DM5300 – Major Project

Assignment 3

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14/05/2004

DM5300 Major Project

Lateral collision reduction investigation

Assignment 3

Final report

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Mechanical Engineering & Design MEng

14/05/2004

ABSTRACT

According to the National Highway Traffic Safety Administration (NHTSA), more than 43 percent of all fatal accidents reported in 2001 involved a lane or road departure. These lane departures can be attributed to a number of causes including driver distraction and poor situational awareness. These are both extremely significant. It has been suggested that poor situational awareness is a greater cause of accidents than excessive speed or improper driving technique (Gugerty, 1997). It has also been suggested by the American Automobile Association that accidents resulting from distracted drivers is one of the most serious public health hazards of the 21st century.

There are a number of systems currently on the market that monitor the driver lane position or use radar technology to track the position of other drivers. The majority of these systems and available research focuses on the prevention of longitudinal collision or lane departures.

The primary aim of this study is to design and develop a system that reduces the likely hood of a lateral collision. The problem is addressed in two ways; the first way is by increasing the driver's situational awareness; giving information about the location of vehicles and other objects in the cars vicinity. The system also addresses the issue of driver inattention. A far more time critical response needs to be delivered when the driver is in a position of impending collision.

The sensing of the environment and the processing of is data are outside the remit of this investigation. The aim of this investigation is to design, develop and evaluate a number of feedback methods in order to raise driver situation awareness and to inform inattentive drivers of impending collisions.

KEY WORDS: Collision avoidance; Lateral; Lane departure; Collision avoidance; Situation awareness; Warnings; Safety; Driving simulator; Human factors; Ergonomics;

Acknowledgements

I would like to start by thanking Prof Neville Stanton for agreeing to support me throughout this project. I am extremely grateful or his continuous support and advice and for sharing his vast knowledge in and around this subject; without which, this project would not have been possible.

Many thanks go out to Dr George Simpson and Paul Turnock for their continuous support and grounding influence keeping my project on target and manageable.

I would like to thank to Dr Guy Walker for his advice and support particularly on the setup and use of the Brunel driving simulator.

Thanks also to Tara Kazi for her support, and her help in the design of experiments and the analysis of the results.

I would like to thank all those who volunteered to take part in the numerous trials throughout the study as without there help this investigation would not have been possible. Each of the trials received no financial incentive and relied on the good will of friends and family.

Many thanks also to my friends on the campus for there input to my work and to those who volunteered as guinea pigs to debug the software used in both the pilot and the main trial.

A special thanks go out to my family for there constant unfaltering support and guidance throughout this project and my degree as a whole.

Last but by no means least; a very special thanks to Oliver Betts and Liam O'Grady for keeping me sane and making the whole experience partially unmemorable, but truly unforgettable.

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Assignment 3 Table of Contents

1 Introduction

This document has been developed as a summary report for a larger investigation. This is the third and final document and covers the main section of testing along with the discussion and conclusions to the project. This document is a continuation of the first two documents and in effect picks up where they left off.

This document is accompanied by user manual for the system and a CD Rom containing video footage of the testing environment, a summary interactive flash presentation and PDF versions of all of the submissions. Both of these can be found in Appendix F in pouches in the back of this document.

2 Results of the main trial

Assignment 2 documented the design and development of the experiments for the main trial. From the previous pre-trial the number of initial concepts was reduced from 14 to 6 icons carried forward for further investigation, 3 auditory and 3 visual.

It is important that the displays are considered in their natural environment as the initial testing allowed the participants to evaluate the tasks using their entire mental capabilities. In the real life situation the drivers will only have a percentage of their cognitive ability to devote to the task as part of it will be taken up completing the driving task. It is highly likely that this will affect the way in which the participants react with the feedback.

2.1 Results from stage II (Pilot trial)

The aim of the pilot trial was to run through the experiment to investigate any potential problems that could occur in the main trial. It was established from the first participant that the experiment required very little modification as many of the changes required had been established in Stage I (the pilot trial). The timing was established to be just less than 30 minutes.

2.2 Results from stage III (Main trial)

The results from the main trial showed that many of the participants found it hard monitoring the road and the graphical display. This was elicited from participant comments and from the large difference between the participants reaction time for the auditory and visual displays.

"Many of the participants found it hard monitoring the road and the graphically display"

When each of the reaction times for the visual and the auditory displays are averaged the results can be seen to be significantly different.

Visual	Auditory
1.96 seconds	0.75 seconds

Table 2-1 Main trial reaction time comparison

When these times are considered as a distance the significance is further highlighted. The participants were instructed to run the simulator trial at an average speed of 70 mph, this equates to 31.3 m/s.

"The significance of the results can be greater understood when considered as a distance"

The table below shows these reaction times as distances travelled from the point of the warning being presented to the point at which it was responded to. It is important to also remember that this is not the stopping time it is purely the reaction time to the stimuli. In a real life situation breaking time would also be a factor however this would be constant and irrespective of whether the warning was auditory or graphical.

	Visual	Auditory
Reaction time	1.96 s	0.75 s
Distance	61.3 m	23.5 m

Table 2-2 Main trial reaction time comparison

It can be seen in Figure 2-1 that with the visual response the car would have travelled an additional 37.8 meters this equates to over 9 Ford Focus' (Based on a Ford Focus of length 4174mm travelling at a speed of 70mph).

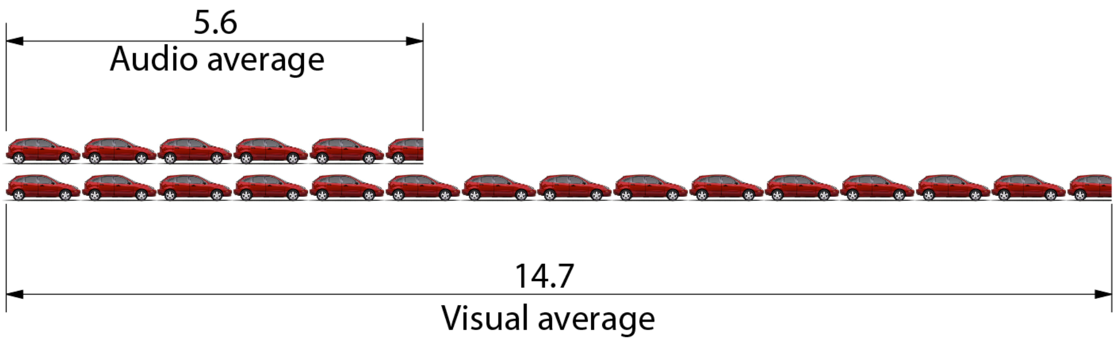


Figure 2-1 Graphical representation of elapsed time

2.2.1 Visual feed back

A common theme that ran through the visual displays was the inappropriateness of the yellow as a warning colour; with the situation of the light falling on the display the yellow tone was not clearly distinguishable from the white screen. It is entirely reasonable to assume that this difficulty would carry over to the head up display in a real car.

"Yellow inappropriate"

The following sections give a summation of the data and verbatim captured from the participants. (The verbatim captured from both the pre trial and the main trial can be found in Appendix B in the back of this document in the fold out A3 summary sheets):

2.2.1.1 The geometric radar display

The geometric and realistic radar displays were very similar and many of the participants stated that they could not see a significant difference. A lot of people commented that the number of colours was too great and that only one colour should be used.

The comment was also made that the lines were too confusing and that the division lines should not be included.

"Division lines too confusing"

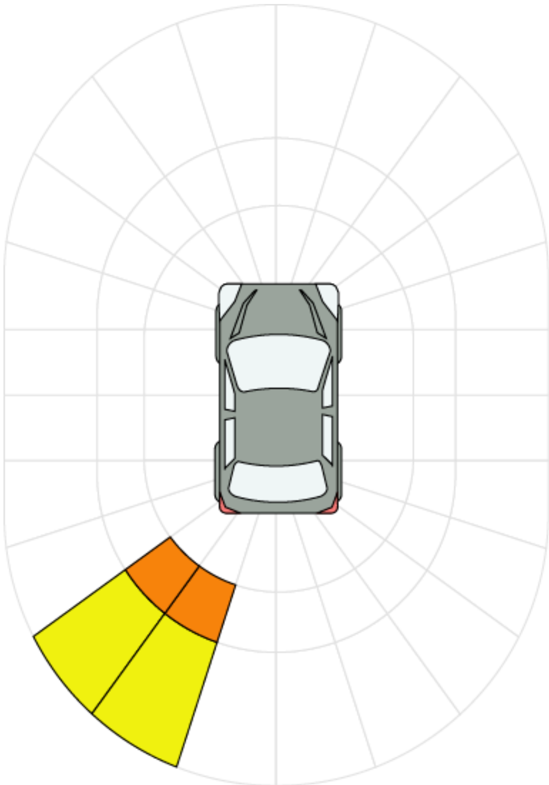


Figure 2-2 Geometric radar display

The scores used were the same as in the pilot trial. The appropriateness rating and the urgency rating were originally taken out of 5, relating to a Likert scale with 5 options of very appropriate ranging through to very inappropriate. This figure was then multiplied by 2 to give a score out of 10. The reaction times were an average of the participant's time to respond and kept as a time in seconds.

Appropriateness rating	8.00
Urgency rating	6.34
Reaction time (seconds)	2.06

Table 2-3 Results for Geometric radar display

2.2.1.2 The realistic radar display

As with the geometric radar the display was criticised for the yellow and the number of colours. The improvement suggested again was to investigate looking at removing the separation lines.

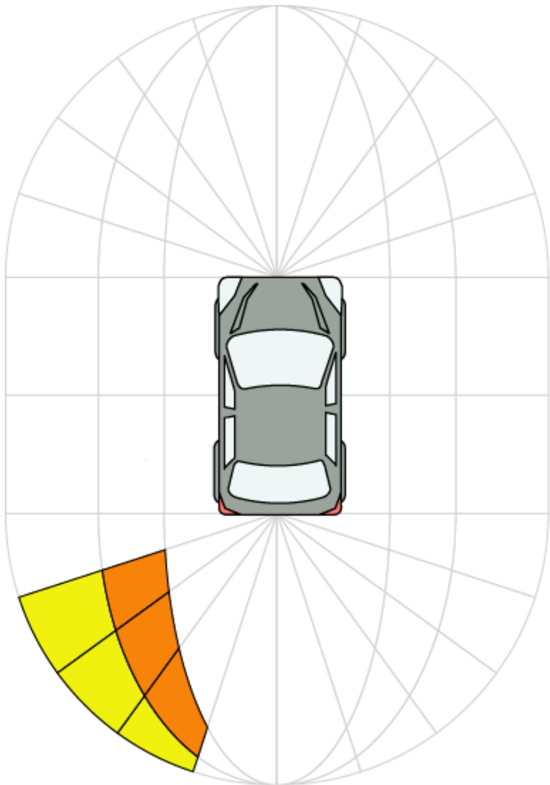


Figure 2-3 Realistic radar display

Appropriateness rating	7.84
Urgency rating	6.34
Reaction time (seconds)	1.94

Table 2-4 Results for Realistic radar display

2.2.1.3 The car representation display

The use of the car symbols received a lot of positive feedback many comments were made about the ability to visualise the hazard and interpret the meaning of the display. However as with stage I (pre trial) the comment was made that confusion could arise if the vehicle represented by the car was in fact another type of vehicle such as a truck or motorcycle.

"Confusing if another type of vehicle"

The comment was made the display was also easier to detect in peripheral display due to the block colour. The recommendation was also made that the windscreen should be filled in so that more block colour is present.

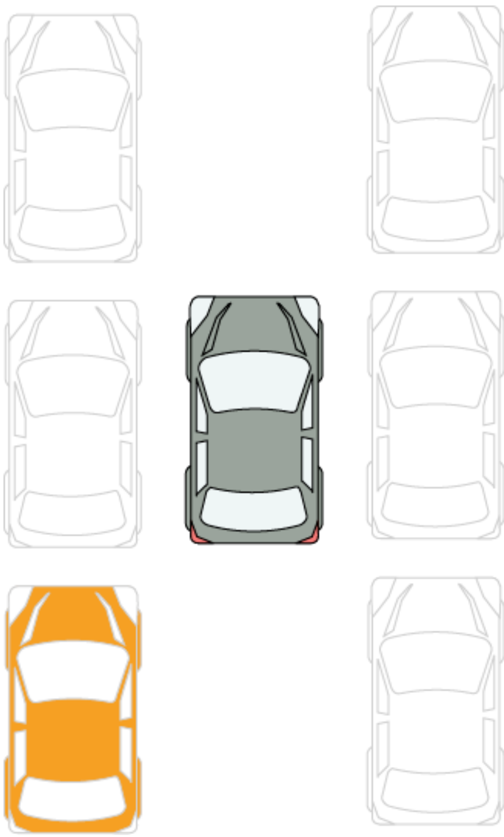


Figure 2-4 Car representation display

Appropriateness rating	7.12
Urgency rating	6.84
Reaction time (seconds)	1.89

Table 2-5 Results for car representation display

2.2.1.4 Comparison of visual feedback

Table 2-6 shows the rankings of the three displays it is clear that there is no clear optimum solution. No single display scored high in all three sections.

Appropriateness

1	Geometric radar
2	Realistic radar
3	Car representation

Reaction

1	Car representation
2	Realistic radar
3	Geometric radar

Urgency

1	Car representation
2.5	Realistic radar
2.5	Geometric radar

Table 2-6 Rankings of visual displays

2.2.2 Audio feedback

The audio feedback was recorded in the same way as the visual feedback. Reaction times were recorded by the software and the participant was asked to rate the sounds on both urgency and appropriateness.

2.2.2.1 The sound of a car horn

The sound of the car horn was reasonably well received. The issue still exists that was found in stage I that many drivers claimed that the sound could be too easily confused with the external environment. However a number of participants did state that they liked the semantic link between cutting someone up and the sound of the horn

Appropriateness rating	7.00
Urgency rating	7.16
Reaction time (seconds)	0.72

Table 2-7 Results for car horn sound

2.2.2.2 The sound of a truck horn

The sound of the truck horn received very similar feedback to the car horn. The majority of the participants stated that the sound of the truck horn was more alarming than the car horn due to the size of the vehicle from which they would expect it to originate from. It was also commented that the truck horn sound was more suitable as less common than the car horn in the driving environment.

"Truck horn more alarming than car horn"

One participant requested that a different sound be played to match the sound of the encroaching vehicle for example a motor bike horn for a motor bike. This is a valid suggestion however it would require very sophisticated sensing technology and would add another level of complexity in to the warning, which may confuse drivers further.

Appropriateness rating	6.66
Urgency rating	8.50
Reaction time (seconds)	0.84

Table 2-8 Results for truck horn sound

2.2.2.3 The sound of electronic beep

The abstract sound of the electronic beeping taken from a smoke detector was also reasonably well received. The sound was described by some participants as being too high pitched and hard to distinguish the direction.

