there is a low likelihood of a collision followed by a separate imminent warning, if necessary. Most researchers recommend two stage warnings for a lane change assistant systems (Talmadge *et al.*, 2000; Campbell *et al.*, 2007). However, for systems with any type of warning levels, care should be taken to determine whether drivers find the levels intuitive or confusing (SAE, 2007).

A lane change assistance system may issue visual, auditory or haptic warnings. The type of warning is important because, if used improperly, it can be distracting to the driver. Equally, an improper warning may be missed. Visual warnings can display information continuously to the driver and can be designed to operate with minimum nuisance, but they should not be used when it is critical that the warning is relied on to capture the driver's attention (Campbell *et al.*, 2007). This is because visual warnings depend on the driver looking at the warning location. Campbell *et al.* (2007) recommends that visual warnings are placed on (or next to) both the side-view mirrors and the rear-view mirror; however, other research shows that drivers do not always use these mirrors (Lee *et al.*, 2004). For these reasons, visual warnings should be reserved for lower priority information (Campbell *et al.*, 2007). For example, visual warning displays are useful for indicating the status of the system to the driver (Olsen, 2004). Visual warnings are also useful for cautionary warnings, which are likely to be more frequent than imminent warnings and could therefore become a nuisance if more intrusive warnings are used (Campbell *et al.*, 2007).

Auditory warnings can attract drivers' attention irrespective of where they are looking. However, they can also annoy drivers if the warning is issued too frequently. Auditory warnings should therefore be reserved for high priority alerts and warnings (Campbell *et al.*, 2007). There is very limited information on auditory lane change assistance warnings and their effects. However, simple reaction studies indicate that auditory warnings result in faster response times than visual warnings (Belz *et al.*, 1999; Keifer *et al.*, 1999). It is also suggested that drivers' performance can be improved by combining auditory and visual messages (Belz *et al.*, 1999; Keifer *et al.*, 1999; Campbell *et al.*, 2002). Simple auditory tones are good for gaining the driver's attention and, if properly implemented, can be used to warn of imminent danger (Campbell *et al.*, 2007). However, their meaning has to be learnt and hence an unfamiliar tone may produce an inappropriate response. There are similar drawbacks associated with complex tones (Campbell *et al.*, 2002). Auditory icons that recreate familiar environmental sounds are recognisable by most drivers (Belz *et al.*, 1999) and produce faster reaction times (Belz *et al.*, 1999; Graham, 1999). However, one issue to consider is whether the driver may become confused when presented with an auditory icon that occurs naturally on the road (Graham, 1999; Campbell *et al.*, 2007). Speech warnings may be easier to interpret the message, but result in longer reaction times because the message cannot typically be understood until the message is complete (Graham, 1999; Keifer *et al.*, 1999).

Haptic warnings may also be used in a lane change assistance system. Haptic warnings are more easily detected than visual warnings assuming that the body is in contact with the tactile feedback (SAE, 2007). However, like auditory warnings, they can also annoy drivers if the warning is issued too frequently. Haptic warnings should therefore be reserved for high priority alerts and warnings (Campbell *et al.*, 2007). In this application, haptic warnings could be used instead of auditory warnings for the main imminent warning. However, they should not be used together because the may overload drivers (Tijerina *et al.*, 1995) and increase response times (Stanley, 2006 referenced from SAE, 2007). There is very limited information on haptic lane change assistance warnings and their effects. General research on the effectiveness of haptic warnings compared with other modes is mixed. Some studies have shown that people respond faster to haptic signals compared with visual or auditory warnings (Spence and Tan, 2005; Stanley, 2006 referenced from SAE, 2007). However, there are also examples where haptic warnings were less effective (Keifer *et al.*, 1999). It seems likely that these studies are influenced greatly by the specific system evaluated and may not be a true indication of the effectiveness of the system in principle. Steering wheel torque warnings were shown to be effective in prompting drivers to cancel unsafe lane changes quickly and consistently (Farber *et al.*, 1991 referenced from Campbell *et al.*, 2007); however consideration must be given as to whether this type of system is a lane change assistant system or a lane keeping system. Steering wheel vibrations have been shown to be effective in other driver assistance systems (Tijerina *et al.*, 1995; Le Blanc *et al.*, 2006). However, some types of haptic warnings can also be interpreted as a problem with the vehicle (SAE, 2007).

A.3.4 The effect of lane change assistance on driver behaviour

The purpose of a lane change assistance system is to help the driver to perform lane changes safely, thereby reducing the risk of collisions. Systems are being developed by car manufacturers and their suppliers; nevertheless, the technology is relatively new with very limited market presence to date (eSafety Forum, 2008). In fact, very few vehicles on the road today are equipped with lane change assistant systems. In the absence of data from the real world, researchers often make assumptions about their effectiveness. These assumptions are usually derived from the observation that the majority of lane change collisions occur because the driver failed to see another vehicle in the adjacent lane. Since a lane change assistance system will warn drivers of the presence of other vehicles, it is considered that the system will reduce the frequency of these collisions. However, it is also important to consider whether lane change assistant systems have any real influence on the behaviour of drivers when they are fitted in vehicles. In addition, driver's views on the value of these systems should be taken into account. These views are likely to be influenced by the performance of the system in normal driving. For instance, some drivers may find the systems to be an unnecessary nuisance, particularly if they feel that false alarms are too frequent. Finally, it is important to examine whether there are any unintended consequences of the use of lane change assistant systems before they become more widespread.

Very little research has been published on the evaluation of lane change assistance systems in the field. This may be due to commercial sensitivities surrounding these advanced systems. There may also be a reluctance to sponsor such research due to the difficulty in assessing whether the system has prevented a collision. Nevertheless, one of the aims of the LATERAL SAFE project was the development of a stand alone lane change assistance system. LATERAL SAFE was a sub project of the Integrated Project PReVENT: a European automotive industry activity co funded by the European Commission under the 6th Framework Programme. Floudas *et al.* (2007) described the validation of the LATERAL SAFE system, which comprised a lateral and rear area monitoring system, a lateral collision warning system and a lane change assistance system. However, much of the detail was contained in a series of unpublished project deliverables.

In the United States, the Department of Transport has supported a number of projects on the development and field testing of collision avoidance systems. Lane change assistant systems have been supported to a lesser degree, although Talmadge *et al.* (2000) included some test work as part of the development of performance guidelines. In addition, Kiefer and Hankey (2007) examined the effect of a blind zone alert system on driver behaviour. However, it would appear that the recent focus in the United States has been on the development of an integrated vehicle-based crash warning system that addresses rear end, lateral drift (i.e. lane departure) and lane change. The University of Michigan Transportation Research Institute (UMTRI) is leading a programme of on going research to assess the safety benefits and driver acceptance of the system through operational testing (UMTRI, 2007).

