BRIDGE STRIKE REDUCTION: THE DESIGN AND EVALUATION OF VISUAL WARNINGS

By

Timothy John Horberry

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Abstract

The aim of this investigation was to consider the problem of road vehicles that strike rail-over-road bridges and how such incidents can be reduced. In particular, it examined the design of both the warning markings placed on bridges and the road signs situated some distance in front of the bridge, each warning of reduced clearances ahead.

Initially, a literature review was conducted to reveal the nature of the problem, including the history of bridge strikes, previous attempts to quantify why bridges are hit, the cost of strikes, countermeasures to prevent them and the legal restrictions relevant to the area. It was concluded that no single countermeasure had been found to be effective when the cost and the legal restrictions were taken into account.

A field assessment of possible causal factors was performed in order to compare a group of bridges that had been frequently struck, against a group of control bridges. It was found that frequently struck bridges generally were in busier environments (as might be expected), and in more visually complex environments where there were, on average, more advertisements nearby - thus more potential distractions were present at these sites.

The research then considered what drivers look at when driving towards low bridges, specifically focusing on the amount of visual attention given to warning signs prior to a low bridge, and on the specific areas drivers look at in the final few seconds before reaching the bridge. It was found that the bridge warning signs and bridge markings performed badly on measures of visual attention. In addition, if an advertisement was placed on the top section of a bridge, this was looked at for a large proportion of the time – thus reducing the proportion of time which the drivers gave to other features of the environment.

The development and evaluation of alternative bridge warning signs was then considered. Newly created and existing signs were evaluated on tests of comprehension and hazard perception. The results demonstrated that text-based versions of the warning sign with a yellow border performed best.

The development and evaluation of markings for low bridges were then examined by evaluating newly created and existing markings. The research focussed on their capacity to make a bridge appear lower than it really was - so influencing drivers' judgement of height when they approach such a bridge. The current low bridge marking standard achieved inferior scores on the experimental measures employed when compared to several of the alternative bridge marking designs that were developed.

Finally, the investigation examined driver responses to both the bridge signs and markings. Using a virtual reality road scene, an experiment was performed which assessed if the existing and modified designs of the signs and markings identified earlier had any behavioural effects upon drivers as they approached the 'virtual' bridges. The addition of warning signs before the bridge was found to have no significant influence on subjects' decisions regarding stopping before the bridge. However, the type of markings displayed on the bridge did significantly affect their responses.

Acknowledgements

I would like to thank and recognise the help of my supervisors Professor A.G. Gale and Dr. L. Ball from the University of Derby, and Mr. B. McGrane from Railtrack. For reading and critically commenting on the thesis I acknowledge Professor Russell Beck. In addition, I am grateful to the following people who gave me specialised technical input: F. Bolarin (for designed the initial version of virtual road scene for Chapter 7), N. Douglas (for helping to create the stimuli for the first experiment in Chapter 5), J.N.V. Miles (for performing part of the statistical analysis for the first experiment in Chapter 5), C. Owen (for writing the 'authorware' programme for the first experiment in Chapter 5), K. Purdy (for helping to set up experiments for Chapters 4,5, 6 and 7, and for checking the eye movement analysis in Chapter 4) and N. Williams (for helping to create the animated road scene for the first experiment in Chapter 6). Finally, I thank Rebecca Morris and the members of the AVRU for their ideas and support.

The general topic of research originated with British Rail / Railtrack. This gave rise to a series of research contracts with the University of Derby from 1994 -1997. Another researcher, Mark Halliday, (formerly of British Rail, now an independent consultant) and myself jointly undertook these contracts, they are described in Chapters 3, 5 and 6 of the thesis. For the contracts, we jointly planned the overall nature of the research, carried out the experiments and wrote up the results. However, our roles differed in that Mark Halliday project managed the work (mainly in terms of budgets, and project milestones) and I undertook more of the academic component (in the form of designing the specific experiments and writing the results for academic conferences).

The remainder of the research contained in this thesis was carried out entirely by myself.

Tim Horberry, December 1998.

Notes

1. The Department of Transport has recently become part of the Department of the Environment Transport and the Regions. In this thesis, however, it will always be abbreviated to 'DoT'.

2. For this entire thesis railway bridges crossing over roads (rail-over-road bridges) will be referred to simply as 'bridges'. Where other types of bridges are discussed they will be defined fully (e.g. a bridge with a road over another road will be specifically referred to as a 'road-over-road' bridge).

3. As bridge heights are currently displayed in Imperial units of measurement (occasionally their Metric equivalents are also displayed), this thesis will employ miles, yards, feet and inches rather than metres as the standard units of measurement.

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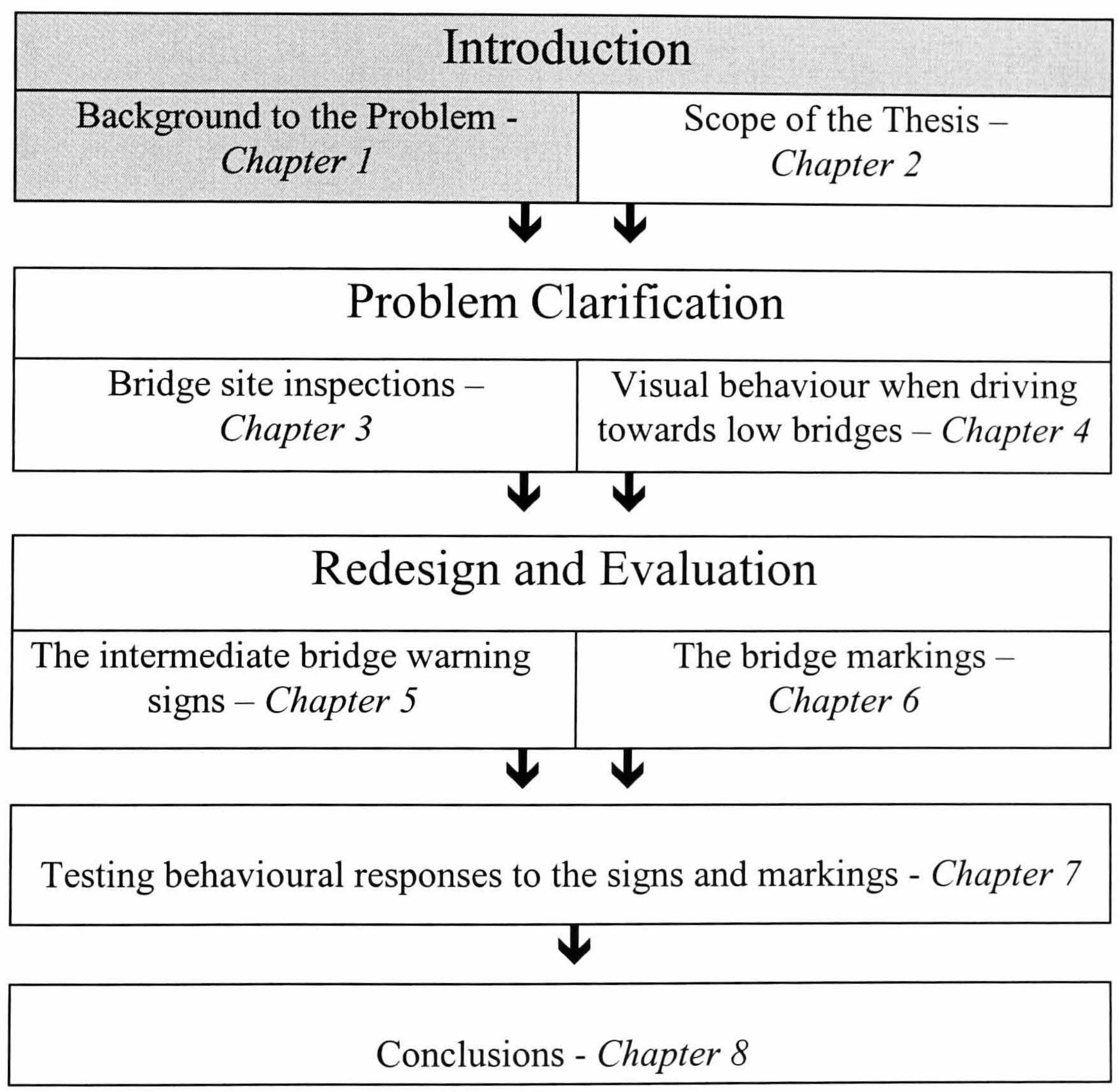
Background to Bridge Strikes



1.1 Introduction

The growth of both rail and road networks in the past 150 years has inevitably led to these two transport modes physically crossing each other. Of specific concern in this research are the instances where the rail lines cross over a road by means of a bridge. In some cases, road vehicles can be of such a height that they hit or strike the bridge above the road that carries the railway line.

In 1982 it was reported by the DoT that there were over 6,000 railway bridges crossing over roads in the UK. A later internal report for British Rail, however, puts the number nearer 10,000 (BR, 1993). Of these, 3,400 are considered 'at risk', due to their low height (i.e. below 16'6"). Subdividing this further, the types considered to be at most danger are those bridges with horizontal steel girder or concrete beams, because a disturbance to their structure can easily (in comparison to stone 'arch' bridges) displace the railway line above (DoT, 1988). Furthermore, 74 of the bridges 'at risk' are situated over trunk roads, thus being situated on major transport routes for which the local authorities are not directly responsible. Figure 1:1 shows a typical girder type bridge.

Figure 1.1: Example of a girder bridge

There is a wide range in the heights of bridges over roads. They vary from less than 6' to over 20'. As many of these were built in the last century, when bridge strikes by high-sided vehicles were almost non-existent, the average height of a bridge built then was between 13' and 15'. The current standard minimum height of bridges built today in the UK is 17'5", with all 'low' bridges (below 16'6") requiring signs warning of their height (DoT, 1982).

Concern about the number of high-sided road vehicles crashing into bridges rose significantly in the early 1970's, as the reported number of strikes grew (DoT, 1982). Between the early 1970's and the present day the number of strikes has greatly increased, from less than 300 reported cases a year to over 700 a year in the early 1990's (DoT, 1993a). Indeed, in 1993 and 1994 the number of reported strikes was almost 1,000 a year (McGrane, 1995, personal communication). Part of this rise can be explained by the tightening up of the reporting of bridge strikes in 1989 (DoT, 1993a). There is, however, a widespread belief by Railtrack bridge engineers (McGrane, 1995) that the current figure of almost 1,000 strikes per year is still an underestimate, as many minor strikes in more remote areas are simply not reported as the driver of the high-sided vehicle involved drives off to avoid possible prosecution.

The types of vehicles that strike bridges are quite varied, with bridges being struck in large numbers by cars, vans, skips and buses/coaches. The most likely vehicle to strike a bridge (where the type of vehicle has been assessed) is a lorry, with 58% of strikes belonging to this general 'lorry' category- although this probably includes other similar vehicles, e.g. tippers (DoT, 1993a). The main point to note here, however, is that it is not just lorries that hit bridges. For example, caravans, transit vans and small lorries can all be driven on a normal car licence and have all been involved in bridge strikes. In fact, anybody holding a normal car licence is legally able to drive a high-sided vehicle (i.e. high enough to hit the top of a low bridge).

Similarly, there is a wide range in the height of bridges reported as having been struck, with damage being reported on bridges as low as 5' to over 16' in height. The most common height of bridges that are struck are those with a clearance between 12' and 14' (DoT, 1993a), although this can be partly explained by the large number that were built in this range when compared to those of lower heights.

How then do drivers explain their bridge strikes? An analysis of 1,550 incident reports (DoT, 1993a), where an explanation was given by the driver, found that the most likely causes were as follows: height of vehicle not known by the driver (given as the cause in 32 % of cases), equipment (e.g. on mobile cranes or tippers) left raised when driving (in 26 % of cases) and poor warning signs (in 13 % of cases).

These figures are all based on explanations given by the driver after a strike and so must be treated with a great deal of caution. Indeed, other researchers have stated the limitations of such data as follows:

"...studies using interviews and questionnaires with accident-involved road users are limited by the inaccessibility of over-learned behaviours to verbal reports, and the problems of post hoc interference or forgetting, as well as deliberate concealment of critical information" (Clarke, Forsyth and Wright, 1998, p1060).

Bridge strikes also vary greatly in their severity (British Rail, 1993) ranging from superficial, with minor scratches or gouging of brickwork, to catastrophic, where the superstructure or the whole bridge deck is either damaged or displaced on a busy railway line. An example of the most serious kind of bridge strike occurred in Ireland in 1975, where the strike impact damaged the railway line sufficiently to derail a train, which resulted in the deaths of several passengers on the train. However, in general less than 2 % of reported strikes are in the most serious class (DoT, 1993a).

Bridge strikes, however, are expensive. The costs fall into three main areas (DoT, 1988): damage to the bridge (including inspection and repair), damage to vehicles striking the bridge, and railway operational delays while the bridge is inspected (this being the largest cost area). In 1992 the total cost of bridge strikes was estimated at £3 million for British Rail alone, not including vehicle damage (DoT, 1993a) and in 1995 it had increased to £5 million (DoT, 1995b). Due to the privatisation of British Rail, inflation and the increased number of strikes (with recent passenger injuries), this figure of £5 million a year is probably a small proportion of the total cost of bridge strikes today. The main financial problem with bridge strikes for Railtrack (who, since the privatisation of the UK rail network in 1995/6, have taken over from British Rail as the 'owners' of the bridges) is the possibility of a major accident occurring with loss of life, for example a strike causing a train derailment, as described above. The 1992 figures put the estimated cost of a major accident at around £20 million if fifteen deaths occurred, but this again is most likely to be a large underestimation of today's costs. Other costs, which are more difficult to quantify, are delays to road users after a strike has occurred, and the general reduction in public confidence in the safety and efficiency of the UK railway system.

The legal restrictions for high-sided vehicles in the UK are few when compared to other European countries. With the exception of a few classes (e.g. public service vehicles, such as buses), there is no height limit for vehicles on most roads in the UK (DoT, 1982), although in 1993 the DoT reported that other European countries generally have a vehicle height limit of 4 metres (13' 1.5"). Indeed, until recently the majority of vehicles in the UK did not need to display their maximum height in the cab, thus drivers often did not know the correct height of their vehicles (as previous research by Galer, 1980 and 1981, found and which is discussed in more detail in Chapter 6).

An earlier recommendation by the DoT (1993a) was that driver education needed further attention because many drivers did not know the exact height of their vehicles and could not estimate it very accurately either. More recently (DoT, 1995b) this educational need has now been replaced by insisting that the vehicles' maximum height be displayed in the cab. The DoT (1995b) proposed an amendment to the existing traffic regulations which obliges any vehicle above three metres high (9'10") either to carry a sign in the cab indicating the vehicle height or to carry relevant information concerning the vehicle and its journey. This proposed legislation change was, however, considered earlier by the DoT (1993a) to be somewhat problematic because of the resistance from the haulage companies, who argue that stating the height of the vehicle in the cab was not successful previously, and because of the lack of its enforcement by the police or by the highway authorities. (As drivers not knowing the exact height of vehicles was cited as one of the main reasons why low bridges were hit, this issue is addressed later by means of experiments designed to manipulate the perceived height of a bridge, see Chapter 6).

The recent privatisation of British Rail has not reduced the problem of bridge strikes. Indeed, the opposite has probably occurred because:

- Less money is available to be spent on bridge strike countermeasures.
- Railtrack, the new owners of the track, signals and bridges are financially responsible to the train operating companies if the track is not operational due to a bridge strike, and track delays are expensive (McGrane, 1995).

1.2 Traffic Signs

Traffic signs are an integral part of the road environment on the approach to a low bridge. As will be seen below, there are certain types of traffic signs that inform the driver of critical details about the bridge, such as how high it is. It is a central tenet of this research that improving the design (and implementation) of such traffic signs will have a positive effect on the number of bridge strikes by overheight vehicles.

The term "traffic sign" can be defined as:

> *"... includes not only upright signs giving warnings and instructions to traffic, speed limits, directions and other information, but also road markings, traffic light signals, motorway matrix signals, zebra and pelican crossings and cones and cylinders used at road works"* (DoT, 1991, p 4).

The history of traffic warning signs for vehicles on UK roads dates back to the last century where signs warning of dangers such as steep hills and sharp bends were put in place for cyclists and early engine-powered vehicles. The first signs covering low bridges were implemented in "The Traffic Signs (Size, Colour and Type) Provisional Regulations 1933" (DoT, 1991). Following this, "The Traffic Signs (Size, Colour and Type) Regulations 1950" (S.I. 1950, No. 953) further considered low bridge warning signs by recommending the addition of small circular reflecting glass lenses to the sign to increase its conspicuity, especially at night.

The most influential change in the signing of all-purpose roads came with the Worboys committee in the early 1960's that introduced symbolic signing and colour coding for different types of directional signing (embodied in S.I. 1964/1857). Other more recent changes to traffic sign regulations (relevant to low bridges) came with the traffic sign regulations of 1981 (SI 1981, No. 859 Road Traffic) where height restriction signs could be shown in metric alongside their imperial equivalents (if needed it can be in the same sign). The 1989 regulations (reported by the DoT, 1991) allowed highway authorities to erect mandatory signs at low bridges (for which it is an offence for a vehicle higher than the clearance given in the sign to proceed to the bridge), in the place of triangular warning signs without the need to make a Traffic Regulation Order.

The current British Standard for traffic signs is BS 873. The important sections for the signing of low bridges are part 1 (1983)- methods of testing signs; part 2 (1984)- miscellaneous signs including hazard markers, and part 6 (1983)- retroreflective signs.

The Traffic Signs Manual is the comprehensive government publication that deals with traffic signs. Again the important parts for the signing of low bridges are Chapter 1 (1982) – Introduction, and Chapter 4 (1986) - Warning Signs. At the time of writing, the Traffic Signs manual is being comprehensively revised.

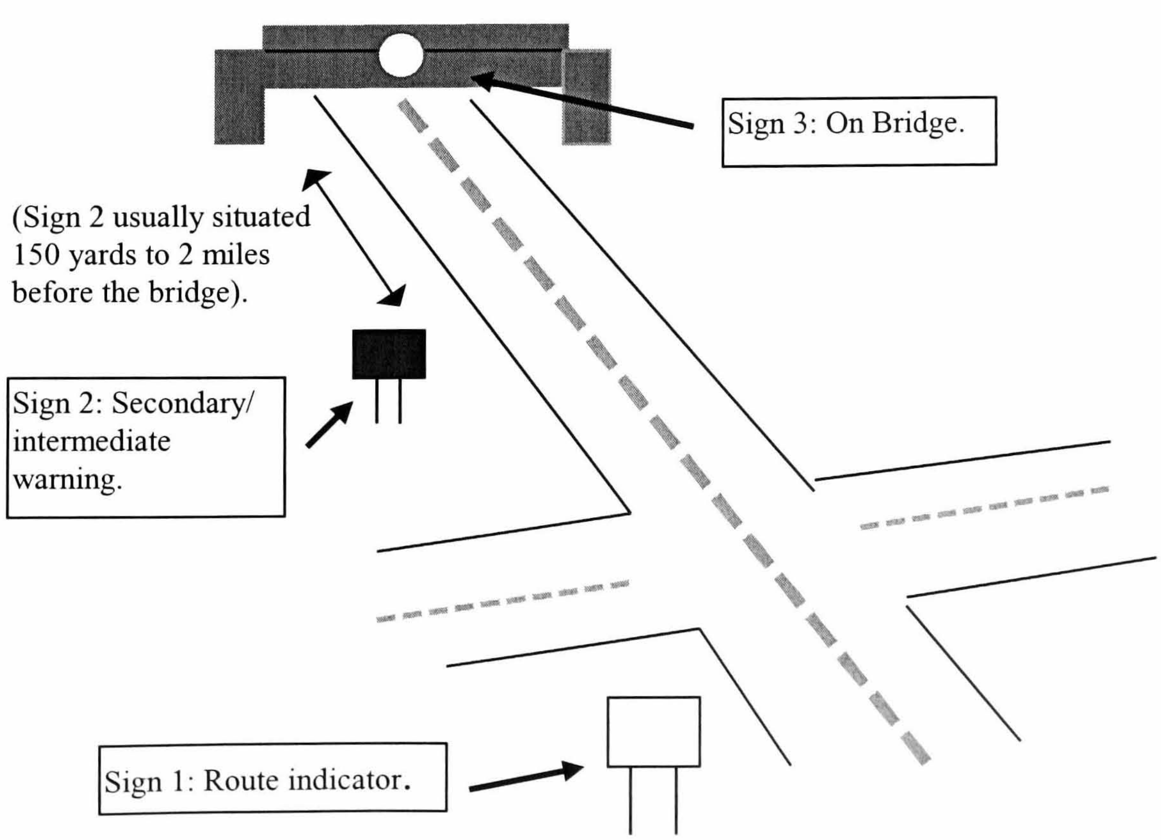
The most important and easily obtained source of information about traffic signs for drivers is the Highway Code (1996), which is revised periodically.

1.2.1 Traffic signs for low bridges

Low bridges have a variety of signs on the roads leading to them and on the bridge itself. The following describes this specified sequence, and introduces the applicable design standards.

Following consultation with the DoT (Elkin, 1994, personal communication), the signing along a road going towards a low bridge was stated to be in three distinct stages. Figure 1.2 displays this sequence using a schematic drawing of a road scene.

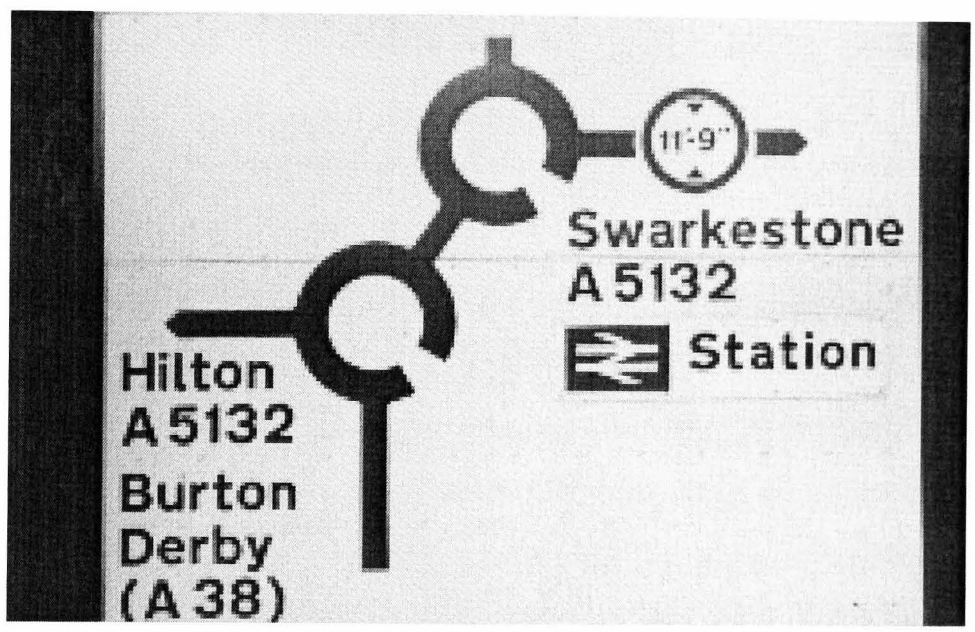
Figure 1.2: The three types of traffic signs for low bridges.



The route indicator.

The first stage, the "route indicator", informs the driver of a bridge height restriction ahead, as part of a directional sign. This sign may also contain appropriate diversionary information for overheight vehicles. A typical example of this type is shown in Figure 1:3, where one of the junctions shows a sign indicating a reduced clearance ahead (i.e. a low bridge).

Figure 1.3: A route indicator sign



The intermediate bridge warning (IBW) sign

The second, or 'intermediate', stage signing, is found closer to the bridge hazard. This provides details about the bridge, how high it is (in feet and inches) and how far away it is (given in miles or, if closer, in yards). This information is critical for drivers of high-sided vehicles if they are to manage the hazard ahead. At present this type of sign is classified as an information sign, it is rectangular with a blue background, having white lettering and a small white border. A mandatory height restriction roundel[1] may also be incorporated within the sign (Veal, 1994, personal communication). A model of this type of sign is shown in Figure 1.4.

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[1] A roundel is a circular sign with a white background and a red border. The height limit in black letters is displayed within the sign. A roundel is shown in the top right hand side of Figure 1.3.

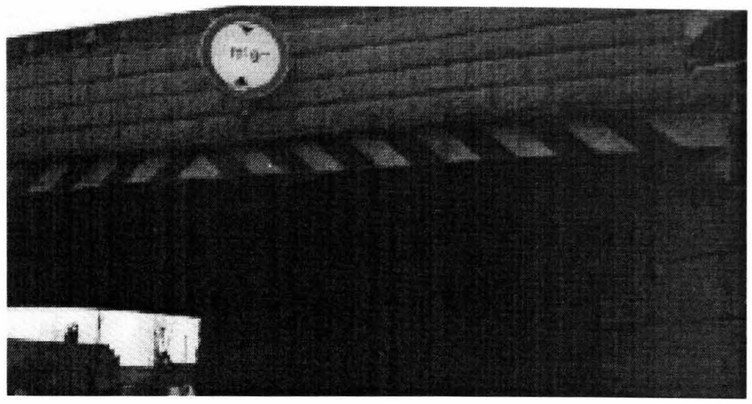
Figure 1.4: An intermediate bridge warning sign

The DoT's drawing number for this type of sign is (P) 669.1 (DoT, 1992) and the sign's colours and design comply with BS 873 part 6 (1983). It is the design of this category of road sign that has been investigated in the present research. No previous driver behavioural research has dealt specifically with this type of sign, however, a large amount of research has been performed on similar types of traffic signs, and these are discussed further in Chapter 5.

The third stage bridge sign.

The third stage signing can be categorised as containing those signs immediately prior to, or more commonly on, the bridge itself. This re-emphasises the height restriction and, where necessary, often includes more specific information, such as the 'chord marking' – that is, the width across an arch bridge to which the height information applies. Third stage signs are of two types: either a mandatory circular roundel prohibiting vehicles over the height marked in the sign to pass the sign (DoT's drawing number (P) 629.2, DoT, 1992), or a warning triangle which warns of the bridge clearance (DoT's drawing number (P) 530, DoT, 1991). In both cases the signs have a white background, black letters and a red border. As with the IBW signs, the colours and design comply with BS 873 part 6 (1983). An example of this type of sign is shown in Figure 1:5.

Figure 1.5: A third stage bridge sign.



For girder type bridges (the bridge category considered most 'at risk') the DoT (1993b) recommend the use of mandatory roundel signs. This follows work published in an earlier DoT report ('How to sign low bridges' undated but published in the late 1980's) which found that mandatory signs were generally more successful in stopping more overheight vehicles attempting to pass under low bridges when compared with bridges displaying the warning triangular signs.

Although the sequence described above is the prescribed 'normal' standard for the signing of low bridges, in practice it is often not adhered to. Often some of these signs are not present, especially the first and second stage signs (see Chapter 3). Additionally, however, especially on the low bridges over trunk roads, some signs are supplemented by an active warning sign (DoT, 1993b), which flashes a message to overheight vehicles if they try to drive towards a low bridge (this type of sign is discussed further in Section 1.3.3 of this Chapter).

1.2.2 Bridge markings

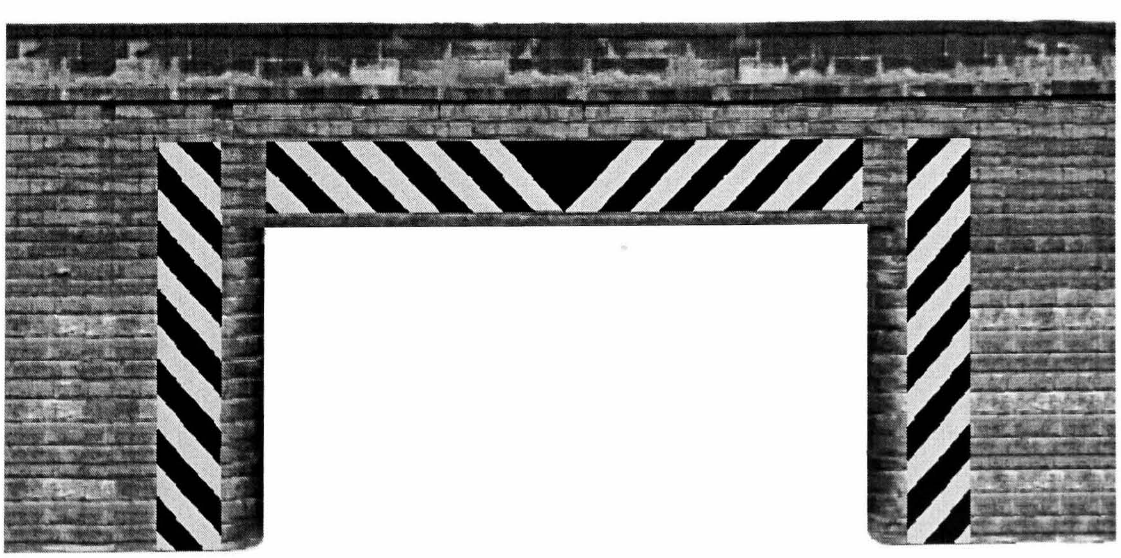
By the definition of a traffic sign given above, the markings sometimes placed on low bridges certainly fall into the traffic sign category. As with the IBW sign discussed above, no previous research has been undertaken specifically with this type of marking or concerning the history of why the present design is employed. Indeed, Veal (1994, personal communication) reported that the DoT had no knowledge of previous research on the marking design.

One of the earliest descriptions of the current standard was in a report by the DoT in 1982 which quotes their previous (now outdated) circulars on roads (22/73 in 1973 and 8/76 in 1976), in which it suggests painting black and yellow diagonal stripes on the face of the bridge to make high risk bridges more conspicuous. Since then the use of the marking has become widespread and DoT drawing standards exist to aid the correct implementation of the design.

The current design and use of the markings is as follows (Figure 1.6) with the design covered by BS 873 part 6 (1983) and the DoT's drawing standard (P) 530.2 (DoT, 1991):

- The marking is alternative bands of yellow and black placed around the face of a bridge to a depth of 300 mm.
- The bands of colour are slanted diagonally to the faces of the bridge at an angle of 45 degrees.
- The bands of yellow and black are of equal size being within 150-250 mm wide.
- A height restriction sign (either triangle or roundel) can be placed in the centre markings on the top face of the bridge (i.e. on the parapet) - if no sign is present the markings form a 'V' point in the centre.
- The marking can either be painted on to the bridge directly, or, as is more preferable, the markings may be on sheets attached to the bridge faces.

Figure 1.6: Illustration of the current marking standard



Although the DoT in 1982 stated that these markings should be used on high risk bridges, it is now common (see Chapter 3) for nearly all bridges to have some kind of yellow and black marking on them.

1.3 Previous Bridge Strike Countermeasures

Attempts to reduce the number of high-sided vehicles striking low bridges have been taking place for over 20 years (DoT, 1982), however they have increased substantially since the late 1980's (DoT, 1993a).

How can an unsafe situation be stopped? A commonly held view in ergonomics and safety management (e.g. Haslegrave, 1992; Wogalter, 1994) is that there are three general ways of doing so:

1) **Remove the problem-** by designing it out. In the case of bridge strikes, this would be by stopping high-sided vehicles and low bridges ever meeting by, for example, increasing all bridge heights, reducing all lorry heights or re-routing high-sided vehicles.
2) **Place a barrier around the object-** to stop the problem occurring. This may be by putting a beam before the bridge that would stop any overheight vehicle from actually reaching the bridge.
3) **Warn of the danger-** to try to induce safe (driving) behaviour. For bridge strikes, this may be by means of warning signs before the bridge or by publicity aimed at specific groups of people -i.e. those most likely to be driving high-sided vehicles.

The following three sections summarise the main approaches to the problem, all of which fall into one or more of the above categories. The majority of approaches attempt to stop bridge strikes occurring, however, some methods only attempt to reduce the extent of the strike if it occurs (and some of the methods attempt both). A fourth section describes countermeasures that can be applied **after** the bridge has been hit.

1.3.1 Remove the problem

There are two main ways of removing the problem, either raise the heights of all low bridges or limit the maximum height of a vehicle (DoT, 1993a). The DoT considered both of these options in detail (DoT, 1988) and concluded that it is only cost effective to raise the heights of a few low bridges (by either lowering the road or by increasing the bridge's height), thus the majority of bridges would remain unchanged. It was also concluded that as there is no 'safe' height for a bridge (as those up to 21 feet have been hit), it is, in general, pointless to limit vehicle heights (although special permission is needed for very high vehicles). Indeed the limiting of vehicle heights would require a change in UK and EC laws and would meet with much resistance from haulage companies (DoT, 1993a). As discussed earlier, the introduction of height markings in the cabs, however problematic, should at least help drivers to know the height of their vehicles.

Another measure to remove the problem is simply to close the road at the bridge (Hewitt, 1994). This can only be carried out at a small number of sites. An example of where this has been carried out in the Midlands is in Burton-on-Trent, where a frequently hit low bridge is now a no-through road for all motorised vehicles.

Other traffic engineering measures proposed by Hewitt (1994) are for traffic calming measures (for example the use of speed bumps or rumble strips to reduce vehicle speeds) and for traffic lights at arch bridges, to enable drivers of high-sided vehicles to safely pass under the bridge at its highest point (the middle of the road) without causing problems to oncoming traffic.

1.3.2 Place a barrier around the object

Arrester beams are a series of structures over a road, the same height as the low bridge. They are situated in front of the bridge and are used to slow down an overheight vehicle gradually, so preventing damage to the actual bridge. This option, although appealing, has several problems. Firstly, as reported by the DoT repeatedly (DoT, 1982, 1988 and 1993a) it is, at present, illegal (under the Highway Act, 1980) to obscure the public highway by placing an obstacle in front of the bridge (unless it is actually part of the bridge structure). Thus placing objects before the bridge, such as beams, barriers and visual warnings (e.g. conspicuous markings suspended above a road), or audible warnings (e.g. gongs which make a noise when hit), are all illegal in the UK at present. Unless the law is amended, such devices cannot be used for low bridges.

Secondly, it can be very expensive. For example the cost of an arrester beam would be more than £250,000 per bridge at 1988 prices (DoT, 1988), thus it is difficult to justify for most bridges.

Beams on the bridge that either crush or dissipate much of the energy from a bridge strike are acceptable and have been recommended both by Hewitt (1994) and the

DoT (1988) as a possible measure. These have the problem that they do not actually reduce the number of bridge strikes, but they can minimise the consequences of the strike (especially for minor strikes) to the bridge, the vehicle and the rail track above. The beam, however, often needs to be replaced after any strike occurs, which thus increases the expense of this option.

Placing the barrier on the vehicle rather than the bridge is another option in certain cases. Vehicles such as skip lorries and tippers could be fitted with a visual, or auditory signal to alert the driver that the equipment has been left in the raised position. This requirement is slowly being phased in though a change in legislation (DoT, 1993a), as it is possible to fit such a device to these vehicles to prevent them from moving unless the equipment is lowered.

1.3.3 Warn of the danger

Warnings for low bridges fall into two general categories, either via driver publicity/education or via warning signs in the road environment.

Publicity has generally been directed at potential drivers of high-sided vehicles to increase their awareness of the problem and to help them to prevent bridge strikes through the safe planning of their routes. Following recommendations from the DoT (1988, 1993a), leaflets produced by the DoT (1995a) and by British Rail (1993) graphically illustrate the consequences of a bridge strike and show how it can be avoided by safe route planning, through knowing the vehicle's exact height, and by knowing what the various 'low bridge' traffic signs actually mean. The leaflets have been distributed in relevant places for drivers of high-sided vehicles, for example depots or transport cafes.

The planning of routes to avoid low bridges has been made easier by the introduction of the AA's Truckers Atlas (1993) which shows most (but not all) low bridges as part of the atlas. At the beginning of the atlas there are also several pages outlining the problem of bridge strikes and what drivers should do if they hit one. The gradual introduction of in-vehicle navigation systems reported by Gale (1996a) should further aid safe route planning by showing which roads to avoid if driving a high-sided vehicle.

Warning signs in the road environment are aimed at inducing safe driving behaviour by increasing driver knowledge of a bridge hazard ahead and how, if necessary, it can be avoided (Horberry, Halliday, Gale and Miles, 1995). Chapters 2, 5 and 6 review the research in the general area of road signs and warnings but the following describes previous work that has been specifically aimed at reducing the number of bridge strikes through the correct implementation of prescribed signing standards or through the improvement of the sign's environment.

Recommendations to improve bridge signing have been made by several sources in the past (e.g. Hewitt, 1994; DoT, 1988; DoT, 1993a) and these have included simple measures such as improving the sign environment by reducing the vegetation around the sign (DoT, 1988). Guidance for local authorities and others involved in bridge signing concerning the correct implementation of signing standards has been given by the DoT in Circular Roads 5/87 (1987) and 2/89 (1989) and in a Network Management Advisory Leaflet (1993b). These deal with issues such as the correct types and sizes of signs, where and when to use bridge markings, and changes in the UK's legislation for the signing of low bridges. They have not, however, attempted to quantify the reduction of bridge strikes that may occur by using the correct signing standards. Other signing countermeasures have been undertaken by 3M PLC into the type of material used for signs. 3M PLC have produced both a report (1993) and an earlier leaflet (1987) showing that using their products can make traffic signing safer, although it must be noted that these are commercial publications.

The use of 'active' warning signs has been discussed in previous DoT reports (1982,1988 and 1993a). The general idea for these types of signs is that where an overheight vehicle is travelling along a road towards a low bridge it will break a beam (usually infra-red) which will cause a sign located before the bridge to inform the driver that the vehicle is overheight and that it should divert from the bridge. Flashing lights above and below the message on the sign are intended to attract driver attention, to increase the effectiveness of the sign (details obtained from an advertising brochure by Coeval Ltd. - a manufacturer of this type of product). Results published by Hewitt (1994) and the DoT (1993a) found that this type of sign can prevent over 90% of overheight vehicles travelling towards a low bridge from actually reaching the bridge - i.e. the drivers diverted when the vehicle triggered off the sign). Although these signs are expensive, over £30,000 per bridge at 1993 prices, the DoT (1993a) state that they can be considered as an option for implementation at certain bridge sites. It does not recommend their use for the majority of bridges (mainly due to cost and maintenance factors), thus active signs will not solve the need for effective warning signs at most bridge sites.

1.3.4 Countermeasures after a bridge strike

Measures that are applied after a bridge has been struck fall into two general groups, those that attempt to minimise some of the consequences of the strike, and those where the countermeasures make a future strike less likely.

Countermeasures to minimise some of the consequences of the strike are designed to alert the authorities (i.e. Railtrack and sometimes the Police) that a strike has occurred so that trains can immediately be stopped from passing over the damaged bridge and that bridge inspections and repairs can be carried out as soon as possible. Such measures include: sensors on the track which send an alert signal if the rail track has been corrupted due to a strike (reported by Hewitt, 1994); emergency telephones near a bridge to enable a report of a strike to be made (DoT, 1988); cameras to monitor the bridge integrity and to record an actual strike (Hewitt, 1994), and inspection by semi-qualified inspectors who report the damage and who sometimes authorise trains to pass over the bridge before a fully qualified bridge engineer arrives (British Rail, 1993; Hewitt, 1994).

There are two main countermeasures that can be used to make future strikes less likely. Firstly, by ensuring drivers of vehicles who have struck a bridge are prosecuted (DoT, 1988; DoT, 1993a) - which can also help to publicise the dangers of bridge strikes and can help to prevent badly offending drivers (or companies) from driving, by having their licences either removed or not renewed. Secondly, by collecting adequate accident statistics it is possible to identify trends and factors in bridge strikes for individual bridge sites (as described in Chapter 3). For example, if excess vehicle speed was identified as a factor, then signs reducing the speed limit before the bridge could perhaps control it. The problem with such countermeasures, based on accident statistics, is that the solutions tend only to be specific to one particular bridge site. Additionally, accident statistics depend on having a comprehensive reporting procedure (Brown, 1990) and inadequate or poor statistics can lead to inappropriate countermeasures. Indeed, as will be mentioned later in Chapter 3, Railtrack has only introduced countermeasures at individual bridge sites, based on previous accident statistics, to a limited extent.

1.4 International Bridge Strikes

1.4.1 The extent of the problem

In 1982, the DoT carried out a survey examining the problem of bridge strikes in other countries and it was found that:

- **Ireland** reported 84 strikes in 1979 (of which approximately 10% were considered serious).
- **France** notified 240 strikes at 180 specific bridges in 1973/4.
- **Germany** recorded an average of over 200 strikes per year in the mid-1970's.
- **Finland** on average had 2 severe strikes a year (there were no figures for the total strike number).
- **Victoria Railways, Australia** reported 90 bridge strikes in 1978.

Later, in 1994 Hewitt carried out a similar survey and additionally reported that:

- **West Japan Railway Company** has over 3,600 bridges and that there were 96 reports of strikes in 1993.
- **Westrail, Australia** had a maximum of 2 - 3 strikes per year.
- **Central Japan Railway Company** has 3,000 rail over road bridges and only an average of 3 reported strikes a year (but it has not been recorded whether those reported were only the severe strikes).
- **Mississippi State Highway Department** has 37 low bridges/underpasses of which 3 were hit in 1989, at an average repair cost of £130,000 per bridge.

According to Hewitt (1994), other countries and organisations that considered bridge strikes to be a significant problem (without directly quantifying it) were: Spoornet

(South Africa), Caminhos de Ferro Portugueses (Portugal), Nederlandse Spoorwegen (Holland), Southern Pacific Lines (USA) and Amtrak (USA).

It would therefore seem to be appropriate, even as early as 1982, for the DoT to summarise the situation by stating that:

> "*No country has recorded as many impacts as Britain but in relation to their number of low bridges other countries have a problem*" (DoT, 1982, p37).

1.4.2 Countermeasures

Both the DoT (1982) and Hewitt (1994) agree that for those countries with a bridge strike problem, the two most frequently used countermeasures (not including static signing) are: collision protection beams (which, as has already been described, cannot legally be used in the UK) or some kind of height gauge - usually an overheight detector system attached to an active warning sign (which is in general only being used at high risk sites in the UK).

Additionally, the DoT (1982) reported that both the French and the Finnish authorities had set up working groups to try to reduce the bridge strike problem. Both groups' recommendations are broadly in line with those of the DoT, in particular they emphasise improving the bridge signing, increasing the publicity to drivers of high-sided vehicles, improving the crash resistance strength of bridges, developing warning devices to stop or warn overheight vehicles and undertaking specific assessments of high risk sites. Indeed the DoT (1982) stated that one of the main countermeasure recommendations of the Finnish working group was that:

> "*Warning actions* (should) *include indication of the clearance height by means of traffic signs and improvement of the awareness of the object by means of conspicuous colouring*" (DoT, 1982, p 64).

As will be seen later, this central recommendation of the Finnish group is supported by much of the work undertaken in the current research investigation that examines the design of bridge warning signs and bridge markings.

1.4.3 Traffic signs for low bridges

Hewitt (1994) reports that most countries that took part in his survey used some kind of low bridge clearance warning signs. These countries included Australia, USA, South Africa and much of Western Europe. The DoT (1982) reported that the French and Finnish bridge strike working groups and the German authorities emphasised the importance of proper and clear signing and stated that drivers who ignored or missed them were the main reason for bridge strike incidents.

The DoT (1994) state that the UK has different designs for first and second stage signing when compared with other European countries. However, third stage mandatory signing (i.e. circular signs on or immediately before the bridge) has been standardised across Western Europe (including the UK) since 1975. The biggest difference between the UK and the rest of Europe is, of course, in the measuring system. Europe uses a Metric system while the UK and Ireland still use the Imperial system of feet and inches (with the metric equivalents being used only on some low bridges since 1981). Thus, although the sign itself has been standardised across Europe, the information contained in the sign generally has not. As has been discussed previously, it has been difficult enough for the road and rail authorities to educate or persuade UK drivers to learn their vehicle heights in the old Imperial system, obliging them to now know their correct heights both in feet and inches and in Metric units would be even more troublesome. The situation will improve as the UK driving population fully adopts the Metric system - although this will not happen in the short term. The only answer in the UK at the moment is to use both types of measurement system, either in the same sign or by having one sign of each system located next to each other. The problem with this is that it increases the complexity of the signing environment for a driver, especially if they only have a limited amount of time to read the information contained in the sign. For instance, Agg (1994) found that too much information on a sign can cause overload for a driver, with potentially negative consequences for safe driving behaviour.

In terms of the markings for bridges, no other country has been found to use the same yellow and black marking standard as used in the UK. The Dutch use 0.15 m wide white stripes on a black background, the space between the stripes must be 0.25m of black and the height of the markings is recommended to be 0.5 m (minimum 0.25m).

The stripes must be vertical on the top of the bridge and at an angle of 45° on the sides (Hagenzieker, 1994). In Belgium and South Africa white and red striped markings are used, while in the USA, no widely applicable standard is used, with markings being of a variety of shapes, sizes and colours (Buck, 1995).

Overall then there is no internationally used standard marking system that a driver can recognise for signifying a low bridge. At least in the UK (unlike the USA) there is a nationally implemented standard. However, there are two key questions with regard to the UK standard:

1. Is it correctly implemented at individual bridge sites?
2. Is it the best standard anyway?

Both of these questions will be addressed later in this thesis.