The abstractness of the sound was well received by some participants stating that they would not get it confused with external natural sounds. Other participants contradicted this view stating that in a new car they may not understand the intention that the warning is trying to communicate.

A significant proportion of the participants found that the sound created a semantic link with a warning as to them the sound represented a warning tone.

Appropriateness rating	6.16
Urgency rating	8.00
Reaction time (seconds)	0.69

Table 2-9 Results for electronic beep

2.2.2.4 Comparison of audio feedback

Table 2-10 shows the rankings of the three auditory tones as with the pictorial displays it is clear that there is no clear optimum solution. No single display scores consistently high with each of the displays taking a 1st 2nd and 3rd.

Appropriateness		Reaction		Urgency	
1	Car horn	1	Smoke alarm	1	Truck horn
2	Truck horn	2	Car horn	2	Smoke alarm
3	Smoke alarm	3	Truck horn	2	Car horn

Table 2-10 Rankings of audio feedback

2.3 Statistical analysis of the data

SPSS was used to evaluate the differences in the data and to see if there were any statistically significant differences between the ways the different displays were rated, and to determine whether rank ordering the displays was a valid method for selection.

The first stage was to look at the reaction time data using an ANOVA. The data was organised so that comparisons could be made based of type of feedback (auditory or visual) and then by the six different groups (geometric display, realistic display, car representation, car horn, truck horn and electronic beep). From the ANOVA it was found that there were significant differences between the groups and the types of feedback.

The next stage was to do a paired 't test' on the data to look for significant differences. When each of the visual displays were compared against each other it was found that the only displays with a significant difference in reaction time were the cars display and the geometric display; with the cars display being significantly faster.

When the paired 't test' was conducted comparing in turn each of the auditory tones it was found that there was no significant difference in the reaction times for the sounds.

"No significant difference in the reaction time of the sounds"

When analysis was conducted on the appropriateness ratings and the urgency ratings it was found that there was no significant differences in the data.

2.4 Summary

This chapter has detailed the findings of the experiments.

The data analysis has shown, as expected that there is a statistically significant difference in the reaction times between the auditory and visual displays; with the auditory responses being significantly quicker. Further investigation into the statistics showed that there was not enough statistical difference between the warnings within there groups to use this information as a selection criterion.

The following chapter will address the reasoning behind the results and explain how the decision will be made on which is the optimum feedback method.

3 Discussion of results

3.1 Introduction

This chapter looks at the findings of the results section and by looking back to the literature review attempts to discuss and explain the findings.

3.2 Stage III testing: the main trial

It is clear from participant verbatim that the use of both the pictorial and the auditory display is required. Participants were much slower at reacting to the pictorial display making it unsuitable in very time dependant warnings. The average reaction time for a visual display was more than twice that of an auditory display. The issue of driver distraction and driver inattention also make a purely visual based system inappropriate. However the use of the pictorial display in the total system is justified by the participant verbatim that the sounds would get really annoying if they were going off all the time. The visual display is far less intrusive than its auditory counterpart. Because of this it is far more suited to the task of raising situational awareness and the development of a mental model.

"It is clear from customer verbatim that the use of both pictorial and auditory display is required"

This use of dual modality is supported by the NHTSA who comment that auditory signals should be reserved for more urgent warnings. This decision is also supported by Pohl and Ekmark (2003) who comment on the problems arising from frequent auditory warnings in the domestic automobile and poor driver acceptance of these systems. (See literature review in first document)

3.2.1 The visual feedback

Instant recognition of the meaning of the pictorial display is less important than it is for the auditory icon. The main reason for this is that the pictorial display is used in situations where the presence of a potential hazard is less important. The purpose of the display is less of a warning function and more of a monitoring function. By locating the position of the hazards and correlating this to the real world even an unfamiliar driver should be able to infer the purpose of the display and create an accurate mental model. This interpretation and understanding allows the drivers level of trust and confidence in the system to

"The visual display aids in the development of a mental model"

increase. The pictorial display used in the radar displays also ties in very well with Gibson & Crooks (1938) psychological interpretation of driving, which details a path of safe travel (see Appendix A section 8.2.4).

From the work of Burns (2000) it is also reasonable to assume that by tracking the display and hearing the warning tones that within time drivers would change there driving habits to reduce the onset of warnings. The system is therefore training the driver to drive in a safer more suitable way. (See Appendix A section 8.4)

"The sounds would encourage drivers to change there unsafe driving habits"

3.2.2 The auditory feedback

An important consideration to make about the icons selected for the auditory sound and their appropriateness is that the rating given by the participants does not really consider the ability to determine the meaning of the sound. The participants were explained the function of the testing and therefore knew that the sound was a lateral collision warning. It has been established that one of the most important functions of the sound is that it informs the driver what the root cause of the alarm is. As this inference test could not be included, it is important that the drivers interpretation of the sound needs to be considered along side the numerical results.

The NHTSA make the point that the sound should be clearly distinguishable from any other sound in the cab (car in this case). They make no reference to confusion with external sounds, however it should be inferred that confusion should not occur with common sounds originating outside the vehicle that enter the driving environment.

The primary role of the auditory icon is to regain the driver's attention. The meaning can be constantly displayed using the visual part of the display. The purpose of the tone is therefore not intended to communicate information; it is more of an alarm to draw the driver's attention to the display. As discussed in the literature review (in the first report) it is clear that one of the main causes of accidents on modern roads, particularly motorways is driver inattention. The sound is therefore an attention grabbing devise as apposed to an icon charged with meaning.

"The primary role of the auditory icon is to regain driver attention"

3.3 Which displays should be used for the final system?

When addressing the issue of which display should be used, the first point of call would be to address the findings of the experimental data. However the experimental data was not conclusive and found very few statistically significant differences between the displays within the two groups (audio and visual). As stated previously it is also important to remember the limitations of the system and that the inference of the meaning of the displays was not included in the testing, it therefore cannot be established from the results alone.

When the reaction times are viewed it is possible to see how close the reaction times are. This information is shown in Table 3-1

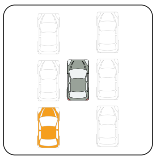
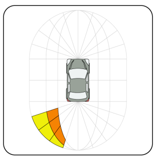
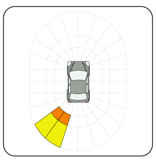
Visual Displays		Auditory Tones	
Cars 	1.89	Elect beep 	0.69
Real 	1.94	Car Horn 	0.72
Geometric 	2.06	Truck Horn 	0.84

Table 3-1 Mean Reaction times for each feedback method.

By examining the data in Table 3-1 it can be seen that in each category there are two slower times. Due to the fact that the real and geometric displays were so similar (commented by the majority of participants) it seems feasible that any problems with inference would be constant between these two displays. It is therefore deemed appropriate to use

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the slower reaction time as a method for eliminating one of the displays. Although the elapsed time seems small in real terms at just 0.12 seconds, this equates to 0.9 car lengths (based on a Ford Focus of length 4174mm).

"The reaction times can be used to eliminate one of the displays when they are very similar"

The same can be said for the car and truck horn as they have a very similar metaphoric suggestion. The difference in these times is also 0.12 seconds or 0.9 car lengths.

Removing these displays from the list it is possible to rethink the selection process. A schematic can be generated to show the possible variations of sound and visual combinations (see Figure 3-1).

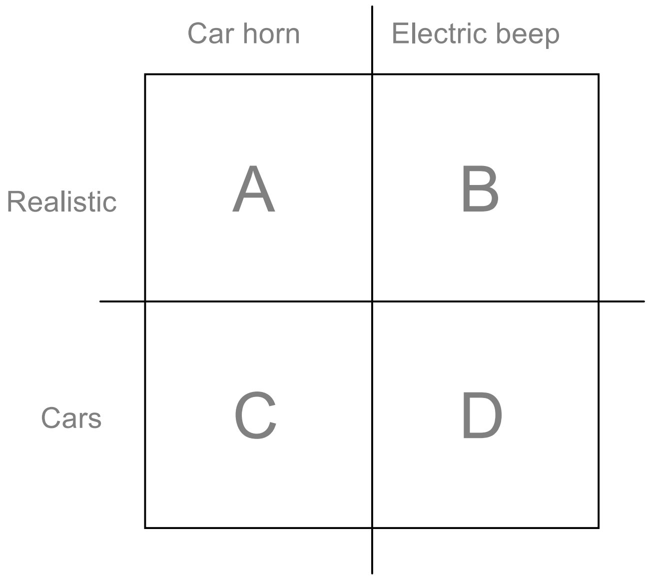


Figure 3-1 schematic showing choices of displays

3.3.1 Sound only

By looking at the individual ratings and the participant verbatim it is clear that there seemed to be two distinct and different opinions contained within the experimental group. Some of the participants liked the arbitrary warning tone (smoke detector) as they thought that a metaphoric tone of a horn may be confused with an external noise and did not associate it with a warning. The other group of participants thought that the abstract sound of the smoke detector beep was too random and they would not be able to deduce meaning from it. These participants stated that the metaphoric sound of the horns allowed them to make a semantic link between the cause of the alarm and the sound generated by the system. It therefore seems that a sound has to be generated that is clearly indistinguishable from an external tone, however the sound still needs to retain some reference so that the participants can still create a semantic link with the cause of the warning.

What has to be remembered that may not have come out in the results is that the inference test was not included in the experiment. The participants were all aware of the purpose of the sound and did not have to attempt to distinguish its message. In the real world this would not be the case and participants could be hearing the sound for the first time and they need to quickly decipher its meaning and still have time to react to it.

“The ability to infer meaning was not included in the testing”

The choice of sound that is adopted for this system is very dependant on the situation in which it is placed. In a situation in which the sound would played without a visual icon for reference the most suitable sound would be the sound of the car horn along with a directional indication given by playing the sound out of either the left or right channel. The car horn sound was selected due to its ability to be rapidly semantically linked to a lateral collision. The use of the electric tone is too arbitrary in a case where there is no visual reference and may lead to confusion if the driver did not interpret its meaning within a suitable amount of time. This decision is supported by the work of Belz et al (1999). Belz et al (1999) conducted testing of the car horn and an arbitrary tone, not only did he find the horn to receive the faster reaction time but when Belz et al (1999) questioned the participants after the test about the meaning only half correctly identified the meaning of the arbitrary tone whereas nearly all correctly identified the meaning of the car horn tone.

For this reason and based on the information in the literature review it is the authors opinion that the best auditory signal for a stand alone tone would be that of a car horn

"Car horn most appropriate if sound to be used alone"

3.3.2 Vision only

The use of a vision only system is not considered suitable for this application for key reasons.

- Difference in reaction time between audio and visual warnings.
- Inability to combat driver distraction
- Inability to combat driver fatigue

"Visual alone is not appropriate"

The significant difference between the reaction times to a visual and auditory display makes it unfeasible to use a visual display on its own. When the time is viewed pictorially in Figure 2-1 it is clear that a visual display is inadequate in a time critical situation. It is also clear from the literature review that driver distraction is one of the most significant causes of lateral collision. The visual display alone is not suitable at tackling this problem due to the fact it relies on the driver being alert and constantly monitoring the display; it is the author's opinion that a solely visual based system is not suitable as it neglects to tackle the driver distraction element that has been attributed to 20% of all accident (ROSPA 2001) this figure is also believed to be conservative as many drivers are reluctant to admit distraction.

3.3.3 Sound and vision combination

When considering a combination, the way in which the sound and image work together is important. It is important to consider that by using a dual modality system the characteristics of the independent modes will need to be revisited. In this case, the addition of a visual reference means that it is no longer essential for the sound to fully communicate the cause of the warning nor does the sound need to convey the direction of the warning.

Due to the fact that a high proportion of participants complained that the sound of a horn could be confused with external sounds further thought has to be given. This confusion could lead to a detrimental effect on the reaction times to the warnings. The driver may be more tempted to look out of the windows in an attempt to see the car that delivered the warning (believing that the sound originated from outside the car). It has already been specified that the aim of the sound is to direct the drivers attention to the visual display. In the case of a significant number of false alarms, drivers could become practiced at ignoring the sound of car horns. If this resulted in drivers ignoring external car horns potential accidents could occur along with litigation proceeding against the manufactures of such a system. It is therefore concluded that in situations where the cause is not needed to be transferred the car horn sound should not be used. The exclusion of the car horn tone therefore means that the sound to be used is the sound of the smoke detector and the choice is limited to B and D in Figure 3-1.

Looking at which of the two displays should be used with the sound, it is important to consider what the two displays provide that was not measured in the testing phases. Looking back at the initial development of the two displays in section in the previous reports it can be seen that the car display was selected for its ease of understanding of the purpose of the display. The fact that the display uses cars in the display in a road layout makes it possible for the driver to quickly understand the display purpose. The radar reference display was developed with the aim of creating a greater more accurate positioning system with a wider range of combinations. The radar shape was selected so that driver could develop a mental model of the system.

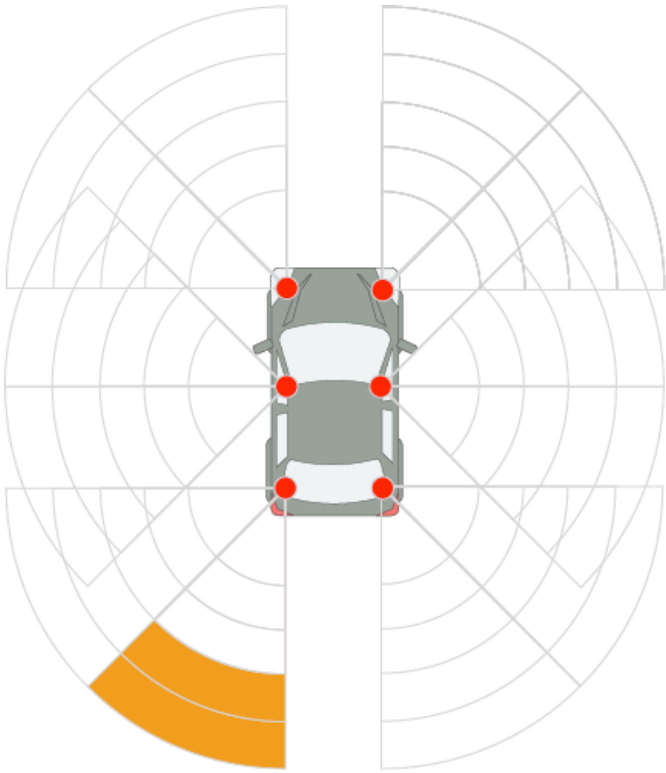


Figure 3-2 Diagram showing starting point for display

The display also provides the driver with some kind of understanding of the limitations of the system. The issue with the 'cars display' still stands that it may be confusing when vehicles and objects other than a car are represented by the display as a car.