The influence of a lane change assistance system can be assessed by monitoring the eye glance movements of drivers. For instance, Talmadge *et al.* (2000) found that drivers looked at their mirrors more frequently when the mirrors were lit up by the warning system (compared with a baseline period when there was no warning). This suggests that the drivers were at least noticing the warning. It is often hypothesised that a lane change system will allow drivers to spend more time looking straight ahead. This is because it should reduce the amount of time needed to scan the mirrors and look in the adjacent lane. However, Talmadge observed the contrary with the average driver spending less time looking straight ahead when the system was in use. This may have been due to the novelty effect of the visual warning placed in the mirrors, or it may have been a result of a lack of trust in the system by drivers that were unfamiliar with the technology.

Kiefer and Hankey (2007) made similar observations using a blind-zone only system. The analysis revealed that the glance rates associated with the most common glance behaviours for left and right lane changes (left driver-side side mirror glance for left lane changes and rear view mirror glance for right lane changes) increased when the system was available. Furthermore, the drivers looked over their shoulder with similar frequency. These findings were attributed to the system raising the drivers' general safety awareness via the regular warnings. This suggests that a lane change assistant system will remind the driver of the risk of the manoeuvre and focus their attention on what is needed to reduce the risk.

While very limited research has been carried out, drivers' satisfaction with lane change assistance systems is generally high (Talmadge *et al.*, 2000; Floudas *et al.*, 2007). However, it was not always clear how the participants of these studies were recruited and whether the recruitment process could have affected the findings. For example, Talmadge *et al.* (2000) used members of the project team during test track trials and field tests on real roads. Nevertheless, these studies provide some initial indication as to drivers' acceptance of lane change assistance system and their preferences. Talmadge *et al.* (2000) found an almost even split between having the display in both the centre and side mirrors versus the side only. A similar split was observed in the preference for a comprehensive versus a proximity only system. It was noted, anecdotally, that some drivers welcomed a warning about their blind spot, but felt that they could "handle the rest".

Drivers' acceptance of the system in the long term is likely to be influenced by their perception of the benefits to their safety. It will also be important for the system not to be a nuisance to the driver or annoying to other passengers. Floudas *et al.* (2007) reported that 58 percent of participants in their study believed that the lane change assistant system would increase traffic safety. This followed a series of technical validation tests in which the drivers followed a sequence of critical scenarios (i.e. not normal driving). The false alarm rate (i.e. a warning was issued when no departure occurred) was less than 1 percent of the total incidents, while the missing alarm rate (i.e. no warning was issued when a departure occurred) was around 6 percent of the total incidents. The human machine interface for the lane change assist elements of this system comprised side mirrors with integrated coloured icons with two colours depending on the danger level. Directional audio warnings through the car speakers were used for imminent warnings. It would appear that the technology for these systems has improved greatly in recent years since the system reported by Talmadge *et al.* (2000) had a very high false alarm rate of 42 per hour. Although, drivers reported that the false alarm rate was acceptable in this study, this was probably because many of the false alarms were unnoticed. The system evaluated by Talmadge used visual warnings only, which were placed on the mirrors. The drivers would therefore miss any warnings that occurred when they were looking straight ahead.

Kiefer and Hankey (2007) reported that there were no notable adverse effects of the system on lane change frequency, mirror usage or over-the-shoulder glances. Furthermore, the system did not lead to a more aggressive driving style. Nevertheless, further study is required to be confident that there would be no unintended consequences associated with the use of lane change assistant systems.

A.3.5 The costs and benefits of lane change assistance

Lane change assistance systems were conceived as a way of reducing the number of collisions and hence the number of people killed or injured. If they are fitted to vehicles and are effective in this respect, it would lead to reduced costs for society (i.e. there would be a monetary benefit). However, there would also be a cost associated with their fitment. In fact, there would be a number of elements to this cost including the development of the system, its evaluation and testing and the material cost of the additional parts in the vehicle. It is likely that the additional cost will be passed on to the consumer, although this may be offset by a reduction in the cost of insurance. The cost of some performance tests may be passed on to consumer or they may be covered by another stakeholder.

The market presence of lane change assistance systems is currently very low. The Road Map Working Group of the eSafety Forum estimated that between 0 and 5 percent of vehicles were equipped with a blind spot monitoring system in 2005 (eSafety Forum, 2008). If no extra measures were made to accelerate the fitment of these systems, the Forum estimated that the level of deployment would rise to between 5 and 20 percent by 2010 and to between 50 and 80 percent by 2020. However, more pessimistic figures were proposed by Abele *et al.* (2005), who estimated that just 0.6 percent of vehicles will be equipped by 2010 with the rate increasing to 7 percent by 2020. Such rates are very difficult to predict and can depend on a range of factors. For instance, if drivers perceive a safety benefit from a new feature, demand can increase rapidly. This can depend on the encouragement they receive; if tax incentives, customer awareness programmes and insurance incentives were introduced for advanced driver assistance systems, and with other support actions at a European level, the eSafety forum estimates that between 20 and 50 percent of vehicles could be equipped by 2010 with between 50 to 80 percent by 2020.

Decisions about what society should be willing to pay to encourage (or mandate) the implementation of systems to prevent injuries are often made on the basis of cost benefit analyses. The aim of these analyses is usually to assess the efficiency of an intervention with respect to the current situation. There have been two significant studies carried out recently in Europe to asses the costs and benefits of introducing lane change assistant systems. Both studies assessed lane change assistance systems in combination with lane departure warning systems, hence it is impossible to gauge the cost-benefit of the individual systems. Nevertheless, in each case, the benefits were around twice as high as the costs (Abele *et al.*, 2005; COWI, 2006). The findings of these studies were summarised in Section 1.2.5. A third European study, the eIMPACT project, (also described in Section1.2.5) included lane change assistance; however, the findings were not scheduled to be published until some time after this review. In the meantime, the methodology of eIMPACT was described by Assing *et al.* (2006).

The estimate used for the proportion of collisions that might be avoided by lane change assistance systems was one of the main points of interest from the completed European studies. Abele *et al.* (2005) assumed that lane change assistant systems would help to avoid “side collisions” involving two or more vehicles travelling in the same direction. This was estimated to represent 2.5 percent of all collisions, based on the data reported by McKeever (1998). McKeever used the General Estimates System in the United States to derive injury crash numbers for sideswipe collisions involving vehicles travelling in the same direction. These were considered a reasonable estimate for lane change or merge collisions, although it was recognised that not all sideswipe/same direction collisions are caused by lane changes and that some lane changes result in other crash types. Consideration must be given to the appropriateness of this figure for estimating the proportion of relevant collisions in Europe. While the situation in the United States is likely to be similar to Europe, there might also be some unforeseen circumstances that affect the frequency of lane change collisions.