1.5 Conclusions

It has been stressed that bridge strikes are a large and costly problem for the road and rail transport industries in the UK. The situation has become markedly worse in the past 25 years and, despite a large amount of effort directed towards countermeasures, the number of strikes recorded annually in the UK remains at a high level. This is especially so in comparison with other countries.

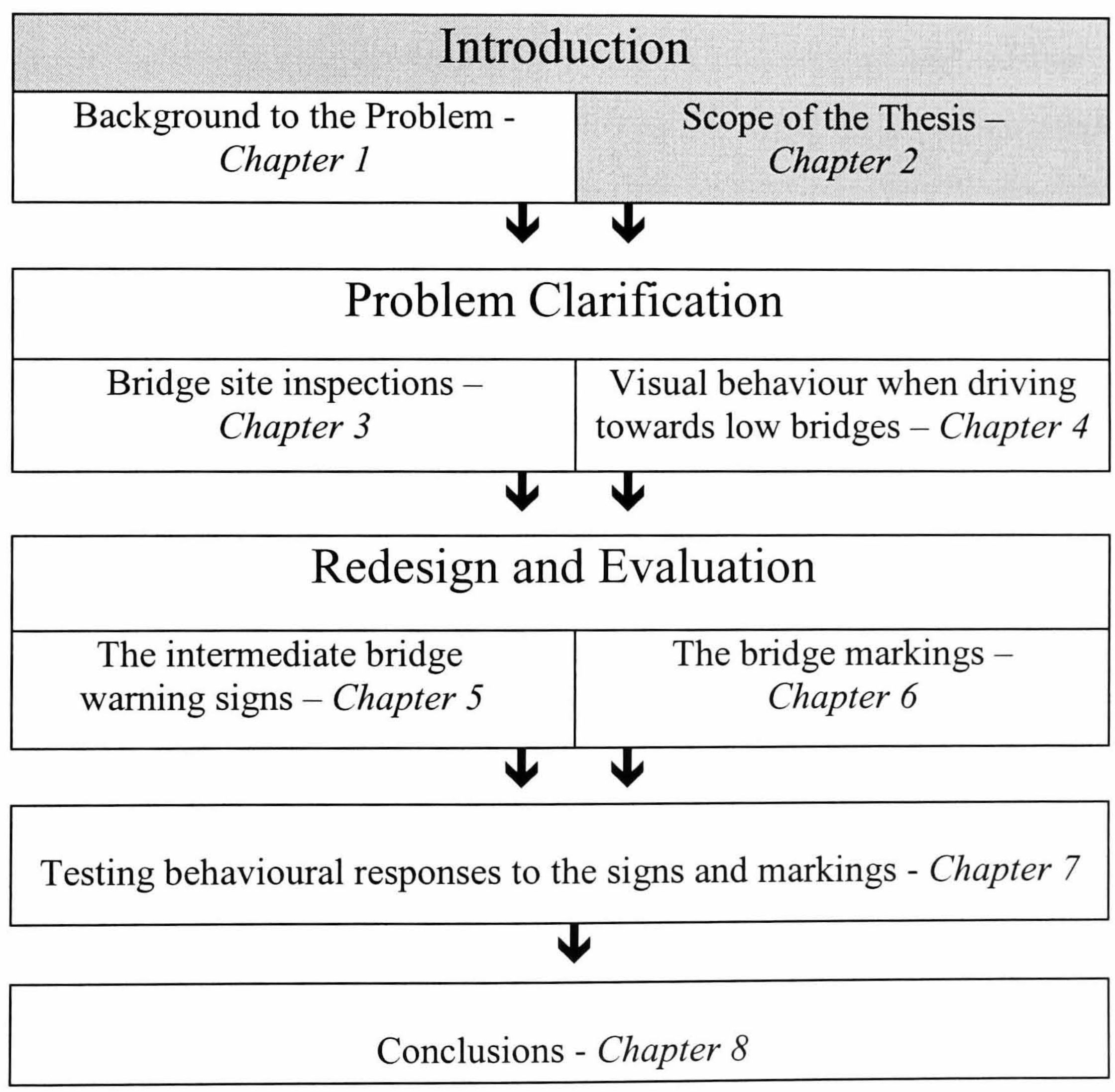
The traffic signing and markings for low bridges, together with the other countermeasures employed, have been described. It has been shown that no single preventative measure is the solution for bridge strike reduction in the UK, when the legal restriction on countermeasures and the cost/benefits are considered.

Bridge strikes also exist in most other industrialised countries, and no distinct cost-effective solution has been employed by these countries in their attempts to deal with strike incidents. The UK, however, seems to be the country with the greatest problem.

Despite the large amount of work involved in considering the effectiveness of various countermeasures (after installation) on strike rates, little previous research has been undertaken concerning road vehicle drivers' behaviour and how they react to the visual warnings of a low bridge ahead. These research areas, together with the optimum design of the visual warning for a low bridge, are the central issues of this research investigation.

Chapter 2:

Scope of the Thesis



2.1 *Introduction*

The previous Chapter introduced the problem of high-sided vehicles striking low bridges. In addition, descriptions have been given of the visual warning signs on the approach to a low bridge and the previous countermeasures aimed at reducing the number of strikes, as well as providing a review of the problem outside of the UK. It was concluded that although numerous countermeasures have already been attempted, no previous work that examines the design and drivers' perception of the visual warnings on the approaches to low bridges has been specifically undertaken.

The question of how effective the visual warnings that a driver receives when approaching a low bridge are, and how such warnings can be improved, are the central areas of investigation addressed in this research. A primary consideration for this work is therefore to define how the effectiveness of warnings can be assessed and also by what means an ineffective warning can be amended. It is argued here (following Lehto and Miller, 1986; Fisher, 1992; and Wogalter, 1994) that the primary function of a visual warning is to reduce unsafe behaviour, thus for low bridge warnings their ultimate function is to prevent, or a least reduce the number of, overheight vehicles crashing into bridges.

In warning sign evaluation, Edworthy and Adams (1996a) make a useful distinction between compliance (safe behaviour with respect to an object) and effectiveness scores (the 'extra value' safe behaviour that a warning adds). In terms of bridge strikes, if, for example, 70% of overheight vehicles do not attempt to pass under a low bridge without warning signs present (i.e. 70% is the compliance score) but 90% of drivers do not attempt to pass under the same low bridge when warning signs are present, then the addition of warnings increases compliant behaviour by 20% (i.e. the effectiveness score is 20%). Although ethical constraints may restrict such scores being obtained on a large-scale for bridge warnings on the roads in the UK, they can at least be used in the laboratory when designing and comparing, for example, the effectiveness of different versions of signs. Increasing the effectiveness of the IBW signs and bridge markings through their re-design is therefore the ultimate goal, in terms of practical outcomes, of this research.

What makes a warning effective? Although researchers may disagree on the precise details, it is generally maintained that visual warnings must at least be: seen (elicit visual attention), understood, and heeded or responded to appropriately (c.f. Lehto and Miller, 1986; and Edworthy and Adams, 1996a). Young (1991) has expressed the same view:

"*To be effective warnings must be noticed, comprehended and followed*" (p 580).

Wogalter (1994) extended this slightly and added that a warning should also comply with the users' existing beliefs about the object and, additionally, motivate them to comply with the message if a warning is to be fully effective. This seems closely in line with the earlier argument of Näätänen and Summala (1976) who stated that the motivation to comply with a warning sign was a more important determinant in accident causation than the actual perception and comprehension of the sign. Most signs are capable of being seen and understood by drivers, the main problem is motivating them to detect and comply with the warning message. Thus it is not sufficient to purely analyse drivers' perceptual and cognitive skills when designing and evaluating traffic warning signs, both drivers' beliefs and motivations are additional necessary considerations.

2.1.1 The Human Factors Approach

Various approaches could be employed to the problem of bridge strikes, as described in Chapter 1. The current research takes a Human Factors stance and considers the person - equipment - environment interaction in a work situation. In a complex system (such as driving) an accident is caused by the conjunction of the above three elements. Accident reduction, however, can result from the manipulation of any of the three (Brown, 1990). The research considers two aspects of the road environment (i.e. signs and markings) and how changes to these aspects can influence their interaction with the person and the equipment, with the intention of reducing the number of bridge strike accidents.

It is acknowledged that there are other possible ways of preventing bridge strikes including manipulations of the other elements. For example, considering the person element through improved training, or the equipment element through accoutrements in the vehicle cab to prevent an overheight vehicle being driven at a low bridge, but such strategies are not specifically considered here. Other issues shown to be important in transport safety, such as long and irregular working hours of drivers (Hamelin, 1987) or new technology (such as a new braking system) in the vehicle (May, Horberry and Gale, 1996), can also be classified within the same framework, but again are outside the limits of this research.

The current investigation is objective human science research. Where subjective opinion was required (for example in aspects of the bridge site assessments) or where the data could be coded incorrectly (for example the analysis of parts of the eye movement data) then a second observer/rater was employed to increase reliability. Sinclair (1990) and Clarke, Forsyth and Wright (1998) stated that driving skills and behaviour are often not accessible to verbal report, so using interview or questionnaire methods to obtain data about many aspects of driving performance are hugely limited. Thus this research avoided obtaining driver opinion as much as possible and considered that it was not sufficient to merely ask drivers why low bridges were hit. The majority of the data collected in this work were therefore direct perceptual or behavioural response measures (for example eye movements or comprehension tests).

2.2 Research Plan

Following the above, Figures 2.1 and 2.2 introduce the simplified working models for bridge strike reduction that were used in this research (and which are subsequently expanded upon). Figure 2.1 considers the markings and Figure 2.2 considers the signs. They show the roles that both the signs and markings may take in reducing the number of strikes. Both figures consider the case of a person driving an overheight vehicle towards a flat top/girder bridge with the intention of passing underneath it. They show the roles that the signs and markings take in inducing the driver not to attempt to pass under the low bridge.

The additional variables of environmental complexity, inter and intra-individual differences and the task/equipment differences are also shown to have had an effect. An example of environmental complexity is the busyness of the traffic conditions. Individual variables include examples such as risk perception (between different drivers) and level of fatigue (in the same driver at different times). Finally, an example of task/equipment differences is whether the vehicle is fitted with any type of navigational equipment that warns the driver of a low bridge on the route ahead.

Figure 2.1: Simplified working model for the bridge marking research.

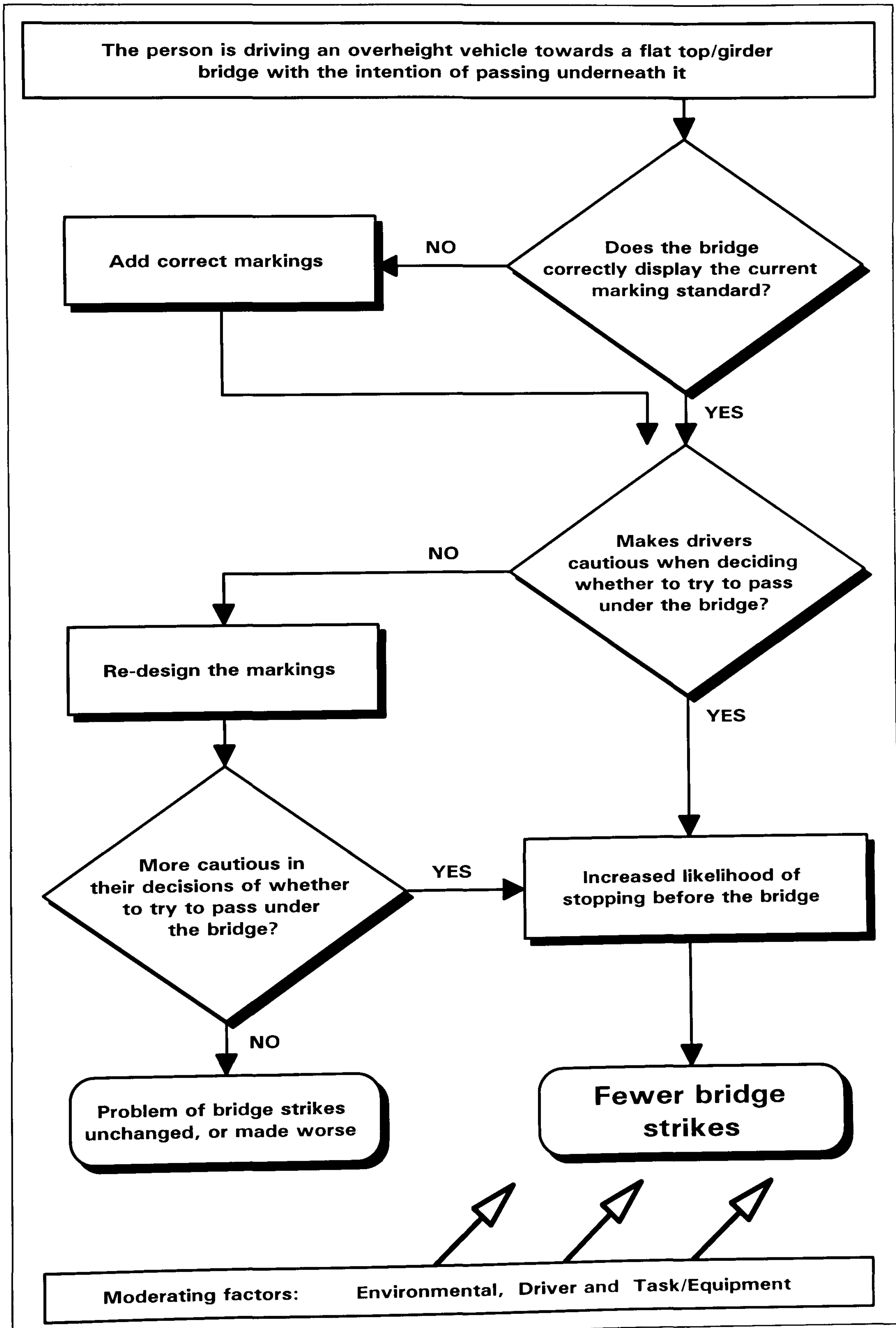
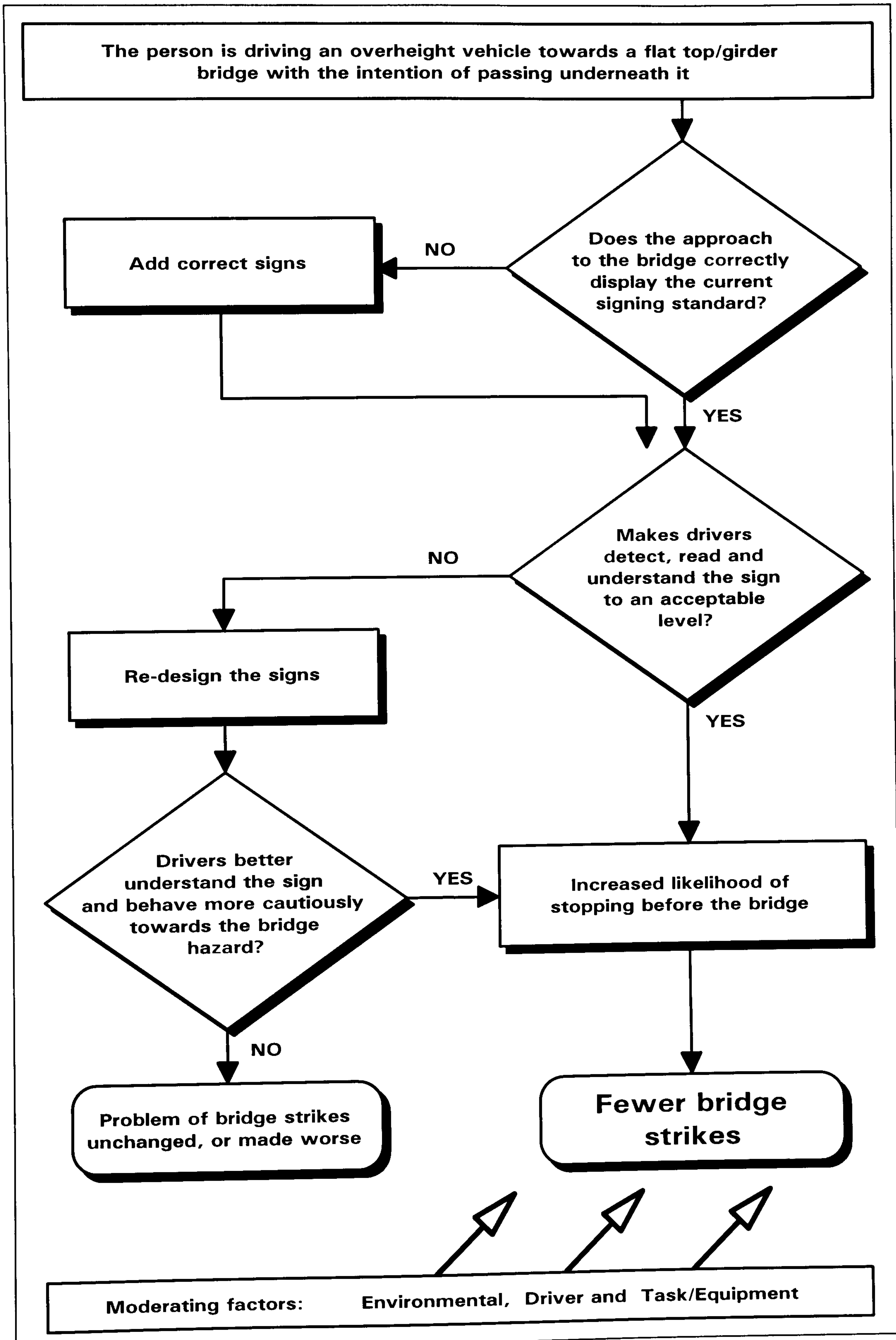


Figure 2.2: Simplified working model for the IBW sign research.



2.3 *Overall Aims of the Research Investigation*

The main aim of the research presented here was to examine one possible approach to reduce the number of bridge strikes. This approach investigated the design of visual warnings for low bridges, and the effects of these warnings upon drivers. Specifically, the overall aims of this approach were to improve the design of the IBW signs and bridge markings, and to further understand drivers' perceptions and behaviour with respect to such warnings. The overall hypothesis was that improving visual warnings in the road environment on or before low bridges would result in more appropriate behaviour by drivers when judging whether to attempt to pass under the bridge, thus reducing the number of strikes by overheight vehicles. To meet these aims, the specific objectives of the experiments described in this research investigation are identified below.

2.3.1 Experimental Objectives

The research is presented here in the form of a problem-solving thesis. To undertake this, the investigation first carried out work to clarify the nature of the bridge strike problem, before moving on to examine the re-design and evaluation of the IBW signs and bridge markings.

The first empirical study in this research investigation was a field assessment of possible causal factors in bridge strikes, undertaken to help clarify the nature of the strike problem. The objective was to explore and to more completely understand the physical characteristics and road environments of frequently struck bridges in order to try to identify potential contributory factors in strikes. These issues are addressed in Chapter 3.

The second stage, to further clarify the problem, was investigated by observing drivers' eye movements when approaching low bridges, the objective being to comprehend and quantify drivers' visual behaviour when in this situation. Specifically, the purpose of this was to establish the effectiveness of the IBW signs and bridge marking in attracting visual attention, thus indicating how effective they might be as warnings. These matters are examined in Chapter 4.

Following initial design and evaluation, re-design and further evaluation of the signs and markings were undertaken to establish if the current standards for such signs and markings could be improved. For the signs, the series of alternative designs developed (and the current sign standards) were evaluated on comprehension (on their own and embedded in a road scene), on hazard perception, on visual attention and finally on the ability of the sign to sensitise the driver to the hazard ahead (i.e. the low bridge). Testing of the different designs on a wide range of response measures was intended to address two broad questions:

1. Could the design of this type of sign be improved (given the work area parameters mentioned later in this Chapter)?
2. If the design could be improved, did the enhanced sign actually have any positive influence on the behaviour of a driver of a high-sided vehicle when approaching a low bridge?

These questions will be addressed later in Chapters 5 and 7.

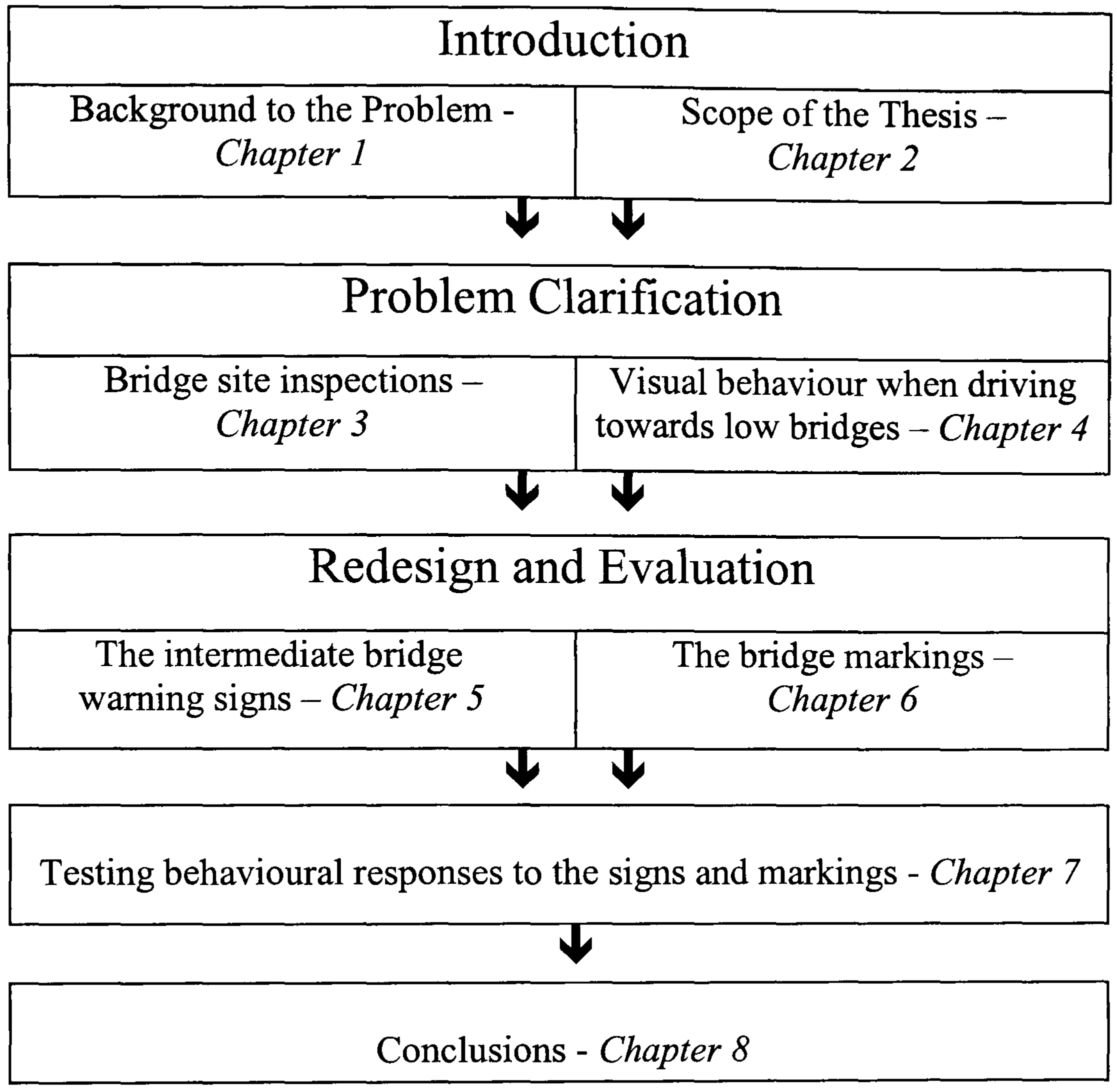
For the bridge markings, the hypothesis tested here was that re-designing the markings to make the bridge look lower would reduce the number of bridge strikes, as drivers who do not know the actual height of their vehicle may use the bridge to visually gauge whether or not they can safely pass underneath it (this point is suggested by the DoT, 1982, and by Galer, 1981). If drivers do not know the height of their vehicles, and are using the bridge as a gauge, then making the bridges appear lower than they actually were (by designing some kind of visual illusion in the markings) should make drivers more cautious when deciding whether or not to try to pass under the bridge. As with the warning signs, two questions were addressed:

1. Could the perceived height of a bridge be modified by the markings placed on it?
2. If so, then did a bridge marking that made a bridge look lower actually influence the behaviour of a driver in an overheight vehicle when approaching the bridge?

These questions will be addressed in Chapter 6 and 7.

The order of the Chapters in the thesis is shown in Figure 2.3. It displays how the objectives described above are presented in the thesis. Future research in this area of investigation would be field trials or the actual installation of the re-designed signs or markings. These areas are discussed in the concluding Chapter of the thesis, which considers the implications of the current research.

Figure 2.3: Order of the Chapters in the thesis



2.3.2 Expected contributions to knowledge

Following the research objectives that were presented above (in Section 2.3.1) it is expected that the experiments will contribute to knowledge in the following ways.

The field assessment research will be the first academic study in which an audit of a large number of bridge sites where strikes have regularly occurred was undertaken, to try and identify factors that might possibly influence bridge strikes.

The drivers' visual behaviour research will record and analyse eye movements in a scenario never previously specifically investigated by other researchers (i.e. visual behaviour when 'driving' a large vehicle that was approaching a bridge).

For the design and evaluation of the IBW signs, this investigation will use previously established research techniques in warning sign design and evaluation (e.g. testing of comprehension) and apply them to a different type of sign (i.e. the IBW sign).

For the bridge markings, this research will adapt previous literature on visual illusions and previous bridge strike countermeasures, and apply them to the design and evaluation of a series of marking standards. No previous experiments have ever been undertaken examining whether it is possible to alter the perceived height of a bridge by the markings placed on it, so this is a very distinctive area of investigation.

2.4 Thesis Research Areas

The above section has described that this research investigation was set up to specifically examine the visual environments on the approach to low bridges and, in particular, to investigate the design of the warning signs and bridge markings. Within this area, the specific design parameters for the signs and markings were determined by the attributes that it was considered the DoT (and to a lesser extent, Railtrack) would conceivably implement. Sections 2.4.1 and 2.4.2 below describe the design variables that were evaluated in this work. A full description of these variables, together with reviews of the appropriate literature, can be found in Chapters 5 and 6.

2.4.1 Parameters for the development of the IBW signs

As described in Section 1.2.1 of the previous Chapter, this type of sign is currently a blue, rectangular information category sign with a small white border. Two versions are used: a completely text-based one and a text-based version that also contains a red and white roundel. After discussion with the DoT (Elkin, 1994) concerning what features it would want to be re-designed and evaluated, it was determined that the following variables should be examined when developing new versions of the IBW sign:

- **Border** - no constraints were placed on the design of the border other than it had to be of limited size (i.e. less that 2" wide), which was similar to the width of the border currently used. One possibility was that if a coloured border was found to be particularly effective then it could simply be 'stuck on' to existing signs over the current small white border, hence greatly reducing the cost of implementing any sign changes.
- **Information content** - the sign needed to contain (in some way) the message 'low bridge' or 'height restriction', how high it was and how far away the bridge was from the sign. This allowed, however, for a different text-based version and

for a symbolic version of the sign to be developed and tested.

- **Sign colour** - the sign currently has white letters and a blue background. This needed to remain the same, as it was classified as an information sign (which usually have white lettering on a blue background). This permitted, however, for signs to be tested with and without a 'Roundel' (as described in Chapter 1).

It was necessary to follow these parameters if the outcome of the current investigation was to have any possibility of adoption by the DoT and Railtrack. The consequence of restricting the number of possible sign combinations to be tested, did, however, preclude variables that previous research had been shown to be relevant to warning sign effectiveness. In particular, areas that could not therefore be considered in this research included:

1. **The size of the sign.** Experiments by Pottier and Pottier (1988), and by King, Sneed and Schwab (1991) found that larger signs were more effective than smaller ones. There are, however, situations where large signs cannot be used (e.g. where the physical space in the road environment is limited).

2. **The colour of the sign's text or background.** Several researchers (e.g. Chapanis, 1994, and Braun and Silver, 1995) have found that the colour of the sign's text or its background colour influences the effectiveness of the warning. In general, red is one of the most effective colours for text (Chapanis, 1994).

3. **The shape of the sign.** As mentioned in Chapter 1 there are a wide variety of sign shapes displayed on the UK roads. Previous research by Riley, Cochran and Ballard (1982) and by Rodriguez (1991) found, in specific instances, that certain sign shapes were more effective than others. There does not, however, seem to be an optimum shape for all types of traffic warning signs.

4. **The font type.** Garvey, Thompson-Kuhn and Pietrucha (1996) investigated a new type of font for possible use on the highways in the USA. They found that their new font increased visibility distances for text-based signs and recommended its widespread introduction for traffic signs.

2.4.2 Parameters for the development of the bridge markings

Because the company sponsoring the research was the same group that owned the bridges (i.e. Railtrack) fewer constraints were placed on the bridge markings when compared with those for the IBW signs. The DoT did not have to take responsibility to install them (or to pay for them). After meetings with both Railtrack and the DoT the following variables were established for the development of the bridge markings.

- **Position and size** - The markings could only be on the bridge (i.e. not extending on to the road or pavement) and in a similar position to the current markings.
- **Design** - Any new design of the markings would be acceptable. Thus designs other than the currently used yellow and black hatching (as described in Section 1.2.2. in Chapter 1) could be developed and tested.
- **Colour** - Any colour or reasonable combination of colours would be acceptable. The only limitation was that in environmentally sensitive areas, certain colours might not be acceptable to local residents. However, this was not considered to be a restriction within the scope of this research.
- **Materials** - The markings had to be made of the same materials that were currently used to make the markings, so they had to be capable of being painted on the bridge itself or displayed on special sheeting (metal or plastic) hanging directly in front of the bridge.

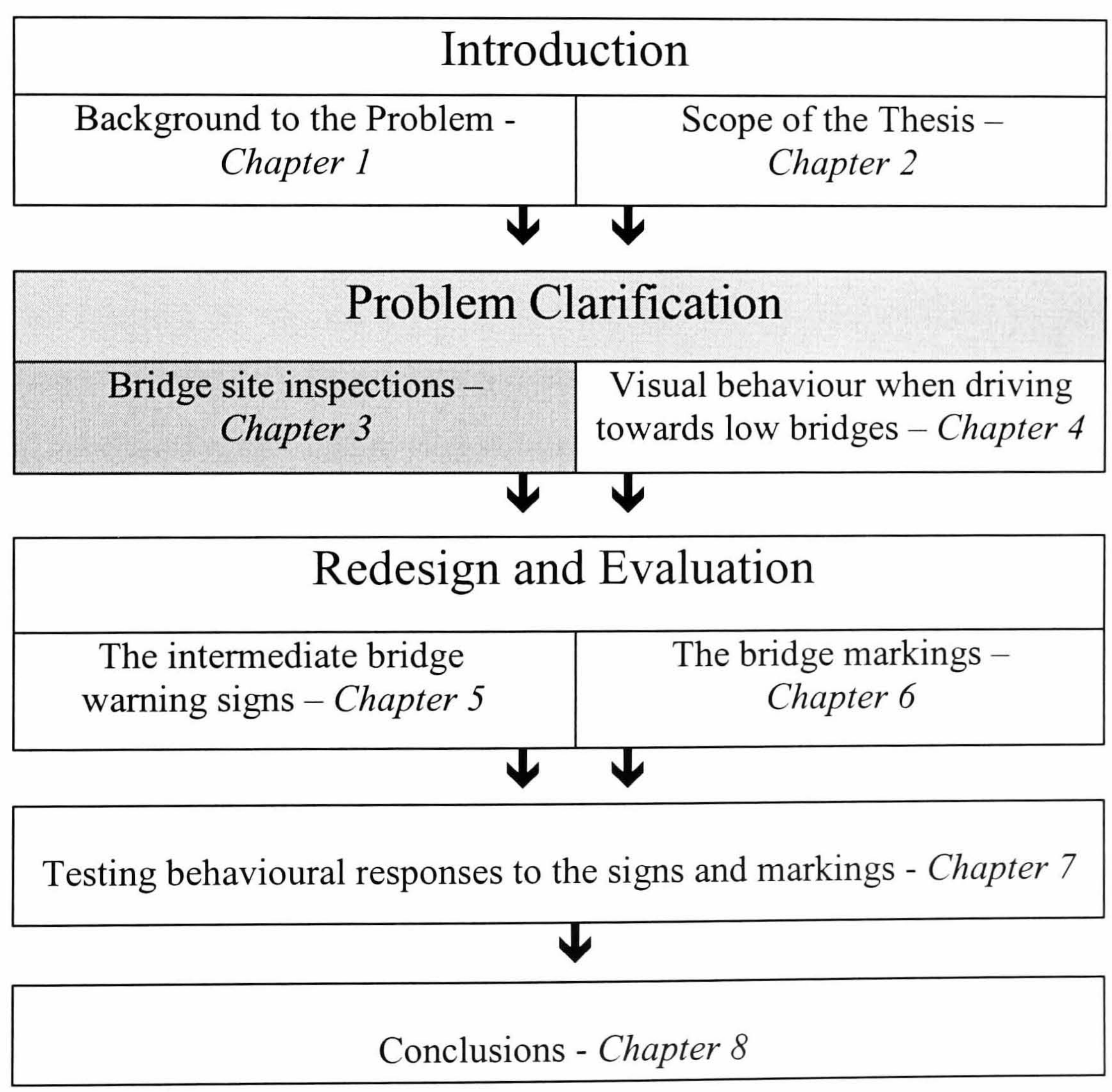
2.5 Conclusions

The general area of research for this thesis has been introduced, together with a summary of the work-plan. The overall aims of the research investigation and main objectives of the experiments were then outlined. Finally, a description was given of the specific variables being tested.

One of the main points stressed throughout this Chapter is that the work undertaken was applied research, and is presented here in the form of a problem-solving thesis. Chapter 3 therefore begins the process of problem clarification by means of performing assessments of actual low bridge sites.

Chapter 3:

A Field Assessment of Possible Causal Factors in Low Bridge Strikes



3.1 Introduction

When a bridge is reported as having been hit by a vehicle it is recorded in a bridge strike database held by Railtrack. These official records have improved markedly since 1989 (DoT, 1993a) and indicate that nearly 1,000 bridges were hit each year by high-sided vehicles in the mid-1990's. Some bridges are struck more than others; a recent publicity stunt by Railtrack (October, 1996) attempted to highlight this issue by driving a double decker bus into the most hit bridge in the country. The bridge is in Swindon and has been hit 83 times in the past 6 years.

From these official records it is possible to identify which bridges have been hit most frequently in the last couple of years, and conversely which bridges are considered 'normal' - i.e. not hit an exceptionally large number of times. The reality that some bridges are hit more than others leads to the question of whether there are any features of frequently struck bridges that make them substantially different from other, non-frequently struck, bridges. Following similar approaches taken by Shinar, Rockwell and Malecki (1980), who compared features of the environment at bends in the road where accidents had occurred against bends where accidents had not occurred, and Retting (1993), who compared crash data from large trucks against other vehicles in a variety of crash situations, a large group of 'strike' bridges (i.e. those frequently struck) was compared to the same number of 'control' bridges (i.e. those not frequently struck). The aim of the current study was to determine the physical characteristics of these two groups in order to try and identify potential contributory factors in bridge strikes.

Based on the review of the bridge strike literature (as described in Chapter 1), the following general groups of factors were considered to be crucial and were assessed for all bridges:

Bridge Height

A recent official report (DoT, 1993a) that surveyed the heights of bridges found that the majority of bridges struck were between 12' and 14' high. Does this imply that frequently hit bridges are struck simply because they are lower than other bridges? The current survey aimed to assess exactly how the average height of a strike bridge compares to the average height of a control bridge by measuring the minimum heights of all the bridges (i.e. bridge height at its lowest point).

In addition, the current legislation in the DoT circular 5/87 (Circular Roads, 1987) states that the figures shown on the signs indicating the available clearance should be at least 3" less than the measured height to allow a safety margin, and should be expressed to the nearest multiple of 3". The research presented here examined whether or not this DoT standard was always followed. To do this, it assessed the minimum height of the bridges, their signed height, and the difference between the minimum and signed heights.

The Bridge Warning Signs and The Bridge Markings

Apart from the research which investigated drivers' understanding of height limit triangles or roundels (e.g. Galer, 1980 and 1981, and Cooper, 1989 – and which are both described in more detail in Chapters 5 and 6), there has been no other previous published research that specifically addresses warning signs or markings for low bridge sites. There has, however, been some related work carried out investigating traffic warnings for railway crossing sites. For instance, Leibowitz (1985) and Meeker and Barr (1989) who both investigated why drivers attempted to cross in front of an approaching train, and Ong and Tierney (1989) who undertook a trial of various signing methods at crossing sites. All this research stressed that the presence of warnings (e.g. signs or flashing lights) were beneficial to help promote safer driving behaviour when approaching the crossing.

Edworthy and Adams (1996a) in their work on warning design for traffic signs and other applications, distinguished between an object's compliance score (the safe behaviour that would have occurred without a warning being present) and the effectiveness score (the safe behaviour that occurs with a warning being present - i.e. the extra safe behaviour that a warning causes). In terms of warnings for low bridges, the effectiveness score could be established by examining strike rates with and without the sign (or marking) being present. While the research reported in this Chapter cannot directly quantify the effectiveness scores for the signs and markings, it does look at how many bridge sites have the various warning signs and bridge markings present. If it was found, using an extreme example, that the strike bridges had no warning signs present and the control bridges all had warning signs present, then it would suggest that the lack of warning signs might be a factor in bridge strikes. Thus assessing how many of the sites have bridge warning signs and bridge markings is considered to be an essential part of the bridge site survey.

The Road Environment

This category assessed a number of variables relating to the road environment on the approach to a low bridge. Unlike the bridge warning sign and bridge marking categories, the general aim in this section was to establish if **too much** visual complexity was present in the environment at strike bridges. In particular it investigated the following:

- The bridge location - i.e. whether strike bridges tended to be in urban/industrial locations (rather than rural ones). This followed the research of Retting (1993) who found that location was an important factor for accidents involving large trucks.
- The lighting around the bridge - i.e. whether strike bridges tended to be less well lit than were the rural ones. This notion was based on the work of Tanner (1958) who found that there was a reduction in the number of accidents when the street lighting was improved.
- General advertising around the bridge (including billboards and advertisements on shops). It has been established that distractions can reduce driving performance. For instance, in the area of in-vehicle distractions, Jancke, Musial, Vogt and Kalveram (1994) found that driving safety became worse when drivers were monitoring radio programmes. Similarly, McKnight and McKnight (1993) found that performance was negatively influenced by the use of cellular phones when driving. In the area of the road environment distractions, previous research found that the inclusion of advertisements can lessen the conspicuity of routing information, with the effect becoming stronger for more or larger advertisements (Boersema and Zwaga, 1985). Thus it is conjectured that the demonstrated negative effect of advertisements on routing information conspicuity may also be a factor in making the approaches to the strike bridge sites more distracting, so possibly reducing driving performance, when compared to the controls.
- General complexity of the environment (including other traffic signs and other road tasks). In the field of wayfinding in complex buildings, research by O'Neill (1991) found task performance decreased as a function of complexity. Driver information overload can also have a negative effect on driving performance (Agg, 1994) and can negatively influence driving safety (Wulf, Hancock and Rahimi, 1989). Thus, similar to the general advertising around the bridge

category described above, it is speculated that the strike bridges are in more complex environments than the controls.

For all the categories described above, the aim was to make the collection of data as objective as possible (thus keeping subjective judgement to a minimum). The only two items that involved a partly subjective judgement were the classification of the amount of advertising around a bridge site and the general complexity of the environment. In an attempt to overcome variation in subjective judgement, two observers were used in the assessments to form a consensus (following the inter-rater reliability results of Doble, 1991).

3.2 Method

3.2.1 The Bridges

The twenty strike bridges were identified from the bridge strike records kept by Railtrack. This group comprised 19 of the top 20 most hit bridges in the country and one other frequently struck bridge (included because at the time of the research it had been hit many times recently). The control bridges were selected especially carefully, being near to the strike bridges themselves, and also, wherever possible, on the same railway line or the same road, so that they were closely matched on their local conditions with the frequently struck ones (thus reducing a source of error due to control bridge sampling). This method of matching was undertaken for approximately 50% of the strike bridges. It was impossible to match the remaining 50% because there were no other bridges near the strike bridge, so these controls were selected from a wider area using the AA Trucker's Atlas (1993). The matching criterion used for these cases was that the control bridge had to be on the same type of road (e.g. B road) as that on which the strike bridge was situated.

3.2.2 Apparatus

A 35mm camera was employed to record features of the bridge and its environment and an ultrasonic measure (Plasplugs Ltd) was used to survey the bridge heights. The manufacturers of the ultrasonic measure (Ahmed, Plasplugs Ltd, 1995, Personal Communication) stated that each measuring device was tested to be accurate to 1%, thus at a height of 12' the error was less than 1.5". To check the accuracy, a laboratory trial of the device was performed by arranging large items at a series of set distances away (up to 25' away - determined by a conventional tape measure) and recording the responses of the ultrasonic measure. It was actually found to be accurate to 0.5 %, thus at a height of 12' the error was less than 0.75". The measurement trial was carried out on three occasions, each of which produced the same results, thus demonstrating the reliability of the distance information displayed.

A bridge assessment checklist was employed to record dimensions of the bridge height, the warning signs / bridge markings present and the specific features of the road environment (such as the general complexity of the environment). Following the identification of the dimensions that were to be assessed, the checklist (which detailed how such dimensions were to be operationally defined) was developed iteratively in the following stages. First, visits to local bridge sites were undertaken to obtain a basic understanding of the relevant factors at bridge sites and their local environment. Second, semi-structured interviews with lorry drivers were undertaken to obtain information concerning their understanding of the relevant bridge features. Third, the draft checklist was presented to each of a group of ergonomists, civil engineers and psychologists to obtain suggested improvements. Finally, local bridge sites were revisited to complete the revised checklist as a pilot study before the fieldwork proper. A copy of the checklist is shown in appendix A.

3.2.3 Procedure

The sets of 20 'strike' bridges and 20 control bridges were inspected between June and August 1995. The inspections were performed by two people for both safety reasons (e.g. to watch for approaching traffic while taking bridge measurements) and to form a consensus where the assessment criteria were subjectively rated. Each bridge, from both the strike and control sets, was assessed from both directions. The checklist was completed from one direction of approach to the bridge, with the differences, where appropriate, from the other direction of approach being noted. To enable a comparison to be made between the different sites, on measures such as environmental complexity, each site was inspected at 13.00 hours (plus or minus one hour). The procedure for each bridge assessment was as follows:

1. Photographs were taken of the bridge and its environment from both directions.

2. The minimum height of the bridge was measured. For girder type bridges the measured minimum height was obtained by taking a series of measurements vertically from the road surface throughout the length and width of the bridge - the lowest figure obtained was the measured minimum height. For arch bridges a chord marking on the bridge structure (generally together with markings painted on the road) showed the point at which the minimum height referred. For this type of bridge the measured minimum height was obtained by measuring at the outside edge of the chord marking throughout the length of the bridge. Additionally, at the same time, the sizes of the bridge markings were obtained by measuring the horizontal width of the markings.

3. Each bridge site was explored to a distance of at least 500 metres along all approach roads to the bridge, in order to gain a fuller picture of any surrounding signs and other potentially relevant features (it was found in the pilot study that the vast majority of the IBW signs, for example, were located within 400 metres of the bridge).

4. The remainder of the bridge checklist was then completed in full, including notes regarding special features (e.g. underbridge advertising). As mentioned in Section 3.1 above, the only two items that involved a partly subjective judgement were the classification of the general complexity of the environment and the classification of the amount of advertising around a bridge site, these were defined as follows:

- The classification of the complexity of the bridge approach was comprised from the following features of the road environment: number of other road signs (i.e. not bridge warning) in the vicinity, the nature and speed limit of the surrounding roads, bridge location (e.g. urban), the number of road junctions and other road tasks (e.g. traffic lights) within 300m of the bridge, and the position of the bridge with respect to the road (i.e. on a bend or a hill).

- The classification of the amount of advertising around a bridge site comprised of the number and the size of advertisements within 100 yards of the bridge. The advertisements were mainly displayed on billboards, bus stops and in shop windows. As a general guide, if the site had one to three medium sized (roughly 3 feet square) advertisements present then it was coded as having few advertisements present – if more than three were present (or they were of a larger size) then it was coded as having many advertisements present.

3.3 Results

As the two bridge groups were not fully matched pairs, where statistical tests were employed an independent groups test was used. Additionally, as the data obtained were not always of Interval level and the sampling of the bridges was non random, it was decided to use a non-parametric Mann-Whitney U test instead of a t-test (using the assumptions of a t-test, quoted by Cohen and Holliday, 1982).

3.3.1 Bridge Heights

Tables 3.1a and 3.1b show for each bridge site the measured minimum heights, the displayed signed heights and the differences between these two figures. From these tables it was found that the mean bridge height (using the measured minimum heights) was 13' 1" for the strike group and 13' 9" for the control group. Thus the strike bridges were, on average, 8" lower than the controls.

Table 3.1a: Measurements for the strike bridges (in feet/inches).