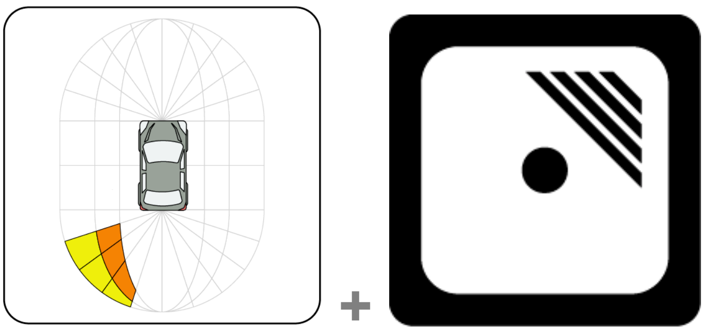
Due to the high level of mental model and versatility of the display it is conclude that the realistic radar display is the most appropriate solution. (Option B in Figure 3-1)

3.4 Summary

This chapter has discussed the results found from the testing phase and aimed to contrast them with the findings of the literature review. The main summation of the selection of the system is detailed below:

- For a single sound the car horn should be used.

- The visual display should not be used alone
- The optimum solution would be to use the realistic radar supply for monitoring purposes with the use of the electronic beep for time critical situations.



"Realistic radar display and electronic beep is the most appropriate combination"

This solution is likely to require further development and optimisation so that it is as effective as possible.

4 Development and synthesis of the chosen idea.

This chapter aims to look at the results and the comments made in the discussion and customer verbatim in order to develop and synthesise the optimum solution for both the pictorial and auditory part of the system. The previous chapter has established an optimum combination of display and sound however there are still key concerns that were raised in participant verbatim that need to be addressed in optimising the final solution.

4.1 The visual display

The main criticisms of the visual displays can be summarised below:

- The yellow part was not visible enough.
- There was not enough block colour in the warning.
- The lines in the radar made it too confusing.

The chosen display needs to go through some modification in order to make it acceptable and suitable. It is still important that as many as possible of the needs expressed in the PDS are catered for, particularly the mental model and the ability to understand the meaning of the display, both things that were not possible to include in the experimental design. The PDS for the visual display from the first report is repeated below:

"The final solution is evaluated again against the initial PDS"

1. The ability to inform drivers of other drivers in the near vicinity of the car.
2. The ability of the system to indicate within a suitable tolerance the exact position of the intrusion into the vehicle vicinity.
3. The ability to locate and identify the purpose of the display when placed in the car.
4. The ability to rapidly interpret and understand the information presented to the driver.
5. The ability to build a mental model of the system.
6. The ability to scan the device and return to the driving function in the minimum amount of time.

The display is shown below as it was presented in the testing

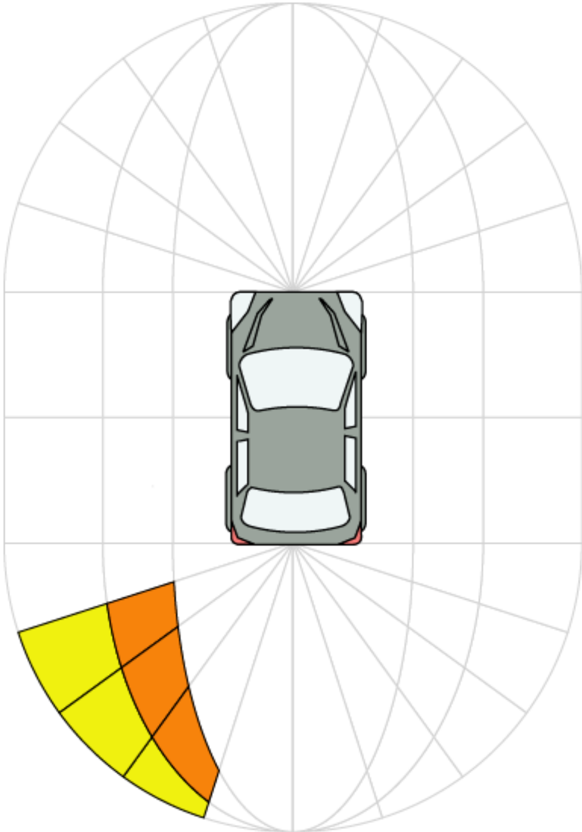


Figure 4-1 Realistic radar display selected from Stage III testing

Addressing the points in order it is clear that the first point is met as the display informs the driver of the position of potential hazards. The second point is also met as the spacing was selected over other displays in the pre trials and, based on customer verbatim and response it is the correct level of divisions.

The ability of the driver to determine the purpose of the display is the questionable point within the list. The display statically may seem to be rather confusing, however with visual feedback through to the external environment the display should be rapidly correlated with external movements, to create a level of trust through the mental model that would be developed.

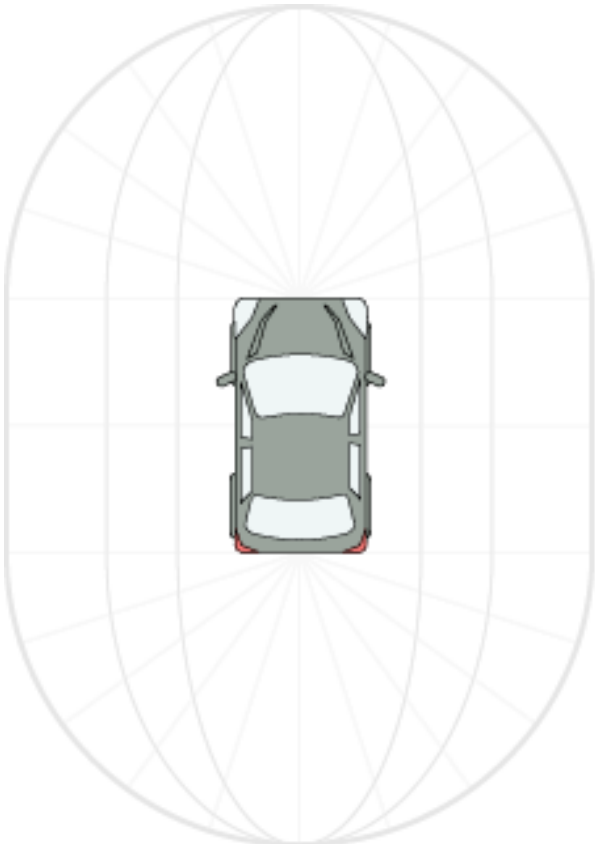
The ability to scan the display is something that could be improved by the use of block colour. It should be possible to scan the display and quickly establish the level of threat that the imposing obstacle poses.

4.1.1 Participant verbatim

From looking back at the participant verbatim in section 2.2.1 it can be seen that particular issues raised were as follows:

- Segment divisions too confusing
- Multi-colour too confusing, only one colour should be used
- Yellow is not visible enough.

These points were taken on board and the improvements can be seen in Figure 4-2 and Figure 4-3.



"Divisions intensity reduced"

Figure 4-2 Modified display

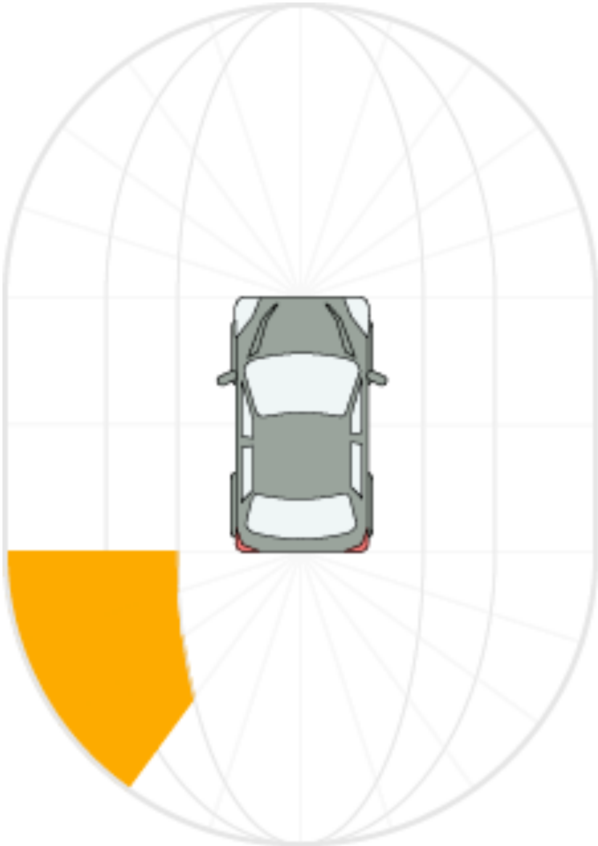


Figure 4-3 Modified display showing warning

"One object is only ever represented by one colour"

It can be seen by comparing Figure 4-1and Figure 4-3 that the divisions have been thinned out and the intensity of the colour reduced to simplify the look of the display. The vertical lines have been left bolder as they fit in with Gibson & Crooks (1938) Field of safe travel depicting the areas that can safely be occupied. The bolder outer ring also highlights the limit of the systems sensing ability and therefore aids in the mental model construction. The display has also been modified so that any singular object only has a single colour. It can be seen in Figure 4-1 that the object was expressed in both amber and yellow as it occupied both the yellow and amber zone. In the modified design the display has been changed so that the whole object takes on the colour of it most urgent colour (see Figure 4-3). It can also be seen that in order to create more block colour and to reduce the confusion the segment outlines have been removed. The aim of this improvement is to make the display simpler to scan so that the threat of the imposing obstacle can be far more rapidly interpreted.

The other change that has been made to the display is to change the yellow tone to a green tone to make it more visible. Cars in this region are no threat to the driver if they remain in this region hence the fact that they are coloured green. The reason they are shown is so that they can be tracked by the driver and monitored to check that they do not become a potential problem.

"Cars that do not present a threat are represented in green to aid in the development of a mental model"

By adding cars that do not directly pose a threat to the driver it is also possible to raise the drivers situation awareness and help them to construct a mental model. By the driver being able to see cars on both the display and the real would environment a rapid understanding of the information displayed in the icon can be gathered. Muir (1994) has shown that in order to gain trust in a system it is first important that it is predictable, from this predictability comes dependency and finally trust.

A better representation of the final display along with construction grids and colour information can be found in the appendix of this document.

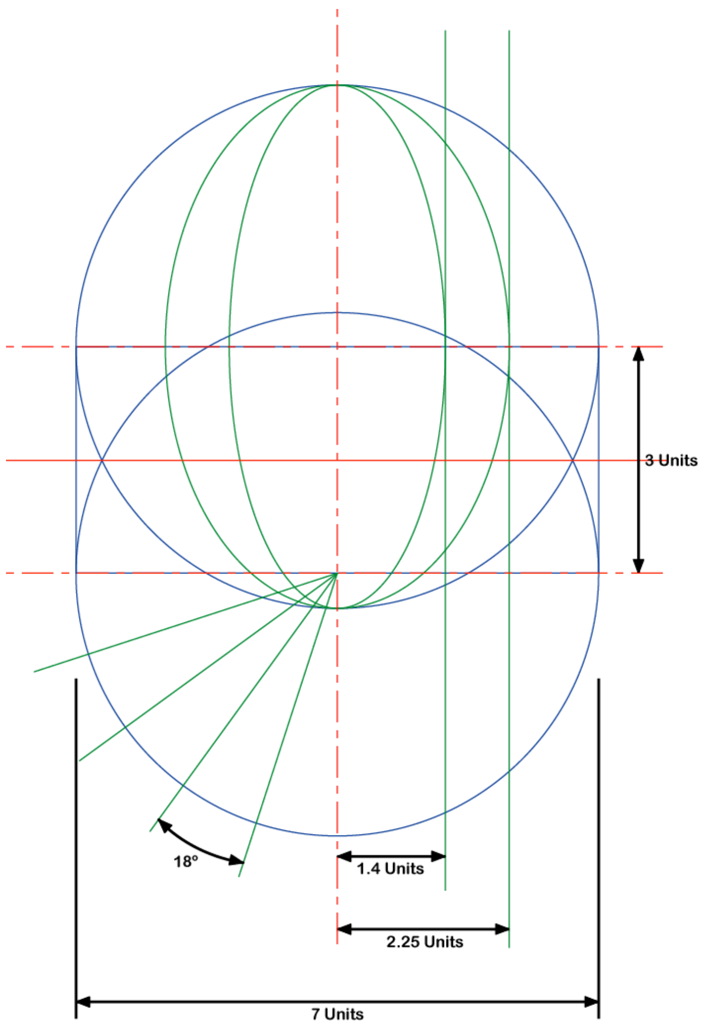


Figure 4-4 Construction grid for generating display (larger version in appendix)

4.2 The auditory warning tone

The main criticism of the auditory tone related to the pitch and the volume. The volume is a factor that is easily controlled without significantly affecting the validity of the test data. Care however has to be taken when adjusting the pitch as this may lead to the effectiveness of the reaction to the sound changing. If the sound is similar enough to the sound tested it could be replaced. The sound would need to sound very similar so that the same mental model is formed and so that the same meaning would be inferred. If the sounds were similar enough it could be assumed that the only factor that would separate them would be the participant acceptance and ranking.

After the comments made I searched again on the internet to find a similar sound that was easier to hear. I found a number of other very similar sounds varying slightly in amplitude and pitch. I then played these sounds to the participants of the main trial to get there feedback on which sound was the most appropriate. Due to the fact that the sounds were so similar it was considered that the reaction time would not significantly change. The sound was considered to be similar enough that the only difference between them would be the acceptance.

The result was that a very similar sound was selected over the original due mainly to the fact that it could be heard much more easily over background noise.

4.2.1 Combating background noise.

It can be seen from the results of the pilot trial that a number of participants commented on the ability to hear the sound over background noises, particularly the car stereo. It would be necessary to link the car stereo in with the system in some way to ensure that the sound is still audible. There a number of possible ways of doing this:

- Play the warning tones through a second set of speakers.
- Mute the stereo while the warning is played and for a set amount of time after.
- Have the warning played a fixed number of decibels louder than the stereo, or at a set level which ever is louder.
- Partially mute the stereo down to a level that the warning is clearly audible.

From a commercial point of view the wiring and equipment needed for a second set of speakers would make the solution unviable.

The act of completely cutting out the stereo may lead the driver to look to the stereo and not take as much notice of the warning. It is important that the driver instantly realises the stereo has only been changed so that the warning can be heard and that there is not a fault with the stereo that needs to be investigated.

"Background noise can be combated by reducing the stereo volume"

There are already a number of systems such as navigation and traffic information systems that work in conjunction with the car stereo. The majority of these systems opt for a method of reduces the car radio volume to a predefined low level and then playing the warning or information at a significantly louder level. This would seem to be the most viable method as it is cost effective and will not startle the driver as they will be used to their stereo volume being reduced when auditory information is delivered to them.