No further information was available on the costs and benefits of lane change assistance in Europe at the time of this review. However, a study from the United States estimated the effectiveness of a lane change assistance system and the potential cost saving per vehicle (Talmadge *et al.*, 2000). The effectiveness of the system was derived from the results of field tests, where unsafe lane changes were used as a surrogate for collisions in the benefits calculation. This revealed that the lane change assistance system was 43 percent effective. Further analysis revealed that the system could save $126 per vehicle if every vehicle was equipped. The authors could not envisage (within the next decade of their study) a system that would cost $126 or less; however, consideration was also given to the overall benefits of the system to the driver and their willingness to pay for these benefits. These included convenience, perceived safety and piece of mind.

A.4 Conclusions

A.4.1 Lane departure warning

- There are three ways that a collision might occur following a lane departure: the vehicle leaves the lane and strikes oncoming traffic in the opposite carriageway; the vehicle leaves the lane strikes traffic travelling in the same direction in an adjacent carriageway; the vehicle leaves the lane and the roadway and strikes a stationary object and/or rolls over.
- Most of the research on the frequency of collisions resulting from a lane departure was carried out in the United States. Although a similar situation might exist in Europe, there could be differences between American and European roads (and driving) that affect the collision statistics.
- Lane departure collisions are a relatively small proportion (around 10 percent) of the total number of police-reported collisions in the United States. Nevertheless, if a similar situation exists in Europe, the number of collisions that could potentially be avoided is significant.
- There are two main lane departure scenarios. In the first scenario, the vehicle drifts out of the lane slowly, for a range of reasons that can include driver fatigue,

inattention or the use of alcohol or drugs. In the second scenario, the driver loses control of the vehicle due to excessive speed (or inappropriate speed in adverse conditions), mechanical failure, once again, the use of alcohol or drugs.

- Most road departure collisions occur on straight sections of carriageway; however, same direction and opposite direction lane departure collisions are distributed more evenly between straight and curved roads.
- Many lane departure collisions occur during daylight with no adverse weather conditions.
- Time to line crossing (a calculated measure of the amount of time before a lane departure would occur) is a key indicator of driver performance and a way of characterising the potential for lane departure.
- A warning threshold based on time to line crossing can be set to give drivers enough time to prevent a departure while avoiding nuisance or annoying alarms.
- Three warning strategies are possible for lane departure warning: visual, audio or haptic.
- Visual warnings are the least effective because they may not be seen by an inattentive driver.
- Auditory warnings are more likely to be noticed by the driver, but may disturb other passengers.
- Haptic warnings can alert the driver without disturbing other passengers.
- Studies of the effectiveness of auditory lane departure warnings in comparison to haptic warnings are broadly inconclusive.
- Lane keeping tends to be improved when the vehicle is fitted with a lane departure warning system.
- The presence of a lane departure warning system has no effect on the frequency of intended lane changes, but turn signal use increases during these manoeuvres.
- Lane departure warning systems are effective in warning drivers (including drowsy drivers) and preventing lane departures.
- More research is needed on the effects of lane departure warning and the potential for unintended consequences, particularly when the system is integrated with other functions.
- The benefits of lane departure warning (in combination with lane change assistance) are around twice as high as the costs. This is based on the findings of two large European studies.

A.4.2 Lane change assistance

- There are three main collision scenarios that can result from an unsafe lane change: the vehicle enters the new lane and experiences a side swipe collision with an approaching vehicle already in the lane; the vehicle enters the lane and experiences a rear impact with an approaching vehicle; the vehicle enters the lane and experiences a front impact with an overtaking vehicle that has braked.
- Most of the research on the frequency of collisions resulting from a lane change manoeuvre was carried out in the United States. Although a similar situation might exist in Europe, there could be differences between American and European roads (and driving) that affect the collision statistics.
- Lane change collisions are a relatively small proportion (around 5 percent) of the total number of police-reported collisions in the United States. Nevertheless, if a

similar situation exists in Europe, the number of collisions that could potentially be avoided is significant.

- Lane change collisions occur because the driver was unaware of another vehicle in the adjacent lane.
- Most lane change collisions occur during daylight hours, or on lit roads, with dry roadway conditions.
- Drivers change lanes to pass another vehicle travelling at a slower speed and hence maintain their current speed.
- Drivers feel comfortable when there is a distance of around 12 metres in front of and to the rear of their vehicle at the start of the lane change.
- Drivers sometimes initiate steering to change lanes when there is an overtaking vehicle present in the adjacent lane. This is done in anticipation of a gap behind the overtaking vehicle.
- Turn signals are not used in a significant number of lane changes and particularly when drivers are returning to their original lane after an overtaking manoeuvre.
- Three warning strategies are possible for lane change assistance systems: visual, audio or haptic.
- Visual warnings are the least effective because they may not be seen by an inattentive driver.
- Auditory warnings are more likely to be noticed by the driver, but may disturb other passengers.
- Haptic warnings can alert the driver without disturbing other passengers.
- Studies of the effectiveness of auditory lane change assistance warnings in comparison to haptic warnings are broadly inconclusive.
- At the present time, there is no evidence that lane change assistance results in any adverse effects on lane change frequency, mirror usage or over-the-shoulder glances.
- Very few field tests or simulator studies have been carried out in which a lane change assistance system is fitted to a vehicle. Further research is needed on the effects of lane change assistance and the potential for unintended consequences.
- The benefits of lane change assistance (in combination with lane departure warning) are around twice as high as the costs. This is based on the findings of two large European studies.

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Appendix B Review of systems

Table B1. Lane Departure Warning Systems on the market.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Other Info
Audi / VW	Lane Assist	Q7, A8	Hella	Video camera behind windscreen monitors vehicle position in relation to lane markings	65 km/h (41 mile/h)	Steering Wheel Vibration	
BMW	LDW	5 Series 6 Series	Siemens VDO & Mobileye	Video camera behind windscreen monitors vehicle position in relation to lane markings	70 km/h (44 mile/h)	Dashboard Display or Steering Wheel Vibration	Works on single lane roads
GM	LDW	Cadillac STS Cadillac DTS Buick	Mobileye	Video camera behind windscreen monitors vehicle position in relation to lane markings	56 km/h (35 mile/h)	Audible & Visual	
Volvo	LDW	V70, XC70, S80	Mobileye	Video camera behind windscreen monitors vehicle position in relation to lane markings	64 km/h (40 mile/h)	Audible	
Citroen	LDWS	C4, C5	Iteris	6 pairs of infra-red sensors at front of car	80 km/h (50 mile/h)	Vibrating Driver's Seat	
MAN	Lane Guidance System	Trucks	Iteris	Video camera behind windscreen monitors truck position in relation to lane markings	60 km/h (38 mile/h)	Audible, virtual rumble strip	
Mercedes	SPA	Trucks	Iteris	Video camera behind windscreen monitors truck position in relation to lane markings	60 km/h (38 mile/h)	Audible, virtual rumble strip	

Table B1. Lane Departure Warning Systems on the market (continued).