Identity and address of bridge	***Minimum height***	***Signed Height***	***Minimum height greater than signed height by***
Whitehouse Road -Swindon	10' 6"	10' 0"	6"
St. John's St. - Lichfield	14' 8"	14' 0"	8"
Gallows Hill - King's Langley	11' 9"	11' 3"	6"
Liverpool Road - Stoke	14' 5"	13' 9"	8"
Mill Lane - Bradford	11' 11"	11' 6"	5"
Aldwarke Road - Rotherham	11' 9"	11' 3"	6"
Thurlow Park Road - Tulse Hill	14' 10"	13' 9"	13"
Southend Lane - Sydenham	13' 6"	13' 0"	6"
Malmesbury Road - Swindon	14' 8"	14' 3"	5"
Dingley Road - Market Harborough	13' 10"	13' 6"	4"
Old Oak Common - Acton	13' 1"	12' 9"	4"
Stuntney Road - Ely	9' 5"	9' 0"	5"
Barrowby Road - Grantham	15' 2"	14' 6"	8"
Gunn Lane - Rochester	13' 11"	13' 6"	5"
Walsworth Road - Hitchin	13' 8"	13' 3"	5"
Stroud Green Lane - Finsbury Park	13' 4"	12' 9"	3"
West Street - Glasgow	11' 0"	10' 6"	6"
Cook Street - Glasgow	12' 10"	12' 6"	4"
Station Road - Langley	13' 11"	12' 9"	14"
Guildford Road - Woking	14' 3"	13' 9"	6"

Table 3.1b: Measurements for the control bridges (in feet/inches).

Identity and address of bridge	***Minimum height***	***Signed Height***	***Minimum height greater than signed height by***
A5127 - Lichfield	15' 5"	15' 0"	5"
Glebe Street - Stoke	11' 4"	10' 3"	13"
No. 90 - Stoke	15' 11"	15' 3"	8"
A6123 - Rotherham	12' 9"	12' 9"	0"
B5008 - Willington	13' 8"	13' 0"	8"
A5132 - Willington	12' 6"	11' 9"	9"
Off A6 - Market Harborough	14' 3"	13' 9"	6"
Toms lane - King's Langley	11' 8"	11' 3"	5"
Scotland Lane - Market Harborough	14' 5"	13' 9"	8"
A50 - Ashby de la Zouch	14' 11"	14' 6"	5"
B5006 - Ashby de la Zouch	14' 0"	13' 3"	9"
B586 - Moira	14' 4"	14' 3"	1"
Bryant Road - Rochester	9' 9"	9' 6"	3"
A6 - Ambergate	16' 3"	15' 9"	6"
A610 - nr. Ripley	14' 1"	13' 9"	4"
A610 (2nd) - nr. Ripley	15' 8"	15' 3"	5"
Bullbridge to Fritchley - Derby	13' 2"	12' 9"	5"
Deadman's Lane - Derby	12' 7"	12' 3"	4"
Off A444 - Castle Gresley to Cauldwell	13' 0"	12' 6"	6"
A444 - Burton on Trent	15' 7"	15' 3"	4"

A Mann - Whitney U test (corrected for ties) detected no significant difference between the two groups on measured bridge height ($Z=1.33$, 2-tailed $p > 0.05$).

The variation between the minimum measured height and the signed height indicated that the signed height was always lower than the minimum measured height, except for one control bridge where the heights were the same (this was an arch bridge). The range of the difference between the minimum height and the signed height was from 4" to 14" for the strike bridges and from 0" to 13" for the control bridges. As mentioned earlier, it is a legal requirement that the signed height of a bridge is at least 3" lower than the minimum measured height, it was found, however, that two bridges in the control group had differences of less than this amount. Applying a Mann - Whitney U test (corrected for ties) revealed no significant difference between the two groups on signed bridge height ($Z= 1.15$, 2-tailed $p > 0.05$) and no significant difference between the two groups on the difference between minimum height and signed height ($Z= 0.71$, 2-tailed $p > 0.05$).

An important point to note, however, was that for many of the bridges, the height was not constant throughout its length. The lowest point used in the tables above may be at any place under the bridge (not necessarily at the entrance or exit).

3.3.2 Bridge Warning Signs

A measure was taken of how often bridge warning signs were employed at the various bridge sites. The three different types of bridge warning signs (primary, intermediate and third stage) are described in Chapter 1. Table 3.2 shows the percentage of different bridge sites that had the three types of bridge signs present.

Table 3.2: Percentages of different sign types present at the bridge sites.

Category of sign	***Strike Bridges***	***Control Bridges***
Primary	55 %	55 %
Intermediate (IBW)	90 %	50 %
Third stage / on bridge	100 %	100 %

The only difference between the two groups was for the IBW signs - where 90 % of strike group sites had these signs present, whereas for the control group only half of all sites had IBW signs. Applying a Mann-Whitney U test (corrected for ties) to the data demonstrated that significantly more strike bridge sites had an IBW sign present when compared to the control bridge sites ($Z= 2.73$, 2-tailed $p < 0.01$).

IBW signs are a rectangular blue sign with white letters. As mentioned in Chapter 1, these are permitted by the DoT to contain a red minimum height roundel. For those sites that had these signs present, it was found that the strike group had proportionately less purely text-based signs and more signs containing a roundel than the control group. The strike bridge signs more frequently contained height information in both imperial and metric units than did the controls (displaying height information in both measurement units in 44 % of cases compared to 30 % of cases for the control bridges). Additionally, the sign for strike bridges was specifically lit (i.e. a light is fitted above the sign) in 50 % of cases compared with 40 % for the signs for the control bridges.

3.3.3 Bridge Markings

The DoT standard for bridge markings is a black and yellow hatching, and each bridge was assessed to determine whether it was painted in accordance with this. Table 3.3 shows these results, in terms of whether the markings were present or absent.

Table 3.3: Percentages of bridges that had markings.

	Strike Bridges	*Control Bridges*
Marking Present	70 %	55 %
Marking Absent	30 %	45 %

Applying a Mann-Whitney U test (corrected for ties) demonstrated no significant difference between the two groups as to whether the bridges had markings present ($Z=0.97$, 2-tailed $p > 0.05$).

The survey also measured the size of the markings on the bridges (i.e. the horizontal width of the markings around the sides and the vertical height of the markings at the top of the bridge). As is shown in table 3.4, the strike bridges had a wider range of marking sizes in comparison to the control group.

Table 3.4: Overall size of bridge markings.

Overall size of the Markings (in feet/inches)	*Strike Bridges*	*Control Bridges*
1' or less	31 %	0 %
1'1" to 2'	37 %	73 %
2'1" to 3'	6 %	27 %
3'1" and over	26 %	0 %

3.3.4 Bridge Environment

In the strike group, a slightly higher proportion of the bridges were in urban/industrial locations than were those from the control group (85% of the strike bridges as compared to 75% of the controls). Eighty percent of the strike bridges were either girder or combination type bridges compared to 55 % in the control group (the remainder in both groups were arch type bridges).

Examination of the lighting around the bridge showed that in 50 % of the strike group cases the bridge was lit, whereas in the control group this figure was only 10 %. However, in terms of the general lighting provision around the bridge (including street lamps), only a small proportion of both groups (5 % for the strike group and 10 % for the control group) had no lighting at all.

The number of advertisements around the bridge approach were coded by the two observers into one of three groups: 'many advertisements', 'few advertisements' and 'no advertisements', the results of this grouping are presented in Table 3.5.

Table 3.5: Number of general advertisements around the bridge sites.

Number of Advertisements	***Strike Bridges***	***Control Bridges***
Many Advertisements	25 %	15 %
Few Advertisements	50 %	35 %
No Advertisements	25 %	50 %

Thus 75 % of bridges in the strike group had advertisements (either 'many' or 'few') compared to only 50 % of bridges in the control group. In addition, those advertisements around the bridge sites in the strike group were, on average, judged by the two observers to be larger than those advertisements around the control sites. However, a Mann-Whitney U test (corrected for ties) detected no significant difference between the two groups on the number of advertisements they had, based on the above three category coding classification ($Z=0.97$, 2- tailed $p > 0.05$). Thus although the strike group, in general, contained more (and larger) advertisements on the approaches to the bridges, this difference is not statistically significant.

As mentioned in Section 3.1, the general complexity of the approach to the bridge environment was also coded into three groups: 'complex environment', 'moderate environment' and 'simple environment'. Although, as referred to earlier, the consensus of two raters viewing the bridge together was employed to score this measure, it still remained the most subjective result in this section. Table 3.6 shows the result this classification system produced for the two bridge groups:

Table 3.6: Complexity of the environment around the bridge sites.

Environment Category	***Strike Bridges***	***Control Bridges***
Complex Environment	45 %	0 %
Moderate Environment	45 %	65 %
Simple Environment	10 %	35 %

It can be seen that almost half the sites in the strike group were classified as 'complex' compared to none in the control group. The control group had over one third of sites classified as being a 'simple environment' - which compares to only 10% in the strike group. A Mann-Whitney U test (corrected for ties) demonstrated a highly significant difference between the two groups on the level of environmental complexity, based on the above three category coding classification ($Z=3.26$, 2-tailed $p < 0.01$). Thus, in general, the strike bridges studied here were in more complex environments than were the controls.

A final point to note was that the top of every bridge examined showed some evidence of strike damage, in fact the top of all the control bridges (and by definition all the strike bridges) had been hit at least once by a road vehicle.

3.4 Summary and Discussion

The main findings are discussed below in the same order that they are presented in the Results Section. It must be noted, however, that the differences found between the two groups of bridges cannot be said to directly cause strike incidents. The work by the DoT (1993a) (which investigated the reasons given by drivers of high-sided vehicles as to why they thought they hit a bridge, and is described in Chapter 1) stated that bridge strikes are a multi-causal problem. If this is the case, then no clear-cut cause and effect can be established in a survey such as the one reported in this Chapter. As the assessments were made after the bridge strikes had occurred, the most that could be determined from this work is that certain factors that may contribute to strikes are present in the environment of the frequently hit bridges.

3.4.1 Bridge Heights

The mean minimum height of the strike bridges was found to be 8" lower than the mean minimum height of the control bridges (this may, of course, be due to the selection of the control bridges). Although the height difference between the two groups was not statistically significant, this 8" difference may be critical. The DoT (1993a) stated that 67 % of bridges hit were between 12' and 14' high. Additionally, the DoT stated that the type of vehicle most likely to hit a bridge is a lorry - most of which are over 12' high. Thus it is proposed here that there is a case for re-designing low bridge warning signs to be specifically aimed at drivers of lorries and similar vehicles instead of being purely an information sign for all classes of vehicles.

The signed height for strike and control bridges was never higher than the measured minimum height, but in the case of the control bridges the standard (Circular Roads, 1987) for bridge signing was not always met because the signed height was not always 3" lower than the minimum height. At the other extreme, in one instance a signed height of 14" lower than the measured minimum height was recorded (for a strike bridge). In addition, the difference between the signed and actual height was generally not constant for the full length of each bridge - with the lowest point often not at the entrance or exit. So, frequently the lowest point was not immediately visible to the driver when approaching the bridge.

Such differences in actual versus signed height (and where the lowest point of the bridge is) may be an important factor in bridge strikes, as they could lead to drivers making wrong assumptions about the bridge height when deciding whether they can pass safely underneath it. This research questions why drivers should trust the height information on a warning sign when it is not always accurate (and could be as much as fourteen inches different from the real minimum height of the bridge). Having drivers know the height of their vehicles needs to be coupled with giving them realistic clearance height information (i.e. minimum bridge height plus a pre-defined safety margin). When a diversion is needed to avoid a low bridge, there are often large penalties for haulage operators (e.g. fuel and drivers' time), if the signs are perceived as inaccurately representing the bridge's minimum height, it is perhaps not too surprising that drivers occasionally deliberately ignore the warning information and try to gauge the height of the bridge for themselves. Although re-designing the markings to make the bridge appear lower than it really is may help to guide the drivers to make a cautious decision about whether they can proceed under a bridge, it should only be viewed as an absolute last resort. A safer system would be to have the height information on the sign accurate and consistent so that drivers can make the decision whether to continue towards a bridge as far ahead of it as possible.

3.4.2 Signs Present

The difference between the two groups was in the percentage of bridges that had IBW signs. Only half of control bridges had these signs compared to 90 % of strike bridges. Although this result may seem unusual, it is not known for each bridge when the signs were introduced (i.e. were they introduced after the bridge had been hit repeatedly?) or whether they have had any effect on the strike rate (in the terms of Edworthy and Adams, 1996a, the effectiveness score of the sign is unknown). If the strike rate has remained high despite the introduction of these types of warning signs, which in some cases seems likely judging by the recent damage to the bridges, it is a good argument for the re-design of this type of sign to be undertaken to make it more effective.

3.4.3 Bridge Markings

The data showed that more strike bridges had markings present when compared to the control bridges (although this difference was not statistically significant), hence the bridges in the strike group were generally marked marginally better than the controls. As for the IBW signs discussed above, it is not known when the markings were introduced and whether they have had any effect on the strike rate. Again, as with the IBW signs, if it is the fact that the strike rate has remained high despite the introduction of bridge markings (as seems likely in most cases, from an assessment of the recent damage to the bridges), it is a justification for the re-design of the markings to be undertaken to make them more effective.

The high percentage of strike bridge sites that have IBW signs and bridge markings may represent attempts by the local authorities to improve the environment of high risk bridge sites, thus compliance with the DoT design standards for the warning signs and markings does not seem to be a large problem. However, if these design standards are not as effective as they could be (in terms of reducing bridge strikes), then the problem of poor visual warning signs and markings remains - producing well-designed standards is a precursor of correctly implementing them. Indeed, at busy traffic sites it might be possible that to add more ineffective signs is counterproductive as they may make an already complex environment even more complex.

3.4.4 Bridge Environment

Generally, the bridge sites in the strike group were located in more complex and distracting environments when compared to those in the control group. This may be explained by a larger number of strike bridges being in urban areas. Strike bridges generally had more advertisements around them than did the control bridges (but not significantly more). The overall environment for strike bridge sites was found to be significantly more complex than for the control sites (in fact no sites in the control group had an environment regarded as 'complex'), although as was stated earlier, the rating was largely a subjective measure. While it may not be possible to easily develop countermeasures to reduce the environmental complexity and busy road conditions of many of the strike bridge sites, it should at least be possible to slightly reduce the distractions for drivers by limiting the number of advertisements displayed near a bridge site.

Bridge lighting was generally marginally better for the strike bridges when compared with the controls (i.e. more strike bridges were specifically lit). However, like the IBW signs and bridge markings, it is not known when the improved lighting was installed (i.e. was it in response to a high number of bridge strikes?).

Finally, the finding that **all** bridge sites had been struck was surprising, and shows the widespread nature of the bridge strike problem. It was also interesting to note that several of the bridges in the control group had no officially recorded instances of being struck (McGrane, 1995), thus showing that the records held by Railtrack under-report the nature of the problem.

3.5 Conclusions

The main results found from this study were that the strike bridges were, in general, slightly lower than those bridges selected as controls. In addition, there were significantly more IBW signs for the strike bridge group when compared to the control group and there were more standard markings on the strike bridges when compared to the controls. Furthermore, the strike bridges were, on average, in more complex environments. There were generally more advertisements near the strike bridges and the overall environment for strike bridges was rated as significantly more complex than it was for those bridges selected as controls. Finally, surprisingly all the bridges inspected (including the controls) had been struck by road vehicles.

Based on these results, the following suggestions for future work are proposed.

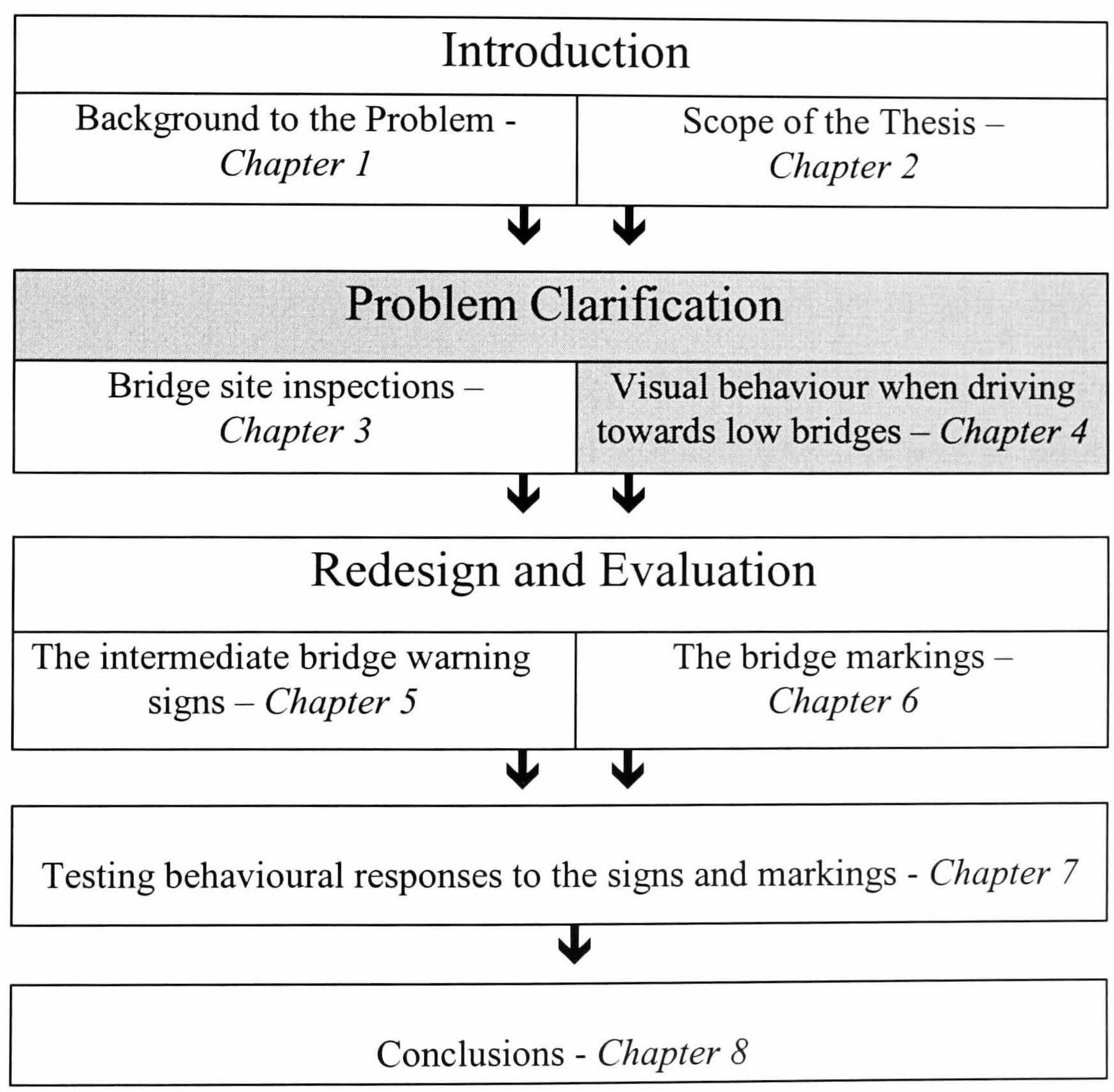
Firstly, the signed heights for bridges should more accurately reflect the measured minimum height of the bridge. Standardising the safety room to an exact amount, e.g. three inches, below a bridge's minimum height should also be considered to improve the accuracy, and hopefully validity, of the sign's height information (this would mean signs would no longer be marked in three inch multiples as they are currently).

Secondly, the number of potential distractions within the bridge environment should, if possible, be reduced. As an initial step, advertisements on, or next to, low bridges need to be reduced as much as possible.

Lastly, the design (as opposed to the implementation) of the IBW signs and bridge markings needs to be further examined. This issue forms the main area of research considered in Chapters 5 (examining the IBW signs) and 6 (examining the bridge markings).

Chapter 4:

Visual Behaviour when Driving Towards Low Bridges



4.1 *Introduction*

As part of the process of improving the visual warnings that a high-sided vehicle driver receives when approaching a potentially dangerous situation (i.e. a low bridge), a section of this research investigation involved an examination of what an operator actually looks at when in this driving situation. Following Gale (1996a), who advocated this approach for driver interaction assessment, the recording and analysis of drivers' saccadic eye movements when approaching low bridges allows the drivers' visual behaviour with respect to the road environment to be identified and quantified. Although a great deal of research has previously been performed in the general area of eye movements during driving (e.g. Zwahlen, 1981; Hughes and Cole, 1986; Luoma, 1988; Taori and Kinya, 1990; Hall, McDonald and Rutley, 1991; Hella, Tisserand and Schouller, 1991, and Theeuwes, 1996), and such research has helped refine the approach taken in this current investigation, no previous work has specifically examined visual behaviour when driving towards low bridges. The research presented here looks at this issue via two related experiments.

The first experiment examined the amount of visual attention a driver of a high-sided vehicle gives to the various warning signs encountered when watching a video of driving towards a low bridge, while performing a simplified driving task. This driving task consisted of the subjects having to use the brake and accelerator pedals to react to the road scenes. The approach followed work by MacDonald and Hoffman (1991) who found a very close correlation between a driver's awareness of traffic sign information in real driving when compared with a laboratory situation in which subjects were performing a simplified driving task. The actual responses subjects made with the brake and accelerator pedals in the current study were not recorded, as the function of instructing them to press the pedals was only for them to think that their responses were being examined. The response measure in the current investigation was the subjects' visual search behaviour, and the aim was to establish how many subjects actually detected the IBW signs. A related question that the current study also examined was how long the signs were actually looked at by each driver. Although it may not be necessary for a driver to fixate on a road sign for too long (and in some cases this may even be dangerous, if they neglect other aspects of the environment), a certain minimum time period to read the information contained in the sign is essential. These data (i.e. the number of subjects who detected a sign and how long they fixated it) were then compared with similar data for subjects looking at other types of traffic signs (used as controls). For the dependent variable of number of subjects fixating a sign, these other traffic signs were matched to the IBW ones in terms of:

1. Location, following Pottier and Pottier (1988) who showed stimuli of simple and complex sites and found that sign detection was significantly influenced by location.
2. Traffic density, after Mori and Abdel-Halim (1981) who found that different traffic conditions influenced road sign recognition and non-recognition. In general, they found that the busier the road environment the worse the signs were recognised. For the dependent variable of total fixation time, the matching between the IBW and other traffic signs needed to be even more strict to allow for a meaningful comparison between times[1]. Therefore, in addition to location and traffic density, these other traffic signs were also matched to the IBW ones in terms of:
3. Size, following King, Sneed and Schwab (1991) who found that the sign size affected perceptual performance.
4. Information content, based on the results of the reading time experiments of Hall, McDonald and Rutley (1991) who found traffic sign reading time increased in a linear manner with the number of words contained on the sign.
If the IBW signs were not detected by many subjects (or fixated for too short an amount of time) when compared with other carefully matched signs, then their effectiveness as a visual warning must be questioned. It is the hypothesis of this section of the study that the IBW signs will compare badly on measures of visual behaviour when compared with other traffic signs.

The second experiment examined where drivers' looked when approaching two low bridges and for how long specific areas of interest in the environment were visually attended to by the drivers. This is similar to the approach taken by Zwahlen (1981) who, in his work concerning driver eye scanning of warning signs, considered

[1]Ideally, for the variable of number of subjects fixating a sign, the other traffic signs would also be matched to the IBW signs for size and information content. This was, however, impossible due to the specific designs of most of these other traffic signs - to apply the stricter matching criteria to both of the dependent variables would have reduced the sign group from 8 to 4. Therefore a weaker matching criterion was employed with the first dependent variable.

durations of fixations for various features in the road environment. The aim of the current experiment was to establish how long relevant features of the environment (e.g. the bridge markings) and irrelevant features of the environment (e.g. advertisements on the bridge) were attended to by drivers. As driving a lorry when approaching a low bridge is a visually demanding task, time spent looking at irrelevant features in the environment perhaps can be considered as 'wasted' time. This is supported by Boersema and Zwaga (1985 and 1990), who found that the inserting of advertisements in a visual scene lessened the conspicuity of routing information. It was therefore the hypothesis of this experiment that the amount of visual attention drivers give to the relevant features of the environment (e.g. the bridge markings) is low, and that the amount they give to irrelevant features, in terms of navigating a high-sided vehicle through a low bridge (e.g. the advertisements on the bridge), is generally fairly high.

4.1.1 Research Objectives

For both of these experiments, the overall objective was to examine visual behaviour when driving towards low bridges. The background assumption was that improving the environment before a bridge, so that the more relevant objects are attended to (for example, warning signs or the low bridge itself), would result in an improvement in the driving behaviour of the drivers of high-sided vehicles, which should therefore result in fewer bridge strikes.

4.2 Experiment 1: Analysis of Drivers' Eye Movements When Passing Traffic Signs

4.2.1 Method

4.2.1.1 Subjects

Twenty-nine staff from the University of Derby were initially employed as subjects. This figure was later reduced to twenty-seven as two subjects wore a type of contact lens which caused the eye movement system to produce unreliable measurements. All 27 subjects held car driving licences. Ten of the subjects (37 %) had regular and recent experience of driving high-sided vehicles, empirically defined as including tractors, transit vans or lorries. Approximately half the group was male (44.4 %) and half female (55.6 %). The age range was between 20 and 49 years with a mean age of 29.6 years.

4.2.1.2 Equipment

The study was performed in a laboratory. A 1987 Ford Cargo lorry cab (1615 model) was used as the vehicle being 'driven' by the subjects. This was mounted to a realistic height on a metal frame. The steering wheel was locked to prevent subjects turning the wheel (as eye position was being recorded through a hole in the vehicle's dashboard in the middle of the steering wheel, and keeping it motionless reduced the amount of eye movement data lost). All the windows of the cab were intact and the brake and accelerator pedals were fitted with small springs to give them the 'feel' of being real pedals controlling the vehicle.

A large, high-resolution monitor was employed to display the video footage of road scenes. This was positioned in front of the driver at a distance of 86 cm from the eye position of the driver (i.e. just outside the vehicle's windscreen). The monitor display subtended 25.55° horizontally and 19.14° vertically at the subjects' eye position. As this study involved looking at traffic signs, containing fine detail, a monitor was chosen as the picture resolution was better than when the image was projected on to a wall in front of the subjects.

An ASL 4000 series eye movement measuring system was employed to record the drivers' visual behaviour. The remote version of the system was used and recorded the subjects' saccadic eye movements through the dashboard of the vehicle. This system works by detecting two attributes of the eye, the pupil and corneal reflex, in a video image. It produces point of gaze data by means of a cursor displayed on a scene monitor. While subjects are watching a video of driving along a road, the monitor displays the scene, together with where the subjects are looking as they traverse all points along the route. A video recording is taken directly from the monitor, to be used for later analysis.

Figure 4.1 shows the experimental arrangement of the equipment.

Figure 4.1: Eye movement recording set-up.

4.2.1.3 Stimuli

A video recording of road scenes whilst driving was made using a Panasonic VHS camera (model M50). This was filmed from the top of the windscreen of a large car at a height of 1.30 metres (4' 3"), so being reasonably close to the eye height a driver in a light truck (following the work of Cobb, 1990, who found that the mean driver eye height in a light truck is 1.63 metres). The camera had an in-built anti-vibration device to minimise the amount of wobble recorded when the vehicle went over bumps in the road. The driving footage was recorded at a speed that a lorry would be likely to be travelling (i.e. 25 mph), and was filmed in urban environments which all had generally light traffic densities. The time of day the recording was made was between 10 a.m. and 1 p.m. and the weather was cloudy but fairly bright. The VHS recording was then copied to S-VHS videotape and edited for subsequent playback to subjects.

The video recording consisted of an initial five minutes of static calibration points (used to calibrate the eye position of the subjects), followed by eight minutes of driving footage which consisted of the following:

- Two minutes of driving (as an introduction).
- Two and a half minutes of the approach to a low bridge (which included all the

warning signs before the bridge).

- Two minutes of general urban driving (which included several warning signs relevant to a lorry driver, such as speed limit signs and road junction signs).
- One and a half minutes of the approach to a second low bridge (again, including all the warning signs before the bridge).

As stated earlier, the main aim of this study was to assess the amount of visual attention the subjects gave to the various bridge warning signs and to compare these with the results obtained for the other general warning signs. Eight traffic signs on the video were identified and the drivers' saccadic eye movements with respect to these signs were coded and analysed. The signs, in order of viewing, were:

1. **Routing sign situated in Swarkestone, Derbyshire (Routing-1)**. This was a large white rectangular sign positioned several hundred metres before a junction, containing information about the various routes ahead. For one of the possible routes it also displayed a height limit roundel to warn of the reduced clearance ahead. This sign was situated approximately 400 metres before the IBW sign.

2. **Sharp bend ahead sign in Swarkestone, Derbyshire**. This was a triangular red and white symbolic sign illustrating the sharp bend ahead. Immediately below this was a smaller rectangular sign with a text-based version of the warning. This sign was positioned 200 metres before the IBW sign, thus being in a similar traffic environment to the bridge warning sign.

3. **IBW sign situated in Swarkestone, Derbyshire (IBW-1)**. This was a blue text based sign with white lettering. It was situated directly at the intersection of two roads, at a busy junction. Because of its position and due to the complexity of the scene in which it was positioned, it was chosen as an example of an IBW sign that would not be expected to be very obvious to drivers of high-sided vehicles. This sign is shown in Figure 4.2.

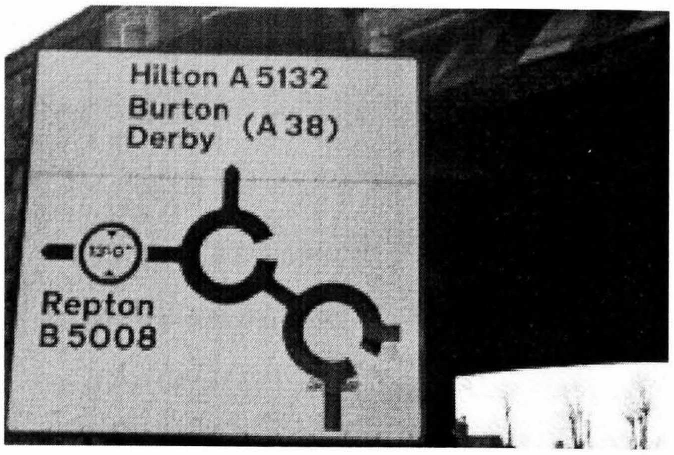
Figure 4.2: IBW-1 sign.

4. **Road junction ahead sign in Swarkestone, Derbyshire**. This was a triangular red and white symbolic sign illustrating a road junction ahead (2 minor roads joining the major route). It was situated approximately 250 metres after the IBW sign so, like the 'sharp bend ahead' sign, it was in a similar traffic environment to the IBW-1 sign.

5. **Third stage bridge warning sign in Willington, Derbyshire**. This was a triangular red and white sign mounted on a post which was positioned immediately before a low bridge, the sign showed the height of the bridge in feet and inches.

6. **Routing sign situated in Willington, Derbyshire (Routing-2)**. Like the Routing-1 sign in Swarkestone, this was a large white rectangular sign positioned several hundred metres before a junction containing information about the various routes ahead. For one of the routes it also displayed a height limit roundel to warn of the reduced clearance of another bridge ahead. This sign was situated next to the low bridge, but gave warning information about another low bridge on one of the routes in front. The traffic environment was judged to be similar to that around the IBW sign in Lichfield. This sign is shown in Figure 4.3.

Figure 4.3: Routing-2 sign.



7. **Speed limit 40 mph situated in Lichfield, Staffordshire**. This was a circular red and white sign with a black '40' in the middle of it. Because it was in a similar traffic environment to the IBW sign in Lichfield, it was compared with this bridge sign for the number of drivers who fixated it (although it must be noted that the speed limit sign was only approximately 10% of the size of the bridge warning sign).

8. **IBW sign situated in Lichfield, Staffordshire (IBW-2)**. This was a blue sign with white lettering. It differed slightly from the IBW sign in Willington in that it contained a red and while roundel containing the height of the bridge ahead. It was a large sign situated directly at the side of a straight road in a traffic environment judged to be fairly simple (e.g. no road junctions were nearby). Because of its prominent position, large size and the simple traffic environment that the sign was situated in, it was chosen as an example of an IBW sign which would be expected to attract the attention of a large number of drivers of high-sided vehicles.

4.2.1.4 Procedure

Each subject was tested individually. Subjects were seated in the lorry cab and the room lights were dimmed to approximately 8 lux to increase the brightness contrast between the road scenes displayed on the monitor and the remainder of the laboratory. Each subject was informed that their eye movements during the experiment were to be recorded and that their eye position would first be calibrated, before the procedure was explained to them. The videotape showing the static calibration points was then displayed to the subjects and they were instructed to look at each point in turn. When the experimenter was satisfied that the calibration was accurate, the experimental procedure below was then read to the subjects.

> *"I want you to try to imagine that you are driving this lorry. On the screen in front of you I'm going to show you videotape of general driving. Please try to watch the video as you would normally when driving. Please try to sit as still as possible when watching the footage."*
>
> *"As well as watching the video I also want you to use the accelerator and brake pedals as you would normally when driving. However, the video will not change due to your responses. The footage will last about 8 minutes, but I will not be recording the first minute to give you chance to get used to things. Any questions before I start the video?"*

The videotape was then started, several seconds later the recording of each subject's visual behaviour was begun. When the tape was finished the lights were turned up, the subjects were helped out of the cab and thanked for their time.

4.2.2 Results

The data on video were coded frame-by-frame and were later separately checked by an independent observer (who was also experienced with the task) to confirm accuracy. Initially, they were analysed in terms of whether subjects fixated on the various road signs. A fixation was defined as being over 200ms. This figure is normally regarded as the minimum time needed for a fixation to occur (Widdel, 1984). In addition, an area of 2° around each sign was defined as the fixation target zone, as the eye movement recording system was accurate to approximately 1°, this therefore allowed for slight recording errors. Following Theeuwes (1996), it was considered that once the eye fixation fell within a pre-defined sign target zone, then the sign could be considered as having been detected. It must, however, be conceded that a direct relationship does not exist between attention and fixation (Gale, 1997). Thus looking at a sign does not necessarily imply that it has been detected (as, for example, some feature in peripheral vision might be being attended to). So, in this experiment, caution must be applied when considering detection of signs, as it is theoretically possible that such fixated signs were not actually perceived. Table 4.1

shows the results produced for the eight different signs (in ascending order).

Table 4.1: Percentages of subjects who detected the different traffic signs.

Sign	***Percentages of subjects who detected the sign***
IBW-1	4 %
Sharp bend ahead	19 %
Road junction ahead	22 %
Routing-1	37 %
Speed limit 40 mph	41 %
IBW-2	48 %
Third stage bridge warning	52 %
Routing-2	63 %

A Wilcoxon Matched-Pairs Signed-Ranks Test was applied to the above data between pairs of signs at least one of which was an IBW sign (matched in terms of location and traffic density - as described in Section 4.1 earlier). The following significant differences, shown in Table 4.2, were found between pairs - with the signs in column A being detected by significantly more subjects than those in column B.

Table 4.2: Significant differences obtained between pairs of signs.

Column A	**Column B**	***2-tailed p = (to 3 decimal places)***
Routing-1	IBW-1	0.008
IBW-2	IBW-1	0.002
Third stage bridge	IBW-1	0.002

There were no significant differences between the following matched pairs of signs involving the IBW signs (again in terms of whether one sign was detected by significantly more subjects than the other sign, at 2-tailed $p > 0.05$).

- 'Road junction ahead' and IBW-1
- 'Sharp bend ahead' and IBW-1

- 'Speed limit 40 mph' and IBW-2
- 'Third stage bridge' and IBW-2
- Routing-2 and IBW-2

As was described in the introduction, the IBW were also matched with other traffic signs in terms of location, traffic density, size and information content. For additional analysis, an examination of total dwell time was performed. This resulted in only the two Routing signs, out of the six other traffic signs used in the previous dependent variable analysis, meeting these stricter matching criteria.

Total dwell time, defined here as the total amount of time that subjects fixated on a sign, including re-fixations, was calculated for the two IBW signs and the two matched signs. The mean total dwell times for the four signs was calculated by dividing total dwell time by the number of subjects who fixated on the signs. This produced the results shown in Table 4.3:

Table 4.3: Total mean dwell time for fixating subjects.

Name of sign	***Dwell time***
IBW-1	0.68 seconds (n=1)[2]
IBW-2	2.25 seconds (n=13)
Routing-1	1.88 seconds (n=10)
Routing-2	1.06 seconds (n=17)

(n = number of subjects who fixated the sign)

Another method of analysing these data was to look at total dwell time that was divided by the whole group of subjects (i.e. n=27) rather than just those fixating on the sign. This allowed all the data to be considered - as subjects who did not look at the sign would be included in the analysis (with a dwell time on that sign of 0 seconds). This produced the results shown in Table 4.4:

[2] Note: caution must be applied to this figure as only one subject looked at this sign.

Table 4.4: Total mean dwell time for all subjects.

Name of sign	*Total mean dwell time for all subjects*
IBW-1	0.03 seconds
IBW-2	1.08 seconds
Routing-1	0.70 seconds
Routing-2	0.67 seconds

Applying a Friedman Two-Way ANOVA to the above total mean dwell time for all subjects produced a highly statistically significant difference between the four figures ($p < 0.01$). To find where the difference occurred a t-test for paired samples was applied, which found:

- A highly significant difference between Routing-1 and IBW-1 ($t=2.96$, 2-tailed $p < 0.01$).
- A highly significant difference between Routing-2 and IBW-1 ($t=3.87$, 2-tailed $p < 0.01$).
- A highly significant difference between IBW-1 and IBW-2 ($t=3.8$, 2-tailed $p < 0.01$).
- No significant difference between Routing-1 and Routing-2 ($t=0.11$, 2-tailed $p > 0.05$).
- No significant difference between Routing-2 and IBW-2 ($t=1.35$, 2-tailed $p > 0.05$).

Thus IBW-1 had significantly lower amounts of mean dwell time when compared with the IBW-2 sign or to the two Routing signs.

Averaging the above data for the two IBW signs produced a total mean dwell time of 0.55 seconds. The average total mean dwell time for the two Routing signs was 0.68 seconds. A t-test for paired samples found no significant differences between these figures ($t = 0.62$, 2-tailed $p > 0.05$), so the Routing signs do not have a significantly higher mean dwell time when compared with the IBW signs.

4.3 Experiment 2: Analysis of the Visual Search of Drivers When Approaching Two Low Bridges.

4.3.1 Method

4.3.1.1 Subjects

Ten people were employed as subjects, eight of these were drivers of high-sided vehicles (all holding some class of HGV licence) and two were car drivers (holding current car licences). Nine were male and one female. The age range was 25-65 years; the mean age was 39.6 years.

4.3.1.2 Equipment

The ASL 4000 eye movement measuring system and the Ford Cargo lorry cab were used in the same arrangement as described in the previous experiment. This second experiment, however, focused specifically on the bridges (as opposed to the focus being on the IBW signs in the first experiment) and so it was necessary to see the approaching bridge as a large object. For this reason, instead of the high-resolution monitor, a Proxima 8300 multimedia projector was used to display the driving video on to a wall in front of the subject, although this did give a slightly lower resolution when compared with the monitor used in the first experiment. The size of the image projected on to the wall subtended a visual angle of 24.8° vertically and 34.7° horizontally at the driver's eye.

4.3.1.3 Stimuli

A recording of driving, filmed from a large lorry cab by a professional BBC cameraman, was used as the stimulus. The height from which the driving was filmed was approximately 2.0 metres, thus it was in line with the measurements Cobb (1990) obtained for truck drivers' eye levels. Filming at the height from which a lorry driver would be viewing the bridge was considered to be critical for an experiment of this nature. The video was edited and copied to S-VHS video. It consisted of three clips. The first was a one minute sequence of general urban driving at 25 miles per hour, to familiarise the subjects with the task (i.e. the height from which the video was filmed and the speed of the lorry). Following this, the second clip was a nine second sequence of the approach to a low bridge (Barrowby Road, Grantham - signed height 14' 6"). The third clip was a nine second approach to another low bridge (Deadman's Lane, Derby - signed height 12' 3"). A one second blank was edited between each clip to indicate the finish point of each specific clip. Figure 4.4 shows the order in which the stimuli were displayed. Figures 4.5 and 4.6 show pictures of the two bridges.

Figure 4.4: The presentation order of the road scenes.

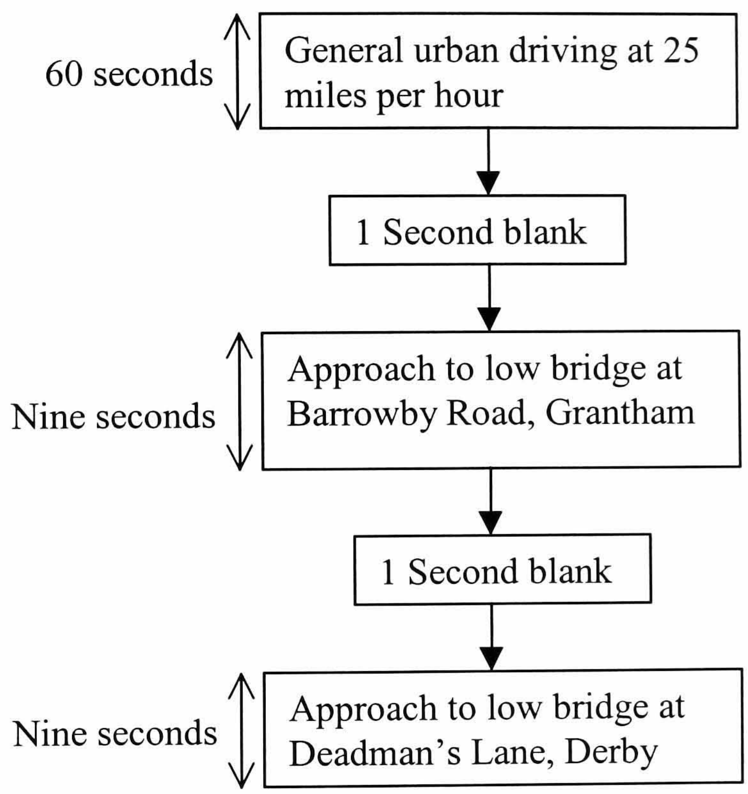


Figure 4.5: Bridge at Barrowby Road, Grantham.

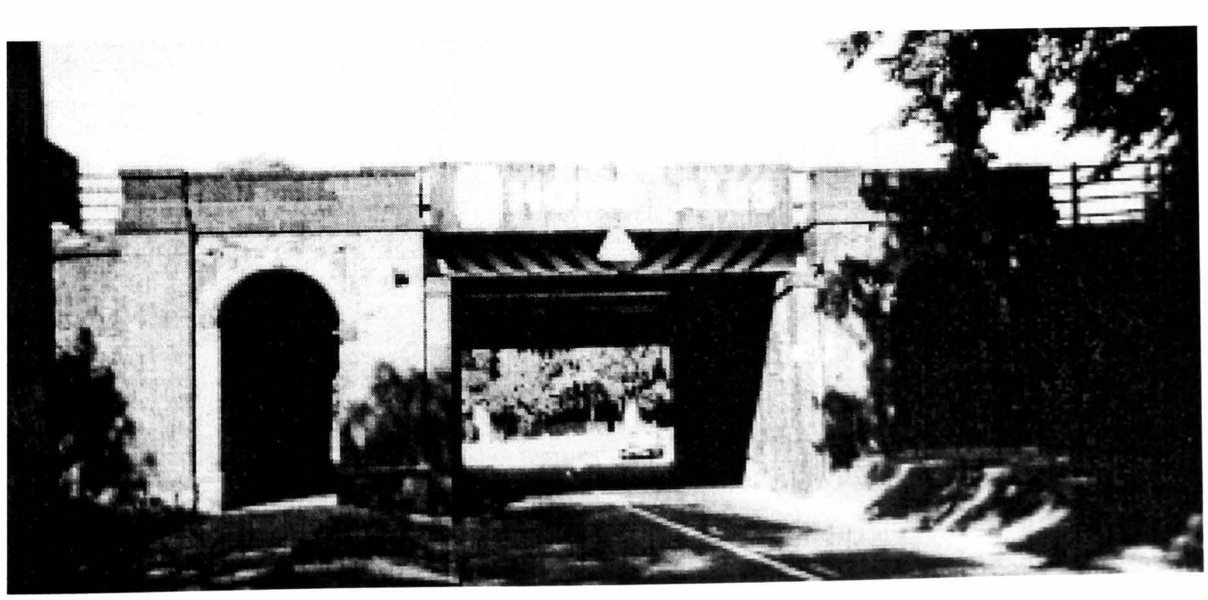


Figure 4.6: Bridge at Deadman's Lane, Derby.

For each of the bridge approaches the clips started ten seconds before the bridge and finished one second before reaching it. This end point was chosen because if the video was any closer than one second away from the bridge nothing else could be seen but the bridge, and it was considered that to record where a subject was looking, when all they could look at was the bridge, would not to be beneficial. Additionally, it was well past the point when a driver could actually stop a real lorry (including the time needed to perceive the hazard, make a decision and initiate a response, as well as the vehicle's actual braking time). This was upheld by Summala (1981) on driving response latencies – where it was reported that at least 1.5 seconds were needed for drivers to respond, by steering, to an unexpected road environment, by Schweitzer, Apter, Ben-David, Liebermann and Parush (1995), where it was discovered that minimum braking time responses, not including the actual stopping distance, were over 0.6 seconds, and by Olson and Sivak (1986) on perception response times to unexpected roadway hazards, where it was found that the majority of drivers applied brakes within 1.6 seconds. Therefore examining a driver's eye movements after a point on the approach to a bridge when a strike accident was inevitable was not directly relevant to this research.