Another common method of combating road noise used in many stereos is to link the stereo up so that its volume increases with speed. This system could also be incorporated so that the predefined level at which the radio is reduced to and the warning is played at is also linked to this system.

4.2.2 The direction element

As discussed in section 3.2.1 the meaning in the auditory icon is not significant. The aim of the sound is to raise the driver's awareness and encourage them to concentrate on the visual display. The original design of the system was for the auditory icon to communicate if the collision warning was on the left or right hand side depending on which channel the sound was played through. As the meaning has been removed from the sound this no longer seems appropriate. It would seem far more practical if the sound were set up so that it appeared to originate from the graphical display thus drawing the driver's attention in to the area that needs to be focused on. The other main advantage of having a unidirectional sound is that it is far easier to respond to; Wallace et al (1996) found that the reaction time increased with the number of speakers, the range from 1 to 6 speakers was 400 ms to 800 ms. Wallace et al also report that participants were quicker to respond to tones presented directly in front of them.

"The sound should be unidirectional and originate from the display"

4.3 The combined system

The combined system would work so the system would track the position of vehicles an example can be expressed of a vehicle that comes progressively closer to the car.

The display would first show the car on the display as a green area on the radar display (See Figure 4-5). At this point the intrusion does not posses a threat to the driver but its inclusion is to raise situation awareness.

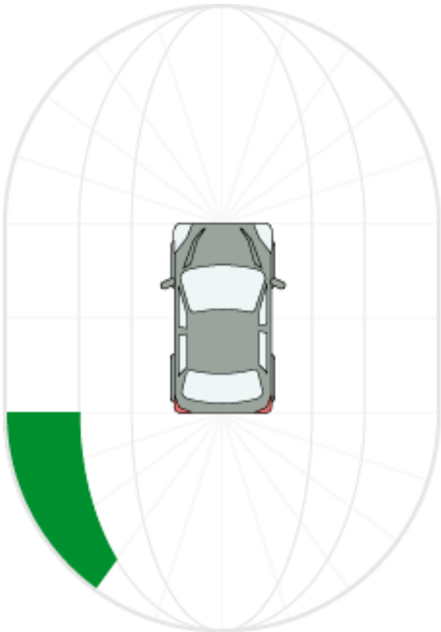


Figure 4-5 First warning of the intrusion

As the intrusion drifts closer to the car in the lateral direction the warning changes (See Figure 4-6). The intrusion now presents a possible threat to the vehicle and the driver may wish to correct his path or move away from the vehicle. At the least, the driver should be continually monitoring the position of the intrusion both on the display and in the external environment.

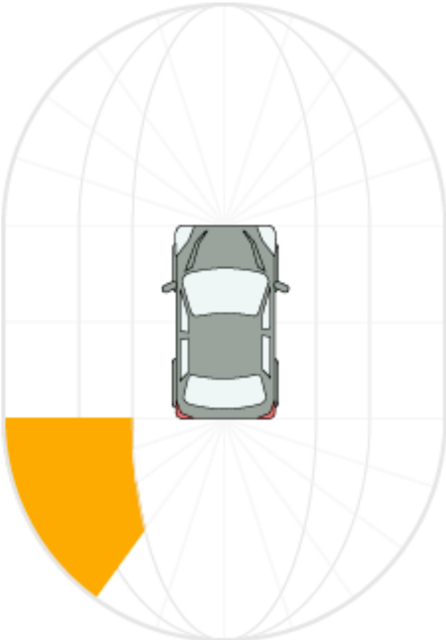


Figure 4-6 Increased urgency as the intrusion gets closer

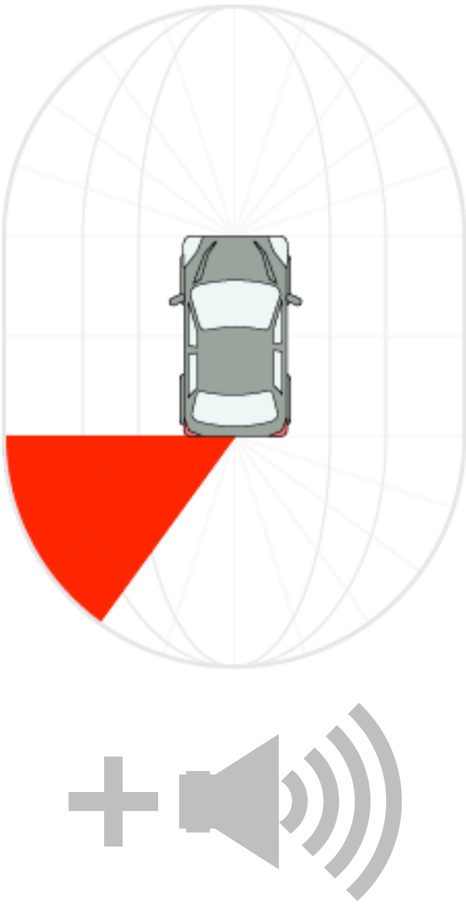
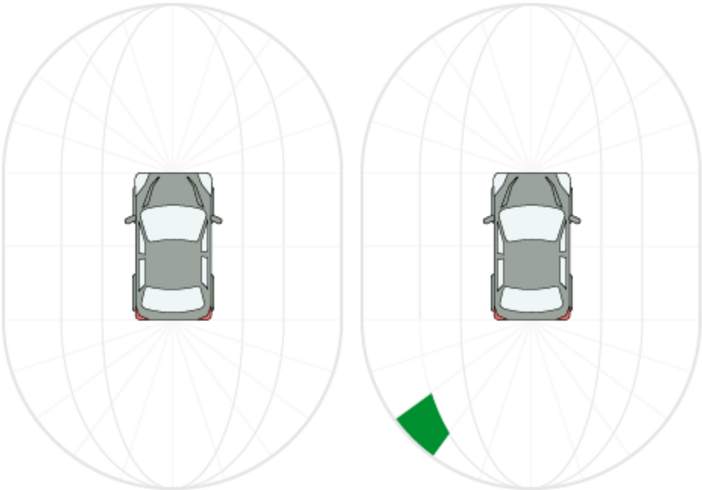


Figure 4-7 Highest level of warning as the intrusion presents an imminent collision threat

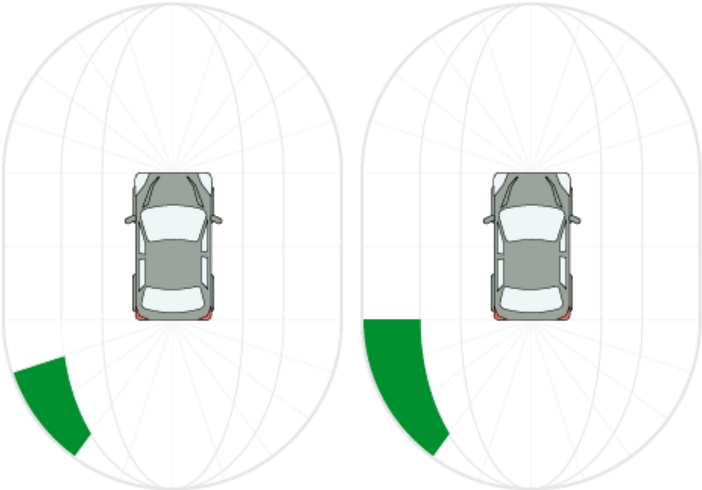
If the driver does not correct his path in light of the position of the intrusion and the intrusion continues to drift towards the car a high level warning is delivered. This Highest level warning is presented by showing the position of the vehicle in red on the display (See Figure 4-7) the graphical warning is also accompanied by the auditory tone of the electric beeping selected in this report.

4.3.1 The display in action

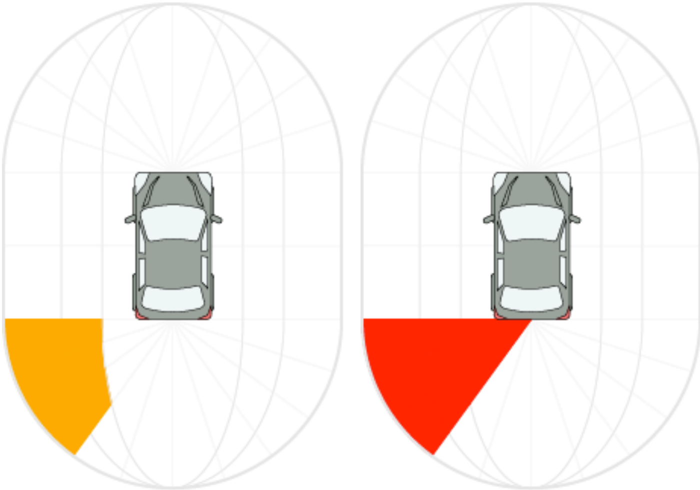
This section shows the display in action, it runs through an example of an object approaching the car. The car quickly reaches a dangerous position it then moves away safely.



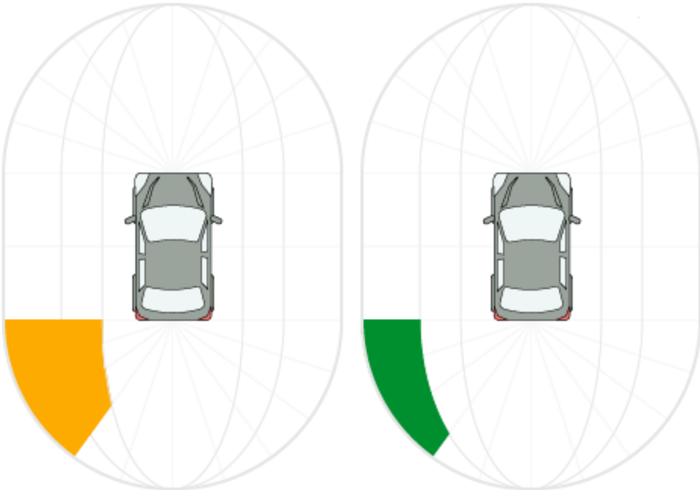
A vehicle approaches from the bottom left corner.



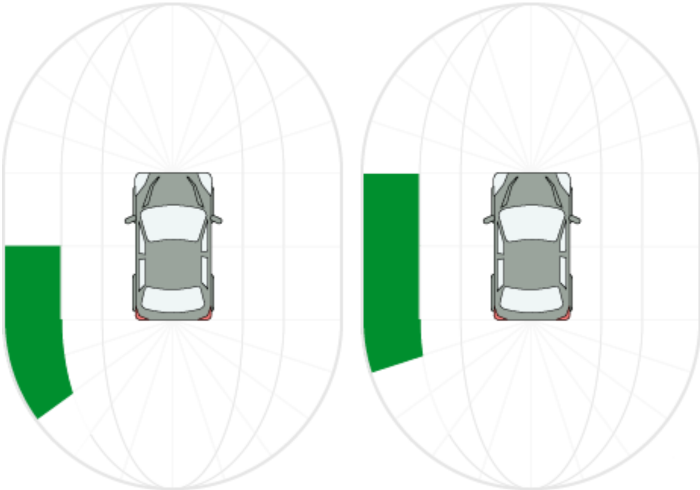
The vehicle moves up accelerating up the left side.



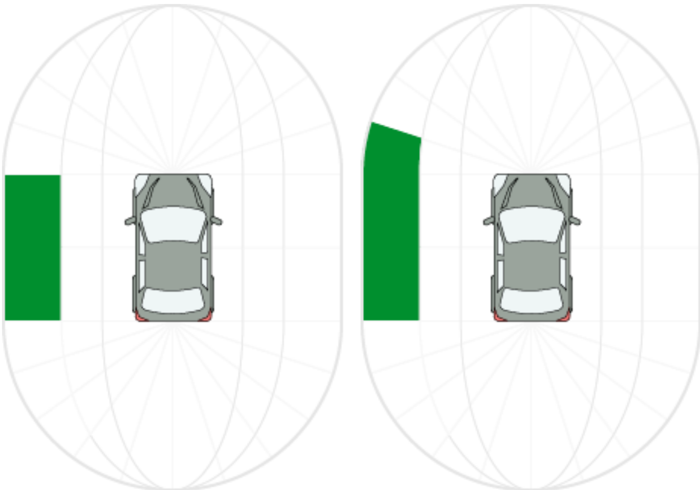
The distance between the two vehicles gets closer and an orange warning light goes on. As no action is taken and the distance continues to close a red light comes on accompanied by the warning tone.



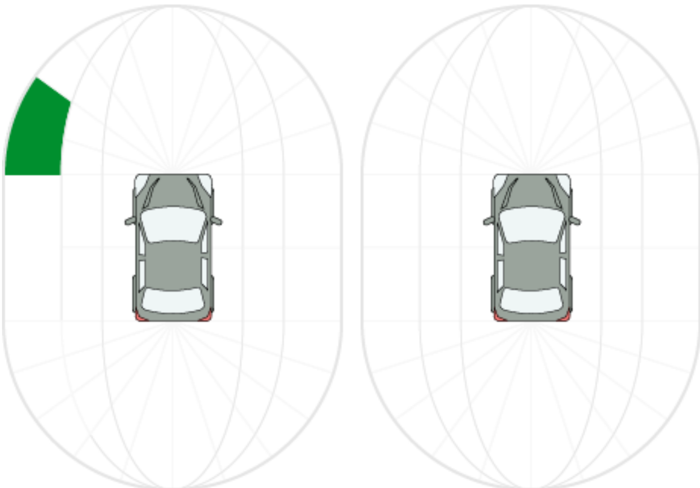
One of the drivers takes action and the distance between the vehicle increases, the urgency changes to amber, as the distance increases more to a safe position it goes back to green.



The other vehicle starts to accelerate up the left hand side



The other vehicle continues to accelerate



Finally the other vehicle moves out of range of the radar system.