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Other Info
Lexus	LDW	LS 460	Denso	Video camera behind windscreen monitors vehicle position in relation to lane markings		Audio-Visual Warning	
After Market	SafeTRAC	Cars Trucks	Assistware	Video camera behind windscreen monitors vehicle position in relation to lane markings		Visual lane position display	Alertness feedback score
Mercedes	SPA	Coach	Iteris	Video camera behind windscreen monitors coach position in relation to lane markings	80 km/h (50 mile/h)	Vibrating Driver's Seat	
Nissan	LDW	Infiniti M45 Infiniti FX	Iteris & Valeo	Video camera behind windscreen monitors vehicle position in relation to lane markings	72 km/h (45 mile/h)	Dashboard Display & Audible	

Table B2. LDW systems in development.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Other Info
—	LDW	—	Delphi	Video camera behind windscreen monitors vehicle position in relation to lane markings	—	Audible, tactile and/or visual	
—	LDW	—	TRW	Video camera behind windscreen monitors vehicle position in relation to lane markings	—	Audible, tactile and/or visual	
—	LDW	—	Continental	Video camera behind windscreen monitors vehicle position in relation to lane markings	—	Audible, tactile and/or visual	
—	LDW	—	IBEO	Laser scanner detects lane markings at front of car	—	Vibrating Steering Wheel or Drivers Seat	

Table B3. Blind Spot Monitoring Systems on the market.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Detection Zone (width x length)	System Inactive
GM	SBZA	Buick	Valeo Raytheon	Radar		Visual sign in mirror	3.5 m x 5.0 m	Can't detect vehicles being overtaken
Mercedes	Blind Spot Assist	S, CL		Radar sensors in front and rear bumpers	30 km/h (19 mile/h)	Visual & Audio	3.0 m x 3.0 m	Can't detect fast overtaking vehicles
Volvo	BLIS	All		Camera mounted under exterior mirrors	10 km/h (6 mile/h)	Visual	3.0 m x 9.5 m	Poor Visibility Snow & Fog
Mazda	BSM	CX-9		Radar sensors in rear bumper	32 km/h (20 mile/h)	Visual & Audio		Spray or snow
Jaguar	BSM	XF	Valeo Raytheon	Radar sensors in rear bumper	16 km/h (10 mile/h)	Visual	2.5 m x 7.0 m	Can't detect fast overtaking vehicles
	Blind Spot	Trucks	Eagle-Eye	Ultra-sonic sensors along vehicle chassis		Visual & Audio	3m	
	Blind Spot	Trucks	Lookout	Ultra-sonic sensors along vehicle chassis		Visual & Audio	3m	
	VORAD	Trucks	Eaton	Doppler Radar		Visual & Audio		

Table B4. BSM systems in development.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Detection Zone (width x length)	System Inactive
—	Side Alert	—	Delphi	Infrared	—	Visual & Audio	—	—
—	Side Object Awareness	—	Visteon	Radar	—	Visual	—	—

Table B5. Lane Changing Assist Systems on the market.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Detection Zone
Audi / VW	Side Assist	Q7, A8	Hella	Radar	60 km/h (38 mile/h)	Display in exterior mirror	50 m

Table B6. LCA systems in development.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Detection Zone
—	LCA (Pro-Pilot)	—	Continental	Radar sensors in rear bumper	60 km/h (38 mile/h)	Visual sign Steering wheel vibrates if ignored	90 m
—	LCA	—	Mobileye	Camera monitoring side and rear of vehicle		Red/Green Indicator in the exterior mirror	
—	LCA	—	Valeo Raytheon	Radar		Visual in exterior mirror, Audible alert	50 m
—	CAPS	—	Bosch	Camera, Radar	—		—

Table B7. Lane Keeping Assist Systems on the market.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Other Info
Nissan	Lane Departure Prevention	Infiniti M45 Infiniti FX	Iteris & Valeo	Video camera behind windscreen monitors vehicle position in relation to lane markings. Applies brake pressure to return vehicle to lane	72 km/h (45 mile/h)	Dashboard Display & Audible	
Lexus	LKA (LDW & LK)	LS 460	Denso	Video camera behind windscreen monitors vehicle position in relation to lane markings. Applies corrective steering		Audio-Visual Warning	
Honda	LKAS	Accord Legend		Video camera behind windscreen monitors vehicle position in relation to lane markings Applies corrective steering assistance	65-100 km/h (41-63 mile/h)	Audio-Visual Warning	

Table B8. Lane Keeping Assist Systems in development.

OEM	System	Models	Technology Supplier	Technology	Trigger Speed	Driver Alert	Other Info
—	Lane Guidance	—	TRW	Video camera behind windscreen monitors vehicle position in relation to lane markings. Capable of providing a light steering input		Audible, tactile and/or visual	
—	LKS	—	Continental	Add-on to LDW system Providing a light steering input		Audible, tactile and/or visual	
BMW	Heading Control	TBA		Camera based system that uses additional sensors to analyse crosswinds, curves & the road profile. Provides steering corrections.			

Appendix C Outline technical/operational requirements – lane departure warning systems

1 Purpose. These technical specifications comprise equipment and performance specifications for lane departure warning systems. The purpose of these specifications is to serve as a basis for discussions about a new UNECE Regulation on lane departure warning and lane change assistance.

2 Application. These specifications apply to all vehicles of category M and N.

[These outline technical/operational requirements are appropriate for all vehicle categories and types, including passenger cars, commercial vehicles and buses. However, the EC may wish to consider whether it would be more appropriate to tailor elements of a regulation to a specific vehicle category.]

3 Definitions. For the purposes of these specifications, the vehicle categories listed in paragraph 2 are defined in UNECE Consolidated Resolution on the Construction of Vehicles (RE.3). Other relevant definitions are provided in paragraphs 3.1 to 3.6 below.

3.1 “Earliest Warning Line” means the innermost limit of the warning threshold.

3.2 “Haptic Warning” means a warning that stimulates the driver’s sense of touch, vibration, force and motion.

3.3 “Lane Boundary” means the borderline of the lane, situated at the centre of a visible lane marking or, in the absence of a visible lane marking, determined by incidental visible road features or other means such as GPS, magnetic rails, etc.

3.4 “Lane Departure” means the point of departure across the lane boundary.

3.5 “Lane Departure Warning System” means a system that has all of the following attributes:

(a) a means to determine the lateral position of the vehicle with respect to the lane boundary;

(b) a means to determine if the warning condition is fulfilled;

(c) a means to warn the driver when the warning condition is fulfilled;

(d) a means to monitor the speed of the vehicle;

(e) a means to determine the geometry of the road ahead;

3.6 “Latest Warning Line” means the outermost limit of the warning threshold.