4.3.1.4 Procedure

Each subject was tested individually as they sat in the driver's seat of the lorry cab in the darkened laboratory (set at 8 lux). Initially, the eye movement system was calibrated by having each subject look at nine points projected on to the wall in front of them. The experimental procedure below was then read out to the subject.

> *"We are going to show you some video footage taken from the driving position in a lorry cab. Please try to imagine that you are driving the vehicle when you see these clips and look at the road scene as you would normally when driving. The video clips will last about one and a half minutes. Please try not to move around too much while the films are playing."*

The video was then set running and the eye movement recording system was started. When the tape was finished the lights were turned up, the subjects were helped out of the cab and thanked for their time.

The only task for each subject was to watch the driving video. It was felt that having a simplified driving task (as employed in the previous study) was unnecessary as the approaches to the two bridges were only of several seconds' duration each.

4.3.2 Results

For the two bridge approaches, areas of interest that were attended to by the subjects were specified. These areas of interest were established by a preliminary analysis of the video recordings, by interviews with the lorry drivers and by following previously used driver visual behaviour analysis techniques. These earlier techniques used by Cole and Hughes (1990) and later by Lansdown (1996), essentially carved up the road scenes into sections. The sections used in the work by Cole and Hughes (1990) included the road ahead, the sky and the environment on either side of the road. For the current experiment, the areas of interest were specified as follows:

- **Road environment through the bridge** - anything that could be seen through the bridge, including the road directly underneath the bridge.
- **Road before bridge** - all the road up to that directly underneath the bridge.
- **Road signs** - all road signs (not just bridge warning signs) on the approach to the

bridge, but not including the actual height sign on the bridge itself (the third stage sign).

- **Top of bridge** - this included the height sign on the bridge, the markings and the bridge underside (additionally, in the case of the Grantham bridge it included a large advertisement along the top of it).
- **Left side of bridge** - all of the left side of the bridge structure.
- **Right side of bridge** - all of the right side of the bridge structure.
- **Sky** - the sky over the top of the bridge.
- **Other / Transition** - this includes situations where subjects were looking elsewhere than those areas indicated above (e.g. at the grass verges) and when they were between fixations (i.e. not looking at anything in particular).

Data were analysed for a period of six seconds (starting seven seconds before the bridge and finishing one second before it). Although the approaches to both bridges were approximately nine second clips, the first few seconds were discounted in order to standardise the amount of time being analysed, as data were often 'lost' in the first three seconds (for example due to the subjects moving their heads).

The video recordings of all the subjects' eye movements when approaching each bridge were coded frame-by-frame and were later separately checked by an independent observer (who was also experienced with the task) to confirm accuracy. The data from nine subjects were analysed (the data for the other person were very poor due to an eye defect and were not accurate enough to be analysed). The percentage of the total time each area of interest was fixated was then calculated for each subject. In turn, mean percentages for all the subjects were determined. This allowed a comparison between the areas of interest for each bridge approach, and to a limited extent between the two bridges (bearing in mind that they were different bridges), to be carried out whilst minimising inter-subject variability. Table 4.5 shows these mean data.

Table 4.5: Mean fixation percentages when approaching the two bridges.

Area of Interest	*Barrowby Road Bridge*	*Deadman's Lane Bridge*
Road Environment Through the Bridge	12.4 %	14.0 %
Road Before Bridge	2.3 %	5.4 %
Road Signs	8.8 %	10.1 %
Top of Bridge	41.3 %	36.1 %
Left Side of Bridge	3.8 %	8.4 %
Right Side of Bridge	0.2 %	4.2 %
Sky	0 %	1.1 %
Other/ Transition	31.2 %	20.7 %

As subjects spent a large percentage of their time looking at the area of interest 'Top of Bridge', additional analysis was undertaken to explore this further. This analysis revealed the following:

1. **Barrowby Road Bridge**. Approximately 40 % of that the time subjects fixated the top of the bridge (i.e. 16.5 % of the total time when approaching the bridge) was spent looking at the height sign on the bridge and 35 % (i.e. 14.5 % of the total time) was spent looking at the advertisement on the top of the bridge. Less than 5 % of this time (i.e. less than 2.1 % of the total time) was spent looking directly at the bridge markings.
2. **Deadman's Lane Bridge**. Approximately 65 % of the time (i.e. 23.5 % of the total time) was spent looking at the height sign on the bridge and, as with the other bridge, less than 5 % of this time (i.e. less than 1.8 % of the total time) was spent looking directly at the bridge markings.

4.4 *Summary and Discussion*

4.4.1 Experiment 1

When driving a high-sided vehicle it would be expected that all drivers would detect signs warning them of reduced clearances ahead, would read the signs, would process the information and would use it to behave in an appropriate manner to avoid an accident. This was found clearly **not** to be the case. In the worst case (IBW-1) only 4 % of drivers fixated, and therefore detected, the sign. In the best case (IBW-2) 48% of drivers fixated the sign – so over half of the drivers tested did not detect the sign warning them of a potentially very dangerous situation ahead.

The main aim of this first experiment was to assess the amount of visual attention the subjects gave to the IBW signs and how this compared with other warning signs. The results showed that there was a wide variation in the number of subjects who detected the eight traffic signs chosen for this study. This ranged from the 4% of the subjects who fixated IBW-1 to 63% who fixated Routing-2. A lower number of subjects fixated the IBW-1 than the two control signs. For example, the sharp bend ahead was fixated by 19% of the subjects and the road junction ahead by 22% of the subjects (but there was no statistically significant difference between the IBW-1 and these two control signs at the 5 % level). There were statistically significant differences when the IBW-1 was compared with Routing-1 or with the third stage bridge sign (both at the 1 % level), with 37 % of subjects fixating the Routing-1 sign and 52 % fixating the third stage bridge sign compared with the 4 % fixating the IBW-1 sign. Thus, overall the IBW-1 compared badly with the other four warning signs in terms of the number of subjects looking at it.

The other IBW sign (IBW-2) performed better. There were no significant differences (in terms of the number of subjects detecting the sign) between this sign and the other signs used to compare it with, that is, the speed limit 40 mph, the Routing-2 and the third stage bridge warning sign. Indeed this IBW-2 sign was fixated by significantly more subjects than the IBW-1 sign (at the 1 % level).

Analyses of the total mean dwell times for the two IBW and the two Routing signs gave similar results. When the total mean dwell time for all subjects was calculated, it was found that the IBW-1 performed significantly worse (at the 1 % level) than the other three signs. The average total mean dwell time for the two IBW signs was lower than for the two Routing signs (but not significantly so). While it may not be necessary (or even desirable) for traffic signs to be looked at for long periods, a large amount of previous work in this area has examined minimum time periods to understand signs. For example: Moore and Christie (1963) concerning laboratory studies of sign reading distances; Ells and Dewar (1979) connected with comprehension of verbal and symbolic traffic signs; Zwahlen (1981) with regard to eye scanning of warning signs in the road environment; Mori and Abdel-Halim (1981) on road sign recognition by means of fixation time in free driving; and more recently by Spijkers (1991) on the recognition of signs in different traffic environments, and Hall, McDonald and Rutley (1991) concerning reading time for direction signs, have all found that at least 0.2 seconds, and generally much more time, is required to read and understand the information on signs as complex as the IBW-1 and -2. So, in the current investigation the 0.03 seconds spent (on average) fixating the IBW-1 was far too short[3].

Thus the hypothesis forwarded earlier, that the IBW signs would compare badly with other traffic signs on measures of visual attention, has to be accepted for the IBW-1 sign when compared with several of its controls (i.e. other matched signs) - both in the number of subjects who detected it and on total mean dwell times.

It must be noted, of course, that this study was not a formal experiment in the sense that no variables (in this case, road signs) were manipulated. As described in the introduction to this chapter, however, the IBW signs were carefully matched as closely as possible to the control signs in terms of traffic density, location, sign size and information content. So the findings that the IBW-1 was looked at less than a sharp bend or a road junction sign, and that the IBW-2 was fixated by only about as many people as was the 40mph speed limit sign, were valid results within the context of a study that examined the detection of traffic signs in their natural environment.

[3] Although it must be noted that the method used to calculate this figure includes those people who did not look at the sign at all, being assigned a time of 0 seconds fixating it. As the vast majority of subjects did not look at this sign it resulted in the figure being very low.

The set up used for this experiment was generally effective, although with certain limitations. First, the use of a large video monitor in front of the subject was not as realistic as a full wide scale video projection covering, at least, the whole of the windscreen. It did, however, have the advantage of having a high resolution picture quality while maintaining a reasonable size of screen in front of the subject. Second, although the eye movement recording system which measured each subject's visual behaviour through a hole in the vehicle's dashboard was generally non-intrusive, after the calibration was completed, the only limitation to the system was that subjects had to sit fairly still. However, a movement of up to 10" to the left or right was still acceptable. Third, it is difficult to estimate the effectiveness of telling subjects to use the accelerator and brake pedals. The intention was that requiring subjects to perform a simple driving task would make them feel partly in control of the vehicle, and would result in them interacting more actively with the driving scene on the video, hence producing eye movements similar to those that would be used if they were really driving the vehicle (see MacDonald and Hoffman, 1991 and Section 4.4.2 below).

Reports from subjects after the experiment was completed were generally favourable. Most thought that using the pedals helped them feel as though they were 'almost' driving the vehicle. One subject, however, reported that concentration on the pedals reduced the amount of attention they gave to the video, although this is not necessarily a criticism - as the task of driving a lorry on the road is more than purely the monitoring of a visual scene.

4.4.2 Experiment 2

For the recording of visual attention when approaching two low bridges, it was found that drivers looked at a variety of areas of interest, with visual attention being given to the road (both before and after the bridge), the road signs before the bridge and the top, left and right sides of the bridge. Other less important features of the bridge environment such as the sky or the road verges were looked at for only a small amount of the time.

Perhaps the most important finding from this work was the amount of visual attention paid to the top of the bridge. Sub-dividing this area as much as was possible (for reasons of accuracy in the eye movement recording) revealed that the sign on the bridge (i.e. the third stage bridge sign) was looked at for a large proportion of the time. Also, if an advertisement was placed on the top of the bridge it too was looked at for a notable amount of time. Although this is the advertiser's intended result, it is not a desirable outcome when a driver should be concentrating on driving a lorry under a low bridge. Clearly, further research needs to be performed to establish the influence of bridge advertisements on visual attention and how this alters driving behaviour. The final important result from this section was the small amount of time that drivers attended to the bridge markings. Although it probably is not necessary for the markings on the bridge to be viewed directly for a long time, it is expected that the re-designed markings would be looked at for more time than they are currently.

The hypothesis forwarded earlier that the amount of visual attention drivers give to relevant features of the environment, in terms of navigating a high-sided vehicle through a low bridge, would be generally small, and that the amount of visual attention they give to irrelevant features would be comparatively high has to be accepted in two instances:

1. The markings on the two bridges (a relevant feature) were directly looked at for only a short amount of time (less than 2.1 % of the total time).
2. When an advertisement (an irrelevant feature) is placed on a bridge, it is looked at for a comparatively long time (over 14 % of the total time).

The hypothesis was not supported, however, in the following two instances:

1. The relevant area of interest 'top of bridge' (and in particular the height sign on the top of the bridge) was looked at for a large amount of time (over 35 % of the total time) for both bridges.
2. Other less relevant features of the bridge environment such as the sky were fixated for only a small amount of the time.

A difficulty with this experiment is defining what exactly is a 'relevant' or an 'irrelevant' area of interest. Fixating areas inside the vehicle cab, which may account for between 8-15% subjects' mean fixation time (Lansdown, 1996), were not analysed. The main point of contention for this experiment, however, was what constitutes a 'relevant' as opposed to an 'irrelevant' area. This was empirically determined by the experimenter, based on interviews with HGV drivers and on eye movement analyses methods previously used by other researchers (e.g. Cole and Hughes, 1990). A relevant area of interest was defined here as that section of the environment which was directly of use to help drivers of high-sided vehicles decide whether they can drive safely underneath a low bridge - thus the top of the bridge (and the third stage height sign on it) would fall into this group. An irrelevant area of interest was defined has that section of the environment which was considered to be of no use to drivers of high-sided vehicles when deciding whether they can drive safely underneath a low bridge, so an advertisement in the scene, would fall into this group. The 'grey areas' are the features of the environment, which may have partial use in bridge navigation, such as the road before and after the bridge, and the left and right sides of the bridge. The approach taken here surmounts these 'grey areas' by only considering in detail the clearly relevant or irrelevant areas of interest.

A further difficulty is that much of the information in the environment can be perceived without fixating it directly. A large object containing information for which high acuity is not needed, such as the road directly in front of the driver, is different from a road sign where a direct fixation is usually needed to perceive the information on the sign (Luoma, 1988 and 1991a, and Gale, 1996b). Although this problem of information perceived through peripheral vision is inherent in a great deal of applied eye movement research, it does mean that some caution should be applied to the results obtained here for some parts of the road environment. For example, the bridge markings may have been directly fixated for only a small amount of time because they could be, in part, perceived peripherally.

The set up was similar to the one used in the first experiment, so the points discussed for that experiment apply equally well here. The two main notable differences were:

First, the stimulus was projected on to a plain wall in front of the cab and was not displayed on a monitor. The limitations on resources available for this work necessitated that there had to be a trade-off between image size and image resolution. In the first experiment, it was considered that image resolution was more important (i.e. it was vital that the subject was able to read the various traffic signs from a moderate distance). In experiment two, the image size seemed most critical, that is, seeing the bridge at a large physical size was considered more important than image resolution (particularly as in this experiment there were few road signs). How the driving information is presented to the subject, however, would seem to be likely to influence their visual behaviour to some degree. So two different solutions for the two experiments were used as they were considered to be the most suitable for their respective situations, given the constraints under which the work was performed (i.e. there was no 'perfect' method of both large scale video projection and very high image quality available).

Second, the simple driving task of using the accelerator and brake pedals was not used in experiment 2 as it seemed redundant due to the short length of time the approaches to the two bridges were displayed to the subjects. Although, as mentioned in Section 4.1, MacDonald and Hoffman (1991) used a simplified driving task in their experiments to obtain successful results, more recently, the work by Ota (1996) found that it was unnecessary for any task other than watching the driving video to be employed. In Ota's study, concerning distance perception in driving, subjects produced similar responses when just watching a video when compared with the responses they produced when driving a real car. Indeed, Ota found similar distance estimation responses between subjects watching a driving video and controlling a car at the three different driving speeds that were employed (ranging from 0 to over 80 kph). So the experimental techniques used in previous research are equivocal concerning the use of a simplified driving task while watching a video of driving scenes. The MacDonald and Hoffman and the Ota studies used slightly different response measures and had different experimental set-ups, so whether or not it is important to use a simplified driving task may depend on what the actual response task is and how the experiment is arranged. For this current study, the two bridge approaches were both on fairly level straight roads where a high-sided vehicle driver would probably not perform hard braking or acceleration. So, as experiment 2 was to be more of a 'pure' study of drivers' visual behaviour when approaching two bridges in fairly simple environments, a simple driving task was not included.

4.5 Conclusions

The two research experiments described here set out to further clarify the problem of bridge strikes by examining what drivers look at when approaching low bridges. Both experiments took place in a simulated driving environment. Subjects sat in a lorry cab and watched driving footage, and their visual behaviour was measured by means of a remote eye movement measuring system fitted through the vehicle's dashboard.

The main results of the first experiment were that the IBW signs were generally not effective in attracting the visual attention of drivers in comparison with other, carefully matched, traffic warning signs. For the 'worst case' IBW-1 sign, only 4 % of subjects fixated it, and even for the 'best case' IBW-2 sign, less than half of the subjects fixated it.

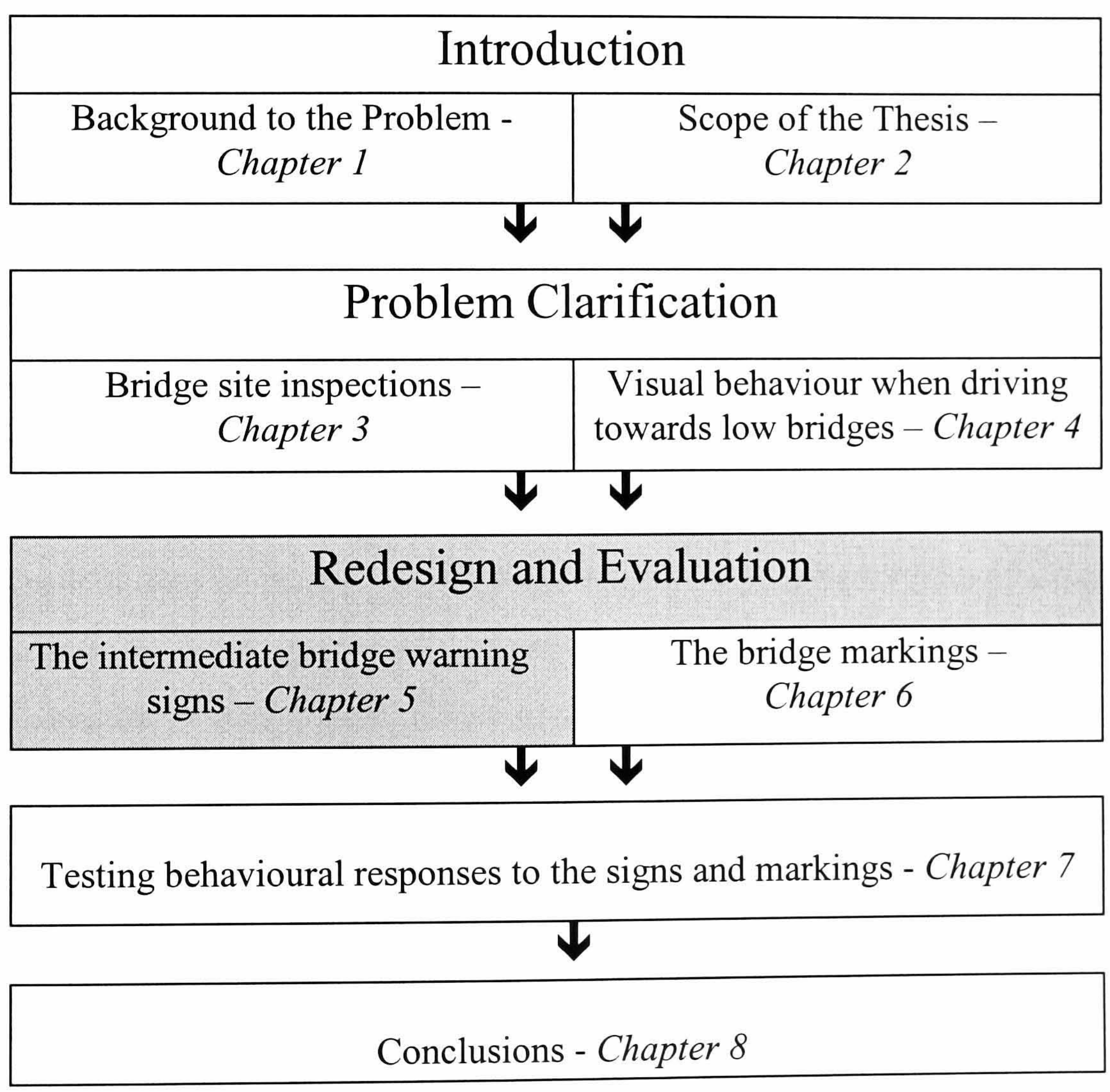
Experiment 2 revealed that a large number of areas in the visual environment are directly fixated by drivers when approaching low bridges, including the road before and after the bridge, and the top, left and right sides of the bridge itself. The top of the bridge was looked at, on average, for over a third of the total time, with the height limit sign in this area being looked at for a large proportion of this time. The markings on the bridges were only directly fixated for a small amount (i.e. less than 2.5% on average) of the total time. If, however, an advertisement was placed on the top of a bridge, it was looked at for a large amount (i.e. over 14 %) of the total time.

As a result of these findings, three suggestions for future research are proposed. First, it should be established whether a re-designed IBW sign would be more effective in attracting visual attention. Second, the amount of visual attention that an advertisement near a bridge attracts should be more fully quantified, and how such an advertisement might influence the task of bridge navigation should be investigated. Thirdly, the value of re-designing the bridge markings to make them more effective in attracting visual attention should be examined.

Finally, as experiments 1 and 2 found that both the IBW signs and the bridge markings were ineffective in attracting drivers' visual attention, their efficiency as visual warnings is questioned further in the subsequent research investigations.

Chapter 5:

Intermediate Bridge Warning Signs: Development and Evaluation



5.1 Introduction

The multi-causal nature of bridge strikes, together with the complexities of the driving task and the road environment, make it difficult to quantify the exact contribution that poor warning signs make to bridge strike incidents. As has already been mentioned in Chapter 1, the DoT (1993a) attempted to define this by asking drivers why they thought they had hit a bridge. It was found that poor signing was given as the main reason in 13 % of cases. Although, as discussed previously, these figures cannot be relied upon fully, they do imply that the signs warning drivers of a low bridge ahead could be improved. This is supported by the fact that in the current investigation less than half of the intermediate bridge warning signs were detected by drivers in a simulated lorry environment. Thus there seems to be a strong case for the development and evaluation of alternative versions of this type of warning.

In 1996 Wogalter and Laughery argued that controlled testing of variables in warning signs can lead to better designed and more effective warnings, which in turn can have positive safety outcomes. The hypothesis proposed in the current investigation is therefore that the testing of variables in bridge signs should result in more effective warnings, which can reduce the number of bridge strikes. Equally, it is the assumption of this work (as described in Chapter 2) that the drivers' perceptual and cognitive capabilities (for example their ability to comprehend a sign's meaning) as well as their motivations are essential issues to consider when evaluating the effectiveness of alternative versions of a sign. The importance of driver motivation is based on the reports of Näätänen and Summala (1976); Summala and Hietamaki (1984); Wogalter (1994), and Edworthy and Adams (1996a) who, in the fields of both traffic and product warnings, all argued that motivation with respect to the warning is essential for eventual compliance with the sign's message.

The effectiveness of traffic signs has been well researched over the past 40 years. Older examples of this included Moore and Christie (1963) who examined issues such as sign layout, colour and size for a wide range of UK highway signs and found, for example, that reading distance was influenced by the size of the sign's letters, and Hoskovec, Stikar and Raouf (1974) who investigated the effects of sign background and numerals and found, for example, that certain designs of numbers were more effective than were others, in terms of the errors made by the subjects. No specific research, however, has previously been performed on the intermediate bridge warning sign, although, as will be described below, a large amount of research has been performed with other warning signs and much of this is applicable to the experiments in the current investigation.

5.1.1 Modification of the Signs

5.1.1.1 The Sign's 'Form'

A variable that had previously been found to influence warning sign / traffic sign effectiveness is the way in which the information is displayed in a sign. There are, currently, two versions of the intermediate bridge warning sign - one purely text-based and the other a combination of text and a height limit Roundel. Over the past twenty years there has been a large amount of research investigating the best form for information contained in a sign, in particular whether a symbolic version of a sign is more effective than a text-based one. This large interest is probably partly due to the increased use of symbolic signs in Europe and the USA (Edworthy and Adams, 1996a).

Laboratory research by Ells and Dewar (1979) found that general traffic warning signs (e.g. 'Hill ahead') with symbolic messages were understood more quickly by drivers than those solely with text-based messages. Furthermore, they found that when the signs were visually degraded there was a greater decrease in performance for the text-based than for the symbolic signs. This was later supported by Babbitt Kline, Ghali, Kline and Brown (1990) who, when also using general warning signs (e.g. 'road narrows') found visibility distances for icon type (i.e. symbolic) traffic signs were higher than for text type signs for young, middle-aged and older subjects.

Similarly, Kline and Fuchs (1993) found that the average distance at which a symbolic sign could be identified was about twice that of a text-based sign, distances for the symbolic signs generally being over 200m and for the text-based ones generally less than 100m. Additionally, MacDonald and Hoffman (1991) found that drivers reported a significantly higher level of sign information in a driving field experiment with the various symbolic signs (including warning signs) along their route when compared with the text-based signs.

In the related area of product warning signs, similar results have been obtained. Laughery and Young (1991) and Young (1991) found that adding a pictogram or an icon to a warning reduced the time required to find and recognise the warning, thus enhancing the "*noticeability*" of the warning information. Lastly, Edworthy and Adams (1996a) summarised the previous work on the advantages of symbolic over text-based signs and concluded that:

- Symbols can be recognised by those who do not / cannot read the language.
- There is a greater recognition distance for symbolic signs.
- Symbols are often recognised more quickly and accurately than words.
- Symbols can withstand greater degradation and still be recognisable.
- Symbols, used with text in the same sign, may be more effective ihan the use of text alone.

Therefore, based on previous research, it would appear that there are good grounds for hypothesising that versions of the intermediate bridge warning sign that were either symbolic or a combination symbolic/text (i.e. the currently used 'Roundel' version) would be effective, so should be tested in these experiments.

There are, however, some negative points with using symbols. Loo (1978) compared symbolic with text-based traffic warning signs and found that the textual ones were reacted to significantly faster (in terms of sign perception) than were the symbolic ones. It must be noted, however, that the Loo study did not use the same types of signs in the two groups (e.g. a symbol of a train was used in one group and the text 'School' was used in the other). In terms of driver opinion, Robertson (1977) compared 6 versions of the 'same' traffic sign (a sign warning of following too close to other vehicles) and found that drivers preferred the text-based ones. These differences may have been due to subjects being unfamiliar with the symbols, and further testing after the symbolic signs have been employed for several months on the roads may have produced different results.

An additional problem is to decide what precise design of warning symbol should be used in the sign (Cole and Jacobs, 1981). In the case of a low bridge sign should it display a low bridge, a high-sided vehicle, both bridge and vehicle or an abstract design? A final difficulty with warning symbols pointed out by Edworthy and Adams (1996a) is that some complex situations cannot be captured in symbolic form without a good deal of appropriate learning. For instance they give the example of a complex situation 'Look up! Low door!' which cannot easily be symbolically displayed. A low bridge may be a similar situation, so designing the symbol for this situation may have the same types of problem.

Edworthy and Adams (1996a) argue that the way around such problems is to have any proposed symbol appropriately tested, and comprehension testing is recommended by them as a major part of this evaluation procedure. From the foregoing it therefore seems that symbols in some warning signs can be effective, but that careful testing is needed to establish if one can be used successfully in a newly designed version of the IBW sign.

5.1.1.2 Border Type of Sign

The second variable that has previously been found to influence warning sign / traffic sign effectiveness is the adding of a border to the sign. At present the two different versions of the intermediate bridge warning sign, as indicated earlier, have only a small white border around the blue background of the sign (which here is termed a 'plain' border). Previous research has recommended the use of a larger border to increase the effectiveness of the sign. For instance, in the field of product warning signs, Edworthy and Adams (1996a; 1996b) found that larger borders could increase the perceived urgency of a sign. In the traffic environment, Spijkers (1991) found that having the background of a sign a different colour from the environment behind it enhances its recognition. For example, sign background colours such as blue (against a cloudless sky), grey (against concrete buildings) or green (against grass) would not be easily recognised. Additionally, several researchers have found that the use of a coloured border on a traffic sign could increase its conspicuity (Cooper, 1988, and Tompson-Kuhn, Garvey and Pietrucha, 1996), and improve its detection rate by drivers (Dunne and Linfield, 1993).

A possible negative effect of using borders was, however, raised by Young (1991). In his work on product warning information, it was found that the addition of a border to a warning did not significantly reduce search and recognition time for the warning. Furthermore, he cautions that the tight fit of a border around warning text can reduce the legibility of the words in the warning. This is the phenomenon of *"contour interaction"* (Young, 1991). Young goes on to assert, however, that if the border is sufficiently far enough away from the text it should improve response times, although he does not quantify exactly how far apart the border and words need to be, or what the beneficial spatial frequency of the sign should be[1].

Thus the work reported above suggests that the addition of coloured borders can have a positive influence on the effectiveness of traffic signs as long as the border is not too close to the words / message contained in the sign. Therefore it is hypothesised that adding borders to versions of the intermediate bridge warning sign should have significant effects on the evaluation measures employed.

5.1.2 Evaluation Methods

It has already been argued that alternative versions of the current bridge warning sign need to be evaluated, under controlled conditions, to establish the influence of the sign variables 'form' and 'border type'. Although not in a realistic setting, an experiment in the laboratory allows for a like-for-like comparison between different versions of a sign to be undertaken (Edworthy and Adams, 1996a).

The intention of the two experiments was to examine if differences existed between the signs (on the response measures employed) when presented for a limited, but realistic when driving, time period. It was therefore important not to have an overlong presentation time so that all subjects comprehended virtually all the information on the signs. It was, of course, also necessary not to have too short a time period so that no information was comprehended.

As might be expected, there has been some previous research in the area of the presentation times for road sign and in-vehicle stimuli. This includes the work by Cole and Jacobs (1981) who displayed sign stimuli for 750 and 1500 ms, Shoptaugh and Whitaker (1984) who displayed stimuli for 180 ms., and Galer (1985) who presented slides of vehicle instrument panel designs for 450 ms. Additionally, Pottier and Pottier (1988) found that responses were more accurate when signs were

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[1] In an object such as a road sign each pair of light and dark colours makes up one cycle of a sinewave pattern. The spatial frequency is the number of cycles of the object (e.g. light and dark bars in a sign) usually described in cycles per degree. It gives an indication of the size of the bars, thus relatively thick bars of colours are low frequencies. As this unit of measurement depends on the number of cycles that fall on the eye, the spatial frequency will change with viewing distance.

displayed for 1000 ms or 500 ms compared with 250 ms. and Spijkers (1991) found responses were more accurate when signs were displayed for 350 ms when compared with 200 ms. Avant, Thieman, Brewer and Woodman (1986), however, obtained a significant effect for traffic sign meaning when exposure durations were as low as 16ms.

So the majority of these studies displayed stimuli for approximately 300-1000 ms and the studies by Pottier and Pottier (1988) and Spijkers (1991) found that sign presentation times below 300ms produced less accurate responses when compared with longer display times. It was therefore considered appropriate to use a range of 300-1000 ms as a starting point to establish the exact presentation times to be used in the current experiments.

The evaluation measures employed in these experiments follow the overall model for sign testing used earlier (see Chapter 2) and are as follows:

5.1.2.1 Comprehension

For a traffic warning sign to produce appropriate behaviour on the part of the vehicle operator, it is essential that the sign can be understood by a relevant sample group (i.e. drivers) under relevant conditions. One of the first stages in ensuring compliance with a warning is for the user to comprehend what the warning sign actually means (as recommended by Young, 1991; Edworthy and Adams, 1996a). Although no previous comprehension testing has been performed on intermediate bridge warning signs there has been similar work carried out on other traffic warning signs (see Kline and Fuchs, 1993, and Lajunen, Hakkarainen and Summala, 1996). However, studies that seem to be most relevant to the current work were carried out by Cooper (1989) and Galer (1980, 1981). Cooper (1989) surveyed the comprehension of signs by drivers and non-drivers and found that the height limit sign (i.e. the third stage bridge sign, on the bridge itself) was fully understood by 95 % of drivers - so indicating that most 'users' of this sign at least know what it means. Similarly, in earlier work by Galer (1980,1981) it was found that 72% of high-sided vehicle drivers were either fully or acceptably correct in their understanding of the third stage bridge sign when it was presented to them in isolation and not as part of a road scene. Although there were minor differences in the Cooper and Galer studies (e.g. where and when the surveys took place), the higher comprehension figure for the height limit sign obtained in Cooper's 1989 study must be viewed as positive, in terms of increased driver understanding of reduced clearances. Indeed, the comprehension scores for the height limit sign obtained in the Cooper study were higher than the comprehension scores for the majority of other highway signs that he included in his study (for example 'weight limit' or 'no waiting'). Another factor found in the Galer work was that when the signs were presented in context (e.g. on a photograph of a bridge), the percentage of drivers who understood the sign increased.

Based on the above studies, the two experiments proposed here will test drivers' understanding of newly designed, as well as the currently used, versions of the IBW sign. Although it is not expected that any sign will be fully comprehended by all the drivers, it is predicted that some comprehension differences will be obtained between the different versions. Those signs that are not well comprehended will show that they are likely to be ineffective as warnings.

5.1.2.2 Hazard Perception

In addition to being well understood, a warning sign needs to "*incline*" the observer to behave appropriately with respect to its message (Wogalter, 1994). In terms of Wogalter's model (introduced in Chapter 2), the warning needs to fit in with the individual's beliefs and attitudes, as if the message does not conform to these beliefs and attitudes then it is likely that it will be ignored. Part of the effectiveness in inclining an individual to follow the message is for the person to perceive the warning's referent (i.e. the object or situation to which the warning refers) as a hazard (Wogalter, 1994, and Edworthy and Adams, 1996a). The notion of hazard perception in driving or warning research has been examined by West, Wilding, French, Kemp and Irving (1993) in terms of the effects of alcohol on driving hazard perception latency and driving speed; by Edworthy and Adams (1996b) in terms of hazard perception and product warning signs; by Wogalter, Jarrard and Simpson (1994), in terms of the influence of warning label signal words on perceived hazard level; by Goldhaber and DeTurck (1988) in terms of perceived hazard level after the installation of 'no diving' signs in swimming pools, and by Ogawa, Renge and Nagayama (1996) in terms of the structure of the perception of hazards when drivers viewed video recordings of driving scenes. The central concept behind all of these papers was that perceiving something (e.g. a product or a traffic situation) as hazardous was more likely to lead to safe behaviour than not perceiving that object/situation as a hazard.

So, generally, from a safety point of view, the higher the hazard perception score a warning sign can produce, the better. Hence a bridge warning sign needs to promote a high level of hazard perception in drivers of high-sided vehicles in order for the sign to be effective. As with the comprehension measure, any IBW signs that produce a low perception of hazard will be considered to be ineffective as warnings.

To summarise, the work discussed above has described similar relevant research in the area of traffic and warning sign development and evaluation. The overall rationale behind much of this research is that the careful testing of such signs in controlled conditions is a necessary stage in the development of better designed warnings. Following this, it is the overall rationale of the following experiments that redesigning bridge warning signs to make them more comprehensible, and to be perceived as more of a hazard when viewed for a short (but realistic) time period, will identify effective warning sign design variables, and that the implementation of such variables in the sign should ultimately lead to less bridge strikes.

5.1.3 Experimental Objectives

The two experiments were designed to assess:

- The comprehension levels of the newly developed and existing bridge warning signs when viewed on their own for a brief time period (Experiment 1).
- The hazard perception levels of the modified set of bridge warning signs when viewed as part of a road scene (Experiment 2).
- The comprehension levels of the modified set of bridge warning signs when viewed as part of a road scene (Experiment 2).

For the above three aims it was also considered important to assess the effects of the variables of 'form' and 'border type' on comprehension and hazard perception levels.

5.2 *Experiment 1: Initial Development and Evaluation of the Intermediate Bridge Warning Signs*

5.2.1 Warning Sign Development

Although any possible alternative signs developed were restrained by the parameters placed upon the work by the DoT (as reported in Chapter 2), it was still possible for a wide range of alternative signs to be produced. The restrictions did, however, limit the alternative signs in some respects, they had to be similar to the currently used signs in the following ways: they had to be the same size, have the same information content and font type, and use the same colours.

In terms of the information content for any alternative designs, the key elements which intermediate bridge warning signs needed to have were a notification of:

- What the hazard ahead was (e.g. 'low bridge' or a symbol representing the reduced clearance).
- How high the bridge was (for this study using imperial measurements) – for example 12' 9".
- How far away the bridge was (again, using imperial measurements) – for example 400 yards.

By utilising the previous work reported in the area, a set of alternative intermediate bridge warning signs was developed. These designs used variables which previous research had shown to influence subjects' responses to signs. Specifically, these were the 'form' of the sign and the 'border type'. Both of these variables are described below.

As mentioned earlier, the current form of the intermediate bridge warning sign can either be a purely text-based sign, or a textual sign with a Roundel. Consequently it was necessary to test both sign forms. Additionally, two new forms of the sign were developed and tested. Thus the four 'forms' of the sign tested were as follows:

1. **Existing text-based** – This contained the message of the restricted height limit, the exact clearance available and the distance from the sign to the hazard.
2. **Roundel** - This sign contained details of the hazard and how far away it was, together with a red warning roundel in which the height available was displayed.
3. **New text-based** - The 'new text-based' sign used a different vocabulary than the

two current intermediate signs. Instead of having 'height limit' the sign contained the words 'beware bridge' to describe the hazard ahead (see Wogalter, Jarrard and Simpson, 1994, who found that the keyword 'beware' generally increased the perceived hazard level).

4. **New symbolic** - The 'symbolic' sign included a pictographic representation of a low bridge together with the consequences of an overheight vehicle ignoring the warning, namely, a bridge strike. Thus a front view of a bridge, with the road passing underneath it, and with a lorry stuck underneath it was used.

The overall sizes of the signs were the same for all the forms tested.

Only one border type is currently used for the intermediate bridge warning sign, so two new border types were developed. The three border types tested were therefore as follows:

1. **Plain border** - This was the sign with the small white border around the blue background.
2. **Yellow border** – This was the first of the new border types. It consisted of a yellow border placed around the edge of the sign, following the increased conspicuity results obtained by Cooper (1988) when evaluating yellow borders. This border was approximately twice the width of the plain border,
3. **Yellow / red border -** This was the second of the new border types. It had a yellow and red striped pattern around the edge of the sign, of the same width as the yellow border (again, based on the increased conspicuity results mentioned earlier).

The overall sizes of the signs were the same for all the border types tested.

All the sign designs were tested with all border types - thus four sign 'forms' and three 'border types' produced a total of twelve sign to be tested. A representative selection of these signs is shown in appendix B.

5.2.2 Method

5.2.2.1 Subjects

Sixty-four subjects took part. Half of these were drivers of high-sided vehicles (defined as someone who regularly drives a vehicle over 8' high, i.e. the height of a transit van), the other 32 subjects were car drivers (i.e. held a valid UK car licence).

All subjects, except two, reported normal vision. Of the two exceptions, one had poor visual acuity in one eye, the other had some degree of colour defect. Fifty-nine subjects (92.2 %) were male and five female (7.8%), all the high-sided vehicle drivers were male. One subject (1.6 %) was aged less than 25 years, 25 subjects (39.1 %) were between 25 - 40 and 38 subjects (59.4 %) were over 40 years old. All subjects were paid an inconvenience allowance for their participation in the study.

5.2.2.2 Equipment and Stimuli

The four "sign forms" and three "border types" defined above yielded twelve signs. The sign set additionally comprised a "null" sign - this sign was designed as 'badly' as possible, adopting the opposite approach of effective warning designs as recommended by, for example, Lehto and Miller (1986). For example, the sign had a small and uneven font size and had the wording spaced randomly over the sign. However, the sign still retained the key information elements of the low bridge hazard, how high it was and how far it was to the low bridge. This sign was used as a benchmark to assess the performance of the other designs.

As each subject was to be tested on all the signs at the same sitting, the bridge height and the distance to the hazard were manipulated so that it was different for each of the sign versions. This was to prevent subjects retaining information on the signs that would improve their performance on subsequent trials. For the bridge heights, the information on the signs was in 3" multiples, across the range of 10' - 16' high. These figures therefore represented realistic low bridge heights. Similarly, for the distance to the hazard the measurements were in 50 yard multiples, in the range of 100 to 600 yards ahead. These figures therefore represented realistic distances to the bridges ahead.

Additionally, to prevent subjects becoming aware that the study was purely about low bridge warning signs, the experimental signs were combined with a set of 12 signs from the Highway Code, such as 'no right turn', 'weight limit ahead' and 'give way'. This technique followed Hole, Tyrell and Langham (1996) who presented their experimental stimuli as half of the total number of road scene slides shown to their subjects.

Each subject viewed all the 25 signs presented (i.e. the low bridge warnings and other traffic signs) so that the scene subtended to an angle of vision at the eye of 8.8° high and 9.6° wide (subjects were positioned at a fixed distance away from the screen). The signs were presented in a random order on a visual display unit using a specially written 'Authorware' computer program. Following the presentation times that previous researchers have used for displaying road sign stimuli (mentioned in section 5.1.2), the signs were presented for a fixed time period of 500 ms (±5 ms)[2]. This was upheld by a pre-experimental trial that revealed that having a shorter presentation period (250 ms) was insufficient to recall virtually any information from the intermediate bridge warning signs.

5.2.2.3 Procedure

The lorry drivers were tested in a specially adapted area of a transport café, which, although not as controlled as a laboratory, had a constant lighting level (measured at 350 lux) and was generally quiet. The car drivers were tested in an experimental room with an ambient lighting level set at 350 lux. Apart from the different sites at which the two groups were tested the procedure for both groups was identical.

Each subject was tested individually. A mask of random 'noise' of similar colours to the signs was displayed on the computer monitor prior to and following each sign's presentation. Subjects were instructed to fixate on a cross in the centre of the pre-stimulus mask and then pressed the space bar on the PC keyboard to reveal the sign. This follows the stimulus presentation approach of Nunes, Peralbo, Risso and Vieiro (1996) in their laboratory study involving the detection of traffic signs with or without alcohol ingestion. Following the presentation of each sign, the subject was instructed to state its meaning. Verbal responses to all the 13 IBW sign designs

[2] Measured using a high-speed video camera that recorded at 200 frames per second.

were scored against the keyword set (shown on the results form in appendix C). Two observers recorded each subject's responses to the signs, to increase the reliability of the results. Each subject's verbal responses to the other signs from the Highway Code (1996) were also recorded (to give the appearance to subjects that these signs were also of interest) but these responses were not analysed.

After all the signs had been viewed, the computer program displayed a message that the test was over, and the subjects were thanked for their time.

5.2.3 Results

Following Galer (1980 and 1981) for drivers' understanding of third-stage height limit signs and Wogalter (1994) for warning sign evaluation, a keyword set was used to assess each subject's comprehension of the IBW signs.

These responses were scored on a four point scale (1-4) such that:

- A score of 1 was given if the subject correctly answered all the information on the sign.
- A score of 2 was given if they answered the information acceptably correct (i.e. knowing it was a bridge hazard, knowing how high it was and that it was ahead).
- A score of 3 was given if they answered the information partially correct (i.e. knowing it was a bridge hazard ahead but not knowing the exact height).
- A score of 4 was given if the response was incorrect.

(Further details of the keywords and the scoring criteria are shown on the results form in appendix C).

The mean comprehension score of 3.98 for the null sign was significantly worse than the mean of every other sign's score. It was therefore considered as an outlier and excluded from all further analyses.

The remaining 12 signs were analysed in a 2 x 3 x 4 mixed factorial ANOVA. The factors were:

- 2 driver types – car and lorry drivers.

- 3 border combinations – plain, yellow and yellow/red.
- 4 sign form combinations - existing text-based, new text-based, symbolic and Roundel.

The ANOVA revealed that there were no significant differences between the responses of car drivers and lorry drivers to the signs overall ($p>0.05$). Table 5.1 shows the results produced for the 12 bridge warning signs for both groups of subjects combined.

Table 5.1: Mean comprehension scores for the intermediate bridge warning signs.

Sign Form	**Border Type**			
	Yellow	**Red & Yellow**	**Plain**	**Overall MEAN**
Roundel	2.672 (0.644)	2.922 *(0.674)*	2.797 (0.671)	**2.797**
New text-based	2.266 (0.895)	2.438 (0.753)	2.547 (0.733)	**2.417**
Symbolic	2.422 (0.989)	2.375 (0.807)	2.703 (0.971)	**2.5**
Existing text-based	2.328 (0.714)	1.953 (0.628)	2.109 (0.911)	**2.13**
Overall MEAN	**2.422**	**2.422**	**2.539**	**2.461**

Standard Deviations are shown in brackets.

The ANOVA further revealed overall significant effects for:

1. Sign form ($p< 0.001$).
2. Border type ($p< 0.05$).
3. Sign form by border type interaction ($p< 0.001$).

These three significant effects are further explored below.

Regarding the significant main effect for sign form, the mean comprehension scores for the different versions, from best comprehended to worst, were:

1) Existing text-based (mean comprehension score 2.13).
2) New text-based (mean comprehension score 2.417).
3) Symbolic (mean comprehension score 2.5).
4) Roundel (mean comprehension score 2.797).

As lower scores represent higher comprehension levels, it was therefore shown that the text-based versions of the sign were on average understood better than the symbolic or the Roundel versions.

Regarding the significant main effect for border type, the signs with yellow and yellow/red border had an equal mean comprehension score (of 2.422), and both were better than for the signs with plain borders (mean score 2.539). Thus signs with coloured borders were overall understood better than those signs with plain borders.

Regarding the form by border interaction, a paired samples t-test was employed to further analyse the data. Each sign's comprehension score was compared to the overall mean for all 12 signs. The results of this revealed that two signs were comprehended significantly lower than the overall mean and two signs significantly higher than the overall mean ($p<0.004$ following adjustment by the Bonferroni post-hoc multiple comparison test).

The two signs that scored significantly lower (i.e. were comprehended worse) than the group mean were:

- The Roundel form with a red and yellow border type ($p< 0.001$).
- The Roundel form with a plain border type ($p< 0.001$).