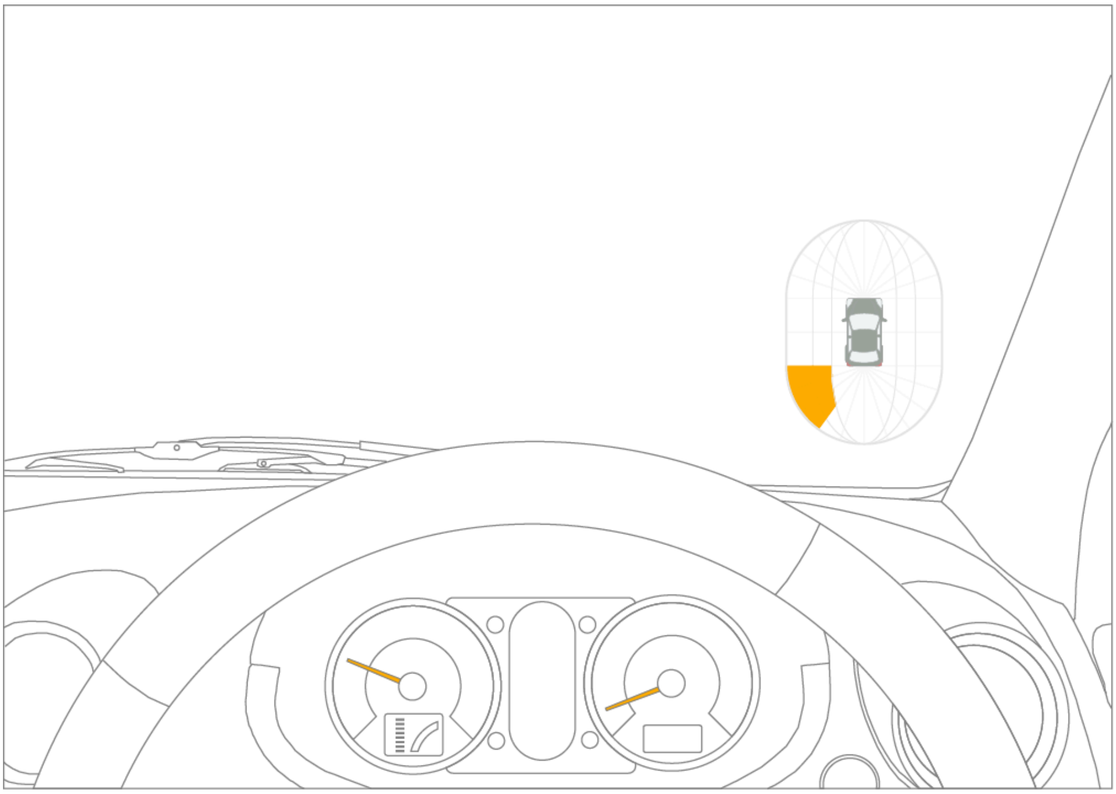


Figure 4-8 Schematic showing location of warning device

Figure 4-9 Warning device in situ

The above demonstrations show how the system works. Figure 4-8 shows the location of the display. The display is located in the bottom right hand corner of the windscreen. Figure 4-9 shows the system working and the display picking up the position of another vehicle.

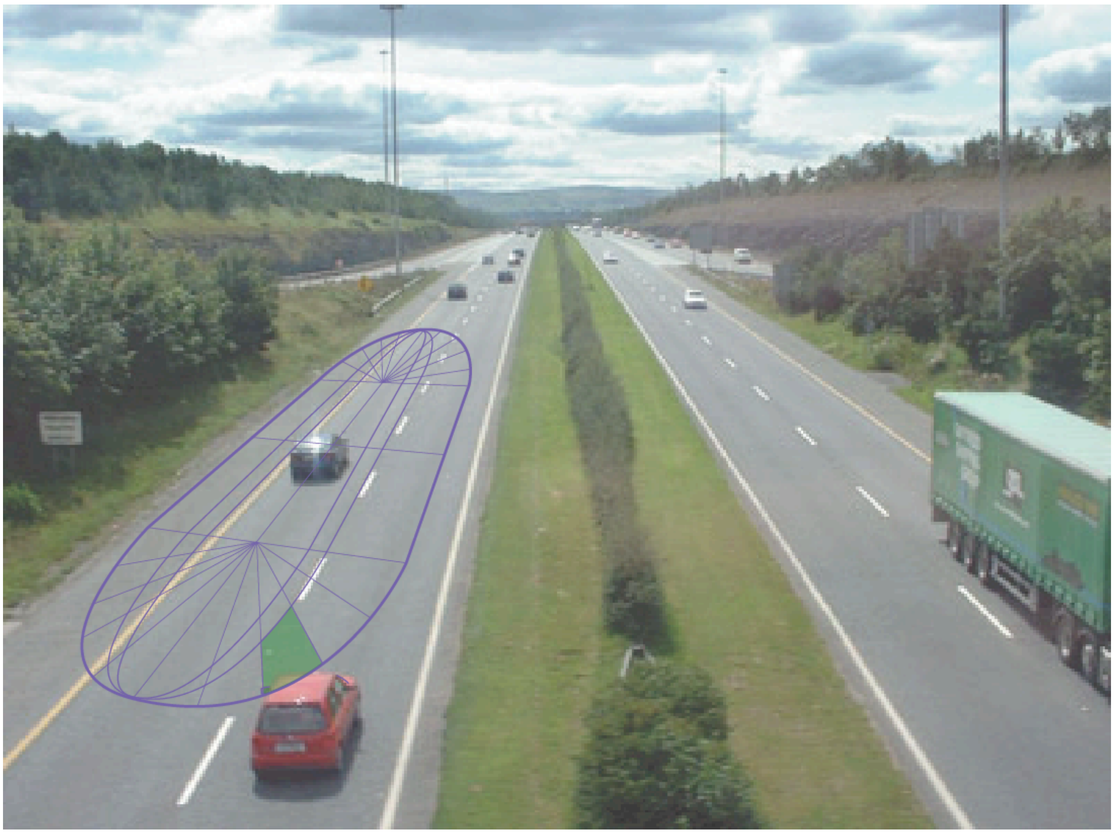


Figure 4-10 Illustration showing how system works

Figure 4-10 to Figure 4-12 are illustrations to show how the sensing of the vehicles work. The feedback display has been included to help the understanding of how the real world environment translates into an image projected on to the windscreen. It can be seen that in Figure 4-10 and Figure 4-12 the display is green as the cars are passing at a safe distance. Figure 4-11 shows the vehicle at an unsafe distance from the car; this would be represented in red and accompanied by an auditory warning.

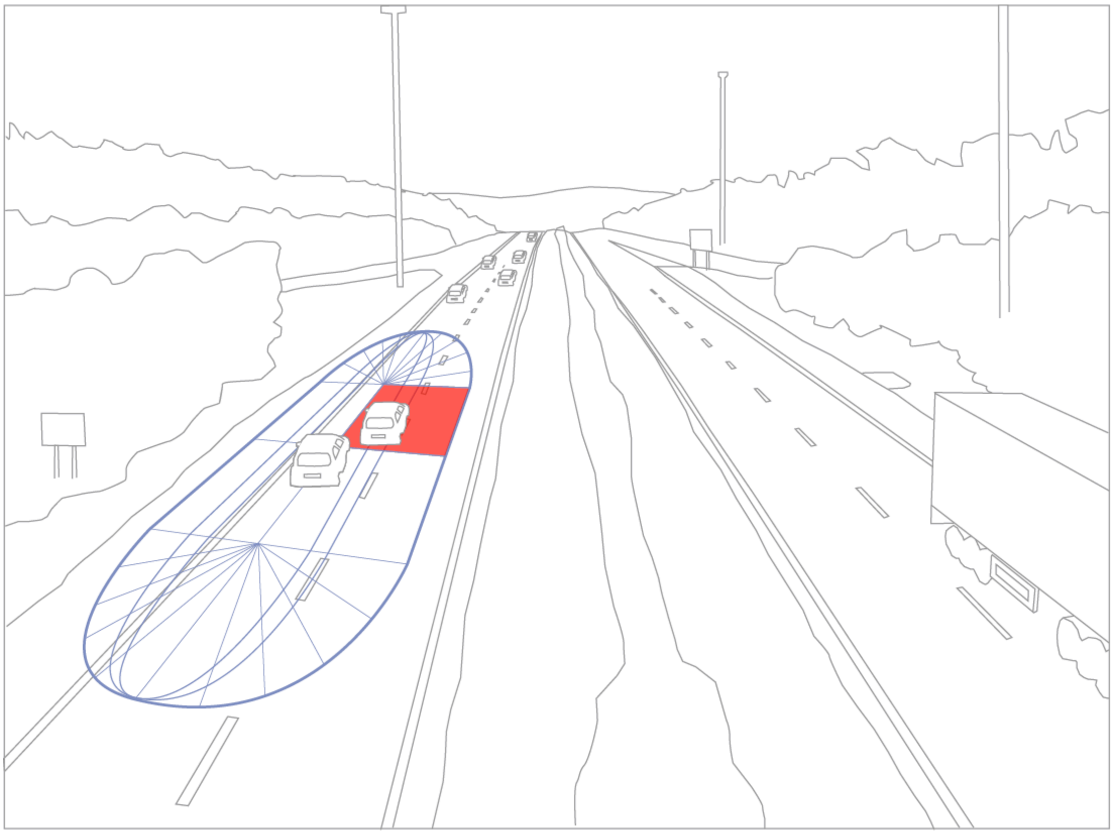


Figure 4-11 Illustration showing how system works 2

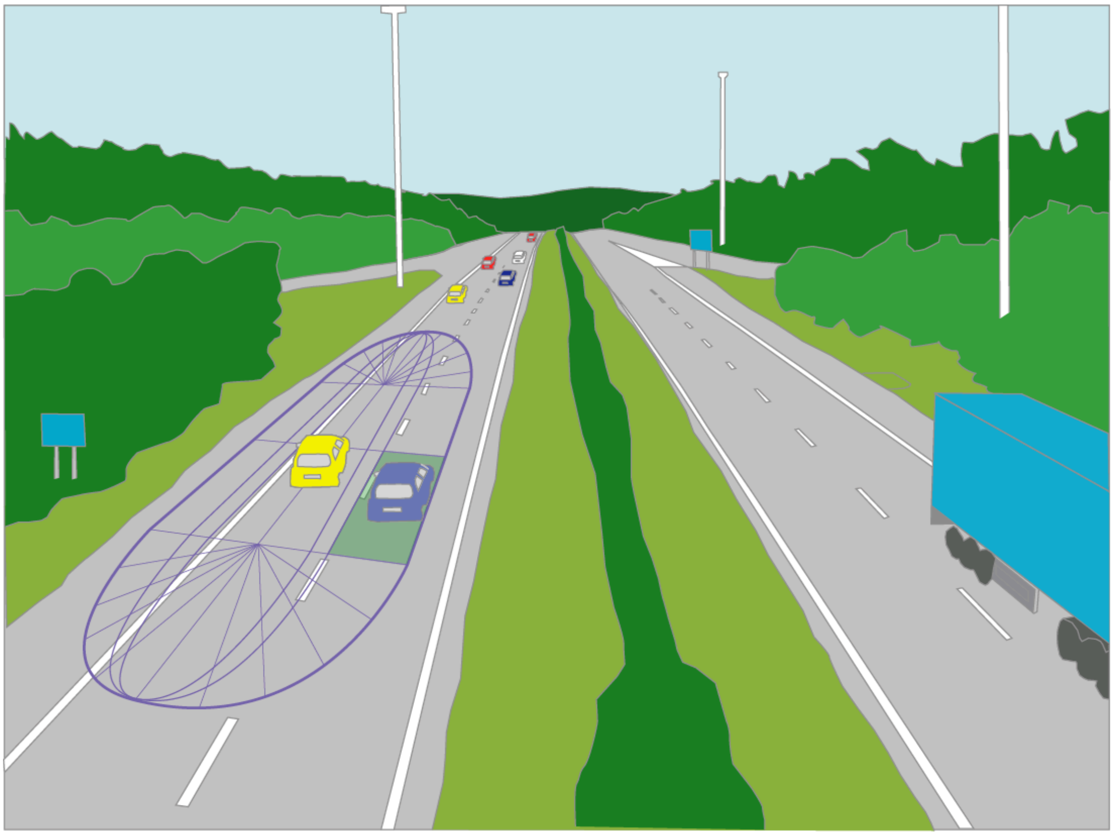


Figure 4-12 Illustration showing how system works 3

4.3.2 Further demonstration of the system

The system has been demonstrated graphically in 4.3.1. In order to demonstrate the system in a dynamic situation where the sound can be heard a Macromedia Flash presentation has been developed.

The presentation was developed to summarise the project and to convey it in a viva situation. The presentation shows the system working compared to a birds eye view; allows the user to listen to the sounds tested; lets the user try the pre-trial software and can see the display as it would look in the car. Screen shots of the presentation can be found in the appendix of this document.

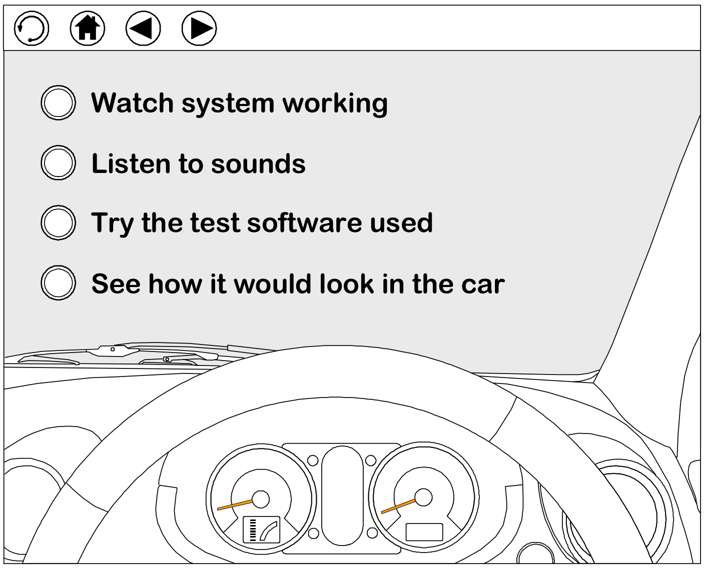


Figure 4-13 Flash presentation title screen

There is a CD Rom in the back of this document containing the interactive presentation. The CD also includes the following

- Assignment 1 pdf
- Assignment 2 pdf
- Assignment 3 pdf
- Hand book pdf
- Movie of participant taking part in the trial (shot from inside the car)
- Movie of participant taking part in the trial (shot from outside the car)
- Programs used in the pre-trial
- Programs used in the main trial

Figure 4-14 CD Rom containing additional material

In order to summarise the operation of the system a user guide was developed. The guide covers the purpose of the display, how it works and how to interpret it. As well as being tucked in the back of this document (Appendix F) the pages of this display are also included in the appendix of this document (appendix B).

Figure 4-15 Situational display user guide

4.4 Symbol design

As discussed in the literature review there may be times where the system would need to be disabled. These situations would include, during road works when cars are driving unusually close where numerous false alarms would occur. As with other similar safety features (traction control, adaptive cruise control) a switch needs to be included that allows the driver to temporarily disengage the system. The switch would be included in the switch clusters in the instrument panel (Figure 4-16).