3.7 “Warning Threshold” means the location where the warning is issued on the road, which corresponds to a warning trigger point set in the system. The threshold is placed in a zone defined by an earliest warning line and a latest warning line.

4 General Specifications. Each vehicle equipped with a lane departure warning system shall meet the general specifications outlined in this section.

4.1 Functional Specifications. A lane departure warning system shall be one that:

(a) is capable of emitting an audible or haptic warning, at the latest, by the time the vehicle is level with the lane boundary;

(b) is classified as shown in Table C.1 and is capable of warning the driver in at least one of the warning conditions in the Table;

Table C.1: Lane departure warning system classification

Vehicle speed m/s	Radius of curvature m
≥ 17	≥ 250

[ISO 17361:2007 classifies lane departure warning systems according to the radius of curvature of the road and the vehicle speed. The Standard defines two types of system based on these two criteria, although systems are permitted to warn drivers under both sets of conditions.

The values proposed in Table C.1 represent the requirements for a Class II system according to the Standard. These are more stringent than those for a Class I system. There was no information in the literature or from the review of systems regarding the capacity of current systems to achieve these requirements.]

(c) is operational over the full speed range of the vehicle, during all phases of driving, except:

(i) when the driver has disabled the system [If this function is considered desirable];

(ii) when the minimum warning conditions in Table 1 are not met;

(iii) while the initial start-up self-test checks are completed, not to exceed [TBC] s from starting the vehicle;

(iv) when the turn signal is activated;

(v) when the vehicle is driven in reverse;

4.2 A lane departure warning system shall monitor the status of the system at all times and identify when the system:

(a) is switched on [if a switch is fitted – see 4.3];

(b) is operational;

(c) has developed a fault;

(d) is unable to function due to temporary conditions;

4.3 Human-Machine Interface Specifications. A lane departure warning system shall power-on with the ignition of the vehicle and it shall be impossible for the driver to disable the system

[No legitimate reason could be found to permit the driver to disable a lane departure warning system in everyday driving. However, it may be the case that there are specific conditions, such as narrow country roads, or through roadworks, that could generate a high number of false alarms. It may, therefore, be useful to consider the following ALTERNATIVE: A lane departure warning system shall be equipped with an on/off switch to allow the driver to disable the system at any time. The switch shall be illuminated when the vehicle's headlamps are activated.]

4.4 A lane departure warning system shall provide a continuous, visual indication to the driver of the system status.

4.5 A lane departure warning system shall emit an audible or haptic signal to indicate a change in the status of the system.

4.6 A lane departure warning system shall issue an audible or haptic warning when the vehicle crosses the warning threshold.

4.7 A lane departure warning system shall indicate the direction of the lane departure.

4.8 Any visual indicators shall be displayed in direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened.

4.9 Any visual indicators shall be detectable in direct sunlight or at night.

5 Performance Specifications. Each vehicle equipped with a lane departure warning system shall meet the performance specifications outlined in this section.

5.1 During the warning generation test defined in the test method of ISO 17361:2007, the lane departure warning system shall provide warnings prior to crossing the latest warning line, but not before crossing the earliest warning line for each test case.

[The warning generation test in ISO 17361:2007 is carried out on a flat, dry asphalt or concrete surface. However, it would be desirable for a lane departure warning system to be operational in a range of weather and environmental conditions. A method of assessing this aspect of the performance of lane departure warning systems is missing from current standards.]

[The warning generation test in ISO 17361:2007 is carried out on visible lane boundaries that are marked "in accordance with applicable standards for lane marking design and materials". The characteristics of the lane markings are not defined further. A vehicle may encounter a range of lane markings and patterns. It would be desirable for a lane departure warning systems to be operational irrespective of the lane marking type (within the range of markings used in Europe). A method of assessing this aspect of the performance of lane departure warning systems is missing from current standards.]

5.2 During the repeatability test defined in the test method of ISO 17361:2007, the lane departure warning system shall provide warnings within a zone having a width of 30 cm for each group of test trials. No warnings shall be issued outside of this 30 cm warning threshold placement zone. If a particular test group includes more than four trials within the required speed tolerance band, only the first four trials that are within the required speed tolerance band shall be considered.

[The width of the zone used to assess the repeatability of the lane departure warning system was derived from the ISO Standard. It is assumed that this zone would permit a meaningful examination of the system's repeatability; however, testing would be necessary to comment further on its suitability.]

5.3 During the false alarm test defined in the test method of ISO 17361:2007, no warnings shall occur between the two earliest warning lines.

[During brief periods when the lane departure warning system cannot determine the position of the vehicle with respect to the lane, the system should extrapolate the current position based on previous estimates of lane geometry and vehicle trajectory. A method of assessing this aspect of the performance of lane departure warning systems is missing from current standards.]

5.4 Lane Departure Warning System Technical Documentation. To ensure that a vehicle is equipped with a lane departure warning system that meets the definition of "Lane Departure Warning System" in paragraph 3, the vehicle manufacturer must make available the documentation specified in paragraphs 5.4(a) to 5.4(b):

(a) System Diagram. The diagram must identify all of the system hardware and describe the function of each component.

(b) Written Explanation. A brief written explanation to describe the basic characteristics of the lane departure warning system. This explanation shall include the outline description of the system's capability.

Appendix D Outline technical/operational requirements – lane change assistant systems

1 Purpose. These technical specifications comprise equipment and performance specifications for lane change assistance systems. The purpose of these specifications is to serve as a basis for discussions about a new UNECE Regulation on lane departure warning and lane change assistance.

2 Application. These specifications apply to all vehicles of category M and N.

[These outline technical/operational requirements are appropriate for all vehicle categories and types, including passenger cars, commercial vehicles and buses. However, the EC may wish to consider whether it would be more appropriate to tailor elements of a regulation to a specific vehicle category.]

3 Definitions. For the purposes of these specifications, the vehicle categories listed in paragraph 2 are defined in UNECE Consolidated Resolution on the Construction of Vehicles (RE.3). Other relevant definitions are provided in paragraphs 3.1 to 3.6 below.

3.1 "Blind Spot Warning Function" means a function that detects the presence of target vehicles in one or more of the adjacent zones defined in ISO 17387:2008.

3.2 "Closing Speed" means the difference between the target vehicle's speed and the subject vehicle's speed.

3.3 "Closing Vehicle Warning Function" means a function that detects the presence of target vehicles in one or more of the rear zones defined in ISO 17387:2008.

3.4 "Haptic Warning" means a warning that stimulates the driver's sense of touch, vibration, force and motion.

