

**Whole Life Cost-Benefit Analysis for
Median Safety Barriers**

by G L Williams

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WHOLE LIFE COST-BENEFIT ANALYSIS FOR MEDIAN SAFETY BARRIERS

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by G L Williams (TRL Limited)

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Client: Safety Standards and Research Department, Highways Agency (Mr Daniel Ruth)

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Executive summary

Whole Life Cost-Benefit Analysis for Median Safety Barriers by G L Williams, TRL Limited

HIGHWAYS AGENCY TASK REFERENCE	: 3/372/R22
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TRL Limited has been commissioned by the Highways Agency to examine the performance and cost effectiveness of median barriers installed on major roads in Great Britain. This report consists of two inter related parts - a review of median and median barrier accidents which resulted in casualties, and the relative costs associated with median steel safety fences and concrete barriers. A detailed whole life costing survey for the most common types of safety fences and barriers currently in use on the median of major roads is also included.

In order to obtain detailed information relating to accident statistics and whole life costs associated with median safety barriers, one area of the Highways Agency's Network, the M25 Sphere, was identified, and pertinent information obtained and analysed. In addition a letter was also distributed to all fourteen of the Highways Agency's regional Traffic Operations Departments, their Agents and their Term Maintenance Contractors. The letter was also sent to Britpave (representatives of UK concrete barrier manufacturers) and a similar letter sent to UK metal safety fence manufacturers.

Three distinct types of accident were investigated - those in which a vehicle crossed the median, those in which a vehicle was redirected across the carriageway, and those in which the vehicle remained close to the median after impact. This was applied to accidents in which a vehicle struck either an object in the median or, in a more specific search, struck a median safety barrier. This analysis was carried out for cars, HGVs and 'other vehicles'. Data were extracted from the STATS 19 accident database for the years 1990 to 2002 inclusive. The main findings were as follows:

- Between 1990 and 2002 there were 1,449 accidents per annum in which a vehicle struck a median safety barrier. This is 1.2% of the total number of UK accidents, and 50.0% of the accidents in which an object was struck in the median. This object may have been a median safety barrier, lighting column, sign post, matrix signal, or any other item of roadside furniture. Within these accidents, the most serious casualty was rated as 'fatal' in 34 (2.3%) incidents, 'serious' in 216 (14.9%), and the remaining 1,199 (82.7%) were rated as 'slight'.
- Within the 1,449 median barrier accidents, there were a total of 2,019 casualties, these being 1.2% of the total number of casualties resulting from vehicle accidents during this period. Of these casualties, 38 (1.9%) were rated as 'fatal', 274 (13.6%) as 'serious injuries', and 1,706 (84.5%) as 'slight injuries'.

When considering vehicle trajectories following an initial impact with a median barrier, it was seen in the STATS19 data that whilst a crossover accident is less probable than one in which a vehicle is rebounded or retained close to the barrier, it is almost three times as likely that a fatal injury will result.

The data have also shown that when a car impacts a median safety barrier it is more probable that it will be contained, rather than breach it. However, if the impacting vehicle is an HGV, it is more probable that the vehicle will be retained close to the barrier. It is equally probable that an HGV will cross through a median barrier, than be rebounded by it.

For impacts by cars and HGVs, the highest percentage of serious injuries result from crossover accidents, the highest number of slight accidents resulting from those types of accident in which the vehicle remains close to the median barrier.

For impacts by 'other vehicles', the highest percentage of serious accidents comes from those in which the vehicle is retained close to the median barrier. Slight accidents are more prevalent with the crossover accident.

An analysis of accidents occurring on the M25 Sphere has shown that:

1. Of the 373 km of median safety barrier installed within the M25 Sphere,
 - Metal safety fences (including wire rope safety fencing) constitute 87.3% of the total length,

- Concrete safety barriers contribute 12.7%.
2. No fatal casualties have resulted from an impact with a concrete barrier;
 3. The number of serious casualties per kilometre is comparable between steel safety fencing and concrete safety barriers;
 4. Concrete barriers result in a lower rate of slight casualties and total accidents per kilometre than metal safety fences.