Figure 4-16 Example of symbol for switch to disable system (in situ)

The introduction of a switch that enables a driver to disable a safety feature needs to be carefully considered. It has already been identified that there may be times where in traffic where a number of false alarms could become annoying. The ability to disengage the system may also help in acceptance. Drivers may be more likely to try the system knowing that they can disengage it if they cannot cope with it. There are a number of other safety features within the car that have on/off switches such as traction control. The ability to disengage safety features is something that is part of human nature and extremely important as consumers like to feel that they have the choice to use these systems and that they are not prescribed to them. The American market is an extreme case of this where there is a huge market in post manufacture fitting of switches to disable safety features such as airbags.

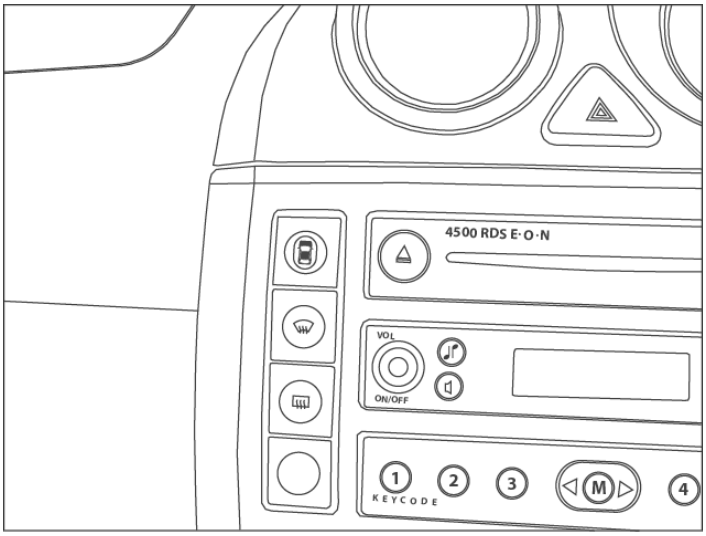
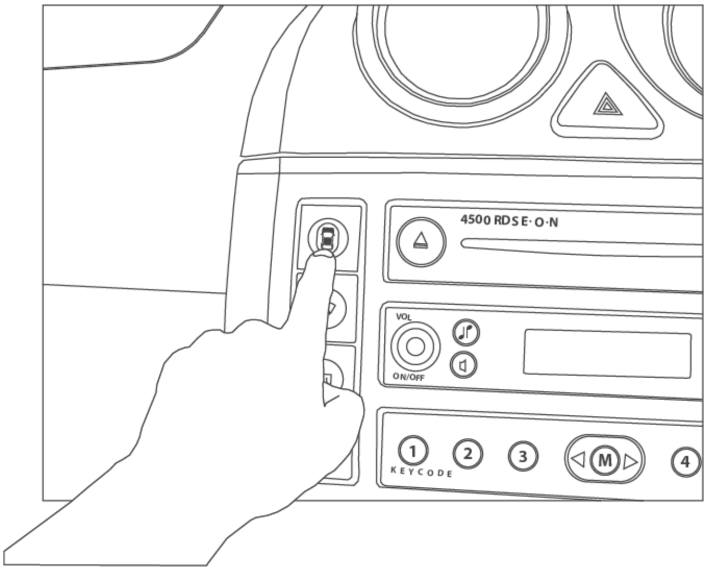


Figure 4-17 Example of symbol for switch to disable system (in situ)

By placing the switch in the instrument panel, a testing function can also be included. The auditory alarm can be tested by pressing and holding down the system activation switch for 5 or more seconds.



This function allows each of the drivers of the vehicle to test the system and hear the sound so that they can familiarise themselves with the sound generated as a warning for unsafe vehicles.

4.4.1 Switch proposals

A number of switch graphics were generated, for proportion and clarity existing switches were investigated. Figure 4-18 shows a switch from a 2003 Ford Fiesta (B257).

Figure 4-18 existing switch

A number of graphical solutions were developed for an international market. The displays were designed to be distinguishable from other icons in the car and selected so that they would not infer another meaning.

Figure 4-19 Graphical examples of on/off switch

"Graphical displays with the aim of transferring meaning"

Another way of informing the driver of the purpose of the button is to use the system initials. The problem with this is that it is not as good at building a mental model. It also does not translate as well internationally. However it is already used in a number of cars for newer applications that are harder to display graphically. Examples of this include traction control (TC) and anti-lock breaks (ABS).

Figure 4-20 Collision warning system

"Acronym as used in ABS and TC"

After investigation and by gathering feedback from the participants who conducted the trial it was decided that the most appropriate symbol for the switch was the one that most closely resembled the on screen image. The division lines were not included as it was felt that they overcomplicated the symbol. The use of the letters was considered too confusing as the acronym was at this time unfamiliar.

Figure 4-21 Most suitable switch symbol design

The switch can also be seen in situ in Figure 4-16.

4.5 Conclusion

This chapter has shown the development of the final idea and explained how the auditory and pictorial display would work together.

5 General discussion

The first document in this series of documents tracked the development of this system from its first concept, through the exploration of the problem, into research around the field.

The second document in the series then focused on the development of initial solutions based upon this initial research. The initial solutions generated were evaluated against a number of participants through three stages of experimentation. The second document tracks the design and development of these experiments detailing the method, the document also reports back on the findings of the first stage of testing.

This, the final document in the series has detailed the findings of the testing along with discussion, development and synthesis of the final idea.

5.1 Introduction

This chapter aims to discuss the findings of the project and evaluate how the objectives have been met.

Both the literature review and the results have highlighted the importance of the appropriateness of the warning ands its importance to be rapidly interpreted. When the distanced travelled in elapsed time is considered the importance of being able to react to a warning can really be seen. If a car is considered to be travelling at 70mph it is covering its own length every 0.13 seconds. (Based on a Ford Focus)

"A car travelling at 70mph covering its own length every 0.13 seconds"

For convenience the aims and objectives stated in the first document have been repeated.

5.1.1 Aim

The aim of the project is to design and develop a system of feedback to inform drivers of the position of object that could possess a potential treat to the safety of the driver. The design process will evaluate single and multi modal characteristics of feedback to improve the drivers' situational awareness as well as inform the driver of impending collisions resulting from lane departure.

5.1.2 Objectives

- To ascertain the most effective way of communicating to the driver an imminent lateral collision.
- To ascertain the most effective way of communicating to the driver the unintentional departure from the lane.
- To ascertain the most effective method of communicating information about the location of objects in the vicinity of the vehicle for monitoring purposes.
- To evaluate a number of combinations of feedback methods to collect data to prove the final choice of feedback method.
- To investigate the user acceptance and the cognitive workload a situation awareness system would place on the driver.

It is clear that the generated solution has met the aim; the display clearly shows objects of potential harm. The iterative process conducted looked at each of the senses that the human body is capable of and investigated each of the feasible alternatives. Multimodal feedback was also considered. Based on the literature review it seemed appropriate that two modes be used, reserving the auditory mode for high danger situations, and thus taking in an urgency inference.

From reviewing the objectives it is also clear that all have been met. By a process of experimentation and by thorough literary research it can be seen that the selected method is the most optimum way of feeding back information when assessed against the PDS set in the first report

The system developed is not a lane departure warning system. Therefore the act of unintended (this is determined by the fact the indicator was not used) lane departure is not communicated if the lane change is safe. By definition if the lane departure is safe it is not necessary to inform the driver. If the driver attempts to depart the lane when the lane is occupied a warning would be generated. This decision reduces the number of false alarms delivered to the driver. This in turn increases the driver's acceptance, by only sending auditory warning at points of significant danger the driver knows that when the alarm is signalled corrective action is required.

"Safe unintentional lane departures are not warned against"

The communication of the location of objects has been selected so that it meets the PDS in the first report. Particular attention has been placed on the systems ability to generate a mental model. The synthesis of the display in section 4.1 also addresses the ability of the driver to rapidly scan and interpret the meaning of the display.

The results and experimental design section of this document have detailed the evaluation of a number of warnings presented in a number of modes. The issue of cross modal interaction has been thoroughly examined to ensure its compatibility.

The user acceptance of the displays has been thoroughly investigated. The cognitive workload taken by monitoring the display was inferred by both the driver acceptance rate and the driver's ability to react to the display.

5.2 Comparison of the system against Lane departure systems

This sections aims to look at the differences between the collision warning system (CWS) proposed in this document and the camera based lane departure warning systems (LDW) explored in literature review that are currently on the market.

Table 8-2 shows a number of situations pictorially and comments as to whether an auditory warning would be generated. The grey car represents the car fitted with the system. The red car represents another vehicle. Each of the common situations is presented in turn; a tick indicates that a warning would be presented; a cross indicated that a warning would not be presented. These ticks and crosses are coloured green if the response is desirable and red if undesirable.

It can be clearly seen in Table 8-2 that the existing lane tracking systems are presenting undesirable warnings in three of the six situations. The LDW system does not allow the driver to make safe unintended lane changes. This leads to a massive increase in false alarms and an increase in customer dissatisfaction. More worryingly the system does not send a warning if the driver indicates and enters an occupied lane it can be seen in section 8.1.1 that this is the most common road accident for vehicles travelling in the same direction according to the NHTSA. The LDW warning also fails to send a warning if another vehicle enters the lane occupied by the driver. This is because the system purely tracks the lane markings and is unaware of the movements of other road vehicles and obstacles.

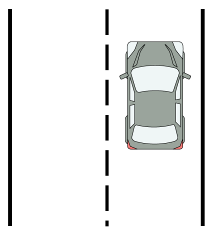
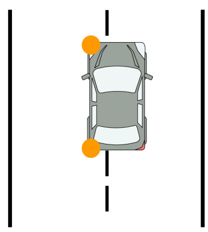
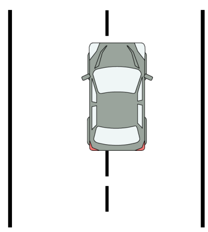
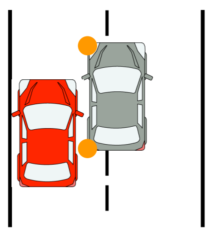
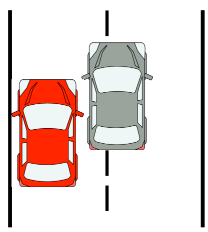
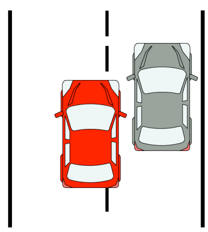
Situation	Description	CWS	LDW
	Driver in lane safely moving down road alone.	✗	✗
	Driver moving down road alone. Departing lane indicating	✗	✗
	Driver moving down road alone. Departing lane NOT indicating	✗	✓
	Driver departing lane into occupied lane. Indicating	✓	✗
	Driver departing lane into occupied lane. NOT indicating	✓	✓
	Driver in lane Other vehicle entering drivers lane	✓	✗

Table 5-1 States where auditory warnings may be presented

"Comparison of proposed system against conventional Lane departure warning systems."

6 Conclusions & areas for future research

6.1 Conclusion

The literature review for this document has shown that the issue of feedback in the demanding and varied task of driving is very complex. It has been shown that if the feedback is delivered incorrectly it may result in detrimental effects.

The literature review also demonstrated the great potential of a product both in saving lives and commercially, it is clear that two of the most significant factors affecting road accidents are poor situational awareness and driver distraction. This project has focused on both of these key areas and has followed through a structured process in order to propose a solution that will reduce the effect and implications of both of these key areas.

The final solution generated is supported by the results of the main trial. The selection has followed a clearly defined iterative process that has considered participant feedback at each of the key stages. The final solution has been build upon the extensive literature review covering the investigation by others in and around the field. The final deliverable of this project is a justifiable solution to the key issue of lateral collision avoidance and increased situation awareness.

"The selection has followed an iterative process considering participant feedback"

The final generated solution is unique and fundamentally different from lane departure warning systems. The majority of lane departure warning systems work using a camera to track the position of road markings. The system is disabled by the driver putting on their indicators; these systems are purely a warning for unintended lane departure. The system discussed in this document is fundamentally different as it also warns against intentional unsafe lane changes. By monitoring other drivers as apposed to the lane markings it also provides a warning of other drivers who move into the 'safe zone' of the car fitted with the system.

The system designed represents quite a significant leap in the way that we drive our cars. As cars have developed the driving task has changed more and more, the introduction of features such as power steering have allowed drivers easier control of the car particularly in parking, they also have the benefit of allowing drivers with limited strength to drive. The downside of these kinds of features is that they detach the driver from the mechanism; reducing the tactile feedback to the driver and thus significantly changing the task of driving. Looking forward at what is happening in the industry it is clear that x-by-wire is the way that most manufacturers are heading. The next step in steering advancement is a move to steer-by-wire technology to completely remove the physical connection with the steering. This has a number of clear benefits in crash worthiness and developing left and right hand drive derivatives of models. However by detaching the mechanism, the ability to naturally transmit feedback is also removed; this means that only simulated feedback will be available to the driver from the steering. As more and more of the functions within the car are automated the task of driving is moving away from a mechanical task to more of a task of vigilance and response to computer instigated feedback. Stanton and Marsden (1996) state that one of the main benefits of vehicle automation is the reduction of human error. It is clear from the literature review that human error is the main cause for accidents and therefore a step towards automation moves to reduce the frequency of accident. The discussion of vehicle automation can be found in section 8.1

The act of constantly monitoring the display has advantages when Stanton (2003) malleable attention resource theory is considered. Stanton's (2003) theory suggests that when a driver is required to go from a very low cognitive load task to a high cognitive load task it takes a significant amount of time. Stanton's theory indicates that if the cognitive load at its low level is increased the transition to the high level cognitive task is much quicker. The method selected to carry out this constant monitoring is the head up display for its advantages in focal distance change. The head up display has already demonstrated its worth in the aerospace industry and it is feasible to assume that this system could work well in the automotive world. The advantage that the aerospace industry has is that the pilots are trained to a higher level and receive continual training. It is therefore easier to introduce new technology into the cockpit.

The acceptance of the system is a complex issue it is understood that this technology and way of driving the car proposes a significant change. It is clear from human nature that change is often slow in its acceptance. This proposed solution may therefore have to be introduced in stages or introduced into the market through a niche product aimed at a population group that has high acceptance for new technology.

In a similar study Bishop and Jackson (2001) state that, while only 43% of the drivers surveyed would purchase an ACC (adaptive cruise control) system, 98% of drivers who actually drove with an ACC said they would purchase the system.

6.2 Areas for future research

As explained in the introduction to the first document this study was purely interested in the feedback method used. The ability of this system to sense and process information about the system was considered to be outside the remit of the project. It would be a very valuable study to investigate the ability of the system to work holistically by including the sensing and processing elements of the product. By completing the system full larger scale trials could be conducted to investigate the issue of driver acceptance further.

Further verification of the final choice in a real life situation would be essential. A follow up study could be conducted using a range of cars fitted with a prototype of the system. This could also be expanded to investigate the usage on a number of road types and environmental conditions.