3.5 "Lane Change Assistance System" means a system that has all of the following attributes:

(a) a means to detect the presence of target vehicles in the areas adjacent to, and to the rear of, the subject vehicle;

(b) a means to determine if the warning condition is fulfilled;

(c) a means to warn the driver when the warning condition is fulfilled;

(d) a means to monitor the speed of the vehicle;

3.6 "Roadway Radius of Curvature" means the horizontal radius of curvature of the road on which the subject vehicle is travelling.

3.7 "Subject Vehicle" means the particular vehicle under discussion that is equipped with the lane change assistance system.

3.8 "Target Vehicle" means any vehicle that is closing in on the subject vehicle.

4 General Specifications. Each vehicle equipped with a lane change assistance system shall meet the general specifications outlined in this section.

4.1 Functional Specifications. A lane change assistance system shall be one that:

(a) is capable of detecting target vehicles that are at least the size of a highway-legal motorcycle;

(b) is capable of emitting an audible or haptic warning when a lane change manoeuvre poses a risk of collision;

(c) provides both blind spot and closing vehicle warning functions as defined in ISO 17387:2008;

(d) is capable of warning the driver in the following conditions;

Table D.1. Target vehicle closing speed classification.

Maximum target vehicle closing speed m/s	Minimum roadway radius of curvature m
20	125

[ISO 17387:2008 classifies lane change assistance systems according to the maximum target vehicle closing speed and the minimum roadway radius of curvature. The Standard defines three types of system based on these two criteria; however, a system may belong to more than one type. For example, a highly capable system may meet or exceed the minimum requirements defined individually for the three types.

The Standard suggests there is a relationship between the maximum closing speed and the road curvature. Systems capable of achieving the most stringent closing speed are permitted to achieve the least stringent road curvature, and vice versa. The values proposed in Table D.1 represent the most stringent requirements for each individual criterion. There was no information in the literature or from the review of systems regarding the capacity of current systems to achieve these requirements.]

(e) is operational over the full speed range of the vehicle, during all phases of driving, except:

    (i) when the driver has disabled the system;

    (ii) when the vehicle speed is below [TBC] km/h;

    (iii) while the initial start up self-test checks are completed, not to exceed [TBC] s from starting the vehicle;

    (iv) when the vehicle is driven in reverse

[A lane change assistance system should warn the driver only when they intend to change lanes. This is important to prevent needless or distracting warnings during normal driving. Different methods have been proposed to resolve this issue. For example, some lane change assistance systems operate only when the turn signal is used. With such an approach, the system responds when there is a clear indication of the driver’s intent. However, drivers do not always use their turn signal when changing lanes, or if it is used, it is turned on relatively late in the manoeuvre. This implies that a system linked to turn signal use will not be operational during some lane change manoeuvres, and potentially when it is needed. It is possible to predict the driver’s intent using other means, but this has proven challenging.

For the purposes of these specifications, it would be desirable to state that a lane change assistance system shall operate only when a lane change manoeuvre is intended. It would also be desirable to state that a system shall detect a lane change irrespective of turn signal use. However, more information is required regarding the capacity of current lane change assistance systems to meet these specifications.]

4.2 A lane change assistance system shall monitor the status of the system at all times and identify when the system:

(a) is switched on;

(b) is operational;

(c) has developed a fault;

(d) is unable to function due to temporary conditions;

4.3 Human-Machine Interface Specifications. A lane change assistance system shall power-on with the ignition of the vehicle, but shall be equipped with an on/off switch to allow the driver to disable the system at any time. The switch shall be illuminated when the vehicle's headlamps are activated. [ALTERNATIVELY: A lane change assistance system shall power-on with the ignition of the vehicle and it shall be impossible for the driver to disable the system.]

[It may be impractical for a lane change assistance system to perform according to its normal capabilities when a trailer is connected to the vehicle. While it would be desirable for the system to recognise that it is incapable of performing its normal function, it may be necessary to consider allowing the driver to disable the system.]

4.4 A lane change assistance system shall provide a continuous, visual indication to the driver of the system status.

4.5 A lane change assistance system shall emit an audible or haptic signal to indicate a change in the status of the system.

4.6 A lane change assistance system shall issue an audible or haptic warning when the warning criteria are met.

4.7 Any visual indicators shall be displayed in direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened.

4.8 Any visual indicators shall be detectable in direct sunlight or at night.

5 Performance Specifications. Each vehicle equipped with a lane change assistance system shall meet the performance specifications outlined in this section.

5.1 The lane change assistance system shall meet the requirements of the target vehicle overtaking subject vehicle test set out in Clause 5.5.3.2 of ISO 17387:2008.

5.2 The lane change assistance system shall meet the requirements of the subject vehicle overtaking subject vehicle test set out in Clause 5.5.3.3 of ISO 17387:2008.

5.3 The lane change assistance system shall meet the requirements of the false warning test set out in Clause 5.5.3.4 of ISO 17387:2008.

5.4 The lane change assistance system shall meet the requirements of the target vehicle moving laterally test set out in Clause 5.5.3.5 of ISO 17387:2008.

5.5 The overall system response time from the time at which a target satisfies the warning requirements to the time that the warning indication is activated shall be no more than 300 ms during each of the tests described in 5.1, 5.2 and 5.4.

5.6 The overall system response time from the time at which a warning is no longer allowed to the time that the warning indication is deactivated shall be no more than 1 s following each of the tests described in 5.1, 5.2 and 5.4.

[A lane change assistance system should not respond to stationary objects at the side of the road. A method of assessing this aspect of the performance of lane change assistance systems is missing form current standards.]

[A lane change assistance system should not respond to vehicles travelling in the opposite carriageway. A method of assessing this aspect of the performance of lane change assistance systems is missing form current standards.]

5.7 Lane Departure Warning System Technical Documentation. To ensure that a vehicle is equipped with a lane change assistance system that meets the definition of “Lane Change Assistance System” in paragraph 3, the vehicle manufacturer must make available the documentation specified in paragraphs 5.7(a) to 5.7(b):

(a) System Diagram. The diagram must identify all of the system hardware and describe the function of each component.

(b) Written Explanation. A brief written explanation to describe the basic characteristics of the lane departure warning system. This explanation shall include the outline description of the system’s capability.

Appendix E Target populations by accident type

E.1 Lane departure warning

Table E.1. Target population for head-on collisions (Type A).

Vehicle type	Severity	Occupant of equipped vehicle		Occupant of other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	176	1416	67	378	16	378	259	2172
	Serious	958	7460	716	5666	76	2644	1750	15770
	Slight	3595	8088	4457	10029	138	310	8190	18426
M2/M3	Fatal	0	0	0	7	0	0	0	7
	Serious	10	189	0	10	0	0	10	199
	Slight	35	79	16	36	3	7	54	122
N2/N3	Fatal	0	3	0	10	0	0	0	13
	Serious	13	94	19	94	3	283	35	472
	Slight	28	63	67	152	1	3	97	218

Table E.2. Target population for leaving roadway collisions (Type B).