Additionally, the two signs that scored significantly higher (i.e. were comprehended better) than the group mean were:

- The existing text-based form with a red and yellow border type ($p< 0.001$).
- The existing text-based form with a plain border type ($p< 0.001$).

5.3 Experiment 2: Continued Evaluation of Intermediate Bridge Warning Signs

5.3.1 Warning Sign Selection

In the previous experiment the comprehension of the signs was tested in isolation, that is, they were presented to subjects on a plain background. The aim of the second experiment was to test comprehension and hazard perception in more realistic environments. This followed the approach of Pottier and Pottier (1988), Spijkers (1991), Lambert and Fleury (1994), and Hole and Tyrell (1996) who, in laboratory experiments, all presented road scene stimuli to subjects in both rural / simple and urban / complex environments. Consequently two photographs were taken, one in a rural location and one in an urban location, showing a road scene with a traffic sign on the left of the picture (i.e. where a bridge sign may realistically be located). These two pictures were digitised and the bridge signs were edited over the current sign in the picture. The effect of having the same signs tested in both rural and urban locations was that twice as many versions needed to be tested. To prevent the experiment being over-long it was therefore necessary that the number of sign combinations used in the first experiment was reduced.

The previous experiment found that the existing forms of the intermediate bridge warning sign generally performed either very well (the existing text-based) or very badly (the Roundel) on the test of comprehension, and the two new designs produced comprehension levels between these two extremes. Because the new forms did not produce results as good as one of the current forms it was decided to only consider the best performing form of the sign (i.e. the existing text-based) and to compare it to the other form of the sign currently in use (i.e. the Roundel). Thus the 'new text-based' and 'symbolic' forms of the sign were not tested in this experiment.

Additionally, the previous experiment found that the signs with yellow and yellow/red border types produced equal levels of mean comprehension, and both produced better results than the signs with plain borders. As the worst performing border type was the currently used version (i.e. the plain border) and the two alternative borders produced equal results, it was felt that all three border types needed to be tested further.

Therefore, this experiment tested two sign forms (existing text-based and Roundel), in three border types (yellow, yellow/red and plain) thus making six different sign designs to be tested. In addition they were presented in two environments (one rural and one urban – shown in appendix D), so making twelve experimental sign/scene combinations involving the intermediate bridge warning signs.

5.3.2 Method

5.3.2.1 Subjects

Fifty-seven car and high-sided vehicle drivers took part in the experiment. One third (n=19) were regular drivers of high-sided vehicles (defined here as somebody who regularly drives a vehicle the height of a transit van or above, i.e. over 8'), the other 38 subjects were car drivers. None of the subjects employed in this study took part in the previous sign evaluation experiment.

All reported normal or corrected-to-normal vision (one subject had some degree of colour defect).

In terms of ages, 24.6 % were aged less than 25; 56.1 % were aged 25-40, and 19.3% were over 40 years old.

The high-sided vehicle drivers were paid for their participation in the study. Twelve of the car drivers were students who received course participation points for being subjects. The remainder of the car drivers were not paid.

5.3.2.2 Equipment and Stimuli

The six experimental signs described above all contained the same warning information (i.e. that a 12' 9" low bridge was 250 yards ahead). As the subjects were told they were driving a 13' lorry, this should have been regarded as a large hazard ahead. These signs were edited over the digitised urban and rural scenes such that they appeared to be realistic in the scenes (following the same approach taken by Lambert and Fleury, 1994). In addition, the position of each of the six signs was kept constant within each of the two scenes, but the position varied between them.

The size of the signs was kept constant both within each of the scenes and between the two scenes (i.e. the bridge warning signs were the same size in all twelve versions).

For the experiment, the twelve experimental warning signs set in scenes (6 set in rural and 6 set in urban scenes) were embedded in a set of 18 other scenes - 12 of these were photographs of other locations (a mixture of rural and urban) and 6 using the same urban and rural scenes but with other warning signs from the Highway Code (1996) (such as 'Road narrows', 'Level crossing ahead' 'Stop when lights show') edited in place of the bridge warning signs. In total, 30 scenes were created (12 involving bridge signs and 18 others). All subjects viewed all the thirty scenes. The presentation order was randomised to prevent order effects influencing the results, except for the first scene, the introductory one, which was the same for all subjects.

The scene images were stored on and run from a Pentium PC and were projected on to a blank wall using a Proxima 8300 high-resolution data projector. The size of the image on the wall subtended to a visual angle of 24.8° vertically and 34.7° horizontally at the subject's eye. Subjects sat in the driver's seat of a lorry cab (1987 Ford Cargo 1615 model) mounted on a frame.

Similar to the previous experiment, the intention of this study was to examine if differences in comprehension and hazard perception existed between the signs when presented for a limited (but realistic) time period. Following the presentation times other researchers have used for displaying traffic signs or road scenes (described earlier), the previous experiment (using signs presented on their own) used a time of 500 ms. As the current experiment showed the signs as part of a road scene, the presentation time needed to be longer to include both reaction time and search time[3]. The presentation time for this experiment was therefore set at 1000 ms (± 50 ms).

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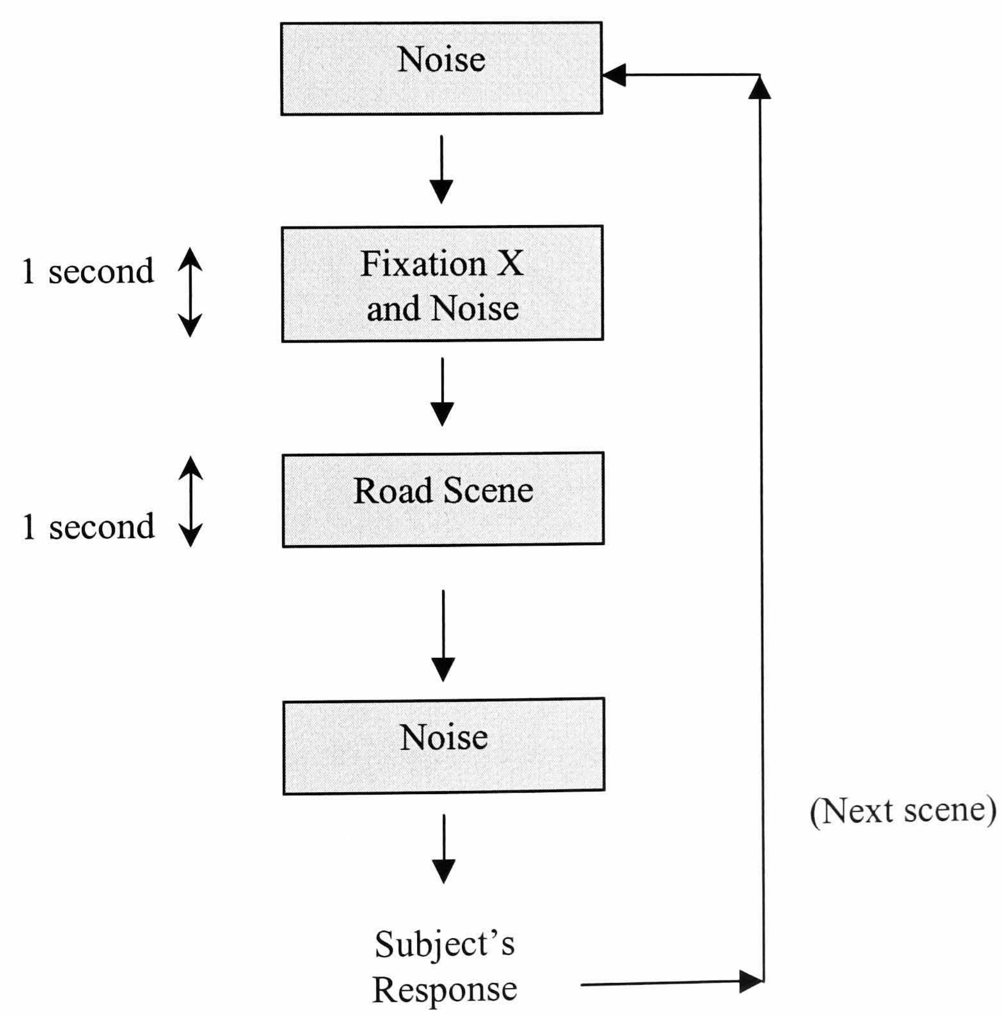
[3]It takes approximately 250 ms for an eye movement to occur, thus there is a quarter second delay before the scene can be scanned.

5.3.2.3 Procedure

The experiment, using the simulated lorry driving environment, took place in a darkened laboratory. Each subject was tested individually. They were told to imagine that they were driving a 13' high lorry and were then informed of the test procedure. The experimental procedure consisted of subjects viewing a random 'noise' mask that was projected on to a white wall in front of them. A red cross then appeared in the centre of the mask for one second and subjects were instructed to look at this cross. The road scene then appeared for one second (i.e. 1000 ms) before returning back to the mask, at which point the subject was to respond. Figure 5.1 shows a flow diagram of the sign presentation procedure.

Figure 5.1: The sign presentation procedure.



For their responses, subjects were asked how hazardous they rated the scene to be and what features of the environment were responsible for the hazard rating they gave. If the scene was one containing a low bridge warning sign, they were occasionally prompted for further information about that sign in order to establish their comprehension level of it (the experimenter was careful not to infer that the experiment was purely about low bridge warning signs). A copy of the scoring sheet showing the hazard perception scale and the comprehension keyword set is shown in appendix E. Each subject's hazard perception ratings to the other scenes and the other signs from the Highway Code (1996) were also recorded.

The first scene was always the same one for all subjects (and not one of the bridge signs). The purpose of this was to familiarise the subjects with the procedure and the method of scoring. After the experimenter had finished scoring each sign and the subject was ready for the next one, the red cross again appeared in the centre of the mask for the procedure to be repeated again. This was carried on until all thirty scenes were viewed and scored, after which the experiment was stopped and the subjects were thanked for their time. For each subject the experiment generally lasted slightly less than 30 minutes.

5.3.3 Results

The two experimental measures of hazard perception and comprehension were considered separately.

5.3.3.1 Hazard Perception

Responses for hazard perception were scored according to the seven point rating scale shown in the scoring sheet in appendix E. For example, a score of 1 was given if the subject thought the scene was a slight hazard, a 4 was given if they thought it looked a moderate hazard and a 7 was given if they thought it looked an extreme hazard.

Table 5.2 shows the mean results produced by the hazard perception response measure. Note for hazard perception **higher** numbers indicate more of a hazard – and so for this part of the experiment are considered 'better'.

Table 5.2: Mean scores for the experimental signs for Hazard Perception.

Sign Name	**Mean Hazard Perception score**
Text-based-urban-plain border	5.44
Text-based-urban-yellow border	5.61
Text-based-urban-yellow/red border	5.56
Text-based-rural-plain border	5.12
Text-based-rural-yellow border	5.18
Text-based-rural-yellow/red border	5.28
Roundel-urban-plain border	5.54
Roundel-urban-yellow border	5.21
Roundel-urban-yellow/red border	5.54
Roundel-rural-plain border	5.21
Roundel-rural-yellow border	5.00
Roundel-rural-yellow/red border	5.04

Performing an initial descriptive analysis for the above results produced the following:

- Roundel signs have an overall mean score of 5.26; text-based signs have an overall mean score of 5.37.
- Urban signs have an overall mean score of 5.48; rural signs have an overall mean score of 5.14.
- Plain borders have an overall mean score of 5.33; yellow borders have an overall mean score of 5.25, and yellow/red borders have an overall mean score of 5.36.

Applying a Multiple (2 x 2 x 3) ANOVA for Repeated Measures (two types of environment - rural & urban, two forms of sign - text-based & Roundel, three types of border - plain, yellow & yellow/red) yielded the results presented in Table 5.3.

Table 5.3: Repeated Measures ANOVA for Hazard Perception of Bridge Warning Signs.

Variable being tested	F value	Significance of F
Environment	5.52	0.022*
Form	0.78	0.381
Border type	0.70	0.499
Environment by form	0.00	0.983
Environment by border	0.14	0.873
Form by border	2.60	0.079
Environment by form by border	0.99	0.376

*Significant difference at the 5 % level

Therefore the following significant difference was found:

- Main effect 'Environment' (i.e. that the two different environments significantly differ in how hazardous the scene is perceived to be). The urban environments with signs were perceived as significantly more hazardous than were the rural environments with signs.

No main effect was found for either form of sign or type of border (or any interaction effects). Thus neither the form of sign nor the type of border had a significant effect on the level of perceived hazard that the drivers experienced. The text-based signs did, however, produce a slightly higher (but non-significant) level of perceived hazard than the Roundel ones.

Further analysis was performed on between-subject variables for hazard perception. An average hazard perception score was calculated for each subject. By applying an Analysis of Variance to these scores it was found that there was:

- No significant difference in mean hazard perception scores by type of driver ($F=0.036$, $p > 0.1$)
- No significant difference between mean hazard perception scores by subject's sex ($F=0.036$, $p > 0.1$)

Thus there were no significant differences between the responses of car and lorry drivers or between males and females.

For overall comparison purposes, a measure of hazard perception was analysed for the other road signs embedded in the same rural and urban scenes.

- For the rural scenes this mean figure was 4.00 (the mean figure for the 'Weight limit' sign was 4.32, for the 'No right turn' sign it was 3.19 and for the 'Road narrows' sign it was 4.49).
- For the urban scenes this mean figure was 3.51 (the mean figure for the 'Hill' sign was 4.05, for the 'One way' sign it was 2.32 and for the 'Stop when lights show' sign it was 4.16).

All figures are therefore much lower than all the bridge sign hazard scores and so were regarded by the subjects as less of a hazard than the low bridge warning signs.

5.3.3.2 Comprehension

Responses for the sign comprehension measure were scored as described in the previous experiment reported earlier in this Chapter; with a 1 if the subject correctly recalled all the information on the sign, a 2 if they recalled the information 'acceptably' correct (i.e. knowing it was a bridge hazard, knowing how high it was and that it was ahead), a 3 if they recalled the information partially correct (i.e. knowing it was a bridge hazard ahead but not knowing the exact height) and a 4 was given if the response was incorrect.

Table 5.4 shows the mean results produced by the comprehension measure. Note for comprehension **lower** numbers indicate a high level of comprehension (so for this part of the experiment are considered 'better').

Table 5.4: Mean scores for the experimental signs for Comprehension.

Bridge Name	**Mean Comprehension scores**
Text-based-urban-plain border	2.61
Text-based-urban-yellow border	2.33
Text-based-urban-yellow/red border	2.49
Text-based-rural-plain border	2.42
Text-based-rural-yellow border	2.28
Text-based-rural-yellow/red border	2.47
Roundel-urban-plain border	2.93
Roundel-urban-yellow border	3.00
Roundel-urban-yellow/red border	2.74
Roundel-rural-plain border	2.61
Roundel-rural-yellow border	2.70
Roundel-rural-yellow/red border	2.96

Performing an initial descriptive analysis for the comprehension measure yielded the information that:

- Roundel signs have an overall mean score of 2.82, text-based signs have an overall mean score of 2.43.
- Urban signs have an overall mean score of 2.68, rural signs have an overall mean score of 2.57.

- Plain borders have an overall mean score of 2.64, yellow borders have an overall mean score of 2.58, and yellow/red borders have an overall mean score of 2.67.

Applying a Multiple (2 x 2 x 3) ANOVA for Repeated Measures (two types of environment - rural & urban, two forms of sign -text-based & Roundel, three types of border - plain, yellow & yellow/red) yielded the results presented in Table 5.5.

Table 5.5: Repeated Measures ANOVA for Comprehension of Bridge Warning Signs.

Variable being tested	F value	Significance of F
Environment	1.36	0.249
Form	23.85	0.000**
Border type	0.95	0.390
Environment by form	0.09	0.767
Environment by border	6.59	0.002**
Form by border	2.94	0.057
Environment by form by border	2.54	0.084

** Significant difference at the 1 % level.

Therefore the following significant differences were found:

1. Main effect 'Form of sign' (i.e. that the two different sign forms significantly differ in their comprehension scores). The text-based ones were comprehended significantly better that were the Roundel ones.
2. Interaction effect 'Environment by border'. The best comprehension score was for yellow borders in a rural scene and the worst comprehension score was for plain borders in an urban scene.

No main effect was found for either environment of sign or type of border, thus neither had significant effects on the obtained levels of comprehension. However, the signs in rural scenes did produce a slightly (but non significantly) higher level of comprehension than did the ones in urban scenes. Additionally, signs with yellow border types had the 'best' comprehension score, followed by those with plain border types, and 'worst' were those with yellow/red border types. These differences were, however, not significant.

Further analysis was done on between-subject variables for comprehension. An average comprehension score was calculated for each subject. Applying an Analysis of Variance to these scores found:

- No significant difference in mean comprehension scores by type of driver (i.e. car or lorry driver) ($F=0.036$, $p > 0.1$).
- No significant difference in mean comprehension scores by subjects' sex ($F=0.875$, $p > 0.1$).

Thus there were no significant differences between the responses of car and lorry drivers or between males and females.

5.4 Summary and Discussion

Each of the two experiments reported here developed and tested a wide range of different versions of the IBW sign. For the experimental measure of comprehension, both studies found that the 'existing text-based' form was the best understood by subjects. Similarly, signs with yellow borders were, overall, understood better than those with either plain or yellow/red borders. For the experimental measure of hazard perception no significant differences were found for the form of the sign or the border type.

The two studies differed slightly in their precise experimental arrangements. For example, more signs were tested in Experiment 1, but the scenes displayed to subjects were more realistic in the second study. The first experiment had subjects view the signs in isolation (i.e. they were presented on a grey background on the computer monitor), in the second study the task was more authentic, with subjects sitting in a lorry cab watching a projection of a road scene in which there was a sign.

Similarly, the two experiments differed in the presentation time for the signs - in the first study this was set at 500 ms, in the second study it was 1000 ms. Despite such differences the two experiments produced similar results for the comprehension measure. Therefore comprehension was found to be unrelated to sign exposure time.

Both experiments found that text-based signs were better understood than symbolic or Roundel signs - this is at odds with most previous research in the area. For example, most previous studies found that symbolic signs performed better on specific experimental measures (including comprehension) than do text-based ones (e.g. Ells and Dewar, 1979). Also, Edworthy and Adams (1996a) state that symbolic signs are often preferable when the concept the symbol is to describe is quite straightforward. Possibly the problem with the symbolic bridge warning sign was that no single, simple symbol showing the problem of a high-sided vehicle encountering a low bridge was conceivable.

The comparison of currently used signs against new designs may have influenced the results in the first experiment. The sign forms 'existing text-based' and 'Roundel' are currently used signs, and so presumably are familiar to most of the subjects, whereas the forms 'new text-based' and 'symbolic' were designs specially created for this experiment and thus had never been seen before by the subjects. This was probably not a major limitation for the 'new text-based' signs, as the information was in the same position and of a similar length to that in the 'existing text-based' signs, so it could be read as easily. The findings of the experiment support this, with the comprehension performance of the 'new text-based' being only slightly worse than for the 'existing text-based'. For the sign form 'symbolic' this was probably more of a problem. Being presented with a completely new, and quite complex, symbol (a lorry hitting a bridge) for only a brief period of time caused many subjects to misunderstand its meaning (for example thinking the sign referred to a warning for a hump-back bridge), so resulting in a lower mean comprehension score. Although the symbolic form of the sign was not evaluated in the second experiment, there is perhaps evidence for it (or another symbol) to be tested more vigorously at some other time. However, it is not considered further in this investigation.

The value of the addition of a yellow border is, however, supported from the previous literature. Cooper (1988) found that the addition of a yellow border to traffic signs could increase conspicuity. In addition, Adams and Edworthy (1995) found that a border on a warning could positively influence the reported level of perceived urgency of the warning. However, none of these positive results for signs with borders used comprehension as the evaluation measure (most studies examined conspicuity). In a sense, the finding that the addition of a border can help comprehension was unexpected. As a conspicuity measure the addition of a yellow border to delineate the sign from the background would seem logical. But why should a yellow border around a sign increase understanding of that sign? In the sign variable 'form' it was expected that the format in which the information was presented would influence comprehension, but as each 'border type' was tested with all the 'form' types in both experiments, an effect was not expected for a specific border. It is suggested here that the high comprehension scores obtained for the yellow border may perhaps be explained by increased subject attention to the sign. Whatever the reason, both experiments produced similar good comprehension results for signs with yellow borders - therefore increasing the reliability of the findings.

The hazard perception measure of the second experiment did not produce definitive results. As mentioned in the introduction, the objective of this test was to go beyond the comprehension measure to examine motivational aspects of the sign, in particular if the sign in the scene was perceived as indicating a potential road hazard ahead. The hazard response measure was intended to be an intermediate evaluation stage between obtaining data concerning understanding of the sign's message and direct behavioural responses as a result of the sign. The results obtained for this measure found that the text-based signs had a higher hazard rating score than did the Roundel signs (but the difference was not statistically significant). It was expected that signs with both yellow and yellow/red borders would produce higher hazard perception ratings than those with plain borders. However, those with a yellow border produced a **lower** hazard perception score than both the plain and yellow/red border signs (differences in the scores were, however, minimal and not statistically significant). The reason this happened may be due to the experimental arrangement used in this study - as subjects gave their hazard rating score based on viewing the whole scene they may be rating it on other features in the scene apart from the sign. This is supported by the finding that subjects gave significantly higher hazard perception ratings for the bridge signs in rural scenes when compared with the urban ones. Although the scenes were constant for all versions of the border type variable (and the sign form variable), it still represents an indirect assessment of the hazard perception measure, so allowing other factors to influence the subjects' scores. Despite this, all versions of the IBW sign (existing and newly developed) produced higher hazard perception ratings than did the other traffic warning signs used in this study - therefore all were successful in causing subjects to perceive a hazard when compared with these other signs. Therefore every version of the bridge warning sign could perhaps be considered as effective in alerting subjects to the hazard ahead. The only result not conclusively established in the hazard perception part of the experiment was which specific version of the sign was the most effective.

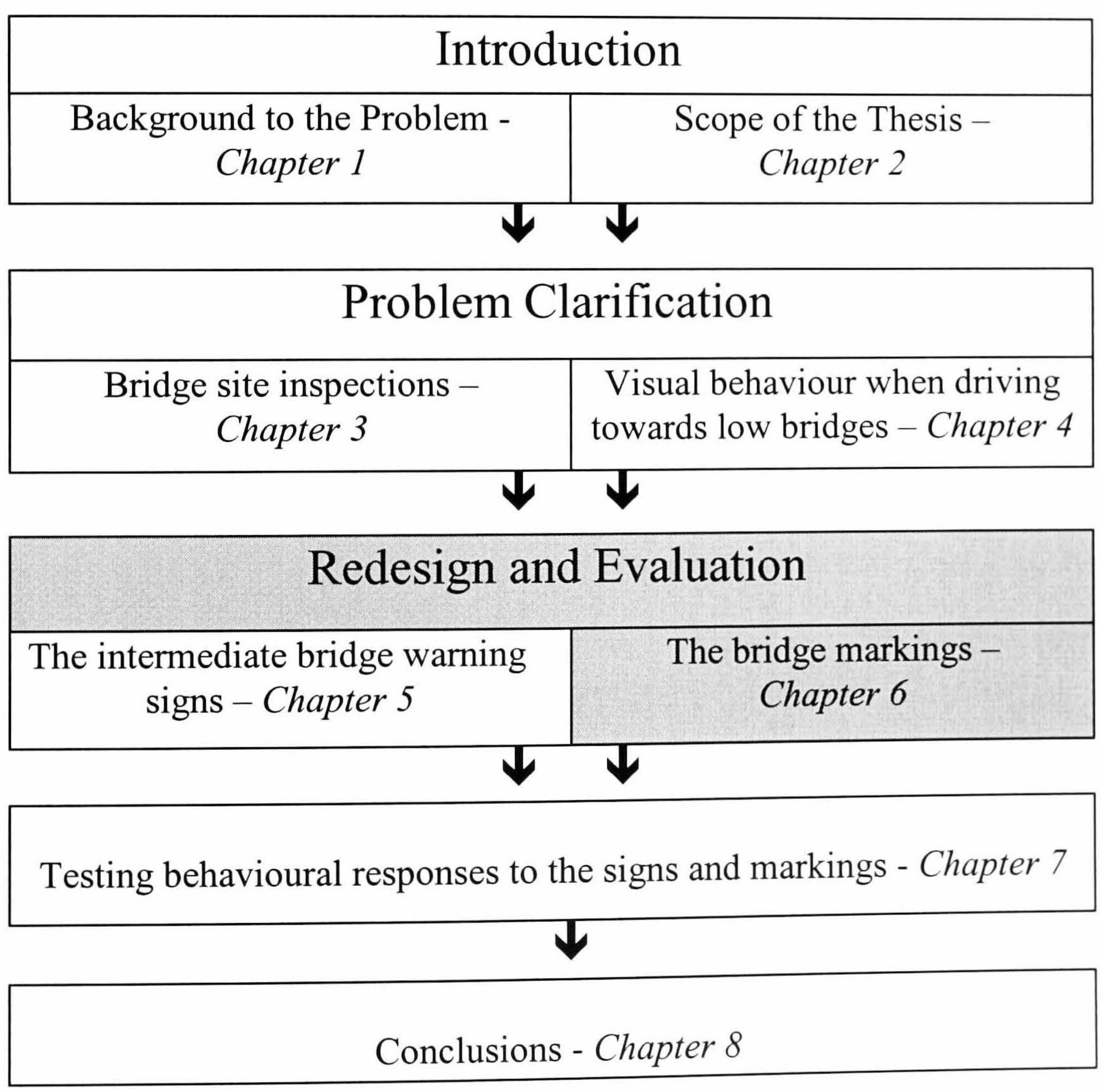
5.5 Conclusions

Both experiments found that 'text-based' versions of the intermediate bridge warning sign performed better than 'Roundel' or 'symbolic' versions of the sign on the specific experimental measures employed. Additionally it was found that those signs having a yellow border overall produced better comprehension results than those signs with either a yellow/red or a plain border.

The central function of an intermediate bridge warning sign, however, must ultimately be to reduce the number of overheight vehicles attempting to pass under a low bridge. Therefore from the research described here, the conclusion was that the best performing version of this warning sign (i.e. the 'text-based' version with a yellow border) should be evaluated further to demonstrate if the presence of this type of sign on the approach to a bridge actually influences drivers' behaviour. Experiments to investigate this topic were therefore carried out and are described in Chapter 7. Prior to this, however, the design and evaluation of the markings for bridges are considered.

Chapter 6:

Bridge Markings: Development and Evaluation



6.1 Introduction

Drivers of high-sided vehicles often attribute their bridge strikes to not knowing the exact height of their vehicles (DoT, 1993a). In addition, Galer (1980, 1981) found that only 12 % of high-sided vehicle drivers could correctly estimate the heights of their vehicles. Although the recently introduced legislation that requires the maximum height to be displayed in the cabs of most vehicles should partially reduce this problem, it can only be considered as a limited measure due to the following reasons:

1. It is not applicable for all high-sided vehicles (DoT, 1995b). For example certain vehicles from other EU States travelling in the UK are exempt from the legislation.
2. The displaying of the height information in cabs is rarely enforced by the authorities (e.g. police), therefore it may not be carried out by all haulage companies or vehicle operators.
3. The height information in cabs usually only gives the vehicle's maximum height, in many cases the actual operating height may be lower than this figure (e.g. due to the vehicle being fully loaded) - thus the drivers may realise this so attempt to pass under bridges that are slightly lower than this stated height.
4. The height information contained in bridge warning signs is not always accurate (see Chapter 3). Thus it may not be fully trusted by drivers when they make a decision as to whether or not they can pass under a bridge.
5. Drivers often do not detect the low bridge warning signs (see Chapter 4). So even if they know the correct height of their vehicles, they still may miss the signs that warn them of the height of the bridge.

It has previously been suggested that drivers judge bridge headroom by 'eye alone' (DoT, 1993a; Galer 1981). This involves them not relying on any displayed height information in their cabs or on the various warning signs, instead they gauge whether or not they can fit their vehicles safely through a bridge by how high the bridge appears to them as they drive towards it. Taking into account the limitations of the legislation of displaying the height in the vehicle's cab makes it likely that this situation will persist. Therefore the bridge itself, including the markings placed on it, can perhaps be best considered as the 'last line of defence' in stopping the driver of an overheight vehicle from attempting to drive his/her vehicle underneath it.

Work by Tkachuk (1994) suggests that people are not very accurate at correctly estimating height/vertical length. In an experiment examining the perception of vertical line length, it was found that 85% of subjects underestimated line length, in addition the mean underestimation was 13 % below the actual length of the object. This result supports Galer (1980, 1981), who found that high-sided vehicle drivers often did not know (or could not correctly estimate) the exact height of their vehicles. Therefore if drivers' decisions of whether to attempt to pass under bridges are occasionally taken by eye alone, it is not surprising that bridge strikes occur.

What are the functions of bridge markings? This has never been specifically answered, however the DoT (1982) tend to consider that the markings act to make the bridge appear more conspicuous - thus improving the drivers' awareness of the object. A recent consultation with representatives from the DoT and Railtrack (McGrane, 1995) affirmed that the exact functions of bridge markings had never been specifically defined beyond generally acting to make drivers' aware of the low bridge. While this must be an essential function of the markings, following Rumar (1990) who argued that visually enhanced designs may reduce traffic collision accidents, it is a contention of this research that the markings can have an additional safety capacity to help reduce bridge strikes, namely: to make the bridge appear lower than it really is. If drivers judge by 'eye alone' when deciding whether to try to pass under a bridge (and they are not very accurate at it), making it look even lower by the markings placed on it should reduce the number of occasions when an overheight vehicle attempts to pass underneath. Accident data from the DoT (1993a) indicates support for this in that a case was reported where a bridge was repainted in a manner that camouflaged the lower edge of the bridge deck (i.e. the top of the bridge) and the strike rate for that bridge tripled. If making a bridge look higher increased the accident rate then making it appear lower should reduce the accident rate.

6.1.1 Modification of the markings

Following the above, it is argued that a marking needs to remain visually conspicuous and to reduce the perceived height of the bridge. In the current investigation Railtrack and the DoT required that any new markings should essentially be the same size and position on the bridge and made of the same materials that are used in the current standard (mainly for reasons of cost). Therefore the two variables that could be modified freely were the colour of the markings and their specific design.

6.1.1.1 Colour of the markings

At present the markings are coloured in alternate bands of yellow and black. The use of yellow had been recommended for visibility by Lum, Roberts, DiMarco and Allen in 1983. They found that yellow as a background colour was better than orange in terms of recognition distance. Additionally, Wade and Swanson (1991) reported that because yellow is in the middle of the visible spectrum of light, it is usually in good focus by the eye. Furthermore, Solomon (1990) reviewed the optometric literature and argued that yellow was the best colour for visibility for accident avoidance, which was also later supported by Zwahlen and Schnell (1997) for conspicuity in the road environment. Yellow also has an advantage over some other colours (e.g. red) in that it is not so greatly affected by colour blindness (Whillans, 1993) or by diminished vision due to night time or eye diseases (Solomon, 1990). Therefore yellow has been widely recommended as being the most suitable colour to use for visibility in the road traffic environment.

If the function of a bridge marking is purely to make the bridge conspicuous, then yellow (when combined with another colour of different brightness and colour contrast, e.g. the wasp-like yellow with black) would seem to be a suitable choice. Indeed the combination of yellow and black for warning visibility was recommended by Lees and Farman as long ago as 1970. The situation is, however, made more complicated as it is argued here that the function of a bridge marking is also to make the bridge appear lower than it really is. As no previous work has been conducted in this area, then other colours need to be tested to establish their effects on bridge height perception.

6.1.1.2 Design of the markings

To make the bridge appear lower it is necessary to incorporate some type of visual illusion into the markings to give a false perception of height. Three types of well-established geometrical optical illusions were identified which it was thought might influence bridge height perception, a summary of these and how they were adapted for bridge markings is given below (more details can be found in Robinson, 1972; or Suzuki and Arashida, 1992).

1. The Oppel-Kundt Illusion

The Oppel-Kundt illusion is also known as the 'illusion of filled extent', where a filled extent is overestimated when compared with an equal unfilled extent (Rothwell and Zaidel, 1990). The basic version of the illusion is shown in Figure 6.1 where the gap between the line below figure A and that below figure B looks larger than the gap between the line below figure B and that below figure C (the letters A, B and C need to be covered over for the illusion to be seen properly).

Figure 6.1: The Oppel-Kundt Illusion.

A B C

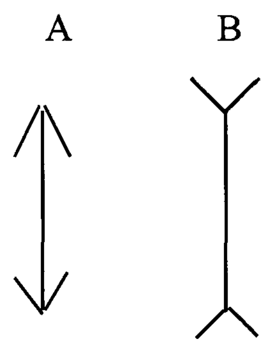
| | | | | | | |

Research by Noguchi, Hilz and Rentschler (1990) found that this illusion occurs not purely between filled against unfilled extents but also between areas filled with different widths of bands. An area which contains a large number of bands of colour that are close together is perceived as larger than the same sized area with a smaller number of wider spaced bands of colour. Adapting this illusion for bridge markings would predict that bridges with a small number of wider spaced bands of marking colours around the bridge face would look smaller (so lower) than bridges with a large number of narrow spaced bands.

2. The Muller-Lyer Illusion

The well-known Muller-Lyer illusion is another illusion of perceived line length. Figure 6.2 shows the illusion, where the vertical line A (with the inward facing 'fins') looks shorter than line B (with the outward facing 'fins').

Figure 6.2: The Muller-Lyer Illusion.

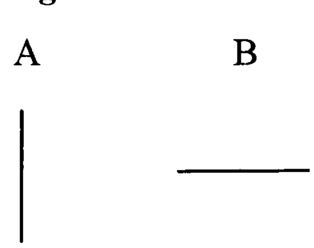


Additionally, line A would look shorter than a plain line of the same length and line B would look longer than the plain line (Robinson, 1972). Adapting the Muller-Lyer illusion for bridge markings would predict that bridges with markings on the bridge sides that faced inwards would look lower than both those with the current design of markings, i.e. plain stripes, and those with markings on the bridge sides that faced outwards. Examples of these 'inward', plain and 'outward' markings are shown in appendix F.

3. The Horizontal-Vertical Illusion

The Horizontal-Vertical illusion states that a vertical line usually appears longer than a physically equivalent horizontal line - often by as much as 20% (Schiffman and Thompson, 1974). Figure 6.3 shows two lines of equal length, with line A generally being perceived as longer than line B.

Figure 6.3: The Horizontal-Vertical Illusion.



Adapting this illusion means that bridges that look wider will consequently look lower when compared to more narrow looking bridges of the same height. It was hypothesised that bridge markings could be designed to make a bridge look wider through the use of bands of colour. It was also predicted that thin vertical bands of colour that were placed at the bridge sides ranging from a light colour on the inner face to a darker colour further out would make the bridge seem wider, and therefore lower, than a plain bridge.

All three of these illusions are fairly robust. For the Muller-Lyer illusion, research by Predebon (1994) and by Redding and Hawley (1993) found that fractional versions of the stimuli (i.e. not showing all four 'fins') still produced the illusion, so stimuli with just one or two 'fins' still influenced judgement of the length of the line. Additionally, earlier Gregory (1974) had reported that the angle of the 'fins' to the line shaft could vary substantially for the illusion still to occur, in terms of making a line look shorter the maximum illusion occurs when the fins are angled between 35 - 75° to the line shaft. In their work investigating the Horizontal-Vertical illusion, Schiffman and Thompson (1974) found that eye movements were not needed for the illusion to occur; when they presented versions of the stimuli for 50 or 100 ms (i.e. faster than the time needed to make an initial eye movement reaction) subjects still demonstrated the illusion. Hence illusions seem to occur both when the stimulus is not a classically 'perfect' version and when it is viewed for only a brief time interval. This is important because using illusions in bridge markings would involve adapting them somewhat (e.g. a two 'fin' version of the Muller-Lyer illusion would be used on each side of the bridge) and because the task of driving a vehicle towards a low bridge may involve drivers looking at the markings only for brief periods.

A related issue is whether previous exposure to the illusion will lessen its effect. Predebon (1992) found no effect of familiar size on perceived size, so familiarity was not an important determinant of perceived size, suggesting that an illusion in a bridge familiar to drivers may still occur repeatedly. However, Brosvic and Finizio (1995) found that when feedback was given to subjects being shown the Muller-Lyer illusion, then the effect of the illusion reduced on subsequent occasions. Although being given direct feedback may reduce the illusion in laboratory conditions, with the stimuli being given to subjects in a short space of time, the effect of the illusion in driving, where a bridge containing the marking illusion may be seen by drivers rarely, may be different. If a marking illusion is seen perhaps once an hour, then a great deal of other traffic environment stimuli will have also been seen and processed by the driver, thus it is probable that the illusion will persist under these conditions (this issue will be discussed further in Chapter 8).

6.1.2 Previous perceptual manipulations

Illusions of size, depth and space have been previously used successfully in the built environment for several centuries (Prak, 1977). Examples of this include St. Peters in Rome where a misperception of space was due to the manipulation of certain cues. In particular, the building looks bigger than it really is due to the huge amount of detail on its walls (Prak, 1977). A similar effect was found by Verillo and Graeff (1970) in the work on size judgement where complex surfaces were judged to be approximately 30% larger than simple surfaces - thus more detail in an object can increase its perceived size. This is supported by Bose and Malhotra (1991) who found that size was overestimated least for unfilled circles, as the amount of fill pattern in the circles increased so did a subject's perception of its size. For both of these experiments the effect seems to be similar to the hypothesised effect for the Oppel-Kundt illusion on bridge markings – that is, having a less complex object (i.e. wider stripes in the bridges' markings) will look smaller than a more complex object (i.e. narrower stripes in the bridges' markings).

Previous perceptual illusions of size are not just due to some kind of variation of the Oppel-Kundt illusion. Gregory (1974) points out that the Muller-Lyer illusion can be seen in corners of buildings, with inside corners displaying outward facing 'fins' (thus increasing the perceived size) and outside corners displaying inward facing 'fins' (so reducing the perceived size). This kind of illusion is, however, generally an unintentional by-product of making corners in buildings rather than a deliberate attempt to manipulate the building's perceived size.

There have also been previous perceptual manipulations in the design of the road environment. The case of thin yellow lines being painted across a road on the approach to a junction is a classic. The concept is that the yellow lines are painted closer together the nearer a vehicle gets to a junction, thus the perceived speed will seem to be increasing and therefore the driver should slow down (Oyama, 1987). In the UK, Denton (1980) found that the installation of such a simple perceptual device could reduce accidents by almost 66% by slowing down traffic at relevant places. Additionally, Shinar, Rockwell and Malecki (1980) found that painting markings on to a road surface to make the road at a bend appear narrower had the effect of reducing vehicles' speeds, thus reducing the accident rate at the site.

Similarly, several researchers have explained some types of driver behaviour in terms of perceptual illusions. Ota (1996) explained speed perception (with increased optical flow for higher speeds) in terms of a temporal version of the Oppel-Kundt illusion. In addition, Leibowitz (1985) argued that the problem of vehicles crossing over level crossings in front of oncoming trains may be due to the drivers thinking they had more time to cross due to a visual illusion of velocity and size, where large objects (e.g. trains) seem to be travelling at a slower speed than smaller objects.

6.1.3 Experimental Objectives

As a result of the research so far and the relevant earlier research findings it is hypothesised that making a bridge appear lower will result in more appropriate driver behaviour, and so will lessen the number of bridge strikes. To verify this, two experiments were performed:

- The first aimed to establish if the markings placed on a bridge can influence drivers' decisions as to whether to try to pass under it.
- The second aimed to design improved combinations for the markings to make a bridge look lower than it really is.

6.2 Experiment 1: Initial Development and Evaluation of the Bridge Markings

6.2.1 Bridge Marking Development

The objective of the first experiment was to establish if a subject's perception of bridge height is affected by the markings placed on the bridge. Therefore it was necessary to develop and test a variety of different marking designs, to ascertain if they had any effects on a subject's bridge height perception. By utilising the existing research reports on visual illusions and colours for markings, a series of marking designs was created for this experiment. These designs were based on the currently used standard in the UK (i.e. the yellow and black hatching), different colour combinations which are commonly used as part of visual warnings on vehicles or roads in the UK (e.g. red and white), visual illusions (e.g. Horizontal-Vertical illusion) and on using a control (i.e. a bridge with no markings on it).

Specifically, five marking designs were tested in this experiment, these were:

1. **The current DoT standard** – that is, yellow and black hatching narrowly spaced around the bridge. The dimensions corresponded to DoT drawing standard (P) 530.2, DoT (1991).

2. **The current DoT standard, but in a different colour combination** – that is, a yellow and red hatching narrowly spaced around the bridge.

3. **A wider spaced version of the DoT standard in other colours** – that is, a red and white hatching, spaced twice the width of the currently used standard (based on the Oppel-Kundt illusion, where space filled with equal distance lines looks longer than unfilled space). By adapting this well-established visual illusion, it was hypothesised that this marking would make the bridge appear lower than it really was.

4. **Shades of colour at the sides of the bridge** - Shades of red[1], from a light shade on the inner face to a darker shade further out (based on the Horizontal-Vertical illusion). As with the marking design above, it was hypothesised that this marking would make the bridge appear lower than it really was - the darkening shades of colour at the sides of the bridge were intended to make the bridge appear wider, and hence illusionally lower.

5. **A Control** - a plain bridge with no markings on it.

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[1] Red was employed because it was a common colour for warning signs and was considered by Railtrack (McGrane, 1995) to be environmentally sensitive (i.e. bridges marked with that colour would probably not cause offence to local residents). However, the use of red may be problematic for drivers who are colour blind.

6.2.2 Method

The experiment took place immediately after the first road sign experiment (reported in Chapter 5). Consequently, both experiments used the same subjects and took place in the same locations.

6.2.2.1 Subjects

The same sixty-four subjects as described in Chapter 5 Section 5.2.2.1 were used (see page 89 for details).

6.2.2.2 Equipment and Stimuli

A dynamic, computer-animated display of bridges in a road environment was developed to assess each subject's perception of bridge height. For this experiment, flat top bridges were utilised, as records held by Railtrack revealed that girder style bridges rather than arch bridges are struck more often, with more severe consequences (McGrane, 1995).

The viewpoint, through which the video was seen, was set to approximate an eye height of 8' 4" (thus corresponding to the real world driver eye height measurements obtained by Cobb, 1990, for heavy trucks). The animated scene comprised a test route (based on driving around a block) featuring four bridges (B1, B2, B3 and B4) of different heights (one of which was 7' 9", which was low enough to be hit), these were:

- 'B1' which approximated a 'real world' height of 7' 9"(i.e. it was 7 inches **below** the eye height at which the animation was set).
- 'B2' which approximated a 'real world' height of 8' 11" (i.e. 7 inches **above** the eye height at which the animation was set).
- 'B3' which approximated a 'real world' height of 9' 7" (i.e. 15" **above** the eye height at which the animation was set).
- 'B4' which approximated a 'real world' height of 12' 0" (i.e. 3' 8" **above** the eye height at which the animation was set).

It was hypothesised that bridge 'B2' would produce more errors of judgement (subjects saying it would be hit when actually it was missed) than would bridges B3 and B4, because they were further away from the animation's set eye height.

The speed of travel around the route was kept constant, approximating to 25 mph, so being similar to the speed at which a high-sided vehicle may be approaching a bridge. To make the road environment rich and as realistic as possible, the test route also featured green grass around the road, a blue sky, white carriageway centre line markings and double yellow waiting restriction markings along the sides of the road.

Five versions of the route were produced; these had a different design of markings for each version. Additionally, all five versions showed the same four bridges - but for each version they were placed in different orders along the route. The PC animation for each marking version was transferred to separate VHS video tapes. All versions were shown on a high quality 14" monitor (JVC, model: PM-150 PSN-K). Each subject viewed all five tapes, and the order in which they were presented to the subject was randomised.

A copy of the animated road environment showing a bridge with markings is displayed in appendix G.

6.2.2.3 Procedure

The lorry drivers were tested in a specially adapted area of a transport café, which although not as controlled as a laboratory, had a constant lighting level of approximately 350 lux and was generally quiet. The car drivers were tested in an experimental room also with a lighting level of approximately 350 lux. The procedure for both groups was identical (apart from the fact that the two groups were tested at different locations).

Each subject was tested individually. They sat approximately 60 cm in front of the screen and the height of the monitor was adjusted to bring their eye height level to a mid point on the screen. All five versions were shown to the subject. For each bridge in each version, the response required was whether they thought that they would hit or miss the bridge. They were instructed to imagine they were driving an open-top vehicle and it would be their actual head that may hit the bridge (so removing the need for subjects to imagine a roof above them that would be hit).

At a specified 'stop-point' before the bridge, the video was blanked out for 5 seconds, during which time subjects were asked whether they thought they could safely pass under or would strike the bridge. The point at which subjects were asked whether they could pass under the bridge was established from a pilot trial as being the final moment that the majority of the pilot subjects made a decision whether to attempt to pass under or stop before the bridge - it was 1.2 seconds before reaching the bridge[2].

After the hit/miss decision was made, the video continued 'driving' through the test route. Subjects were not given explicit feedback as to whether their decision of hit or miss was correct, however, for bridge B4 (and to a lesser extent B3) it was obvious that the bridge was missed, as the animation's set eye height clearly passed under the bridge. The procedure was identical for all four bridges in the route and for all five versions of the route (with the five different marking designs). So, in total, each subject was required to make a decision of whether they would pass under or hit the bridges on twenty occasions.