The cognitive workload taken by monitoring the display was inferred by both the driver acceptance rate and the driver's ability to react to the display. In a larger study this cognitive workload could be investigated with the use of more complicated models.

For the remit of this study the number of factors investigated was limited to a minimum. It would be interesting to open up the scope of this project to investigate the performance differences between different demographic segments of the community and investigate factors such as the effect of driver age on the acceptance and effectiveness of the system. The area of driver inclusion has only been touched upon in this investigation and further investigation would be beneficial. Driver experience and skill would be another very interesting variable to somehow collate. From observations of drivers in the simulator it was clear that less confident drivers found it far more difficult to concentrate on the warning display and the driving task. It is the view of the author that the reason for this is due to the fact that the less confident drivers were using the majority of there cognitive ability maintaining the 70 mph speed and staying on the road and had very little cognitive reserve to monitor display. Drivers who were more experienced or had more exposure to the simulator environment found this task significantly easier.

The effects of cultural influences on driver acceptance would need to be investigated in such a product if its design were to be used globally. The literature that this report has been based on has been mainly sourced from the UK and USA with contributions from Japan and the rest of Europe. It can be seen from differing driving laws from county to country and by observing driving styles from around the world that there is a wide range of driving environments globally. Fay's (1997) figures for seatbelt usage show the regional variations in seatbelt usage. Countries such as Ireland, Belgium and Spain have much lower acceptance rates of seat belts. This level of reluctance could possibly be attributed to many factors including traffic density, type of roads and culture.

Country	**Driver Seat Belt Wearing Rate**
Ireland (1991)	52%
Belgium (1993)	54%
Spain (1995)	61%
USA (1995)	68%
Netherlands (1995)	70%
Sweden (1994)	89%
UK (1995)	91%
Germany (1995)	92%

Table 6-1 Seat belt usage

Table 6-1 highlights the wide range in acceptability of a particular safety feature globally. It is reasonable to deduce from this table that the acceptance of the system proposed in this report may also vary with regional demographics.

In this project the situation awareness display has been considered separately from existing longitudinal collision awareness feedback methods. An area for future research would be to look at a way of combining the solution developed in this project with the most suitable longitudinal collision warning from ACC (adaptive cruise control). The display selected already has a certain amount of this longitudinal element in it however this would need further development if the traditional ACC were to be replaced by this system.

7 References

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8 Appendix A - Additions to literature review

The following section contains information researched after the submission of the first part of the report that is required for an adequate understanding of the discussion and the decisions made in the development.

8.1 What are the implications of vehicle automation?

Vehicle automation is the act of taking some or all of the control from the driver and performing similar or replacement task automatically. Although by definition the system discussed in this report does not automate the vehicle, as it purely senses and feedbacks the data, many of the points covered in vehicle automation still apply

Stanton and Marsden (1996) introduce three main arguments in favour of vehicle automation.

1. Driving is an extremely stressful activity and alleviating this stress could lead to increased driver well being.
2. Human error constitutes the major cause or road accidents (Tamura et al 2001), thus it could be reasonably suggested that the removal of the human element from the control loop may ultimately lead to a reduction in accident statistics
3. Finally if priced adequately automation will enhance the desirability of the product and thus lead to a substantial increase in sales.

"Human error constitutes the major cause of road accidents"

It is clear that different arguments in the above list would appeal to different drivers. There is a section of the driving population that would benefit from the alleviation of the stress placed upon them from the road environment. It is also evident from looking at modern car instrument panels when compared to cars of 20 years ago the information content is much greater. It is therefore clear that the task of driving is changing.

An important consideration highlighted by Stanton and Young (1998) is that automation may, by removing tasks traditionally performed by the driver, leave the driver with fundamentally different tasks to perform.

Stanton and Young (1998) go on to highlight three main concerns with levels of driver automation.

“Automation may leave the driver with a fundamentally different task”

1. Drivers may become over reliant on upon the automated systems
2. Drivers will evoke the systems in situations beyond their original design parameters
3. Drivers may fail to appreciate that the system is behaving in a way that is contrary to their expectations.

8.1.1 When should the system be used?

The way in which current lane departure systems work is by the use of cameras to track the position of the road markings. When an unintended lane departure is detected the system enters an alarm state and the driver is sent a warning by the system. Current systems differentiate between intentional and unintentional lane departure by the use of the indicator. If the indicator is on as the driver makes the manoeuvre no warning is sent to the driver.

This current situation is ideal for motorway and ‘A-road’ driving the problem arises when drivers move onto single carriage way ‘B-roads’ and lower density ‘A-roads’. The system currently manufactured by Iteris does not function below 37mph to eliminate false alarms in residential areas. However certain driving conditions in rural ‘back roads’ mean that the driver could be legally driving at any speed up to 60mph and also using both lanes. In this situation the driver can elect to disable the system. This facility is provided on the Iteris system.

“Current systems to not warn against unsafe intentional lane departures”

The other clear disadvantage with the current system is that it does not inform drivers if they are entering an occupied lane. If they put on there indicator and carry out the manoeuvre no warning will be generated even if the lane is occupied.

An investigation was undertaken in the USA looking at accident data for vehicles travelling in the same direction by the national highway safety administration. Looking at the data it is clear that the most common collision is an intentional unsafe lane change. This is a startling fact when considered that this is not warned against by current systems.

Scenario	Description	Number	%
Lane change	Two vehicles are on parallel paths and one intentionally changes lanes and collides with other vehicle	207,000	38.4
Turn	Two vehicles are on parallel paths, at a road intersection, one vehicle turns across the path of another	89,000	16.4
Other	Relevant but unclassifiable accident	64,000	11.9
Drifting	Two vehicles on parallel paths but one drifts into another without any apparent reason	62,000	11.5
Pass and turn	Two vehicles on parallel paths with one turning at a junction and one passing	46,000	8.6
Passing	Two vehicles on parallel paths but one moves into the others lane to pass a third vehicle	27,000	5.0
Un-park	One vehicle leaves a parked position and hits (or is hit) another vehicle	25,000	4.7
Merging	One vehicle merges into the lane of another from a slip road	19,000	3.5
TOTAL		539,000	100

Table 8-1 Lane change accidents (NHTSA 1999)

“Intentional unsafe lane change the most common”

The accidents in this section can be attributed to a number of causes included; poor situational awareness, poor judgement, driver distraction, and misinterpretation of another drivers actions

The most frequent lane change accident involved the intentional change from one lane to another as illustrated in Figure 8-1. This is a very significant observation as these lane changes are not warned against by current lane departure warning systems as long as the indicator is used.

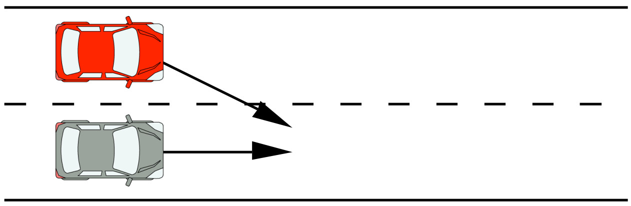

Figure 8-1 Intentional lane departure

The second most common lane change accident was caused by one vehicle crossing the path of another as illustrated in Figure 8-2. In this accident scenario, the driver of the offending vehicle (in red) either fails to notice the other vehicle or misjudges its speed. This may be a case of poor situational awareness or poor judgement.

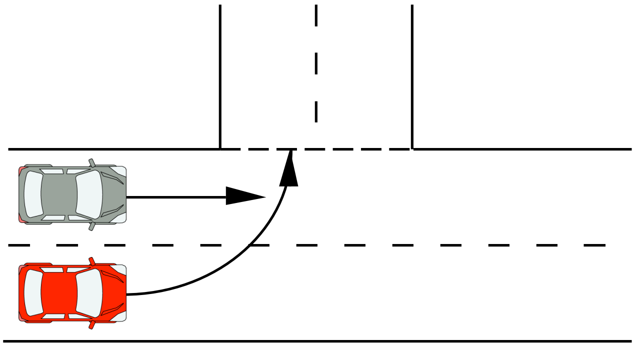

Figure 8-2 One vehicle crossing the path of another

The third most frequently reported lane change accident was caused by drifting of one or both of the vehicles into the others lane. This sort of accident can happen on curved as well as straight roads. An illustration of a drifting lane change is shown in Figure 8-3. Unlike the other scenarios, the drifting scenario is an unintentional lane change. Current systems warn against this only if the driver is the one departing the lane if another vehicle is departing no warning is given. The system discussed in this document would warn the driver of this on the visual display. An auditory tone is also included for the situations where distraction causes the driver to drift out of lane.

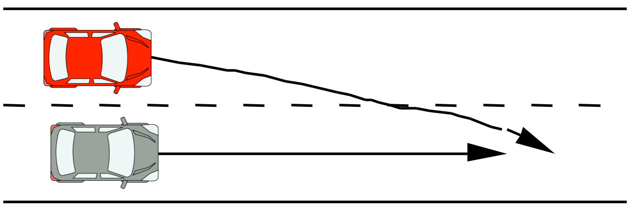

Figure 8-3 One vehicle drifting into the path of another vehicle

The forth most frequently reported cause of lane change accidents was that of one vehicle turning into the path of a passing vehicle, as illustrated in Figure 8-4. This type of accident suggests that the drivers may be unaware of the intentions of each other. This case is very hard to prevent. The driver's situation awareness can be very good and they can know where the other vehicles are. The problem in this case is that the intensions of the other driver have been misunderstood.

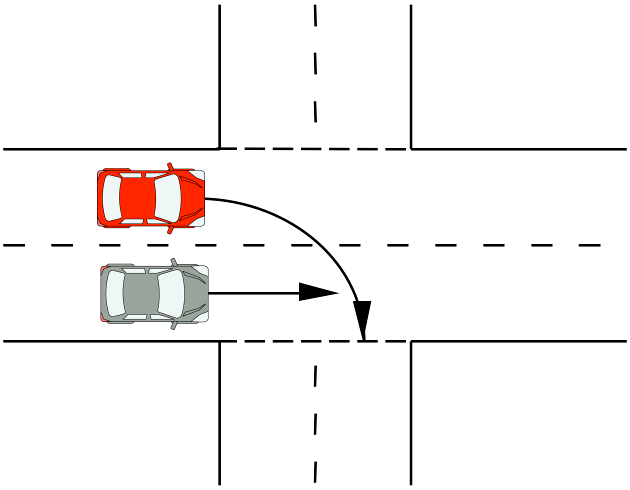

Figure 8-4 A vehicle crossing a passing vehicle at an intersection

The fifth type of lane change accident is when a driver moves into the path of another when attempting to overtake a vehicle. This is illustrated in Figure 8-5. This can be an example of poor situational awareness if the driver was unaware of the car occupying the lane. The other cause for this accident is poor judgement.

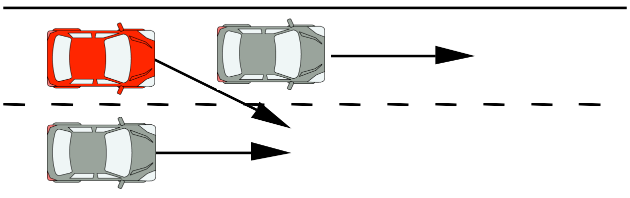

Figure 8-5 One vehicle moving into the path of a passing vehicle

The sixth, and penultimate, lane change incident is where a vehicle pulls out from a parking space and collides with another vehicle moving in the same direction. This is illustrated in Figure 8-6. Again this can be either attributed to poor situational awareness or to poor judgement.

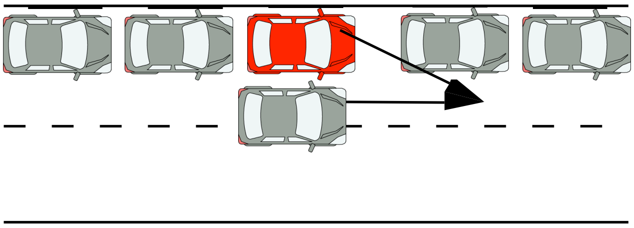

Figure 8-6 One vehicle moving into the path of another when moving out of a parking place

The final lane change incident to be considered and also the least common, is where a vehicle enters a highway from a slip road into the lane occupied by another vehicle, as shown in Figure 8-7. This merging scenario could occur on dual carriageways and motorways, or slip road on any carriageway, in the UK. Again this can be either attributed to poor situational awareness or to poor judgement.

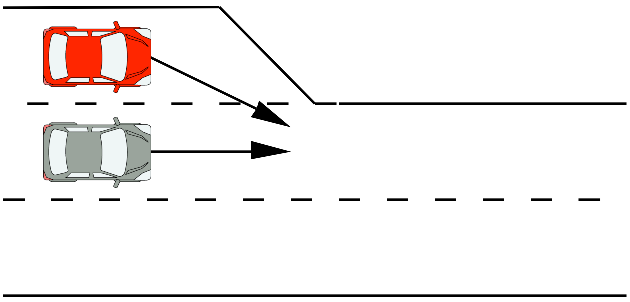

Figure 8-7 One vehicle moving into the path of another when joining the carriage way from a slip road

8.2 Psychological issues

Stanton & Young (1998) highlight the psychological issues pertinent to vehicle automation to help guide future empirical studies.

8.2.1 Locus of control

Stanton and Young (1998) describe the locus of control as determined by the extent to which the drivers attribute their own activities as responsible for the behaviour of the vehicle (an internal locus of control). An external locus of control is defined as being when the behaviour of the vehicle is down to the automated system.

It is suggested in other fields that people with an internal locus of control perform better than those with an external locus of control. In this case the system is only supplying information and control of the vehicle is not affected therefore the locus on control is not an issue.

8.2.2 Trust

There is little written on trust in machines. Muir (1994) likens the trust to a machine to her research on trust in humans. She identifies three key factors.

1. Predictability
2. Dependability
3. Faith

"Predictability leads to dependability which leads to faith"

Dependability is based upon predictability which leads to a leap of faith

This links back to the concept of locus of control if a driver feels completely detached from the system and unable to predict how the system will react in a situation then they will not feel confident depending on the system and in turn will not trust it.

8.2.3 Situation awareness

Situation awareness is being aware of what is happening to the system even though it is in automation. Endsley (1995) defines it as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Stanton and Young (1998) state that separation of the perceived machine state from the actual machine state leads to operational problems. Nilsson (1995) highlights that if the situation awareness is not high enough the driver may not be able to intervene when required. The drivers level of situation awareness can sometimes be increased if the feedback method is somehow designed to create a mental image of how the product works. The aim of this system is to increase situational awareness by supplying suitable feedback method.

"Situational awareness can be increased through feedback"

According to Endsley (1995) Situation awareness can be broken down into three facets that may be important to drivers: mode awareness, space awareness and time awareness.