Vehicle type	Severity	Occupant of equipped vehicle		Occupant of other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	714	4438	0	214	48	148	762	4801
	Serious	4729	23607	283	1203	173	533	5185	25343
	Slight	17634	54259	2487	7652	321	989	20442	62899
M2/M3	Fatal	7	189	0	0	0	5	7	194
	Serious	41	850	0	11	0	0	41	861
	Slight	293	901	11	33	5	16	309	950
N2/N3	Fatal	23	94	0	55	0	5	23	155
	Serious	121	472	0	82	0	22	121	577
	Slight	330	1016	95	291	7	22	432	1329

Table E.3. Target population for side-swipe collisions (Type C).

Vehicle type	Severity	Occupant of equipped vehicle		Occupant of other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	13	94	0	20	0	94	13	209
	Serious	86	472	26	661	0	20	112	1153
	Slight	639	2492	83	1869	0	63	722	4423
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	7	0	0	0	0	0	7
	Slight	10	20	0	13	0	0	10	33
N2/N3	Fatal	0	13	0	0	0	0	0	13
	Serious	0	48	0	36	0	10	0	94
	Slight	45	334	22	250	0	16	67	601

E.2 Lane change assistance

Table E.4. Target population for side-swipe collisions (Type D).

Vehicle type	Severity	Occupant of equipped vehicle		Occupant of other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	34	11	94	6	94	17	223
	Serious	102	1416	85	755	94	836	281	3008
	Slight	1382	8294	2149	12893	588	3525	4119	24712
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	11	0	0	0	11	0	23
	Slight	40	237	47	282	23	136	109	655
N2/N3	Fatal	0	23	0	45	0	0	0	68
	Serious	0	11	94	599	0	56	94	667
	Slight	77	463	2431	14588	26	158	2535	15209

Table E.5. Target population for manoeuvring collisions (Type E).

Vehicle type	Severity	Occupant of equipped vehicle		Occupant of other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	0	0	94	0	0	0	94
	Serious	3	189	5	94	23	94	31	378
	Slight	48	143	135	405	137	410	320	959
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	0	0	5	0	5	0	10
	Slight	13	40	10	30	7	20	30	89
N2/N3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	0	0	0	0	0	0	0
	Slight	0	0	3	10	2	5	5	15

Table E.6. Target population for leaving parking space collisions (Type F).

Vehicle type	Severity	Occupant of equipped vehicle		Occupant of other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	9	0	0	0	17	0	26
	Serious	0	235	0	305	0	1167	0	1707
	Slight	1040	3981	2187	8370	2403	9198	5630	21549
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	0	0	0	0	35	0	35
	Slight	5	17	23	87	46	174	73	279
N2/N3	Fatal	0	0	0	0	11	94	11	94
	Serious	0	0	5	189	25	472	30	661
	Slight	7	26	57	218	96	366	159	610

Table E.7. Target population for HGV turning collisions (Type G).

Vehicle type	Severity	Occupant of equipped vehicle		Occupant of other vehicle		VRU		Total	
		Min	Max	Min	Max	Min	Max	Min	Max
M1/N1	Fatal	0	10	0	0	40	119	40	129
	Serious	94	356	56	168	593	1780	744	2304
	Slight	1002	3006	771	2314	2501	7504	4275	12824
M2/M3	Fatal	0	0	0	0	0	0	0	0
	Serious	0	0	0	10	0	0	0	10
	Slight	33	99	7	20	23	69	63	188
N2/N3	Fatal	0	0	0	0	0	20	0	20
	Serious	0	0	0	0	0	40	0	40
	Slight	0	0	26	79	40	119	66	198

Appendix F Fuel economy data

Figure F.1 to Figure F. 4 shows the relative change in fuel consumption between the modified case (with mirrors) and the baseline case (no mirrors) for each of the vehicles considered.

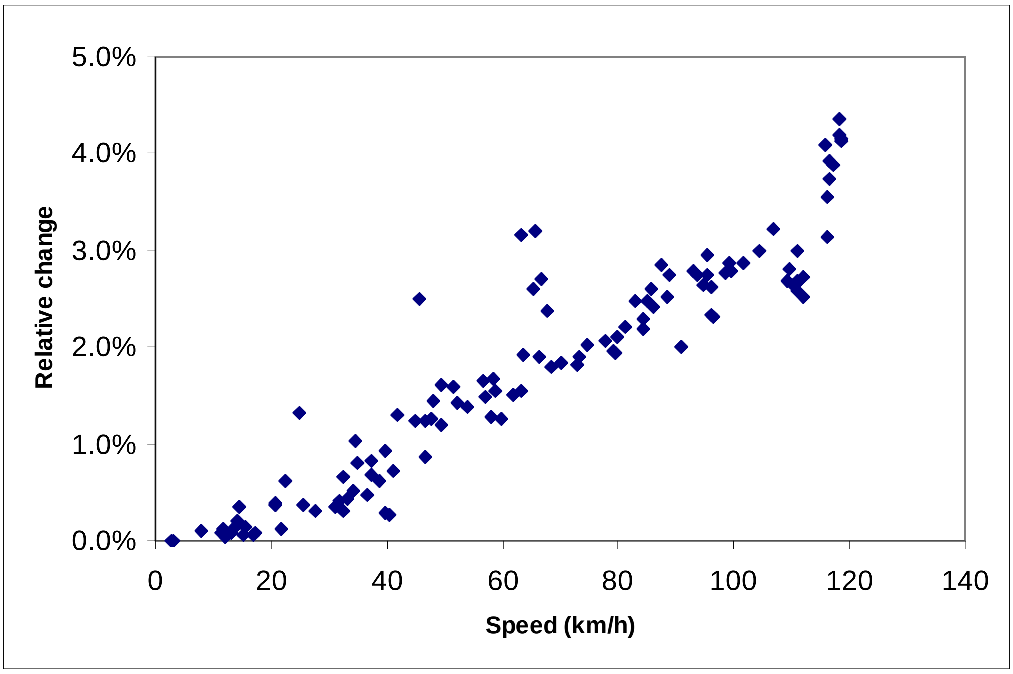

Figure F.1. Change in fuel consumption for passenger car.[4]