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[2] The speed of the driving around the animated scene was set at 25 mph, thus in 1.2 seconds the video would have driven the real world equivalent of just over 13 metres. Deciding whether to try to pass under a low bridge when 13 metres away from it may be a reasonable minimum distance to make the decision when driving a real high-sided vehicle. Lorry stopping distances are discussed further in Section 7.2.2.

6.2.3 Results

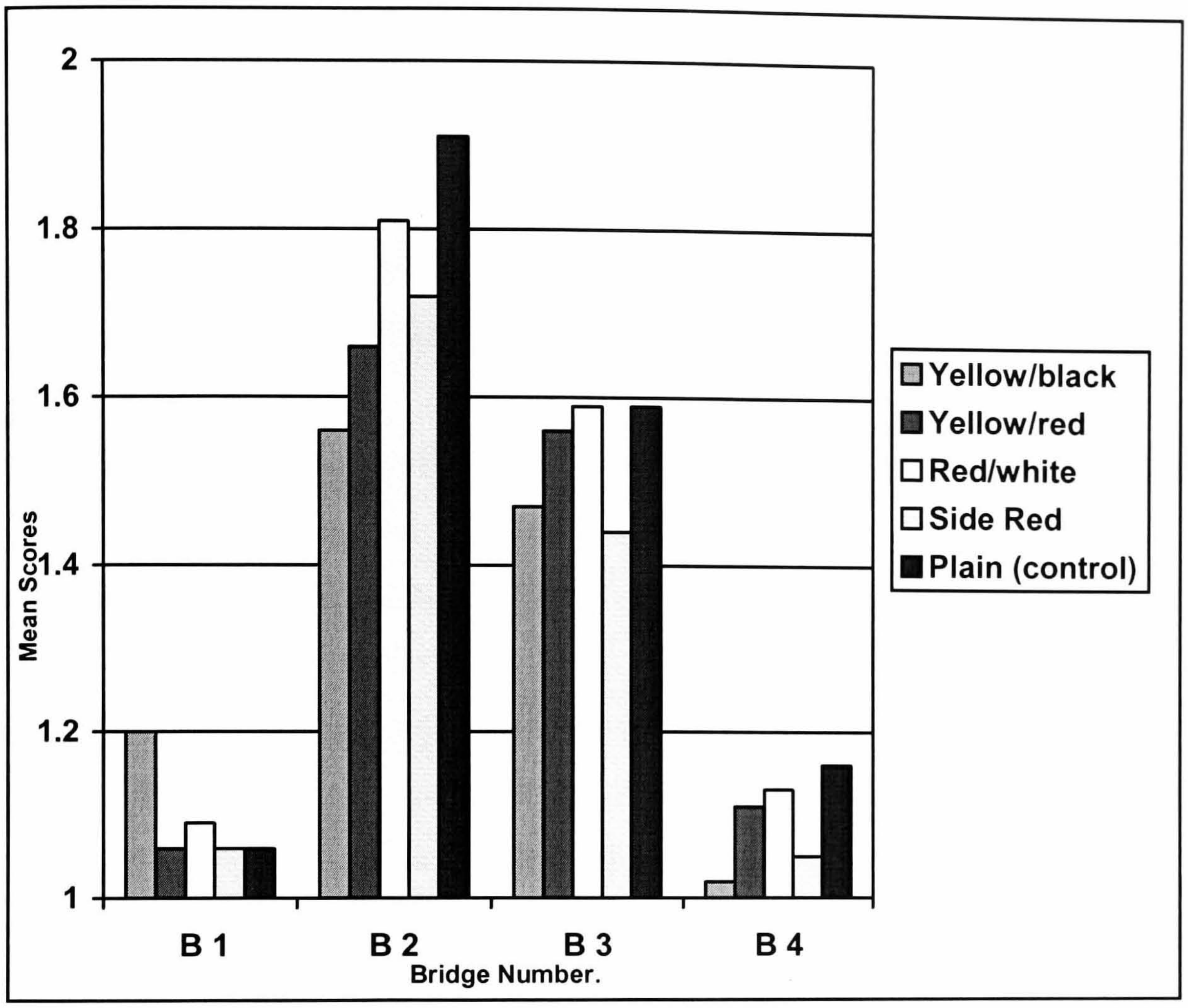
Subjects' responses were scored such that a 1 was given if they correctly decided that they would hit or miss the bridge and a score of 2 was given if this decision was incorrect.

The results were analysed in a 2 x 4 x 5 mixed factorial ANOVA. The factors were:

- 2 driver types – car and lorry drivers.
- 4 bridge heights – described in Section 6.2.2.2.
- 5 marking designs – described in Section 6.2.1.

The ANOVA revealed that there was no significant difference between the car drivers and lorry drivers in terms of correctness of their responses ($p > 0.05$). The remaining analysis therefore considers the data for both groups of subjects combined. This produced the following mean results represented in Figure 6.4. In this figure a low score represents a more accurate decision.

Figure 6.4: Mean scores for each bridge.



The scores are illustrated in more detail in Table 6.1. Note a low score represents a more accurate decision.

Table 6.1: Mean scores for the four bridges and five different marking designs.

Bridge Number (their heights in brackets)	**Marking Design** *Yellow/ Black*	*Yellow/ Red*	*Red/ White*	*Side Red*	*Plain (control)*	Mean
B1 (7'9")	1.2	1.06	1.09	1.06	1.06	1.09
B2 (8'11")	1.56	1.66	1.81	1.72	1.91	1.73
B3 (9'7")	1.47	1.56	1.59	1.44	1.59	1.53
B4 (12'0")	1.02	1.11	1.13	1.05	1.16	1.09
Mean	1.31	1.35	1.41	1.32	1.43	1.36

It can be seen from the table that bridges B1 and B4 were the most accurately judged, and bridge B2 was the most incorrectly judged, followed by B3.

In terms of the correctness of decisions, the ANOVA further revealed the two following significant main effects (both at $p < 0.01$):

- Between the different bridge heights.
- Between the bridge marking designs.

While it was to be expected that the bridge height would have a significant effect on each subject's decisions, the finding that the design of the markings also had a significant effect on hit/miss decisions is a key finding of this experiment.

In addition, the above analysis was based on the use of "correct" response as the experimental measure. This is perhaps only critical where the bridge is low enough to be hit (i.e. B1). For this bridge, if a subject were to respond with a "miss" response, the real world outcome would be a bridge strike. Considering just this bridge, the current DoT standard design (yellow/black hatching) produced the most wrong decisions (thus most potential bridge strikes). The scores for the four other bridge markings (including the control marking) were very similar. Based on these data it must therefore be questioned whether the currently used yellow and black marking standard is the best design possible for reducing the perceived height of a bridge. Although it must be noted, as mentioned earlier in Sections 6.1 and 6.1.1, the current marking design was only employed to make the bridge appear more conspicuous; it was not originally implemented with the specific intention of reducing the perceived height of a bridge.

6.3 Experiment 2: Continued Development and Evaluation of the Bridge Markings

6.3.1 Bridge Marking Development

In this experiment, which extends the previous one by investigating the 'optimum' design of bridge markings, the variables were orthogonally manipulated to establish the ideal arrangement of them for their use as bridge markings. The different markings tested here were based on the design standards for marking low bridges used in other countries, on colour combinations commonly used for warnings on the UK roads, and on the previous research on visual illusions and warnings. Specifically, the following variables were used:

- **The 'form' of the markings.**

Three different forms (meaning the general 'style' of the markings) were developed. These were as follows:

1. The current full UK standard of a hatching pattern on both the top and sides of a bridge (based on the official drawing standard (P) 530.2, DoT, 1991).
2. An adaptation of the Muller-Lyer illusion, where the inward facing 'fins' were positioned on the sides of the bridge to endeavour to make the bridge appear lower than it really was. The top of the bridge had plain bands of the two specific colours used for the markings.
3. An adaptation of the Muller-Lyer illusion where outward facing 'fins' were used on the sides of the bridge. The top of the bridge again had plain bands of the two specific colours used for the markings. Although this form was not expected to make the bridge appear lower, it needed to be evaluated for the experimental design employed (i.e. testing all combinations of the variables so that their effects could be quantified using an ANOVA model, as analysed later in Section 6.3.3).

- **The 'colour' of the markings.**

Four colour combinations were employed; they were all commonly used colour combinations for warnings. Additionally, the combinations used had a high brightness and colour contrast. The colour combinations used were:

1. Yellow and black - this combination represents the existing colour standard for the marking of low bridges in the UK (based on the colours in the official drawing standard (P) 530.2, DoT, 1991).
2. Yellow and red - this combination is used, for example, as a warning on the back of long vehicles in the UK.
3. White and red - this combination is used, for example, on many warning signs on the roads in the UK and also to mark low bridges in other countries (e.g. South Africa).
4. White and black - this combination is used, for example, to mark low bridges in the Netherlands (Hagenzieker, 1994).

- **The 'width' of the markings.**

Two different widths of markings (wide and narrow) were used. These were based on an adaptation of the Oppel-Kundt illusion (where space filled with equal distance lines looks longer than unfilled space). It was hypothesised that having fewer bands of markings of a greater width would make the bridge look lower than more bands of markings with a smaller width.

Therefore the current form of the standard markings was developed with the four colour combinations in the two widths (so making eight designs, including the currently used marking standard). The Muller-Lyer inward facing fins was also created with the four colour combinations in the two widths (so making another eight designs) and the Muller-Lyer outward facing fins was likewise produced with the four colour combinations in the two widths (so also making another eight designs).

In addition, three other marking designs that did not fit the exact experimental design were developed. These were based on an adaptation of the Horizontal-Vertical illusion. It was hypothesised that making the bridge look wider by using bands of light to dark colours would also reduce its perceived height. Of the four colours used to create the markings in this study (white, yellow, red and black) it was observed that white was too similar to yellow for them to be placed together on a real bridge, additionally white on the inside edge of the bridge would not clearly delineate the bridge from the environment. Therefore keeping with the same four colours, it was only possible to produce one design of three bands of darkening colours at the side of the bridge (i.e. yellow/red/black). The top of the bridge had bands of the three colours across it. Additionally, two designs of two colours were created, these were yellow/red and yellow/black. These covered the same area as the three-band design (i.e. by each of the two bands being 50% wider than the bands in the three-colour design). For these two designs the tops of the bridges had bands of two colours across them.

Thus the complete set of experimental bridge markings comprised twenty four versions produced from the manipulation of the variables 'form', 'colour' and 'width', and three versions from the adaptation of the Horizontal-Vertical illusion, so in total twenty seven experimental marking combinations were examined.

In addition, a control bridge marking was produced with which to compare all the experimental versions. This control bridge marking was a version of the current DoT standard and just had the yellow and black hatching along the top of the bridge (i.e. the sides were unmarked). On actual bridges, this version of the DoT standard is frequently used in place of the full DoT standard (i.e. the narrow spaced, yellow and black standard hatching version that was evaluated as one of the twenty seven experimental bridge markings).

Examples of the markings (selected to show all the design combinations) are shown in appendix F.

6.3.2 Method

6.3.2.1 Subjects

One hundred people took part in the experiment, 65% were female and 35% were male. In terms of ages 21 % were aged 20 or less, 35 % aged 21-30, 27 % aged 31-40, 15 % aged 41-50 and 2 % aged 51 and over. All reported normal or corrected-to-normal vision. As the purpose of the experiment was to establish which markings made bridges look lowest (rather than the markings' effects on driver behaviour), it was considered unnecessary to use high-sided vehicle drivers, therefore the majority of the subjects were car drivers. Table 6.2 shows driving experience in terms of the number of years the subjects had driven a car.

Table 6.2: Number of years subjects had driven a car.

Number of years of car driving	Percentage
Never driven*	4 %
3 years or less	33 %
4-6 years	6 %
7-9 years	8 %
10-12 years	8 %
Over 12 years	41 %

* Had driven other vehicles on the road, e.g. motorcycles.

6.3.2.2 Equipment and Stimuli

The twenty-seven markings described previously (together with the Control Bridge marking) were each superimposed on to a picture of a 'real' girder type bridge (which had been scanned into a computer drawing package). The bridges, with the different markings on them, were printed on A4 paper sheets (using the full size of the paper, in landscape orientation) by means of a high quality dye sublimation printer. The sheets of A4 paper were displayed vertically on a specially built stand that kept the images in the correct place.

Subjects were seated to view the markings. The seating position and the position of the stand were fixed so that all subjects viewed the markings from the same place. The stand was positioned in front of a plain coloured wall to prevent unnecessary distractions from influencing the decisions of the subjects. The distance from a subject's eye to the bridge images was approximately 23.5" (60 cm). The size of the images subtended to an angle of vision at the eye of 17° high and 23.5° wide. The experiment took place in a laboratory with a light level of approximately 400 lux.

6.3.2.3 Procedure

Each subject was tested individually. They were informed that they would be presented with two bridge pictures at the same time, one of the pictures was always the control and the other was one of the experimental markings. Their task was to say on their first impressions if the bridge containing the experimental marking looked higher or lower than the control (if they thought they were the same height they were to indicate they were the same). The two bridges were displayed side by side with the viewer positioned equidistant between them.

Each subject was asked how much higher or lower the experimental bridge looked when compared to the control on a seven-point scale. This scale ranged from 1 if the subject thought the experimental bridge looked much lower, to a 7 if they thought the experimental bridge looked much higher - with a 4 if the two bridges were said to be of equal height. After the subject had responded with a number (corresponding to the perceived height of the experimental bridge) the experimental bridge was removed from the stand and another one was put in its place. Each subject viewed all the experimental bridges using the same procedure; the overall sequence in which the experimental markings were presented to each subject was randomised to prevent order effects influencing the results. In addition, several times during the trials, the position of the control sign was moved to the other side (in case, for example, the subject had a bias to always judge the bridge on the left to be higher than the one on the right, or vice versa).

6.3.3 Results

Responses were scored corresponding to the seven point rating scale described earlier. Table 6.3 shows the mean results for the 27 marking designs.

Table 6.3: Mean scores for the experimental bridge markings (in ascending order).

Bridge Marking Description (form-width-colour)	**Mean score**	**Std. Dev.**
Muller-Lyer outward-wide-white/red	3.34	0.98
Muller-Lyer inward-wide-white/red	3.38	0.99
Muller-Lyer inward-narrow-yellow/red	3.39	1.09
Muller-Lyer inward-wide-yellow/black	3.42	1.02
Muller-Lyer inward-wide-yellow/red	3.47	0.90
Muller-Lyer inward-narrow-yellow/black	3.51	1.02
Muller-Lyer outward-wide-yellow/red	3.51	1.04
Muller-Lyer inward-wide-white/black	3.54	1.00
Muller-Lyer inward-narrow-white/red	3.55	1.13
Muller-Lyer outward-wide-white/black	3.56	0.99
Muller-Lyer outward-narrow-white/black	3.57	0.97
Muller-Lyer inward-narrow-white/black	3.57	0.97
Side bands-narrow-red/yellow/black	3.65	1.10
Side bands-wide-yellow/red	3.70	1.02
Muller-Lyer outward-narrow-yellow/black	3.70	1.00
Muller-Lyer outward-wide-yellow/black	3.72	1.03
Muller-Lyer outward-narrow-yellow/red	3.74	1.09
Side bands-wide-yellow/black	3.74	1.06
Muller-Lyer outward-narrow-white/red	3.75	1.06
Standard design-wide-white/black	3.87	1.19
Standard design-wide-white/red	3.93	1.18
Standard design-wide-yellow/black	4.02	1.07
Standard design-wide-yellow/red	4.02	1.15
Standard design-narrow-white/red	4.06	1.20
Standard design-narrow-yellow/black*	4.08	1.09
Standard design-narrow-white/black	4.10	1.24
Standard design-narrow-yellow/red	4.14	1.21

* Indicates the current design used on roads in the UK

In terms of making the bridge look smaller the **lower** the mean score the better. A score of 4 meant that the experimental bridge looked the same height as the control bridge, therefore all the designs with a score above 4 meant that they were worse than the control at making the bridge appear lower. The current design used on roads in the UK (i.e. narrow hatching in yellow and black) performed badly in terms of making the bridge look lower, it had a mean score of 4.08 and was positioned 25th out of the 27 designs tested, so demonstrating that other marking designs were more effective in reducing the perceived height of a bridge.

The three bridges with the bands of colour at the sides also generally performed badly, being in positions 13, 14 and 18 out of twenty seven designs tested. Because they were a radically different design from the other markings they could not be analysed in a Repeated Measures ANOVA model with the other marking designs (which were orthogonally manipulated in terms of form, colour and width), so as they did not perform well, they were excluded from further analysis.

The other twenty-four designs were analysed in a multiple (2 x 3 x 4) ANOVA for Repeated Measures (2 widths - wide / narrow, 3 forms - Current standard /Muller-Lyer inward / Muller-Lyer outward, and 4 colour combinations - yellow & black / yellow & red / white & red / white & black). This produced the results shown in Table 6.4.

Table 6.4: Results of a Multiple ANOVA for Repeated Measures.

Variable being tested (within-subject)	**F value**	**Significance**
Colour	0.52	0.670
Form	38.89	0.000 **
Width	8.46	0.004 **
Colour by form	0.90	0.496
Colour by width	1.34	0.262
Form by width	0.52	0.593
Colour by form by width	0.85	0.531

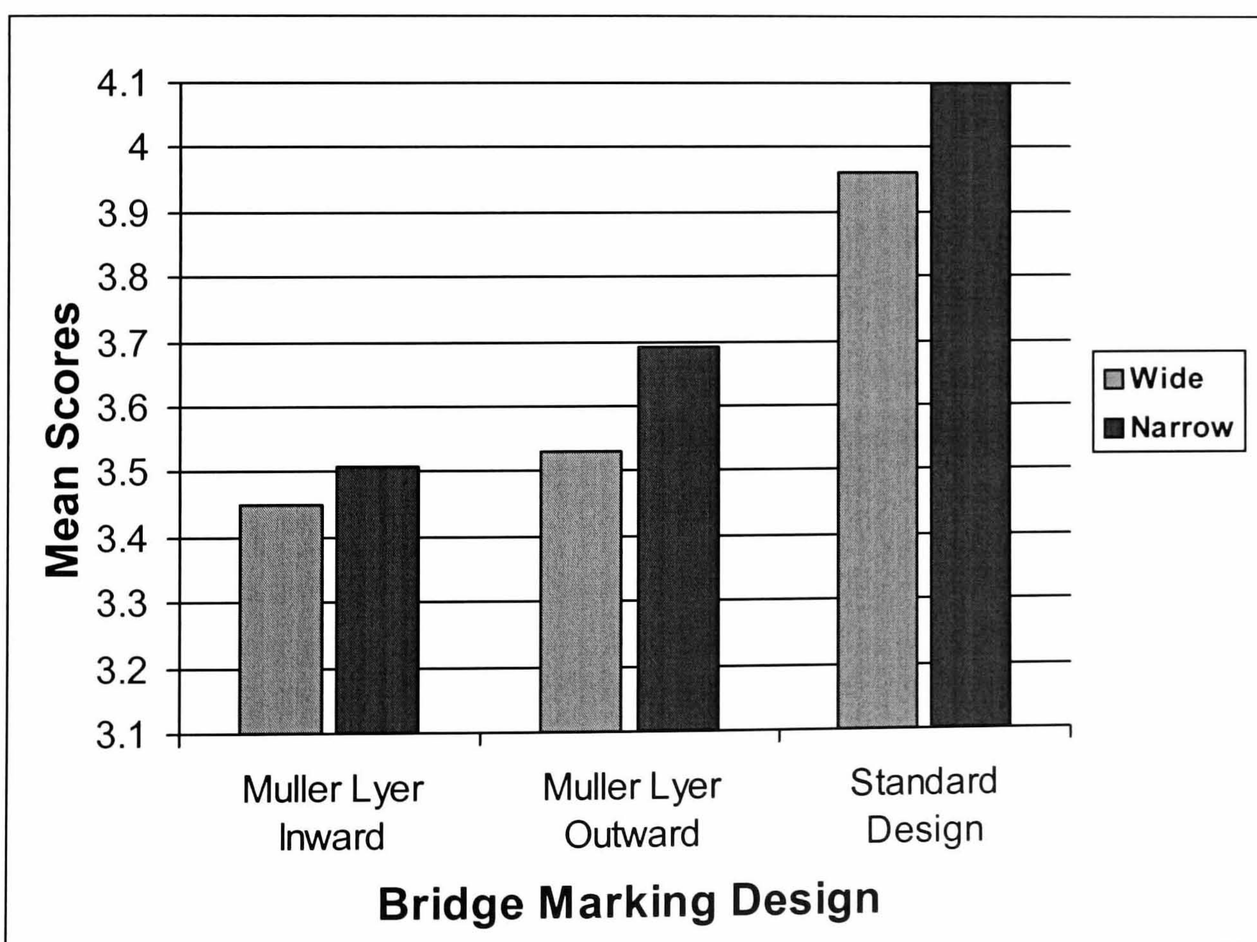
** Indicates a significant difference at the 1 % level.

Thus the two following significant differences were found:

- For the main effect 'form' (i.e. that the three different forms significantly differ in how high they are perceived to look).
- For the main effect 'width' (i.e. that the two different widths significantly differ in how high they are perceived to look).

To further examine these two significant differences, Figure 6.5 shows the mean scores for the data divided into the variables of 'form' and 'width' (i.e. the four variations of the 'colour' variable were averaged for the each of the six combinations of form and width). Note **lower** mean scores indicate lower perceived bridge height.

Figure 6.5: Mean scores for the variables 'form' and 'width'.



With 'width' there are only two levels (narrow and wide). The widely spaced markings have a lower mean score than the narrowly spaced ones, so widely spaced markings are significantly better at making the bridge look lower when compared with the narrowly spaced ones.

With 'form' there are three levels (Muller-Lyer inward / Muller-Lyer outward / Current Standard), thus further analyses needed to be performed to find where the differences were. A t-test for paired samples found the following:

- Muller-Lyer inward was significantly better than Muller-Lyer outward ($t = 2.67$, 2 tailed significance = 0.009).
- Muller-Lyer inward was significantly better than the current standard ($t = 8.11$, 2 tailed significance = 0.000).
- Muller-Lyer outward was significantly better than the current standard ($t = 5.56$, 2 tailed significance = 0.000).

Therefore the design of Muller-Lyer inward (i.e. markings with 'fins' facing towards the inside of the bridge) was the best of the three forms in terms of making the bridge look lowest.

No main effect was found for colour. Hence, based on the combinations used in this experiment, the colours in which the markings on bridges are painted do not alter how high they look.

Further analysis was done on between-subject variables. Analysis of Variance found:

- No differences in the results due to subject's sex ($p > 0.05$).
- No differences in the results due to subject's age category ($p > 0.05$).
- No differences in the results due to subject's driving experience ($p > 0.05$).

So the results found are not significantly altered by the variables of sex, age or driving experience.

6.4 Summary and Discussion

The two experiments described here developed and evaluated a wide range of alternative bridge markings. The overall objective was to test the performance of the current marking standard and to establish if any of the alternative marking designs performed better. The current standard was only specifically designed to make a bridge appear conspicuous, however it has been argued throughout this Chapter that markings need to have the additional function of making a bridge appear lower than it really is. On the height judgement measures, the results found that the current standard did perform badly, and that other markings that were developed for this investigation performed better.

The two experiments had slightly different purposes. In the first, the issue was whether the subject thought the oncoming bridge would be hit or missed and if their decisions were correct. The second experiment purely considered how high subjects thought a bridge displaying the experimental markings looked when compared with a control. Additionally, the stimuli were different for both experiments: in the first experiment a dynamic sequence of bridges in an animated road environment was used, in the second, static pictures of bridges were viewed.

The reason why the experiment using a dynamic road scene was undertaken before the simple height judgement study involving static stimuli, was that it was necessary to develop a moderately realistic road scene to demonstrate the principal of the experiments. That is, can bridge height perception be influenced by the markings placed on a bridge? The first experiment demonstrated that the correctness of each subject's decisions was influenced by both the design of the markings and by the actual height of the bridge. This second result was also important as it supported the validity of the experiment by demonstrating that decisions with respect to the highest and lowest bridges were more often correct than were the decisions for the two 'middle height' bridges, thus being similar to real life where the majority of the bridges hit were not exceptionally low or high (DoT, 1993a; see Chapter 1). Following this, it was then appropriate in the second experiment to develop and test a wide variety of marking designs. Additionally, although the second experiment was not realistic in terms of driving a vehicle towards a bridge, it did provide clear-cut results concerning which marking variables influence bridge height perception. The function of the experiment that will be described in Chapter 7 will be to apply the results obtained in this second experiment to a more realistic driving situation. This will also allow further testing of the markings to be undertaken using drivers' behaviour as the response measure.

Relating the results of the experiments back to the original aims of this particular investigation shows that the two hypotheses are supported: markings placed on a bridge *can* influence drivers' decisions as to whether they should try to pass under a bridge, and improved designs of the markings have been developed which *can* make the bridge look lower than it really is. These findings therefore support the reports of Verillo and Graeff (1970) and Prak (1977), where it was stated that illusions of size could be used successfully to modify the perceived heights of buildings and complex surfaces.

In terms of "what are the 'optimum' designs for bridge markings?" It was found that there were significant effects for 'form' and 'width' of the markings. For 'form' it was found that bridges with Muller-Lyer inward facing markings looked significantly lower than either Muller-Lyer outward facing markings or current standard hatching markings. For 'width' it was found that bridges with wider spaced markings looked significantly lower than those with narrower spaced markings. Although there were no interaction effects found, it seems from the results that the best combination for bridge markings (in terms of making the bridge look lowest) would be to use the Muller-Lyer wide inward facing version.

Bridges with the adaptation of the Horizontal-Vertical illusion in their markings were not successful in making the bridge look low. This may have been due to these markings being displayed as static two-dimensional images. The markings based on the other illusions did, however, make the perceived height of the bridge lower when they were displayed as static two-dimensional images. As types of markings based on an adaptation of the Horizontal-Vertical illusion were radically different from the current standards for bridge marking, the railway authorities would be less likely to implement them rather than a design more similar to the current standard. Therefore, primarily due to their poor performance in the height judgement experiment, but also, in part due to the potential problems with implementing these types of designs as the new standard, such types of markings were not tested further in this research.

The second experiment also found no significant effect for the variable of 'colour' on bridge height perception. In Section 6.1.1 it was argued that a marking needs to reduce the perceived height of the bridge *and* to make the bridge appear visually conspicuous. So conspicuity issues now seem to be the most important criterion when deciding the specific colours of the markings. Solomon (1990) found that there were safety benefits in accident avoidance when using the colour yellow, it performed better for visibility and detection than either plain red or red/white. As the current standard uses yellow and black it probably would make the implementation of an alternative marking standard more likely if it kept the same colour scheme. If for whatever reason, an alternative combination were to be employed, the important issue seems to be that the colours used must have a large amount of brightness and colour contrast between them (e.g. between yellow and black or red and white) to enable the marking design illusion to be distinguishable.

Finally, Experiment 1 demonstrated that the type of vehicle regularly driven (either car or lorry) did not influence bridge height judgement. Similarly, Experiment 2 found that the subject variables of age, sex and experience did not influence bridge height perception. These results are important if the improved design of the new bridge markings is to be successful with the wide variety of people who drive on the roads in the UK.

6.5 Conclusions

In both of these experiments the current marking standard of yellow and black hatching performed badly on the experimental measures employed, when compared with the alternative bridge marking designs.

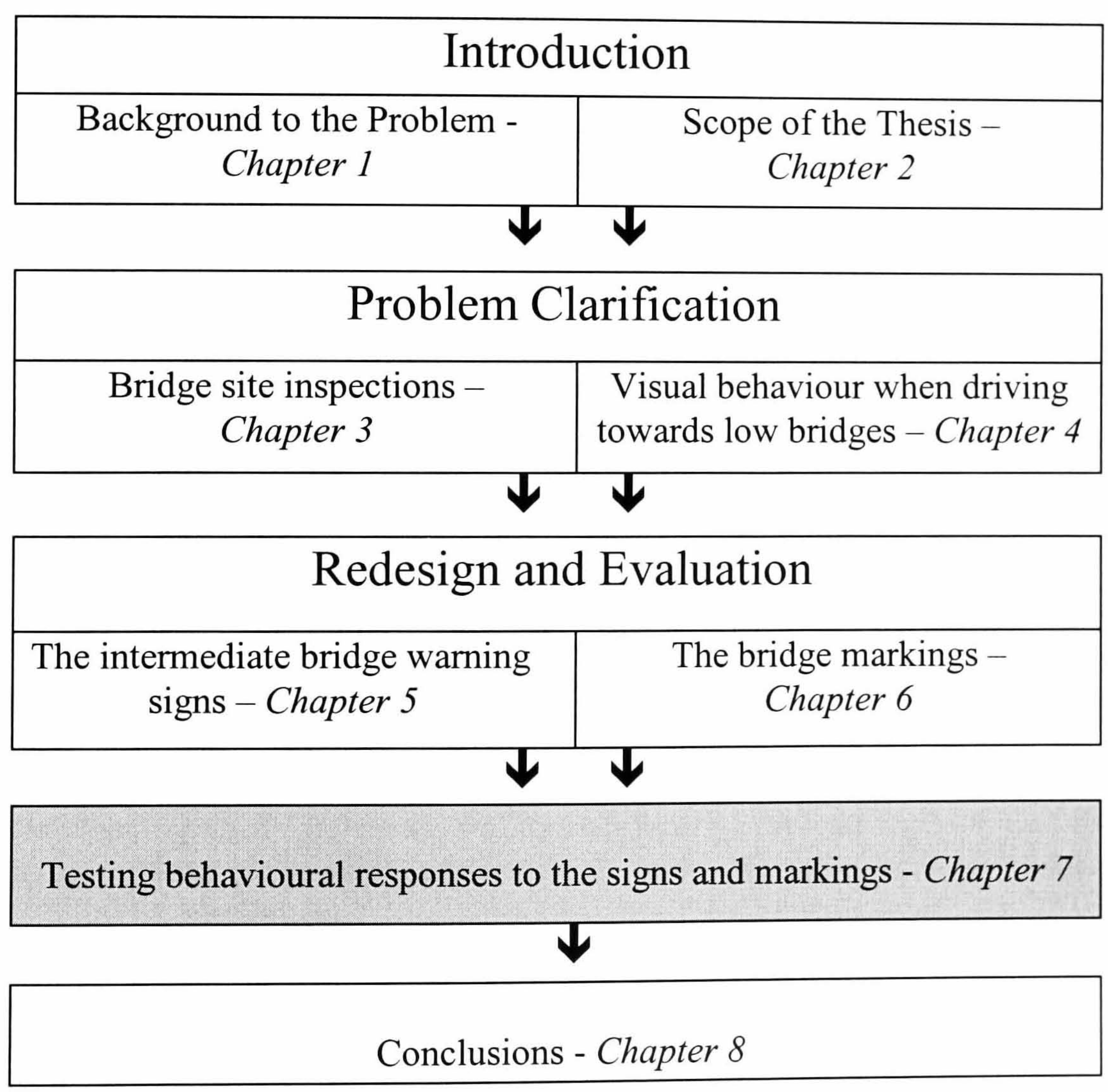
The first experiment found that the specific design of the markings had significant effects on the correctness of the subjects' decisions, thus demonstrating that bridge height judgement can be affected by the markings placed on the bridge.

The second experiment tested a wide set of alternative markings and found two different variables, the 'form' and 'width' of the markings, that can positively influence the subjects' perception of bridge height, so proving that they can make a bridge appear lower.

It was therefore proposed that markings with an ideal combination of the two variables ('form' and 'width') should be tested further. This forms the basis for Chapter 7, which tests the improved markings, to establish if they have a direct influence on the drivers' behaviour when approaching a low bridge.

Chapter 7:

Driver Behavioural Responses to the Bridge Signs and Markings.



7.1 Introduction

The design and evaluation of the IBW signs and bridge markings has formed the major part of this current research investigation to date. None of the experiments so far described have, however, examined the actual behaviour of drivers to the various signs and markings.

Wogalter and Laughery (1996) state that the purpose of warnings is twofold: to inform of potential hazards and **to change behaviour**, that is, to stop unsafe acts being performed. In fact in an earlier report Wogalter (1994) even suggested that the behavioural function was more important than the informational, in that it is more important to avoid the hazard than to know about it and then still be involved in an accident.

Before this, Lehto and Miller (1986) described the ultimate function of a warning when they asserted:

> *"Even if a warning is perceived and comprehended, it will not be effective unless it induces people to behave safely"* (page 89).

Direct behavioural testing of a warning is, however, problematic, and as Wogalter and Laughery (1996) note amongst the difficulties of doing such research are that:

- Direct behavioural observation of warning effects can be time and labour intensive, due to the infrequency of critical events (i.e. unsafe behaviour).
- Allowing hazardous situations to occur must raise ethical concerns.
- Laboratory studies, which allow good control, may not be generalisable to other settings because of the difficulties of creating believable risk situations (i.e. the 'ecological validity' may be low).

Likewise, Edworthy and Adams (1996a) state that although direct objective studies of warning compliance have the advantage of giving immediate notification of the effects of particular independent variables, and so the need to extrapolate from subjective findings to actual levels of compliance is reduced. They still accept that such research has inherent difficulties, such as:

- Subjects having to be deceived that they are at some risk (when they are not).

- Only a small number of variables can be explored in any one study, so cross variable comparisons between large numbers of factors is difficult.
- Apparently minor details of experimental design and procedure can dramatically affect compliance rates. For example, if the subject is stopped before engaging in risky behaviour then any subsequent compliant behaviour could not be observed by the experimenter.

In the specific area of traffic warning information, Luoma (1991b) classified research methods for studying the perception of road signs into three groups: eye movements, recalls and responses. An example of the responses group would be steering or braking changes. Again, similar to the arguments of Edworthy & Adams (1996a) and Wogalter & Laughery (1996), Luoma states that obtaining responses using drivers can have the advantage of producing unobtrusively measured direct behavioural data. However, the disadvantages are no knowledge of the early stages of information acquisition by drivers, the driving responses may be minimal, and that the many different responses can often be difficult to measure.

To summarise, experiments to test the direct behavioural effects of warnings need to be carefully designed. Using laboratory studies may well remove many of the ethical concerns and generally reduce the time (and cost) spent waiting for critical incidents to occur. It does require, however, that only a small number of variables are tested, that the details of the experimental design and procedure are carefully considered beforehand and that generalising the results to the world outside the laboratory must be done with extreme caution (especially if subjects did not think they were at any risk during the study).

7.1.1 Behavioural responses to warnings: previous research

In the area of advance warning signs for passive railway crossings Ward and Wilde (1995) found varying results in terms of driver behaviour. Installing new signs increased drivers' relevant visual search behaviour and resulted in speed reductions. However, they did not promote an increase in drivers' stopping or what they categorised as 'safe' behaviour. They concluded that advisory signing alone was not usually sufficient to improve crossing safety, so other measures at the site (for example increasing the visibility of the hazard) were also needed.

When subjects are familiar with a road environment, Ward and Wilde (1995) suggest that the addition of a sign may not result in actual changes of behaviour. This is supported by Goldhaber and DeTurck (1988) who found that using 'no diving' warning signs in a swimming pool did not affect the actual diving behaviour for those swimmers who regularly used the pool, although it did affect the diving behaviour of swimmers who were not regulars.

Similarly, Harrell (1994), looking at the effects of visibility of pedestrians and of warning signs on motorists stopping, found the presence of a sign before the crossing did not make drivers more likely to yield. Harrell suggested that this may have been due to the design of the sign (i.e. that it was perhaps not conspicuous) and that when it was visible, the driver could see whether or not there was a pedestrian waiting to cross the road. Thus with a differently designed sign in a different situation (i.e. when the sign could be seen, before the crossing was visible) the results may have been different.

This is supported by Van Houten and Van Houten (1987) who found that a specifically worded sign produced speed reductions for vehicles travelling above the speed limit. This was later sustained by Lajunen, Hakkarainen and Summala (1996) who found explicit speed limit signs had more of an effect on driver speed reduction than did more general signs (in their case a built-up area sign).

Likewise, Barker and Helliar-Symons (1997) carried out trials investigating the effect of count-down signs and Roundel markings on speed reduction. They found significant speed reduction only for some of the experimental signs (for the 40-mph Roundels), while other versions of the count-down and Roundel markings had no significant effects. Luoma (1997), however, studied driver behaviour with respect to two types of variable message speed limit signs (fibre optic and electromechanical) and found both types caused speed reductions. Both of these studies tested their warning signs at a limited number of sites, so the results may only be site specific and generalisation to other traffic situations may be problematic (a point accepted by Barker and Helliar-Symons, 1997, and Luoma, 1997).

As mentioned previously, motivation to comply with a warning is critical. Summala and Hietamaki (1984) found that drivers were more likely to respond to traffic warning signs (such as 'speed limit' or 'children') when they were significant to them. It was not the case that the signs were better detected, but more that these signs inclined drivers to respond to them, hence they argued that motivational as well as perceptual factors are important for compliance with traffic warning signs.
In a review of traffic collision accidents, Rumar (1990) came to similar conclusions when arguing that the majority of collisions were due to late detection of the other vehicle or object in the road environment by the driver. He classified most of these late detection errors as being due to either a lapse of cognitive expectation, for example, failure to look for a particular class of road user, such as a cyclist, or due to a difficulty with perceptual thresholds, for example, inability to read a warning sign in time to make a necessary response. Rumar argued that the most effective countermeasures to reduce detection errors (both cognitive and perceptual) were those involving stimulus enhancement. Thus the adding of yellow borders to low bridge warning signs or the re-design of the bridge markings, as described earlier, would, in theory, support Rumar's general argument for effective collision measures.

Based on the above, it appears that traffic warnings generally have only a partial influence on a subject's safe driving behaviour, especially if the subject is familiar with the situation, not sufficiently motivated to comply, or detects the situation too late, in which case the effect of the warning will be diminished. Indeed, Drory and Shinar (1982) found that less than 10% of drivers registered general traffic warning signs under a variety of roadway conditions. From this they concluded that:

> "*...Under normal daylight conditions warning signs are either redundant (contain information directly available) or irrelevant to the driver's perceived needs and the driving task*" (Drory and Shinar, 1982, page 25).

It has been argued throughout this investigation, however, that bridge warning signs are necessary to the task of navigating high-sided vehicles safely under bridges. Drivers need to be informed of the available clearance **before** the bridge, so that they have the time to stop their vehicle and take a different route around the hazard. Thus they are relevant to the driving task of a certain class of road user (i.e. high-sided vehicle drivers), despite the possibility that their effects on safe driving behaviour may be slight.

A separate, but equally important issue, is the problem of unexpected side effects from traffic warnings. Robertson (1997) found unpredicted driver behavioural side effects after the installation of enforcement technology at traffic signals. Red light cameras at junctions produced an increase in the overall mean speed of vehicles that were approaching the junction. This suggests that drivers accelerated to avoid violating the traffic signals. So the technology that was intended to reduce red light violations had the arguably negative side effect of increasing vehicle speed.

So, conceivably, low bridge warnings may not be effective in preventing bridge strikes and possibly may have negative potential side effects. For example, the use of a visual illusion in the design of bridge markings may interfere with other aspects of the driving task, such as, width judgement by drivers of large vehicles. Would it therefore be necessary to make bridges look narrower than they actually are to prevent such collisions? However, although the question of side effects with re-designed signs and markings is important, it was considered to be outside the scope of this current research investigation.

7.1.2 Research Objectives

Much of the work discussed above has stressed that the ultimate function of a warning is to increase safe behaviour when a person interacts with the object to which the warning refers. Fisher (1992) found correct and safe driving behaviour was no more associated with correct recall of a sign than with incorrect recall of the sign, therefore accurate recall of signs and good driving behaviour were not related. From this he argued that traffic warning signs should be assessed on their ability to sensitise drivers to hazards ahead - not their recall correctness. He stated:

> *"The true measure of sign effectiveness is not sign recall, recognition, or naming per se but rather the extent to which, in operational terms, sign*

content affects drivers' preparedness for and subsequent responsiveness to events" (Fisher 1992, page 232).

And continued:

> *"...It may not be important whether or not a motorist can accurately recall a sign (e.g. warning of a wild reindeer crossing the road). The true measure of effectiveness is whether a motorist, having seen the warning sign, responds faster or more appropriately to the sight of wild reindeer crossing the road than would otherwise be the case"* (Fisher 1992, page 232).

Despite the problems mentioned previously (e.g. generally only a slight overall behavioural change resulting from the warning), it still follows that the ultimate function of both bridge signs and bridge markings is to reduce the number of vehicles that are higher than the available clearance, from attempting to pass under the bridge. For the bridge marking, their function is to make the driver more cautious when judging whether to try to pass under the low bridge. For the bridge signs, following Fisher's argument, it is the capacity of the sign to 'sensitise' drivers to the hazard ahead – that is, making drivers more likely to stop before the low bridge if warning signs are present than they would if no sign were present. The specific hypotheses of this investigation are that:

1. Drivers will **stop significantly earlier** for those bridges that are low enough to be hit that display **the new markings** than they would for those bridges that display **the existing markings**.
2. Drivers will be **more 'safe'** (as defined later) in their stopping behaviour when approaching bridges that are low enough to be hit that display **the new markings** than they would for those bridges that display **the existing markings**.
3. Drivers will **stop significantly earlier** when approaching bridges that are low enough to be hit that display **the new warning signs** than they would for those bridges that display **either the existing or no warning signs**.
4. Drivers will be **more 'safe'** in their stopping behaviour when approaching bridges that are low enough to be hit that display **the new warning signs** than they would for those bridges that display **either the existing or no warning signs**.

It also is hypothesised that the following will **not** be significantly different:

1. When approaching **all bridges** (i.e. both those low enough to be hit and those

high enough to be missed) that display **the new markings,** drivers will **not manifest more correct stopping decisions** than when approaching those bridges which display **the existing markings**. This is because drivers could wait until just before the bridge before making their judgement as to whether or not they would pass underneath it - thus responding correctly in the majority of cases.

2. When approaching bridges low enough to be hit that display **the new warning signs,** drivers will **not manifest more correct stopping decisions** than when approaching those low bridges which display **either the existing or no warning signs.** Again, this is because drivers could wait until just before the bridge before making their judgement as to whether or not they would pass underneath it - thus responding correctly in the majority of cases.
3. When approaching bridges high enough to be missed that display **the new markings,** drivers will **not stop significantly earlier** than for those bridges which display **the existing markings**. This is because it is conjectured that the majority of drivers will not stop before these bridges.

7.2 The Development of the Virtual Road

The testing of the signs and markings was carried out in a laboratory. It used a Virtual Reality system to generate and display the road scene stimuli.

The basic version of the virtual road was originally created in a three-dimensional drawing package (3D Studio). This was then imported into a Virtual Reality program (RealiMation) for subsequent modification and to enable the subject to interact with the scene (this interaction is described in section 7.3.3 below). A sub-program of RealiMation, RealiView, was used to display the road scene. As having an exact representation of the created images was important (for example to be able to read the information of road signs) the most accurate 16 bit renderer[1] available (OpenGL) was employed. Using an accurate renderer slows down the RealiView program slightly, but compensation for this was provided by using a Pentium 200 computer with a 3D graphics card (as described in section 7.3.2 below).

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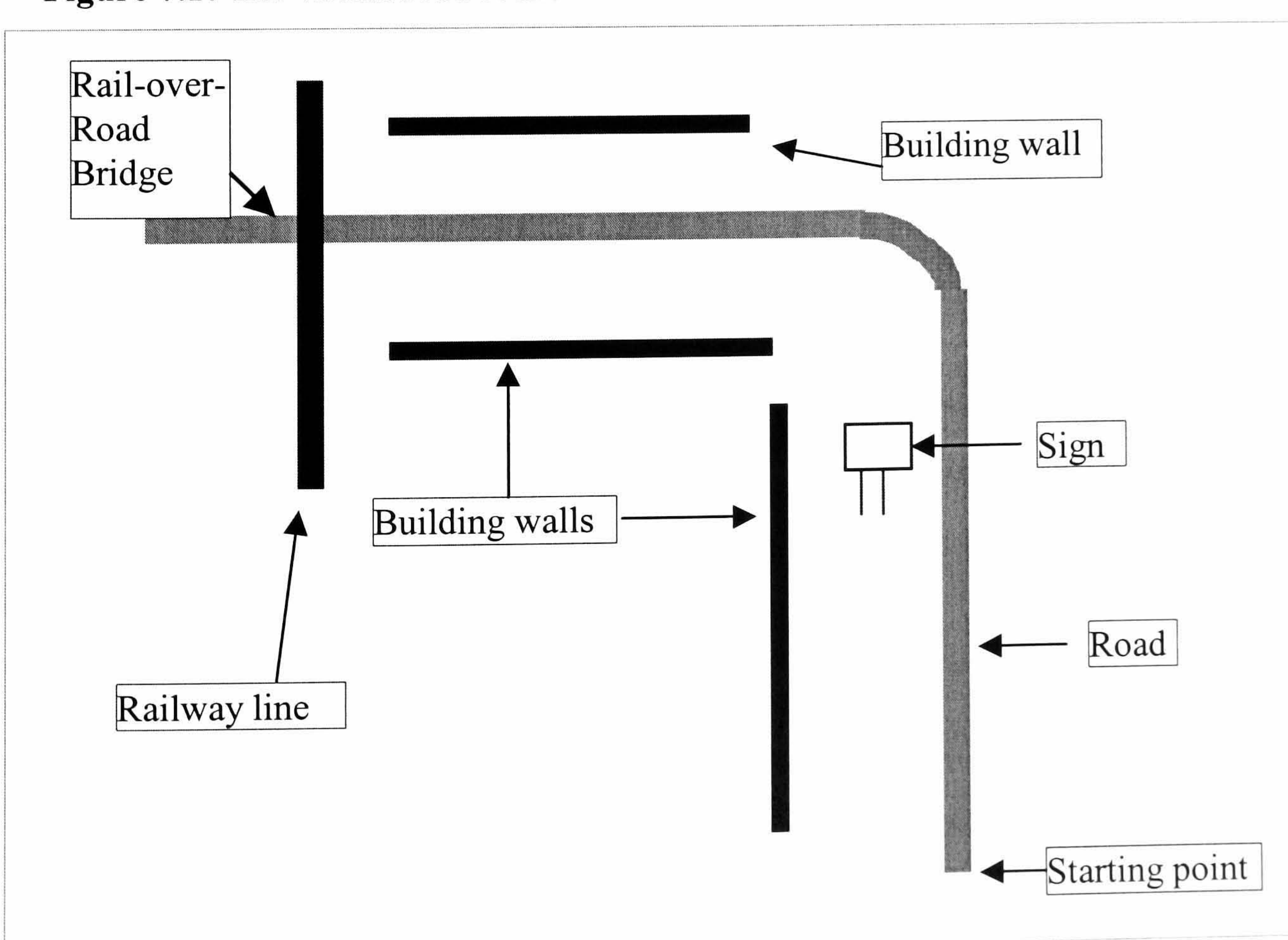
[1]A renderer is software that converts the pre-defined virtual road program into three-dimensional graphical images (including shapes, colours and textures) for display on a computer monitor.