In this case mode awareness simply tells us that the system is currently running and functioning properly. Spatial awareness refers to the awareness of the driver to the position of their vehicle relative to other vehicles and the road infrastructure. Time awareness refers to the awareness of the driver to trajectories and time-to-contact of vehicles. Stanton et al (2003) state that, the dynamic nature of SA (situation awareness) and driving means that these three types of awareness need constant updating and integration for successful task performance.

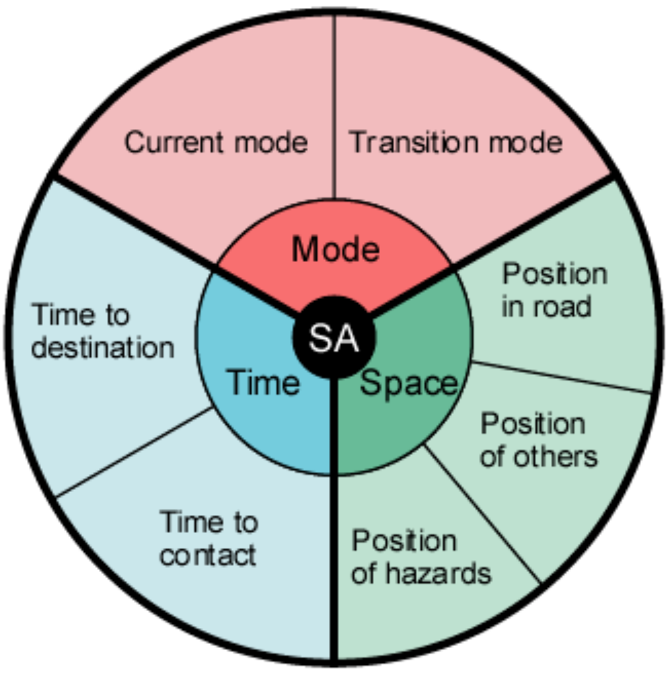

Figure 8-8 Typology of situation awareness (Reproduced from Stanton et al 2003)

Figure 8-8 shows a pictorial representation of the concept of situation awareness. The diagram was originally constructed for a stop & go adaptive cruise control system; however the idea can still be used for lateral collision warning and lane departure warning systems.

8.2.4 Field of safe travel

The field of safe travel is a fundamental concept developed by Gibson & Crooks in 1938

Gibson & Crooks (1938) describe the field of safe travel as a sort of tongue protruding forward along the road. Its boundaries are chiefly determined by objects or features of the terrain with a negative 'valence' in perception

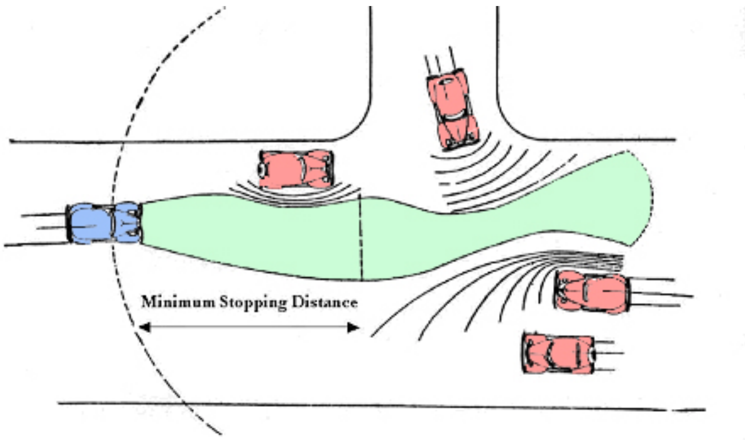

Figure 8-9 Diagram showing illustration of the field of safe travel. (Adapted from Gibson & Crooks, 1938)

"A car is thought of as a tool of locomotion; the problem of driving it is essentially learning to proceed to a destination without colliding with obstacles in the path. Facing the driver is a "field of safe travel"; his problem is to judge the size of this field and to progress down the middle of it. The objects in this field have valences, positive or negative. Deceleration or stopping is called for when there are obstacles which reduce the size of the field of safe travel. The factors which limit the size of this field are natural (ditches), inflexibility at high speeds, obstacles and their "clearance" lines, moving obstacles, potential obstacles (barriers to sight which may conceal obstacles), and legal taboos. Besides the field of driving, two other fields must be considered: the field of the other driver and the field of the car. The field of the car includes kinaesthetic and tactual cues brought to the driver through the car itself, e.g., the "feeling" that the road is slippery. It is suggested that positive instruction in the principles that make certain driving practices dangerous for psychological reasons, instead of admonition or punishment, will lead to a reduction of accidents." (Gibson & Crooks, 1938)

8.2.5 Mental representations

When a person uses a product they create in there mind an image of how it works in order to predict the responses of the machine. These images are called mental models. The accuracy of these mental models can have a large effect on the subject's ability to use the product effectively. It is therefore very important that in order to respond to situations in a rapid manor the correct mental model is supplied to the driver. The model formed by the driver can be influenced by the design of the product. By designing the product well, an accurate a precise mental model can be formed.

"Correct mental models can be introduced through design"

8.2.6 Feedback

The general way in which automation works is by taking away the task of control from the driver (see section 8.1). Possible problems can result from the introduction of automation. When a task is replaced the task is in effect replaced by the task of vigilance which Stanton &Young (1998) state humans can be considered to be poor at.

Norman (1990) comments that it is the role of the feedback method to improve the drivers ability to conduct the vigilance task. He suggests that the problem with automation is that it does not communicate its status to the driver, which would help the driver to remain in the control loop. Therefore feedback from the automated system is required to keep the driver up to date.

Walker et al (2001) investigated the implications of the amount of feedback from the car. The study was broken down into high feedback sports cars and lower feedback cheaper mass production cars. The results showed that drivers of the high feedback cars rated themselves as being under a lesser workload than the drivers of the low feedback cars. Walker et al (2001) attribute this higher level of workload in the lower feedback cars to a number of reasons. It could be due to the more difficult task needed to receive feedback from other methods. Another reason stems from the fact that the drivers have less feedback and therefore less situational awareness this could lead to the drivers finding themselves in more stressful road and traffic situations. The final reason given by Walker et al (2001) is that due to the safety critical and time dependant nature of driving poor situational awareness in itself is perceived by drivers in the form of driver stress or anxiety, thus implicating on mental workload. It was also noted that the drivers of the high feedback cars were more aware of their environment than their lower feedback counterparts.

"Poor situational awareness is perceived by the driver in the form of driver stress or anxiety"

An interesting observation from Walker et al (2001) study was that drivers of the lower feedback vehicles spent more time looking at the instrument cluster than the drivers of the high feedback cars (which also contained more information in the cluster). Walker et al (2001) attribute this to fact that with fewer implicit and multimodal feedback cues being provided by the low-feedback vehicle, drivers may have to search for relevant information themselves. This leads to the driver becoming more remote, not only from the device that they are controlling but from the environment in which they are controlling it

8.2.7 Stress

One of the main causes of stress can be as a result of mental underload and lack of mental stimuli. Matthews at al (1996) report that when the driving task is relatively difficult fatigued drivers perform significantly better than when the driving task is easy. This further supports the comments made that the driving task should be changed to increase the driver's situation awareness. Walker (2003) agrees with this view and comments that Poor situational awareness is perceived by the driver in the form of driver stress or anxiety (see section 8.2.6).

8.3 What is the effect of different driving styles?

It is very important to consider that people drive a wide range of vehicles for a range of purposes and that this in turn effects the way in which they drive and handle a range of situations Batavia (1999) showed by monitoring the lateral position of drivers that he could classify then as tight or loose drivers. The "loose" driver has a larger spread in lateral position than the "tight" driver, indicating that the "loose" driver weaves more than the "tight" driver.

Some people hug one side of the road, as if afraid of getting brushed by traffic on the other side. Others, it seems, sometimes straddle two lanes. Some of these behaviours, such as the tendency to hug one side of the road and corner-cutting, are safe expressions of personal preference. Other behaviours, such as straddling two lanes or weaving wildly, can be unsafe. (Batavia 1999).

“Some drivers may be more prone to cutting corners”

The density of traffic on the road also affects the way in which we drive, at night when the roads are less populated some drivers may adapt their driving from a tight following pattern to a looser one and may even use more than one lane to cut corners.

These driving styles can make it very difficult to design a system that determines a safe or unsafe situation. This is another problem with the current lane tracking systems. For some drivers a lane departure would mean that they had lost concentration and were driving abnormally, for other drivers it may just be their driving style to cut corners.

8.4 Could the system do more harm than good?

It is very important that the addition of the situational awareness system does not in solving one problem create others. The topic of mental loading has already been discussed in the first document. According to one truck manufacturer, drivers report that ACC reduces their stress on the roadway by reducing the number of tasks the driver has to attend to at any one time. ACC allows drivers to focus on the task of lane-keeping and to pay more attention to the traffic around them while devoting less attention to speed control (Bishop and Jackson 2001). This view is questioned by Young & Stanton’s (2002) theory that excessively low mental demands can actually be detrimental to performance. What seems to be important is that the system while alleviating the task from the driver the system still keeps the driver in the loop and provides sufficient feedback to keep the driver occupied and allow the driver to build a mental model of what is happening.

“The system must keep the driver in the loop so that they can build a mental model”

Another key issue that could lead to detrimental results is the hypothesis that by improving the safety of a car you in turn allow the driver to take greater risks. Stanton (2003) states that there is some general concern in the Human Factors literature that drivers may adapt their behaviour in response to new technologies, and that these adaptations may have negative, as well as positive, effects on safety. The main controversy is whether behavioural adaptation and behavioural compensation theories predict that drivers will negate safety benefits in their attempts to maintain a target level of risk (Wilde 1994; Stanton & Glendon, 1996). Burns (2000) studied ten driver's use of a forward collision avoidance system (which would intervene with braking if the vehicle was travelling too fast), with lane support (which would present warning messages), over five days and the effects on their driving behaviour in a simulator. He found that drivers using the system were better at lane keeping and maintaining safe driving speeds when comparing the results to those drivers who did not have the system. The adaptation effects observed by Burns were that the drivers tended to change their driving to avoid the onset of the warnings. Thus the system appeared to have a positive effect on safety

"Collision avoidance systems can train drivers to drive safely"

8.5 When should a warning be initiated?

It has already been identified in section 8.1.1 that there are times when the driver may wish to disengage the system. The main reason for this desire is when the system is sending an unacceptable amount of false alarms usually because of the road type and situation. It is important that the ability to disengage system is supplied for situations such as road works where lane markings are confused or cars are driving extra close to each other, however it should not be designed so that a significant part of the population select to disengage the system all the time.

"The system should be designed so that drivers do not choose to disengage it"

In order to stop people disengaging the system and to increase acceptance it is important that the system only sends a warning for dangerous situations and not for safe intended lane departure. Batavia (1999) goes further and makes that statement that; ideally, warnings would only be triggered in situations that would unequivocally lead to a crash if corrective action is not immediately taken. In other words, a warning should be triggered at time *T*, where:

"An auditory warning should only be delivered when a crash is imminent"

- A warning any later than time *T* would definitely be too late to prevent a crash.
- A warning at time *T* results in the driver successfully avoiding a crash.
- Any crash which is prevented by warning earlier than time *T* could also be prevented by a later

warning. The last possible warning time is preferable to limit nuisance alarms.

Actually reaching time *T* is quite rare, as in most cases, drivers take corrective action well before *T*. Because it is impossible to determine *T*, and the fact that this value changes from driver to driver, drivers need to be warned earlier, to ensure they have enough warning time to react to the situation and avoid a crash. (Batavia 1999)

Clarke et al (2003) found that in general, subjects would like better an "early" warning. Twenty-two subjects (nearly 80%) preferred this "early" timing. A "late" warning was favoured only by 7 subjects.

Batavia (1999) goes on to classify six types of warning alarm that are described below.

- **Safe True Alarm:** An alarm triggered in time to prevent a situation where the driver, in hindsight, recognizes that his actions could have resulted in a crash.
- **Late True Alarm:** An alarm triggered before a crash, but too late for the driver to take corrective action.
- **Safe Nuisance Alarm:** An alarm which triggers in a situation where the driver, in hindsight, does not believe that his actions could have resulted in an ROR crash. Besides the alarm itself, there is no other consequence.
- **Unsafe Nuisance Alarm:** An alarm which triggers in a situation where the driver, in hindsight, does not believe that his actions could have resulted in an ROR crash. In this case, the alarm causes a reaction in the driver which leads to a crash.
- **False Negative:** A situation in which the driver, in hindsight, recognizes that his actions could have resulted in an ROR crash, yet no alarm triggered.
- **True Negative:** A situation in which the driver, in hindsight, does not believe his actions would result in an ROR crash, and no alarm triggered. This is by far the most common outcome.

These six types of warning can be better understood when placed into the following matrix. What is important to understand is that the driver may be subconsciously reacting to important alarms that may have led to an accident and as the reaction is subconscious the driver may believe the alarm to be a nuisance alarm. The matrix below defines a nuisance alarm from the driver's hindsight belief and does not account for the subconscious reaction.

	No Warning	**Warning**
Lane Departure	Miss	Hit
No Lane Departure	Correct response	Fair

Table 8-2 Classification of possible states

Stanton (2003) comments that the issue of driver acceptance of collision avoidance systems is hardly ever mentioned in the Human Factors research, perhaps because the idea of safety enhancement is beyond reproach.

It is important that the system does not send an alarm for indented departure for this reason it is important that the alarm is automatically cancelled when the indicator in activated. Pohl & Ekmark (2003) comment that when the system sounds when overtaking without using the indicator or curve cutting the system is regarded as over patronising and consequently annoying.

8.6 Design for inclusion

Design for inclusion is another important consideration. It would be ideal if the developed system was usable by the widest range of the population possible. The demand to consider the visually impaired is not significant in this case as any driver that is unable to correct there poor vision beyond the DVLA test is excluded from driving. There are however a significant number of deaf and auditory impaired drivers on our roads and a purely auditory response would need to be converted by some after marker devise adding cost and inconvenience to the driver.

"The system should ideally be designed so that it can be used by deaf drivers"

The level of physical mobility in the drivers ranges dramatically on British roads. The current law stands that any driver can hold a driving licence if they can demonstrate there ability to safely control the car. As the adaptation industry has grown along with drive by wire technology it is now possible for drivers with very little motability in there body and only the ability to move one hand to drive. Although it may not be possible to include this extreme into a product, it should be considered that there are many drivers on the road with a wide range of level of adaptation to their vehicle.

8.7 Summary

This chapter has covered each of the key topics covered after the submission of the initial literature review. This section has focused more on the possible acceptance of the proposed system and has looked more closely at how mental models are formed.