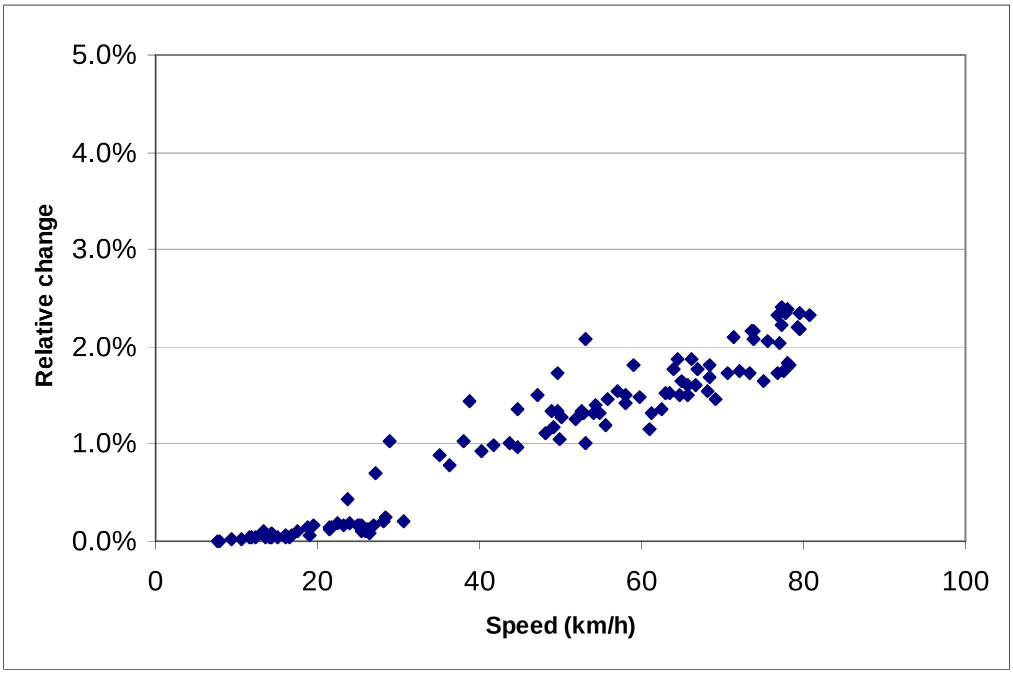

Figure F. 2. Change in fuel consumption for van.

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[4] Outlier of 7.1% at 80km/h not shown in figure

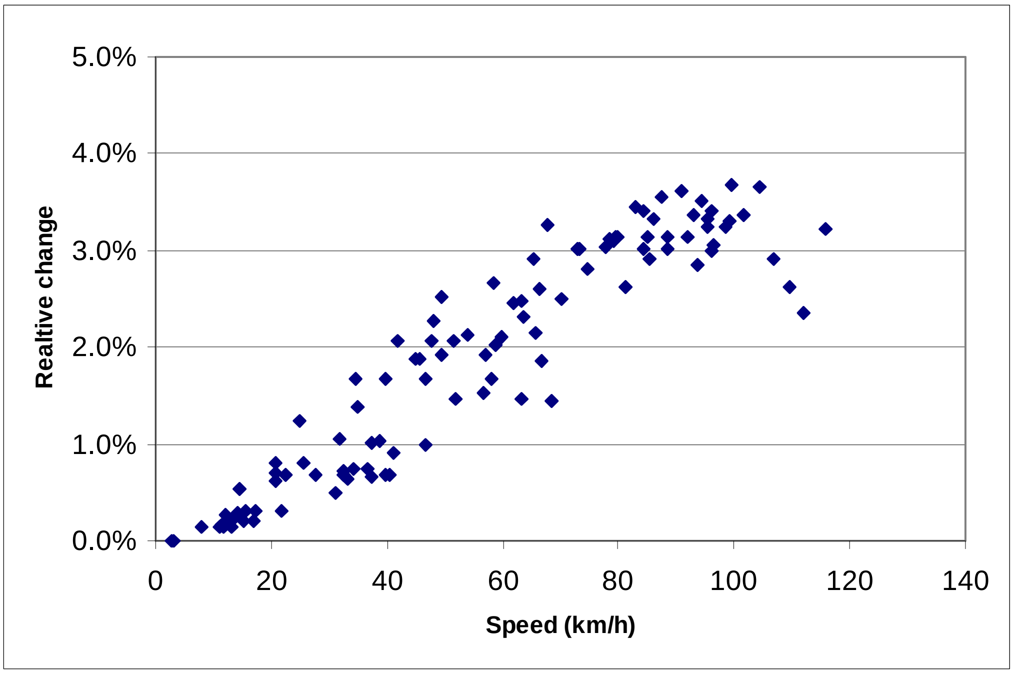

Figure F. 3. Change in fuel consumption for HGV.

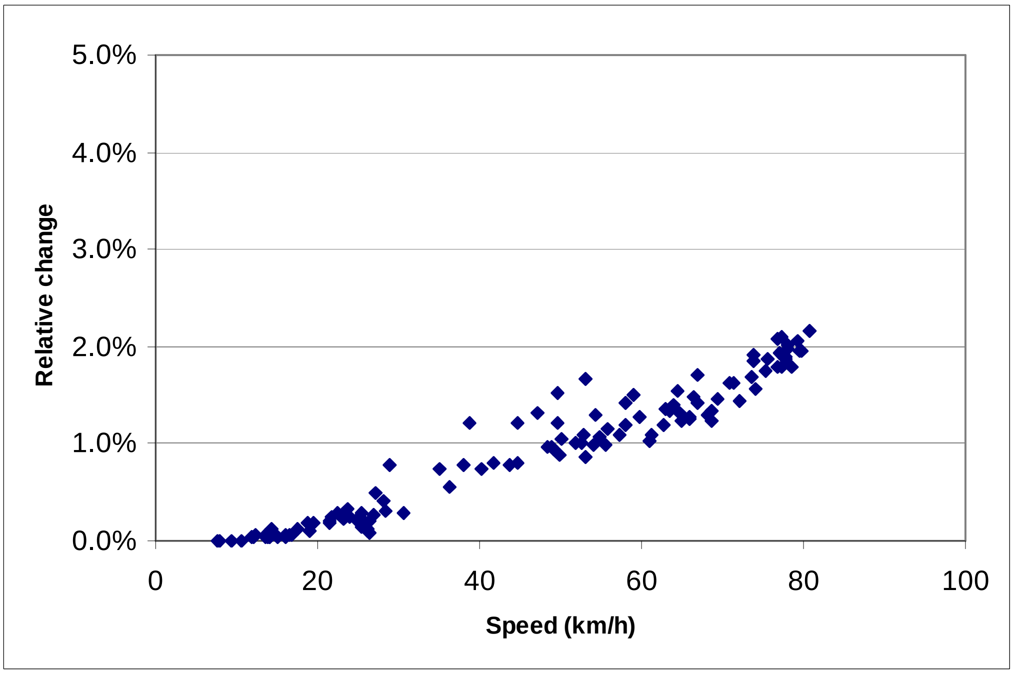

Figure F. 4. Change in fuel consumption for coach.