The road scene comprised a straight road with a bend to the left followed by another straight road on which a bridge was situated. A road sign was positioned approximately two-thirds of the way along the first straight road. The subject 'drove' along the first straight road for approximately 10 seconds, then around the bend for 3 seconds and along the second straight road for approximately 9 seconds before reaching the bridge. Thus the virtual road scene lasted 22 second from starting to move until arrival at the bridge. Having a straight road, then a bend and then a second straight road was implemented for two reasons. Firstly, for the initial section to act as an introduction to the scene (in terms of eye height, general road environment and speed of travel) so that when the bend was passed and the bridge could be seen, the subject would be acquainted with the general virtual environment. Secondly, in order to test the behavioural effect of the bridge warning sign, it was necessary that the bridge itself would not be visible when the sign was seen, as is generally the case with real-world intermediate bridge warning signs, thus two straight sections of road were employed. Figure 7.1 shows a two-dimensional simplified line drawing of the virtual world taken above from a 'birds eye view'.

Figure 7.1: The virtual road scene.



The virtual road scene was created as a simple environment to prevent unnecessary visual cues from influencing subjects' perceptions of bridge height. The road was of uniform width and was coloured grey with no centre markings, the surrounding area was the colour of grassland and the sky was blue. To prevent the bridge being seen until after the bend was passed, several building walls were created and set back slightly from the road, these were coloured grey. The bridge was a 'girder' type bridge and was coloured brown/grey (as per the bridge site survey reported in Chapter 3, which found that this was the most common colour for the building material of bridges).

The experimental arrangement used was based on previous simulated driving environments for road safety research. In particular, it followed two recent studies.

Firstly, Berthelon, Mestre and Nachtergaele (1997) who examined the influence of the road environment on the visual anticipation of collisions. They found that the visual anticipations by drivers were dependent on the various visual cues included in the road environment. So the sensation of self-motion is increased in the presence of a structured environment (see also Denton, 1980). Their stimuli were simple computer simulations of road scenes, which they stopped just before collision. These scenes generally consisted of uncomplicated representations of sky, environment and road. Therefore their experiment was comparable with the present approach in terms of the procedure and stimuli.

Secondly, Haigney, Kennett and Taylor (1997) who used a simulated driving environment to examine risk homeostasis theory. By modifying various road environmental variables in the computer generated display, and analysing their effects on subsequent 'driving' behaviour, they found differences in performance due to engineering safety measures but no effect according to the utility driven compensation models of risk homeostasis theory. They used a driving simulator consisting of a car seat, wheel and pedals with a computer graphic output displayed in front of the driver. Therefore it was akin to this study in terms of the experimental arrangement and modification of the computer generated road stimuli to examine its influence on driver behaviour.

Although the precise results of both these studies are not critical for the current investigation, their importance here is in showing that similar experimental set-ups using computer generated displays and simple driving environments can produce meaningful results in similar research areas of traffic environment design.

7.2.1 The Different Versions of the Virtual Road

The basic virtual world template defined above was used for all versions. Static images of the two marking types are shown in appendix H. Each version of the virtual road was identical except for the manipulation of the independent variables, these being bridge height, marking design and sign type.

The bridge height variable had two levels: a bridge just low enough to be hit (i.e. below eye height when approaching the bridge from the set viewpoint, approximating to 8" below in the 'real world') and one just high enough to be missed (i.e. above eye height and approximating to 8" above in the 'real world').

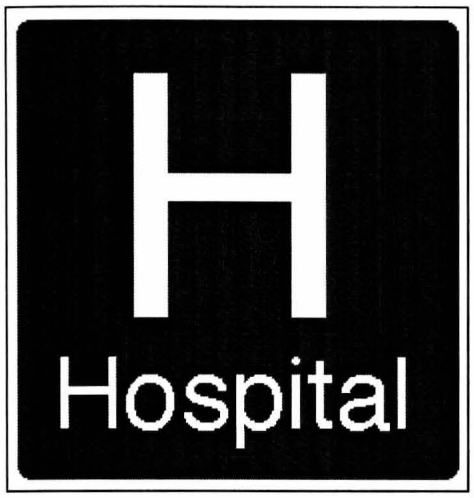
The marking design was of two types: existing markings (the full DoT standard, as described earlier in Chapters 1 and 6) and new markings. These new markings were the type that performed 'best' in an earlier experiment that investigated which marking design made the bridge look lowest (described in Chapter 6). In Chapter 6 they were called "Muller-Lyer inward-facing wide-spaced markings in yellow and black". For convenience, simplicity and brevity they will simply be termed the 'new' markings here. When presented on the bridge, each type occupied the same surface area and used the same yellow and black colours.

There were three sign types employed:

1. The existing text-based bridge warning sign (drawing number (P) 669.1, DoT, 1992).
2. A control sign. This was a sign informing the driver of a hospital ahead. This was chosen because it was of a similar shape and colour as the bridge warning signs but, as it was unrelated to the overhead hazard, it was anticipated that it would not influence the subjects' behaviour with respect to the bridge.
3. A new bridge warning sign. This was the type that performed 'best' in Chapter 5 on the tests of comprehension and hazard perception. In Chapter 5 this was called the "text-based yellow border intermediate bridge warning sign". It will simply be termed the 'new' sign here.

The two bridge warning signs have been previously described in Chapter 5 (and pictures of them are shown in Appendix B). The control sign is shown in Figure 7.2.

Figure 7.2: The control sign.



The two versions of the bridge warning sign contained the height limit of 9'6" and the distance ahead of 250 yards (both of these values were chosen as they approximately represented the bridge height and distance ahead in a real-life road scene). All three signs were the same size and shape.

From these variables the different versions tested were:

1. Low bridge with existing markings and a control sign
2. Low bridge with new markings and a control sign
3. High bridge with existing markings and a control sign
4. High bridge with new markings and a control sign
5. Low bridge with existing markings and the new warning sign
6. Low bridge with existing markings and the existing warning sign

It was considered unnecessary to test high bridges with the bridge warning signs as the purpose of the sign evaluation was to assess their capacity to induce the driver to stop before reaching the low bridge. Their role was therefore meaningless for bridges that can be passed under safely.

In addition, the two (null) versions below were included in the experiment but were not analysed.

7. High bridge with new markings and no sign
8. High bridge with no markings and no sign.

These last two versions were included for three reasons. First, to enable subjects to view an equal number of low and high bridges (4 in both groups). Second, to enable subjects to view a similar number of bridges with the different marking types (4 bridges with the existing markings, 3 with the new type and one without markings).

Third, to occasionally display versions that did not contain any signs or marking types (2 bridges with no signs or markings, 6 with signs and markings). This was to persuade the subjects that the experiment was about stopping behaviour with respect to the perceived height of the bridge, and to prevent them thinking the experiment was purely about several different designs of signs and markings.

7.2.2 Response measures

The experimental arrangement allowed for the three response measures below to be produced:

1. **Whether** the brake pedal was activated.

Activating the brake pedal to stop the scene resulted in the following outcomes.

	Brake pedal hit	**Brake pedal not hit**
Low bridge	Correct response	Incorrect response
High bridge	Incorrect response	Correct response

2. **When** the brake pedal was activated.

If the subject judged the bridge would be hit then the time at which the pedal was activated was calculated by subtracting the time the brake was hit from the time the bridge would be reached (this end point was constant for all the versions). This value was, in addition, used to calculate the spatial frequencies[2] of the markings seen by the subjects when they stopped the scene by pushing the brake pedal.

3. Would the bridge actually be hit?

The third analysis method used both the correctness of the responses and the time of the responses, to produce a 'safety' dimension. The analysis of correct/incorrect decisions was not expected to produce significant results, as subjects could wait until

[2] As the bands on the markings are alternating light and dark colours they have a sine wave pattern. The spatial frequency is the number of cycles of the pattern (i.e. one yellow and one black line) per unit of distance. This can then be expressed as a visual angle at the subject's eye.

just before the bridge before making their judgement as to whether or not they would pass underneath it (thus responding with the correct answer in the majority of cases). In a real-world driving task, this would be very dangerous, as drivers would hit bridges low enough to be hit, because they would be beyond the minimum stopping distance. Therefore it was decided that a more realistic analysis for bridges low enough to be hit would be to classify data into the three safety categories of:

1. Deciding to stop **before** the minimum stopping distance (so avoiding a bridge strike).
2. Deciding to stop **after** the minimum stopping distance (thus resulting in a bridge strike – although the vehicle may have partially decelerated when colliding with the bridge, so resulting in a less severe strike).
3. Deciding **not** to stop (hence resulting in a bridge strike with no deceleration when reaching the bridge).

The minimum stopping distance for the virtual road scene was calculated as follows. The speed of travel was set to approximately 20mph (32.2 kph), this equals 8.94 metres per second. At 20mph the DoT (1996) state that the shortest stopping distance for a car is 12m (6m thinking distance and 6m braking distance). Therefore 6m thinking distance would equal 0.67 seconds (i.e. 8.94/6), plus another 0.67s for the braking distance.

A high-sided vehicle, such as a large truck, has a braking distance of approximately 40% longer than a car[3] (Highway Safety Organisation, 1997). Thus the thinking distance would be the same as for a car (0.67s) but the braking distance would be 0.94s (i.e. 0.67*140%). Based on these figures then the total time to stop would be 1.61s for a large truck. For a truck travelling at 20mph the total distance to stop would be 13.39 m (i.e. 8.94 metres per second * 1.61).

[3] This figure can vary greatly, depending on the road environment (for example a longer stopping time is needed on an icy road) and on the exact type of truck.

7.3 *Method*

7.3.1 Subjects

Forty subjects were used; their mean age was 35 years (range 24 – 53 years). Twenty-six members of this group were male.

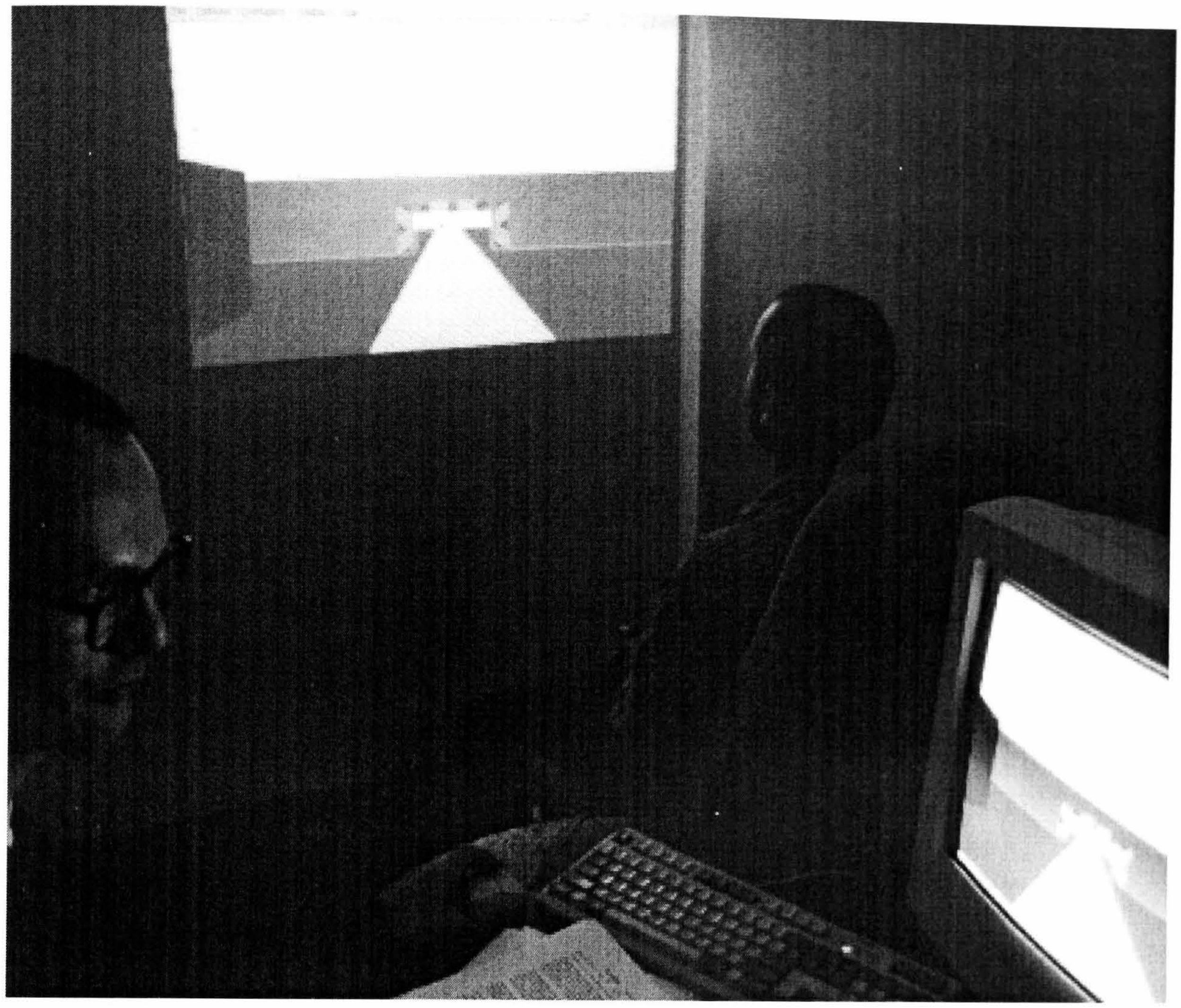
All of the subjects were drivers: 35 % were categorised as car drivers holding a valid UK driving licence, but having little or no experience of driving high-sided vehicles; 32.5 % were car drivers who had experience of driving high-sided vehicles (defined here as the height of a transit van or above, i.e. over 8'), who, on average, drove a high-sided vehicle several times a month, and 32.5 % were high-sided vehicle drivers who, on average, drove a high-sided vehicle over 8' nearly every working day. Therefore in terms of navigating large vehicles the three groups represented a wide range of experience and skills. The majority of the high-sided vehicle drivers were paid for their participation in the study (the remainder of the subjects were unpaid). Those subjects who were paid were participating in the experiment in their own time; the unpaid subjects were university staff members undertaking the experiment as part of their normal working day.

7.3.2 Equipment and Stimuli

The eight different versions of the virtual road scene defined in section 7.2.1 were used. These were stored and run from a Pentium 200 MMX computer (with 32mb RAM and a 3D graphics card). The road image was projected on to a plain wall 120cm in front of the subject using a Proxima 8300 VGA 800x600 data projector. The size of the projected image on the wall subtended to a visual angle of 46.1° horizontally and 27.2° vertically at the subject's eye.

A darkened laboratory room (set to approximately 8 lux) was employed in which a car seat (on an adjustable base) and a brake pedal (mounted on a solid frame) were located. Figure 7.3 shows the experimental set-up.

Figure 7.3: The experimental set-up.



7.3.3 Procedure

Each subject was tested individually. They were first seated in the simulated driving environment then the experimental task was explained to them as follows:

> *"I am going to show you a series of computer generated road scenes. In each one there will be a straight road, then a bend to the left then another straight road on which a bridge will be situated. I want you to think that you are driving along the road. Please try to imagine that the viewpoint from which you are looking at the scene is set at the top of the vehicle you are driving (so being similar to driving an open top sports car where the highest object in the vehicle is your head).*
>
> *When approaching the bridge I want you to judge whether or not you can pass safely underneath it from the viewpoint at which you are seeing the scene. If you decide you would hit the bridge then please press the brake pedal in front*

of you to stop the scene **as soon as** *you have made up your mind. If, however, you decide that you can pass safely under the bridge then please do not push the brake pedal. The scene will stop either when you push the brake pedal or just before you reach the bridge.*

The first scene you see will be a demonstration one to familiarise you with the procedure. After you understand the task I will show you the remaining scenes - each one will be slightly different, however your task (of activating the brake pedal if you think you will hit the bridge) will be the same for all of them. Any questions?"

The introductory scene was then shown to subjects (this was one of the two null scenes, it was again shown later as part of the experiment proper). If they did not press the brake pedal, the scene was shown again and they were instructed to push the pedal, so that they could experience stopping the road scene.

The eight versions of the scene were then shown - the sequence of these was randomised to prevent any order effects. In each case, if the subject did not push the brake pedal to halt the scene, it was terminated by the experimenter slightly less than half a second before reaching the bridge, to prevent the subject receiving feedback about whether their decision to stop or not was correct. After all the experimental versions were displayed, the subject was informed that the experiment had finished, was thanked and allowed to leave.

7.4 Results

7.4.1 Whether the brake pedal was activated.

A value of 1 was assigned if the subject's decision was incorrect and 2 if it was correct, thus **higher** mean scores were **'better'** (i.e. the responses were more correct). Table 7.1 shows these mean results and their standard deviations.

Table 7.1: Correctness of subjects' responses to the bridges in the road scenes.

Bridge number/independent variable type	Mean score	Std. deviation
1 (low bridge, existing markings, control sign)	1.90	0.30
2 (low bridge, new markings, control sign)	1.98	0.16
3 (high bridge, existing markings, control sign)	1.65	0.48
4 (high bridge, new markings, control sign)	1.75	0.44
5 (low bridge, existing markings, new sign)	1.92	0.27
6 (low bridge, existing markings, existing sign)	1.90	0.30

As was hypothesised earlier, no significant differences were found, in terms of correctness of scores, between the following pairs of bridges (all using Sign test, 2-tailed $p > 0.1$):

- Bridges 1 and 2
- Bridges 3 and 4
- Bridges 1 and 5
- Bridges 1 and 6
- Bridges 5 and 6

The versions with the new bridge markings produced more correct answers than those versions with the existing markings (bridge 2 value of 1.98 against bridge 1 value 1.90, and bridge 4 value 1.75 against bridge 3 value 1.65). Similarly those versions with the new design of the warning sign produced more correct answers when compared to either the existing sign or the control sign (bridge 5 value 1.92 against bridges 6 and 1 values 1.90). None of these differences, however, reached statistical significance.

7.4.2 When the brake pedal was activated.

The second measure was obtained by calculating the time (in seconds) before the bridge when the pedal was pushed. In the cases when the pedal was not pushed a score of "0 seconds before the bridge" was assigned. Table 7.2 shows these mean results and their standard deviations. It can be seen that the bridges low enough to be hit produced high mean scores (i.e. on average stopping several seconds before the bridge). Additionally, the bridges high enough to be missed produced low mean scores (i.e. on average the majority of the scores being 0 to represent subjects deciding that they would miss the bridge).

Table 7.2: Time of subjects' responses to the bridges in the road scenes.

Bridge number	Mean score	Std. deviation
1 (low bridge, existing markings, control sign)	3.39	2.01
2 (low bridge, new markings, control sign)	3.89	1.77
3 (high bridge, existing markings, control sign)	1.24	1.89
4 (high bridge, new markings, control sign)	0.91	1.79
5 (low bridge, existing markings, new sign)	3.55	2.02
6 (low bridge, existing markings, existing sign)	3.26	1.91

There was a significant difference, in terms of **when** the decision was made to press the brake pedal, between bridges 1 and 2, that is, low bridges with the same control sign but with the two different markings (Paired samples t-test, 1-tailed $p < 0.01$).

There were no significant differences between the following pairs (at $p > 0.1$).

- Bridges 3 and 4
- Bridges 1 and 5
- Bridges 1 and 6
- Bridges 5 and 6

Therefore the low bridges with the new markings produced significantly quicker responses than the same bridges with existing markings. Additionally, no significant response time differences were found between the high bridges with the two different marking types.

Although the bridge versions with the new design of the warning sign produced quicker response times compared to either the existing sign or the control sign the difference was not statistically significant.

7.4.2.1 Spatial frequencies of the markings when the brake pedal was activated.

For those bridges low enough to be hit (bridge numbers 1, 2, 5 and 6) a calculation was made of the perceived spatial frequency of the markings subtended at the subjects' eye when the brake pedal was activated. This was performed by taking the mean distance at which the braking decision was made for each version of the virtual road scene, and measuring the size of one cycle of yellow and black bands of colour that mark the sides of the bridges. From this, the subtended angle of vision at the subject's eye was calculated (at the experimental viewing distance of 120cm). The results of these calculations are shown in table 7.3 below.

Table 7.3: Subtended angle of vision for the markings when the brake pedal was activated.

Bridge Number	**Mean time before bridge when the brake pedal was activated.**	**Projected size of the yellow and black cycle at this point.**	**Subtended angle of vision at this point.**
1	3.39 seconds	21.5mm	1.03°
2	3.89 seconds	69.88mm	3.33°
5	3.55 seconds	20.16mm	0.96°
6	3.26 seconds	22.84mm	1.09°

For the bridges with the existing (narrow spaced) markings the subtended angle when the brake was pushed was approximately 1° (i.e. 1 cycle per degree), and for the bridge with the new (wide spaced) markings it was 3.33° (i.e. 0.3 cycles per degree). So to subtend the same visual angle, bridges displaying the existing markings would need to be seen much nearer compared to those displaying the new markings.

7.4.3 Would the bridge actually be hit?

The third response measure enabled a further analysis method to be used. The data was coded so that a value of 1 was assigned if the subject did **not** decide to stop; 2 if they decided to stop **after** the minimum stopping distance, and 3 if they decided to stop **before** the minimum stopping distance (using the figure of 1.61 seconds before the bridge as the minimum stopping distance– as calculated earlier in Section 7.2.2).

One significant difference was found when a Wilcoxon Signed Ranks test was applied to pairs of bridges low enough to be hit. This was between bridges 1 and 2, that is, those bridge with the same control sign but with the two different markings ($Z=1.857$, 1-tailed $p < 0.05$).

No significant differences (at $p > 0.1$) were found between:

- Bridges 1 and 5
- Bridges 1 and 6
- Bridges 5 and 6

Thus the low bridge with the new bridge markings produced significantly 'safer' responses than the same bridge that displayed the existing bridge markings. However, no significant 'safety' differences were found between the bridges with the different signs before them.

7.5 Summary and Discussion

This experiment assessed the most effective versions of the signs and markings that had been identified previously, in Chapters 5 and 6. Using the subjects' braking responses as the experimental measures, the performance of these versions was compared to the performance of the existing versions of the signs and markings. The simulated driving environment employed was created to be realistic yet as simple as possible, to prevent unnecessary distractions influencing the bridge navigation task.

The results demonstrated that the type of markings significantly affected subjects' responses, in that low bridges with the re-designed markings were responded to significantly earlier and more 'safely' than those bridges with the existing markings. In terms of reducing the number (and severity) of bridge strikes, this demonstrated a potential benefit of changing the official specification for bridge markings from the existing version to the newly created design. It was found, however, that the addition of warning signs before the bridge had no significant influence on the subjects' behaviour with respect to the bridge. Although the new sign (i.e. text-based with a yellow border) did produce slightly quicker and more 'safe' responses than either the existing or the "no sign" conditions, it was not a statistically significant difference, so this study has demonstrated that the presence of a preceding warning sign does not significantly influence driver stopping behaviour before a low bridge.

The results obtained for the re-designed bridge markings correspond to previous research in the following ways. First, in terms of the visual illusions, it was shown in Chapter 6 that incorporating adapted versions of the Oppel-Kundt and Muller-Lyer illusions into the design of the markings could make a bridge appear lower when it was displayed as a static picture. The bridge marking used in this current experiment produced similar results. Thus the newly designed markings make a bridge look lower when it is displayed as either a static picture or as part of a moving "virtual" road scene.

Second, in a more general context, stopping a large vehicle when a bridge looks too low, due to the markings, is in accord with previous driver behavioural research, for example, the work of Denton (1980) and Haigney, Kennett and Taylor (1997). Both of these studies found that modifications to the visual environment of the road can increase safe driving behaviour.

Finally, in terms of previous studies regarding spatial frequencies, research summarised by both Farrell and Booth (1984) and Humphreys and Bruce (1989) reports that people are most sensitive to mid-range spatial frequencies (i.e. 0.3 to 10 cycles per degree). The results obtained in the current experiment for spatial frequencies at the mean time subjects braked were within this range for both marking types. To subtend the same visual angle in the virtual road environment, bridges displaying the existing markings would need to be seen 2.72s nearer the bridge compared to those displaying the new markings. For a lorry travelling at 20mph (8.94 metres per second) this would result in the vehicle being 24.32 metres (8.94 * 2.72) nearer the bridge. Deciding not to attempt to pass under a low bridge as early as possible is generally beneficial to reduce the number (and the severity) of strike incidents. So the new markings, subtending the same visual angle at 24.32 metres earlier than the existing markings, would be an additional positive result for the re-designed version.

For the warning signs, however, it was found that the newly designed version was not significantly better in sensitising drivers to the hazard ahead than either the existing sign or the control sign conditions. Hence the results found for the low bridge signs are similar to the results obtained by previous workers such as Ward and Wilde (1995) and Harrell (1994), where it was generally found that warning signs can only partially improve subjects' safety behaviour in traffic situations. As the results with stopping before the markings were generally successful, it cannot be argued that motivation to stop before the bridge was the problem, otherwise it would have also manifested itself in the "markings alone" conditions. This experiment was, however, a study of drivers' height judgement (together with their subsequent behavioural responses), so the subjects were not informed of the maximum height of the lorry. Therefore from the results obtained here, it seems that the IBW signs have no significant influence on the stopping behaviour of drivers when, as was the case in this experiment, the heights of their vehicles are unknown to them.

This experiment was purely a behavioural study that tested subjects in a simulated driving environment. Similar to many other driving simulator type experiments, there can be a problem of directly applying these results to real driving situations, as maintained by Wogalter and Laughery (1996). This study was, however, a formally controlled experiment, so a like-for-like comparison between the marking types and the sign types is valid. Future research in a more realistic driving environment would be necessary to augment these laboratory results before any possible implementation of the re-designed signs and markings at real bridge sites. One method to examine this would be to test driver responses to the signs and markings on a test track, where subjects would sit in a moving lorry and approach a realistic bridge structure.

Another area for future research would be to test whether the presence of warning signs (either the existing or the newly designed type) sensitises the drivers to the bridge ahead when the height of their vehicle **is** known. In this study the drivers were not informed of their vehicle height, as the research concentrated on driving behaviour with respect to height judgement. If a similar experiment was performed and drivers were informed they were driving a vehicle of, say, 10'6" high and the information on the signs said the bridge was 9'6" high, it would be expected that they would hit the brake before reaching the bridge. Although the results in this study were better (but not significantly so) for the new sign type, when compared with the other conditions, it is hoped that adding the vehicle height dimension would result in significant differences between signing conditions. Given the beneficial comprehension results obtained for the newly designed signs (see Chapter 5), it would seem reasonable in this experimental arrangement to hypothesise that drivers would display more appropriate stopping behaviour for versions containing these types of signs when compared with the existing sign type or the no sign conditions.

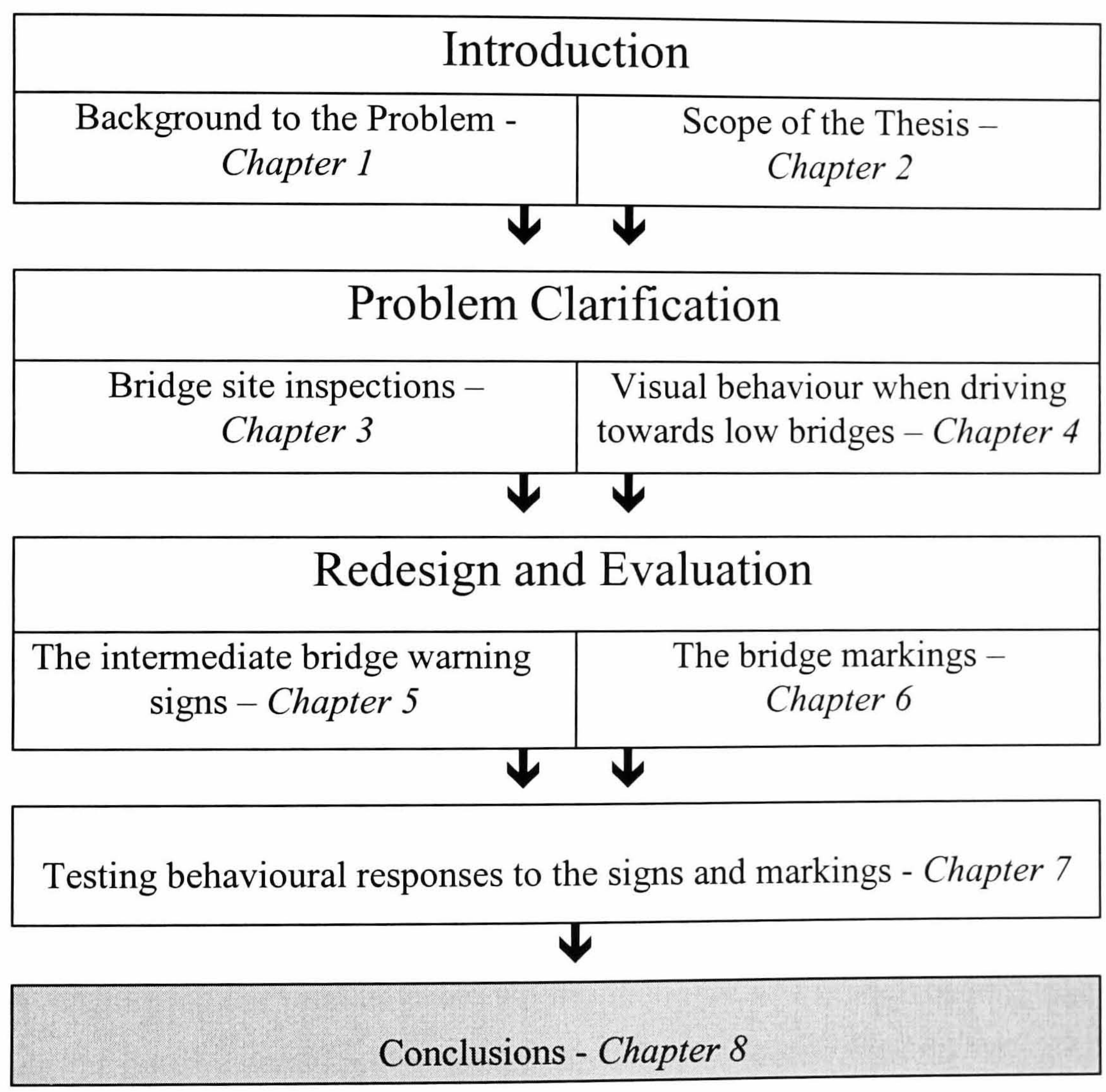
7.6 Conclusions

The experiment found that the type of markings on the bridge did significantly affect subjects' braking responses. Those low bridges with the newly designed markings were responded to earlier and more 'safely' than those bridges with the existing markings. Thus more research geared towards using the newly designed markings for 'real' rail-over-road bridges is proposed.

The addition of warning signs before the bridge, however, had no significant influence on subjects' behaviour with respect to the bridge. Hence it has been found that the presence of a prior warning sign did not affect the driver stopping behaviour before the bridge when the height of the vehicle was not known. It is, however, contended that the use of warning signs may be beneficial when the height of the vehicle is known, and that further research should be undertaken to examine this possibility.

Chapter 8:

Conclusions



8.1 Overall Summary

This research was concerned with the problem of road vehicles that strike the overhead section of rail-over-road bridges, and how such incidents could be reduced. In particular, it has examined the road environment around low bridge sites and road vehicle drivers' visual behaviour with respect to such environments. It then investigated the design of the warning signs and bridge markings and the behavioural effect of these signs and markings upon drivers.

The investigation commenced by reviewing the problem of bridge strikes both in the UK and elsewhere in the world. Consideration was given to the history of such occurrences, the severity of the problem, previous attempts to quantify why bridges were hit, the cost of bridge strikes, previous countermeasures to prevent them, and the legal restrictions relevant to the area. A description was given of the existing UK traffic signs and markings placed on and before a low bridge. The conclusion of this review was that the problem of bridge strikes was still increasing and that no single countermeasure had been found to be effective when the cost and the legal restrictions were considered.

The general area of research to be undertaken in this investigation was then outlined; this focused on the design and evaluation of visual warnings for low bridges. This led to a description of the research plan for the whole of the investigation. The specific variables being tested in this work were then considered. Finally, the objectives of the research were introduced; the overall hypothesis was that improving the visual warnings in the road environment on or before low bridges would result in fewer bridge strikes by overheight vehicles (i.e. vehicles higher than the bridge's available clearance).

A field assessment of possible causal factors in strikes was then initiated in which a group of bridges that had been frequently struck were compared with a group of control bridges. This appraised the physical characteristics of the bridge, the road environment and the current low bridge warning methods. It found that frequently struck bridges generally were in busier, more visually complex environments with, on average, more advertisements nearby.

This supported the work of Retting (1993) who found that increased environmental complexity increased road accident rates for trucks, and that of O'Neill (1991) who found that navigational performance decreased as a function of the complexity of the surroundings. Proposals to improve the environment of bridge sites followed. These focused on the design of the bridge warning signs (including a more accurate statement of the measured minimum height of the bridge), the design of the bridge markings and the reduction of potential distractions for drivers.

Following this, two experiments were designed to assess what drivers looked at when approaching low bridges. In the first experiment the area of specific interest was the amount of visual attention given to the various bridge warning signs and how these compared to the amount of attention given to other traffic warning signs (controls). The results obtained confirmed that, overall, the IBW sign performed badly on measures of visual attention when compared with the controls. This was argued to be in part due to the specific design of this type of sign. For the detection of the two IBW signs, the results upheld the findings of Pottier and Pottier (1988) who reported that sign detection was influenced by location, as the current research demonstrated that if the IBW sign was in a very prominent position, it was detected by significantly more subjects than when it was in a less prominent position.

The second experiment considered visual behaviour in the final few seconds of driving when approaching low bridges. Analyses of drivers' eye movements found that the existing bridge markings were only directly looked at for a small amount of the time, and that the top of the bridge was looked at, on average, for over a third of the total time. However, if an advertisement was placed on the top of a bridge, it was looked at for a large amount of time, thus reducing how long other features of the bridge environment (e.g. traffic signs) were attended to. This therefore supported the findings of Boersema and Zwaga (1985 and 1990), that inserting advertisements into a visual scene reduces the conspicuity of important routing information.

The research progressed to consider the development and evaluation of alternative versions of the IBW sign by means of a further two experiments. In the first, a series of bridge warning signs were developed and then tested on the experimental response measure of comprehension (after Young, 1991, and Edworthy and Adams, 1996a, who recommended comprehension testing as a pivotal method for evaluating the effectiveness of a warning sign). In the second experiment, a modified group of six bridge signs were superimposed onto pictures of road scenes and were made briefly observable to subjects, the response indices used in this experiment were comprehension and hazard perception. Both experiments found that 'text-based' versions of the IBW sign performed better than 'Roundel' or 'symbolic' versions of the sign on the measure of comprehension. Additionally, it was found that those signs having a yellow border produced better comprehension results than those signs with plain borders, so supporting the results obtained by Thompson-Kuhn, Garvey and Pietrucha (1996) for the increased effectiveness of signs with coloured borders.

The research then centred on the development and evaluation of alternative versions of markings for low bridges by means of two more experiments. In the first experiment a group of different bridge marking designs was created and then tested on a computer-animated road scene. The road scene comprised bridges of different heights. The task for the subjects watching this scene was to judge whether they thought they could pass safely under, or would hit, the top of each bridge. The second experiment developed and tested a larger set of markings to find an improved design. Subjects viewed pictures of a bridge on which the markings were superimposed. The task for them was to judge if the bridge containing the experimental markings appeared to look lower or higher than a control bridge. In both experiments the existing marking standard of yellow and black hatching performed badly on the experimental measures employed when compared with the alternative bridge marking designs. In addition, the second experiment identified two different variables ('form' and 'width') within the markings that influenced subjects' perception of bridge height. These findings were therefore in accordance with Prak (1977) who reported that illusions of size have successfully modified the perceived height of buildings for several centuries.

Finally, both the bridge signs and markings were examined to assess if the existing and modified designs of the signs and markings identified earlier had any behavioural effects upon drivers when approaching low bridges. This method utilised the work of Fisher (1992) and Wogalter and Laughery (1996) who argued that the main function of a warning is to increase safe behaviour. A virtual reality road environment was created with which the subject could interact. A bridge was situated in this virtual world, and was capable of being modified by the experimenter in terms of its height and the markings displayed on it. In addition, bridge warning signs were present in some of the road scenes, to test whether they sensitised the driver to the bridge hazard ahead. The task for subjects was to judge if they could pass safely under the bridge.

The experiment revealed that the type of markings on the bridge did significantly affect subjects' braking responses. Those low bridges containing the newly designed markings were responded to earlier and more 'safely' than those bridges with the existing markings (thus supporting the positive results obtained in Chapter 6 for the newly designed markings). The addition of warning signs before the bridge, however, had no significant influence on subjects' behaviour with respect to the bridge. This finding corresponds with the research of Ward and Wilde (1995) who argued that warning signs could, at best, only partially improve subjects' safety behaviour in traffic situations. Hence it was found that the presence of a prior warning sign did not affect driver braking before the bridge when the height of their vehicle was unknown to them.

It is therefore concluded that more research, geared towards using the newly designed markings for 'real' rail-over-road bridges is needed. In addition, it is contended that the use of warning signs might be more beneficial when drivers do know the actual heights of their vehicles.

8.2 Research Implications

The purpose of this section is to consider the implications of the overall results of the research investigation. As stated earlier in section 2.3, the main aim of the research was to examine one possible approach to reduce the number of bridge strikes. Specifically, the overall goals of this approach were to improve the design of the IBW signs and bridge markings, and to further understand drivers' perceptions and behaviour with respect to such warnings. It is argued here that the overall aims of the investigation have been met. The approach taken found that effective new designs of the IBW signs and markings could be developed and evaluated. In addition, the general methodology found that drivers' perceptions and behaviour with regard to these two types of warnings could be successfully examined through the experiments reported in this investigation.

The overall argument was, and continues to be, that improving the visual warnings in the road environment on or before low bridges would result in more appropriate behaviour by drivers when judging whether to attempt to pass under a low bridge, thus reducing the number of strikes by high-sided vehicles. The individual studies are therefore discussed within this context, particularly with reference their specific objectives (as stated in section 2.3.1) and to the assertion that the research findings make a distinct and original contribution to knowledge in the area of bridge strikes.

The field assessment research carried out in the current investigation contributed to knowledge by being the first study in which an audit of a large number of bridge sites where strikes have regularly occurred (and an equal number of control sites) was undertaken, to try and identify factors that might possibly influence bridge strikes. The research achieved its objectives of exploring and more completely understanding the physical characteristics and road environments of frequently struck bridges by actually identifying factors that might influence bridge strike incidents. Finding that frequently struck bridges were generally in busier, more visually complex environments with, on average, more advertisements nearby, resulted in the proposal that the number of distractions within the bridge environment should, if possible, be reduced. Although it would be difficult to remove many distracting features of the road environment (such as other traffic signs), it ought to be possible to limit the amount of advertising on the bridge itself. Another important result was that the signed height of a bridge did not always accurately reflect the measured minimum height of the bridge. It was therefore proposed that this situation should be improved, perhaps by standardising, to an exact amount, the safety room below the bridge's minimum height. The implication of this is that the majority of signs would need changing to this new system, and although this would be expensive, it would improve the accuracy, and hopefully the validity, of the information regarding the signs' height. It would also mean that signs would no longer be marked in three inch multiples as they are currently.

The research into the drivers' visual behaviour made a small contribution to knowledge by recording and analysing eye movements in a scenario never previously specifically investigated by other researchers (i.e. the drivers' visual behaviour when 'driving' a large vehicle that was approaching a low bridge). The research accomplished its objectives by establishing the effectiveness of the IBW signs and bridge marking in terms of attracting visual attention. Finding that the bridge signs performed badly on measures of visual attention implies that the design of these signs could be made more effective. Another important finding was that advertisements placed on a bridge resulted in drivers looking at them for a large percentage of the time, when, it is argued here, their attention ought to be on the possible overhead hazard. This would seem to indicate that advertising on bridges should be reduced in order to limit the distractions for drivers. It must be noted, however, that no causal relationship between the amount of advertisements on bridges and the increased likelihood of strikes has actually been established in this research.

Considering the design and evaluation of the IBW signs, this investigation made a small contribution to knowledge by using previously established research techniques in warning sign design and evaluation (e.g. adding borders to signs and comprehension testing) and applying them to a different type of sign (i.e. the IBW sign). The experiments in this area partly met their objectives. They established that the current standards for the IBW signs could be improved. They did not, however, establish that an enhanced sign actually had any positive influence on the behaviour of a driver of a high-sided vehicle when approaching a low bridge (reasons for this are discussed in Chapter 7). Despite this, the research found that the main advantage of one of the newly designed signs was that it was superior to the existing versions on the two measures of comprehension (and, to a lesser extent, on the measure of hazard perception). The best performing version of the sign was a text-based one with a yellow border. One of the existing versions is a text-based sign with a plain border, so adding a yellow border to this sign should improve its performance. This would have two advantages, it would be fairly inexpensive to modify (simply by attaching borders to existing signs) and it would be in line with the current widespread use of yellow borders by the DoT for traffic sign conspicuity (as established by Cooper, 1988).

For the bridge markings, no previous research has been undertaken examining whether it is possible to alter the perceived height of a bridge by the markings placed on it. This research therefore made a distinctive contribution to knowledge by adapting previous literature on visual illusions and previous bridge strike countermeasures, and successfully applying them to the design and evaluation of a series of marking standards. The two stated objectives of the experiments were both met. Firstly, it was established that the perceived height of a bridge could be modified by the markings placed on it. Secondly, it was found that a bridge marking that made a bridge look lower did actually influence the behaviour of a driver in an overheight vehicle when approaching the bridge. Based on the results obtained, it would seem that the 'optimum' version of the re-designed markings (i.e. wide spaced yellow and black bands of colour pointing 'inwards') for rail-over-road bridges has the following advantages over the existing marking design:

- It makes bridges appear lower.
- On bridges low enough to be hit, drivers respond earlier and in a 'safer' manner.

As the new marking occupied the same surface area of the currently used markings and used the same colours, it would seem that changing bridges to employ this design would be moderately unproblematic and inexpensive as part of the routine replacement of the markings due to ageing or strike damage.

8.2.1 Limiting factors

Considering the use of visual illusions in bridge markings, there is evidence to suggest that repeated exposure (and feedback) to some visual illusions will reduce their effect when presented on subsequent occasions (Brosvic and Finizio, 1995). However, as previously argued, although being given direct feedback may reduce the illusion in laboratory conditions (with the stimuli being given to subjects in a short space of time), the effect of the illusion in 'real' driving, where a bridge containing the marking illusion might be seen by drivers only rarely, may be different. As there are relatively few low bridges (there are only several thousand low bridges across the whole of the UK), then the marking illusion on a bridge would probably not often be seen (for example, on a long journey perhaps only once an hour). A great deal of other traffic environment stimuli will however have been seen and processed by the driver, thus it is conjectured that the bridge height illusion would persist under these conditions.

This point is supported by Predebon (1992) who, in his work examining the influence of object familiarity on magnitude estimates of apparent size, found no effect of familiarity on perceived size, so familiarity with an object (e.g. a bridge) was not an important determinant of its perceived size. Indeed, there is no evidence to suggest that the effect from an illusion will decline to zero (see Brosvic and Finizio, 1995). Thus even if the effect of the illusion does slightly decrease, it is predicted that it will, to some extent, still influence height judgement.

Another important issue when using a visual illusion in the traffic environment is that there may be unexpected side effects. For instance, its use may interfere with other aspects of the driving environment, such as bridges without these markings (e.g. road-over-road bridges). Would it therefore be necessary to put such markings on all bridges to prevent collisions? The question of longer-term side effects with the new markings is important if they are to be implemented. It is, however, outside the scope of this thesis to discuss them further.

Also, as mentioned earlier, driver motivation to comply with warnings is a critical problem. Meeker and Barr (1989), in an observational study of driver behaviour at railway grade (i.e. level) crossings, found that two-thirds of subjects went through flashing warning lights as trains approached. The majority of these drivers slowed down before crossing, thus they had detected the warnings but still ignored them. Summala and Hietamaki (1984) also found that although drivers detected different speed limit signs equally well, their behavioural responses to such signs was mostly a product of the significance of the signs to the driver. This was supported by the work of Underwood, Jiang and Howarth (1993) when they examined safety measure effects and risk compensation in driving. Following a review of previous theoretical models of road users' risk compensation, they argued that engineering measures in driving were often not sufficient to prevent accidents, and that motivational safety measures were also needed. They supported this by means of a series of case studies examining accident rates following different engineering measures. The implication of the three different studies referred to above for this current research investigation is that the bridge warning signs and markings could be detected, understood, but still ignored by drivers of high-sided vehicles. One solution to increase motivation (and compliance) with respect to bridge warning signs would be to make it an offence to drive past such warnings in a vehicle higher than the clearance given in the sign. This is the legal position for Roundel type third-stage bridge signs, however, no such restrictions apply to the 'Information Category' IBW sign. Such a change may be difficult to enforce as high-sided vehicles often need to carry out deliveries at a site that is past the sign but before the actual low bridge.

An important issue regarding the signs (and to a lesser extent the markings) is that they are only applicable to a certain group of road users, that is, those driving relatively high-sided vehicles. For the majority of drivers (e.g. car drivers) a low bridge is not generally a hazard. It is therefore not the case that the bridge is always hazardous to every vehicle on the road. Thus an issue for future research would be how to make such signs and markings salient to a certain group of drivers only. This could be achieved by more high-technology methods such as only displaying the signs and markings if the vehicle is above a certain height, i.e. by breaking a light beam, as was described in Chapter one for the 'active' warning signs. A lower-technology approach might be to use material in the construction of the signs and markings such that they are only visible from a higher eye height when they are appropriately angled, as truck drivers generally have a higher driving eye height than do car drivers (Cobb, 1990). This method may however only be effective on level roads as signs situated on hills may result in the information being visible to all road vehicles.

A final issue for both the signs and markings is that their effectiveness may be more constrained by their implementation rather than their actual specific design. This investigation found that the signs and markings were simply not present at many bridge sites. Having well designed signs and markings is pointless unless they are used, and positioned in the correct locations. Again, this area is outside the scope of this research, but is of huge importance if the results of this work are to be applied in the real world.

8.3 Recommendations for Future Research

The section above has already indirectly mentioned several areas for future research that may help support the results obtained here (e.g. quantifying the decreasing effects of visual illusions, evaluating the possible side effects of the markings, improving the saliency of signs for some drivers only and assessing the problem of implementation of signs and markings). However, in addition to these areas of research, there are others equally, if not more, deserving of attention.

Firstly, it would be valuable to undertake further eye movement research to establish if the re-designed signs attract more visual attention and more successfully than do the existing versions. The studies that were reported only examined the effectiveness of the current signing and marking standards, so no comparisons on measures of visual attention have yet been performed. It is hypothesised that the addition of a yellow border to the signs would increase their detection by drivers (following similar results for signs with yellow borders obtained by Cooper, 1988). Such further research would be relatively simple and inexpensive to pursue.

Secondly, there is a need to evaluate both the new signs and markings in a more natural location using a more realistic driving task. Future research is already planned to evaluate driver responses to the signs and markings on a test track, where subjects would drive a real lorry and approach a realistic bridge structure. In Gibsonian traffic psychology terminology this would be measuring driver behaviour in an ecologically valid environment (Schiff and Arnone, 1995). The end point of such research would be to evaluate the new signs and markings on real roads, where a long-term study examining accident rates at selected test sites could be undertaken.

Thirdly, evaluation of the material used to construct the signs and markings should be a research topic. In the current research investigation these signs and markings have been displayed as projected images or printed pictures, hence the issue of what material they were made from was not applicable. If, however, future research tests the signs and markings in a 'real' driving environment then the issue is of greater significance. For instance, would the use of retroreflective material increase their conspicuity?

Fourthly, the effects of the signs and markings under reduced visibility conditions should be tested. These would include testing at night, in fog and when a bridge is located just after a bend (so that it is only seen for a short period of time). As yet these signs and markings have only been examined under the equivalent of good daylight, thus it would be necessary to see if the effects obtained in this investigation still persist under the types of sub-optimal driving conditions that are frequently experienced in the UK.

Finally, returning to an issue raised in the first Chapter of the thesis, it is again stressed that improving the visual warnings of bridges will never completely stop all strike incidents. So other methods such as collision detection systems fitted to the vehicle as well as the use of further legal measures would probably be of great use in the future to combat the problem. For the foreseeable future, however, while low bridges remain situated over busy roads, it appears that some strikes will be inevitable. However, as bridge strikes are an expensive and dangerous problem, it seems likely and necessary that a great deal of future work should continue to examine the problem from different directions. Examples of such research might include focusing specifically on the driver's personality (for example, their risk taking), on the driving task (for example, route planning to avoid low bridges) and, in a wider context, on the use of non-road transport methods to carry freight and passengers (i.e. using the railways to a greater extent). The research presented here has investigated the problem from a human factors perspective and has concentrated to a large extent on the design and evaluation of visual warnings for low bridges. The main proposals this research investigation made were to reduce the environmental complexity and amount of advertising around bridge sites, to require that the warning signs more accurately reflect the minimum bridge height, to add yellow borders to IBW signs and to change the design of the markings in order to reduce the perceived height of the bridge. It is contended that the implementation of these proposals will all help to reduce the number of bridge strikes in the UK.

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Appendices

Appendix A – The bridge assessment checklist from Chapter 3.

Appendix B – A specific selection of IBW signs from Experiment 1 in Chapter 5.

Appendix C – The results form from Experiment 1 in Chapter 5.

Appendix D – Pictures of the two different road environments used in Experiment 2 in Chapter 5.

Appendix E – Scoring sheet from Experiment 2 in Chapter 5.

Appendix F – Inward and outward facing markings, together with other marking types used in Experiment 2 in Chapter 6.

Appendix G –Picture of animated road environment used in Experiment 1 in Chapter 6.

Appendix H – Pictures of the two different marking types used in Chapter 7.

Appendix I – Relevant Publications by the author.

Appendix A – The bridge assessment checklist (from Chapter 3)

General:

Date...Time...

Bridge location/reference...

Direction of assessment..

Number of lorries under bridge over 5 minutes ....

Actual height of Bridge ....Displayed height of Bridge............................

Is bridge height constant throughout length of bridge: Yes [ ] No [ ]
If not indicate differences...

Type (eg arch, girder, combo)..

Category (eg rural,urban,industrial) ....

Nature and speed of surrounding roads..

Signs present: Primary .... Secondary .... On bridge ....
Others(specify)..

Bridge:

Strike evidence: None [ ] Partial [ ] Widespread [ ]
If evidence, describe type...
....

Colour of bridge..................................Building material ....

Caution devices present: No [ ] Yes [ ] If so, what...................................

Parapet height...

Diversion potential (after sign 2): None [ ] Place to turn [ ] Div'sion road [ ]

Bridge markings: Present good cond.[ ] Present poor cond.[ ] Not Present [ ]
Reflective or non reflective...

Marking size(feet/inches) ....

Extent of markings: Just top [ ] Top and sides [ ]
Other(specify)..................................

Lighting around bridge: Bridge lit [ ] General lighting [ ] No lighting [ ]

Chord marking: Present [ ] Broke/absent [ ] N/A [ ]
-Chord width (feet/inches)...

Vegetation around bridge: Obscures [ ] Slightly Obscures [ ] Little/none [ ]

Width of bridge (feet/inches)...

How much wider is bridge than road:...

Depth of bridge (feet/inches)..

Angle of bridge to road: Straight [ ]less than 40^0 [ ] Over 40^0 [ ]

Signs:

On bridge: Roundel [ ] Triangle [ ] None [ ]
In : Metric [ ] Imperial [ ] Both [ ]
Condition of sign: Good [ ] Poor [ ]

Intermediate: Text[ ] Roundel[ ] None [ ] Other (specify) ....
In : Metric [ ] Imperial [ ] Both [ ]
Condition of sign: Good [ ] Poor [ ]
Height of sign above ground (in feet)..
Sign visibility: Good [ ] Average [ ] Poor [ ]
Is sign lit: Yes [ ] No [ ]
Vegetation around sign: Obscures [ ] slightly obscures [ ] Little/none [ ]

Environment:

Speed limit .... Road width ....

Other significant road tasks within 300m (eg traffic lights) ....

Type of road markings ....

If junctions, how many approaches to bridge ....

Is parking allowed within 100 metres of bridge: Yes [ ] No [ ]

Position of Bridge: Downhill [ ] Level [ ] Uphill [ ]

On straight [ ] (300m) On bend[ ] Before bend [ ] (less than 300m) After bend [ ] (less than 300m)
-If on bend, severity of bend: Sharp [ ] Moderate [ ] Slight [ ]
-If on or after bend, direction of bend: To Left [ ] To Right [ ]

Distracters: -General advertising: Much [ ] Little ads. [ ]No ads. [ ]
-Other road signs: Many [ ] Few [ ] None [ ]
-Environment: Complex [ ] Moderate[ ] Simple[ ]

Tall objects in vicinity of bridge(list)..

Differences approaching bridge from opposite direction..
....
....

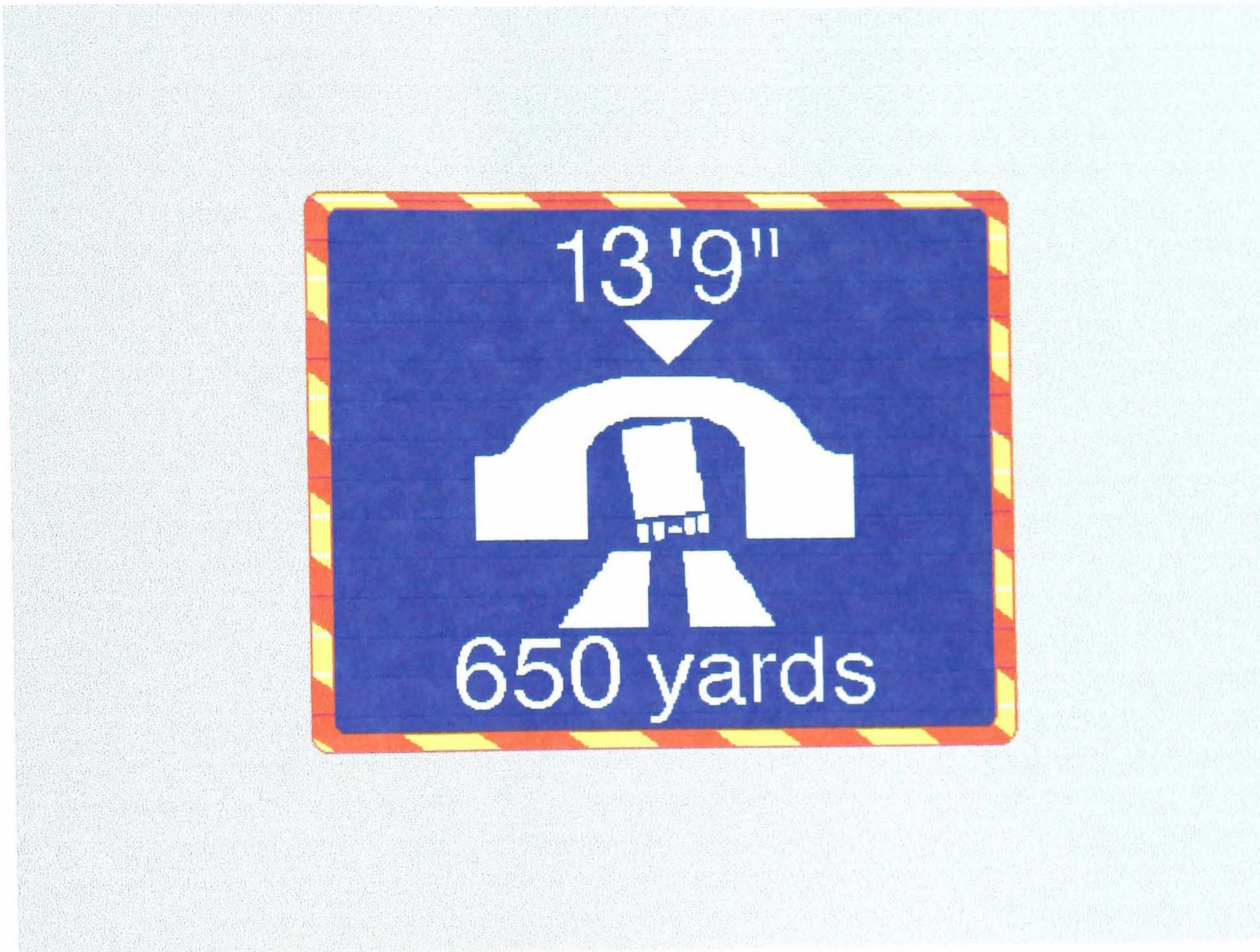
Other areas not covered above:

Appendix B – A specific selection of IBW signs (from Experiment 1 in Chapter 5). Chosen to show all the border and form combinations

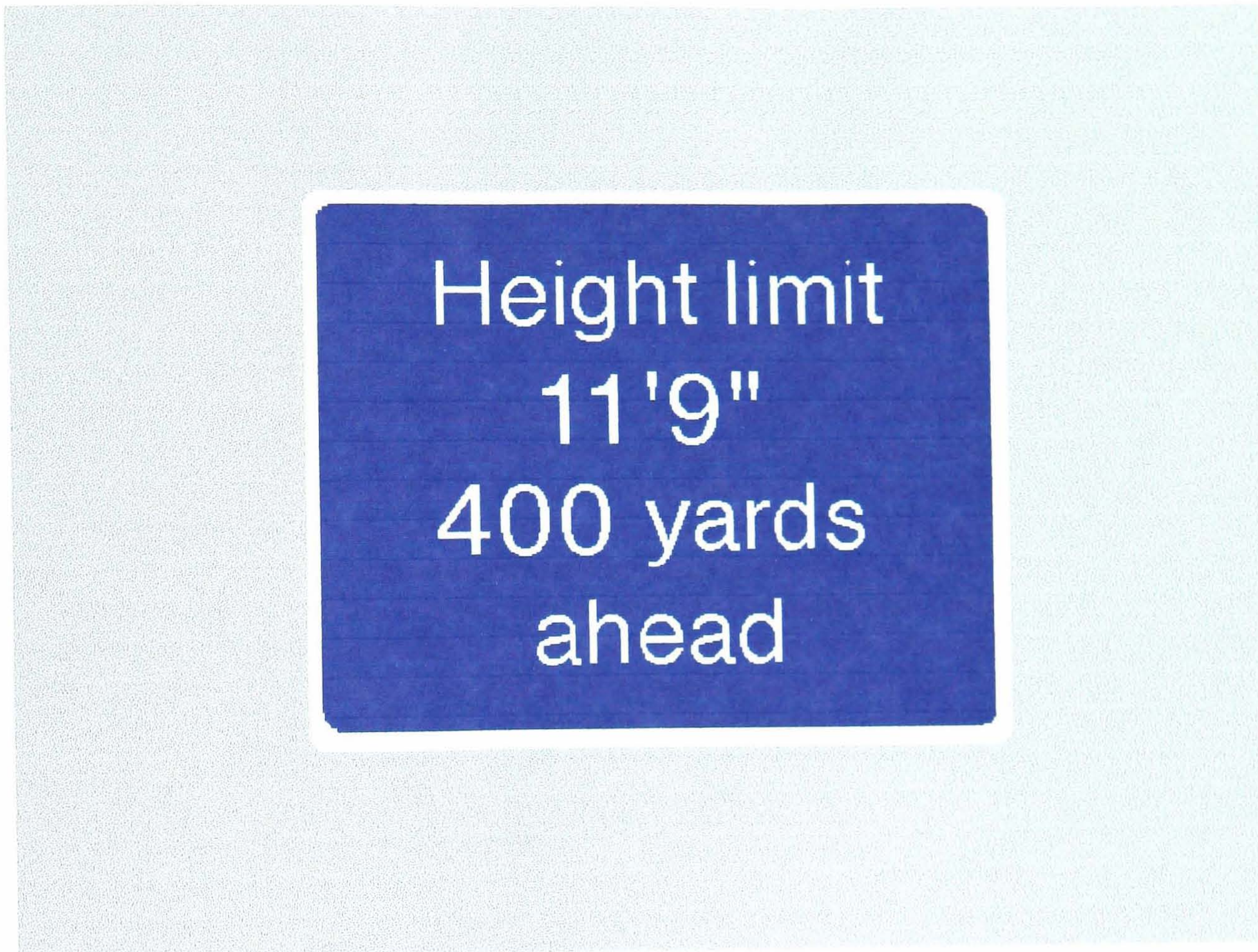
The new text-based sign with a yellow and red border

The roundel sign with a yellow border

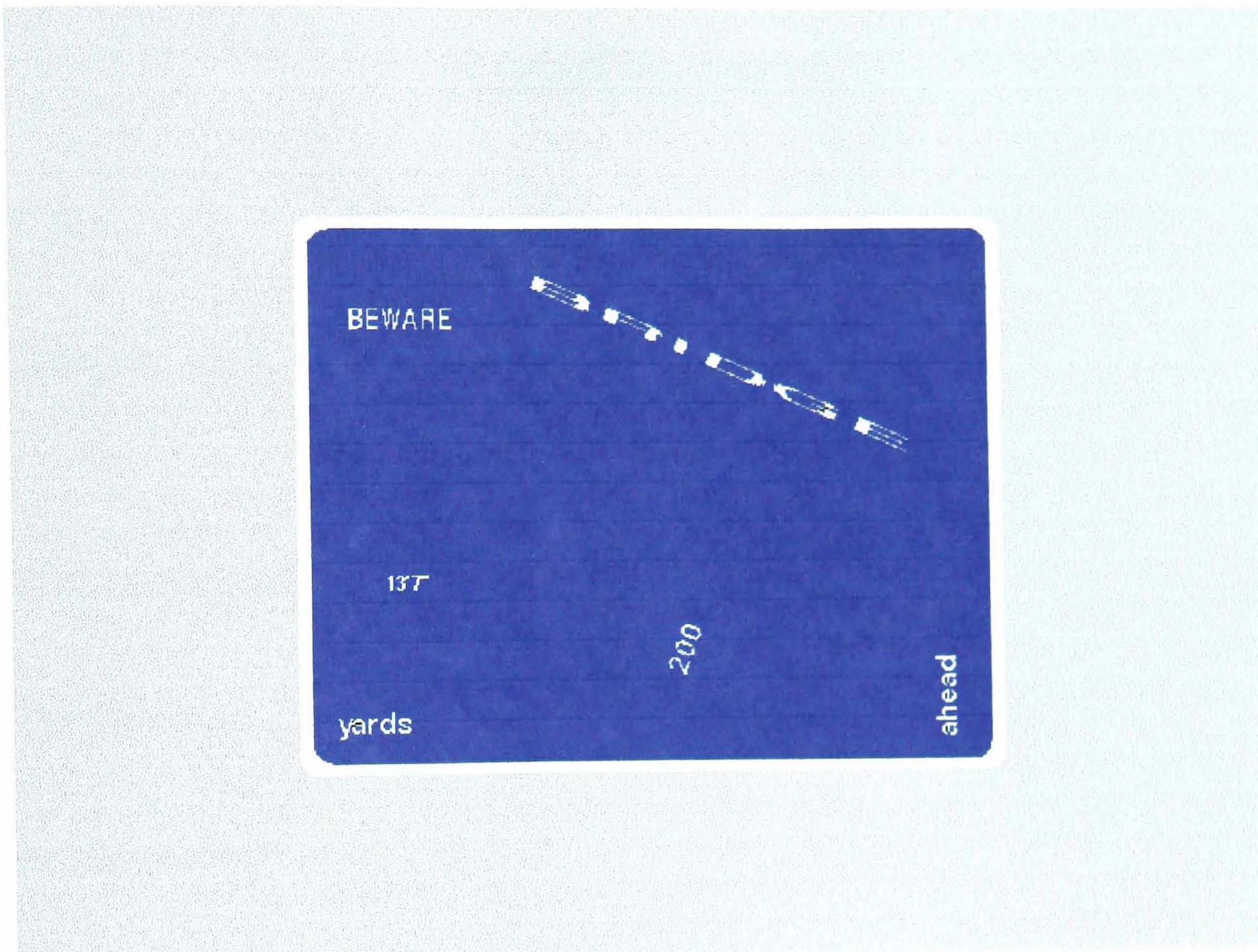
The symbolic sign with a yellow and red border



The existing text based sign with a plain border



The Null (control) sign with a plain border



Appendix C – The results form (from Experiment 1 in Chapter 5)

Results form

1) Sex .... Male (   ) ....Female (   )

2) Approx. age............ less than 25 (   )
.... 25-40 (   )
....Over 40 (   )

3) Is vision normal/corrected to normal.................. Yes (   ) ....No (   )

4) Is the subject......................Lorry driver (   ) .... Car driver (   )

5) Subject Number....... (   )

6) User identification...... (   )

Warning Signs

Comprehension - tick columns/write in heights distances

(1) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(2) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(3) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(4) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(5) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(6) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(7) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(8) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height	Actual sign Distance	
Warning- ask more info	Clearance	Coming up	

(9) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height ……………………	Actual sign Distance ……………………	
Warning- ask more info	Clearance	Coming up	

(10) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height ……………………	Actual sign Distance ……………………	
Warning- ask more info	Clearance	Coming up	

(11) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height ……………………	Actual sign distance ……………………	
Warning- ask more info	Clearance	Coming up	

(12) Sign Name: Score:

(Low) Bridge	Height	Ahead	DoT Sign
Height restriction/limit	Low	Forewarning	(tick if correct)
Hazard- ask more info	Actual sign height ……………………	Actual sign Distance ……………………	
Warning- ask more info	Clearance	Coming up	

(13) Sign Name: Score:

(Low) Bridge	Height	Ahead
Height restriction/limit	Low	Forewarning
Hazard- ask more info	Actual sign height	Actual sign Distance ....
Warning- ask more info	Clearance	Coming up

Keyword scoring:

■ Correct answer: one from each column with actual height/distance

■ Acceptably correct answer: actual height and one word from column 1 (knowing it is a bridge hazard with actual height, but not exact distance away).

■ Partially correct: at least a word from column 1 and another column (but no exact height information).

■ Incorrect meaning: wrong or no understanding of sign (one or less keyword).

Appendix D – Pictures of the two different road environments used in Experiment 2 (in Chapter 5)

The rural scene showing the existing text-based sign with a plain border

The urban scene showing the roundel sign with a yellow and red border

Appendix E – Scoring sheet (from Experiment 2 in Chapter 5)

Sign Experiment

Name: Age: Sex:

Type of driver:	Car	( )	
	High vehicle	( )	If so, approx height of vehicle ( ) feet

Subject number ( )

We want you to try and imagine that you are driving a 13 foot lorry.

We are going to show you a series of road scenes. Before each road scene appears you will see a random pattern called a mask. A red cross will then appear in the middle of the mask and we would like you to focus on this red cross. The road scene will appear quickly after the red cross and will last for one second before going back to the mask.

After you have viewed each road scene, we would like you to rate how hazardous you think that scene is or how hazardous the road ahead may be based on features in the current scene (for example there may be a warning in the current scene about roadworks ahead). By hazard we mean anything in the environment that you should be aware of when driving because you may need to alter your driving behaviour. Please use the rating scale in front of you to rate the hazard.

1	2	3	4	5	6	7
Slight hazard			Moderate hazard			Extreme hazard

Each time after you have been shown a road scene, we will ask you what features of it were responsible for the hazard rating that you gave.

We may prompt you for additional information about certain features in the road environment if you make reference to them.

The first road scene that you see will be an example only in order to familiarise you with the task.
(write down order number and start program)

Subject number (   )

Order number (   )

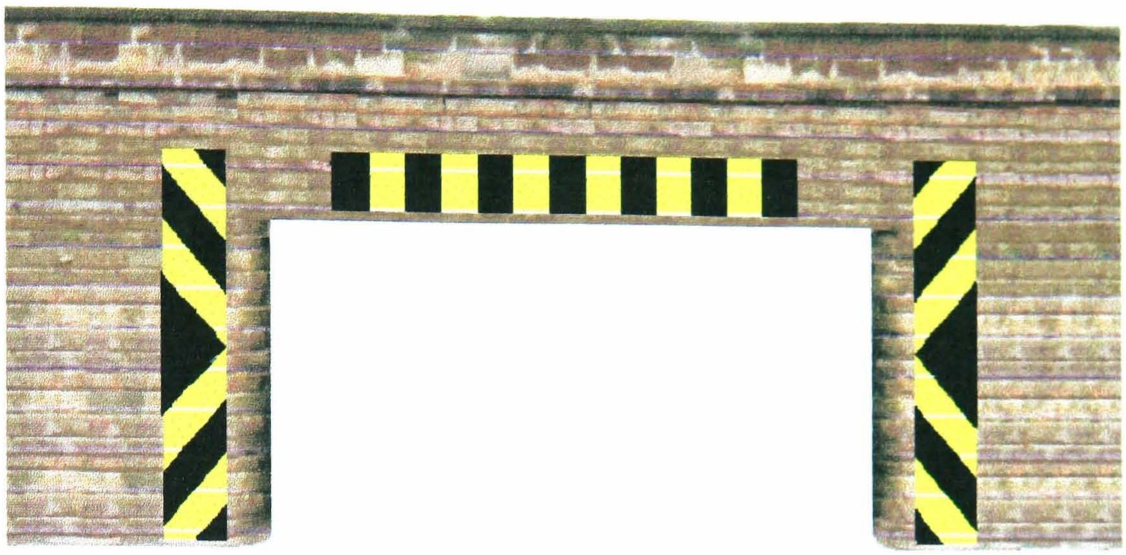
1	1 - 2 - 3 - 4 - 5 - 6 - 7	**16**	1 - 2 - 3 - 4 - 5 - 6 - 7
2	1 - 2 - 3 - 4 - 5 - 6 - 7	**17**	1 - 2 - 3 - 4 - 5 - 6 - 7
3	1 - 2 - 3 - 4 - 5 - 6 - 7	**18**	1 - 2 - 3 - 4 - 5 - 6 - 7
4	1 - 2 - 3 - 4 - 5 - 6 - 7	**19**	1 - 2 - 3 - 4 - 5 - 6 - 7
5	1 - 2 - 3 - 4 - 5 - 6 - 7	**20**	1 - 2 - 3 - 4 - 5 - 6 - 7
6	1 - 2 - 3 - 4 - 5 - 6 - 7	**21**	1 - 2 - 3 - 4 - 5 - 6 - 7
7	1 - 2 - 3 - 4 - 5 - 6 - 7	**22**	1 - 2 - 3 - 4 - 5 - 6 - 7
8	1 - 2 - 3 - 4 - 5 - 6 - 7	**23**	1 - 2 - 3 - 4 - 5 - 6 - 7
9	1 - 2 - 3 - 4 - 5 - 6 - 7	**24**	1 - 2 - 3 - 4 - 5 - 6 - 7
10	1 - 2 - 3 - 4 - 5 - 6 - 7	**25**	1 - 2 - 3 - 4 - 5 - 6 - 7
11	1 - 2 - 3 - 4 - 5 - 6 - 7	**26**	1 - 2 - 3 - 4 - 5 - 6 - 7
12	1 - 2 - 3 - 4 - 5 - 6 - 7	**27**	1 - 2 - 3 - 4 - 5 - 6 - 7
13	1 - 2 - 3 - 4 - 5 - 6 - 7	**28**	1 - 2 - 3 - 4 - 5 - 6 - 7
14	1 - 2 - 3 - 4 - 5 - 6 - 7	**29**	1 - 2 - 3 - 4 - 5 - 6 - 7
15	1 - 2 - 3 - 4 - 5 - 6 - 7		

Appendix F – Inward and outward facing markings, together with other marking types used in experiment 2 (in Chapter 6). All pictures are show in the yellow and black colour combination.

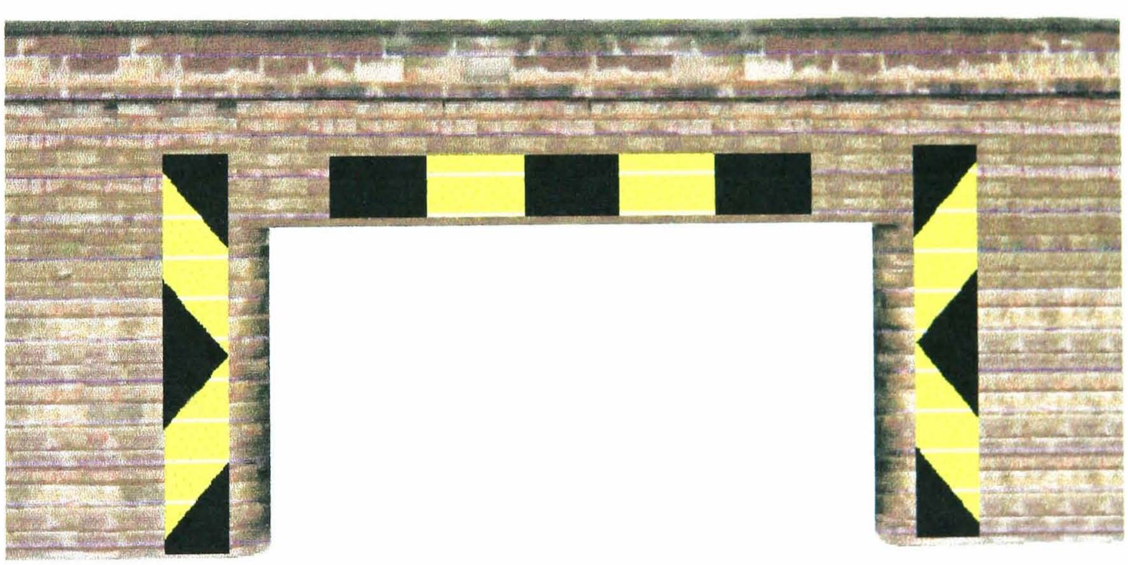
The current marking (DoT standard).

The current marking with double spaced bands (wide)

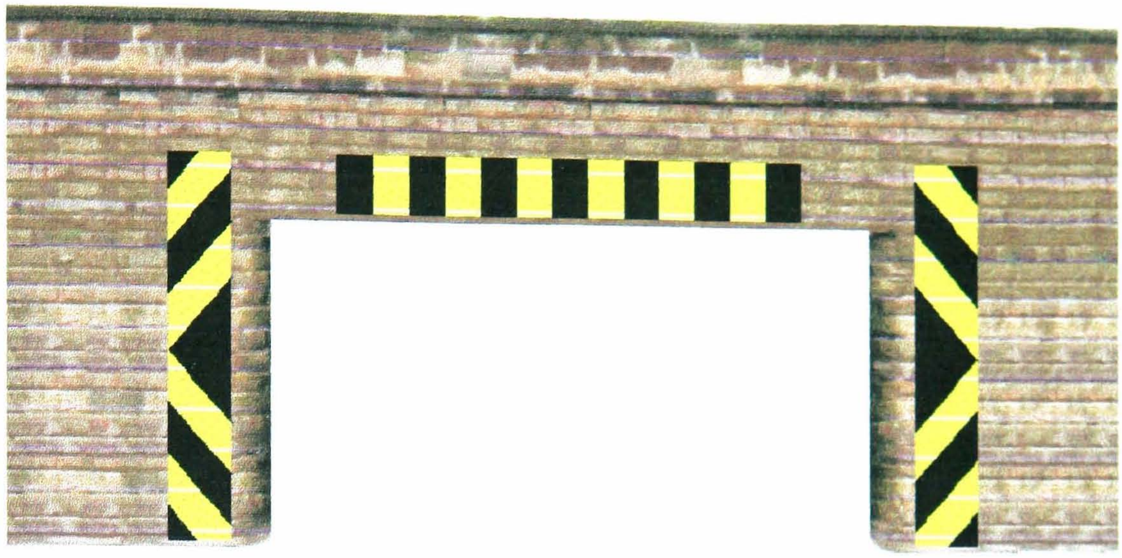
The Muller-lyer inward facing with narrow bands



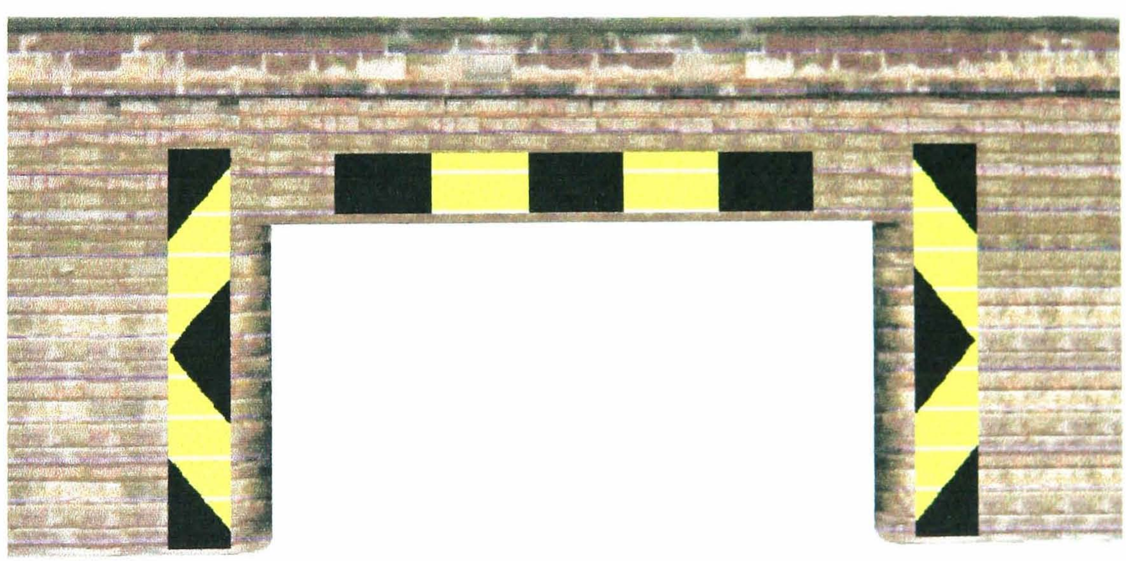
The Muller-lyer inward facing with wide bands



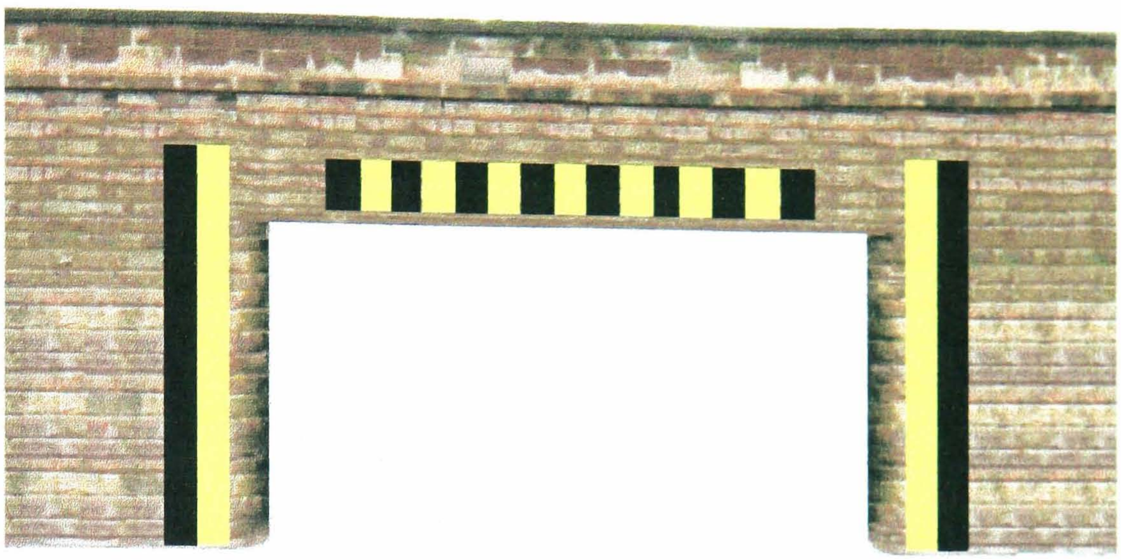
The Muller-lyer outward facing with narrow bands



The Muller-lyer outward facing with wide bands

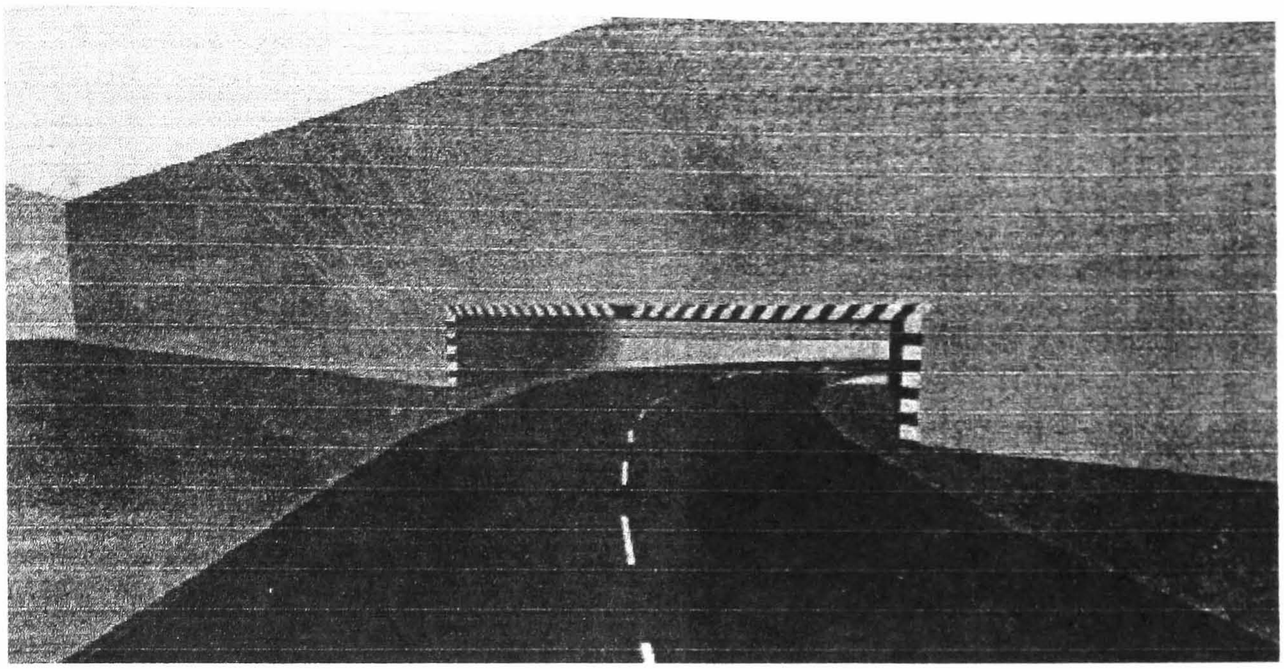


The horizontal vertical illusion with two bands of colour



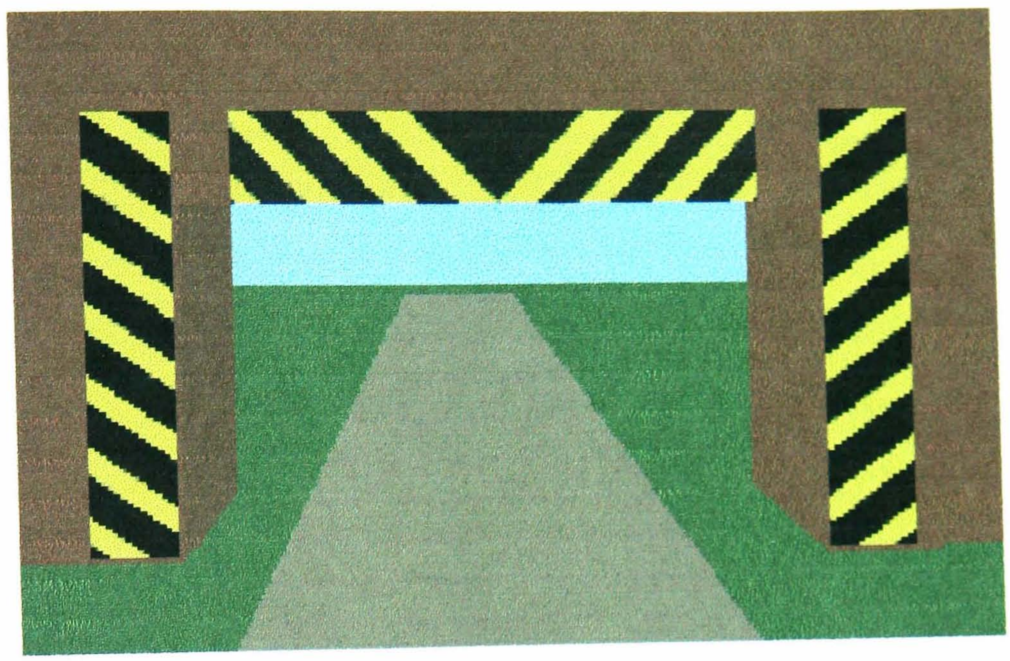
The control bridge marking

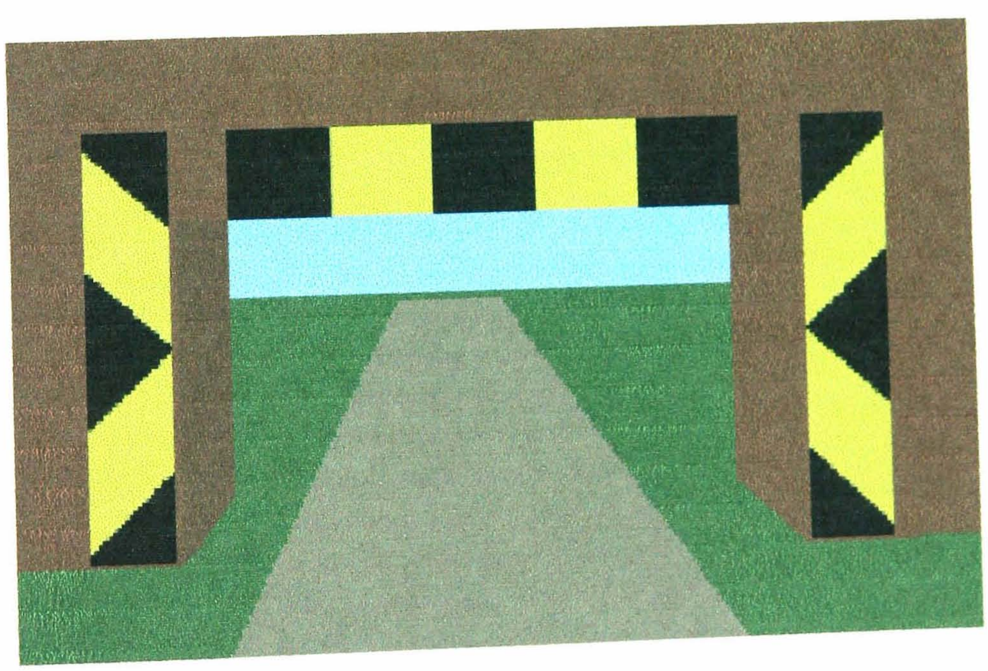
Appendix G – Picture of the animated road environment used in experiment 1 in Chapter 6



Appendix H – Pictures of the two different marking types used in Chapter 7.

The existing marking standard





The newly developed marking design

Appendix I – Relevant Publications by the Author.

Publication – Authors, Where and When Published and Title of Paper.	**Relevant to which parts of the thesis**
Horberry T.J., Gale A.G. International Ergonomics Association Conference Proceedings, Tampere 1997. *"Bridge Bashing: A Review."*	Chapters 1 and 2
Horberry T.J., Purdy, K.J. Gale A.G. Contemporary Ergonomics 1997. *"Mind the Bridge! Drivers Visual Behaviour when Approaching an Overhead Obstruction."*	Chapter 4
Horberry T.J., Halliday M., Gale A.G. and Miles J.N.V. International Ergonomics Association Conference Proceedings, Rio 1995. *"Road Signs and Markings for Railway Bridges: An Ergonomic Design Intervention."*	Chapters 5 and 6
Horberry T.J., Halliday, M. Gale A.G, and Miles, J.N.V. In press, Vision in Vehicles VI. *"Road Signs and Markings for Railway Bridges: Development and Evaluation."*	Chapters 5 and 6
Horberry T.J., Halliday M., Ball L and Purdy K. International Conference on Traffic and Transport Psychology Conference proceedings (book of abstracts), Valencia 1996. *"Optimising the Design of Markings for Low Bridges."*	Chapter 6
Horberry T.J., Gale A.G, and Bolarin F. Submitted for publication, Vision in Vehicles VII. *"Virtually a Bridge Bash: The Use of a Virtual Environment to Evaluate Driver Behaviour."*	Chapter 7