Following this accident data analysis, it was decided to compare the relative whole life costs (WLC) of different classes of safety fence and barrier. The 'normal containment' safety barrier systems examined were the wire rope safety fence (WRSF), double sided and two parallel rows of tensioned corrugated beam (TCB) and open box beam (OBB) and vertical concrete barrier (VCB). The WLC of barriers with greater levels of containment were also examined, these being the Higher Vertical Concrete Barrier (HVCB), the Dutch Step (concrete) Barrier and the Double Rail Open Box Beam (DROBB) safety fence.

A total of seven items of cost were examined, these being safety fence and barrier installation, general maintenance, repairs (following an accident), removal costs, accident costs, and traffic management and traffic delay costs associated with any works to the safety barrier. These were then consolidated on a whole life costing spreadsheet, to enable the WLC for 1km of each safety fence or barrier type to be calculated over a service life of 50 years. After a period of 25 years it was assumed that the metal safety fences would be removed from site and replaced with an identical system. There were a number of items of cost excluded from the whole life cost calculations due to their complex and/or site specific nature. These included the relocation of services (such as lighting columns and signs), the cost of consequential structural damage, and the costs associated with the complete closure of the carriageway during the recovery of vehicles.

Whole life cost calculation have shown that the Dutch Step and Vertical Concrete Barriers have the lowest whole life costs. The Dutch Step Barrier also offers H2 containment, and hence, this increase in containment is provided with a reduced whole life cost.

Calculations have also shown that the introduction of a very high containment safety barrier would only be cost effective if there were 15 accidents occurring on the 1km length of median barrier in its 50 year life. Furthermore, calculations regarding HGV impact only have shown that very high containment median safety barriers may be economically viable if 3 HGV accidents occur on a 1km length of barrier during a working life of fifty years. However, this report has not examined costs associated with structural consequences (i.e. the costs associated with damage to the item of roadside furniture being protected [for example a bridge pier]). In such cases, these structural consequences may be sufficiently high that the use of a very high containment safety barrier would be warranted.

Double sided TCB is seen to be the least expensive metal safety fence system, slightly cheaper than wire rope safety fence.

It was however, assumed in these calculations that the accident rates and severity would mirror those seen in the historical accident data ranging from 1990 to 2002.

Those safety barriers with a containment level greater than 'normal' will deflect less than a normal containment safety barrier when impacted with the small (900kg) vehicle as their rigidity enables them to contain heavier vehicles. Hence it follows that the severity indices (such as ASI, THIV and PHD) for safety barriers with a 'high' or 'very high' containment level will be more onerous than those of normal containment. (European studies such as the RISER and ROBUST projects are currently being carried out to try to correlate these severity indices with 'real life' injuries; however no link, to date, has been found).

Safety barriers with a greater level of containment are less likely to be breached. In the case of central reserve safety barriers this may, in turn, reduce the number of fatalities occurring on the opposite carriageway. However, if the barriers are of a higher and solid construction, a driver's visibility of activity on the opposite carriageway will be diminished.

Due to the rigidity of these high or very high containment barriers, it has been seen through full-scale testing that there is a general tendency for some vehicles with a higher centre of gravity (such as HGVs) to roll over the barriers if they are not of sufficient height. Whilst it is preferable for a vehicle to traverse the median on its wheels rather than on its side, a greater level of impact energy is required to roll an HGV than for it to breach a deformable safety fence.

During the life of a median safety barrier, there may be occasions which arise when legitimate access through the barrier is required. Whilst this action can be quite speedily effected with a metal safety fence, this is not true for the concrete systems. In situations where concrete barriers exist, the use of removable/movable/demountable sections of barrier would be necessary, or a detour around the barrier would be required.

IMPLEMENTATION

Following the investigations carried out under this commission further studies are recommended:

- Identify lengths of major road with a high percentage of HGVs or HGV crossover accidents, as the use of very high containment safety barriers in the central reserve has been shown to be more economically viable where the probability of an HGV impact is high.
- Investigate the costs associated with structural consequences resulting from HGV accidents in the central reserve of major roads.
- Investigate the costs associated with relocating services in the central reserve of major roads.

ABSTRACT

TRL Limited has been commissioned by the Highways Agency to examine the performance and cost effectiveness of median barriers installed on major roads in Great Britain. This report consists of two inter related parts - a review of median and median barrier accidents which resulted in casualties, and the relative costs associated with median steel safety fences and concrete barriers. A detailed whole life costing survey for the most common types of safety fences and barriers currently in use on the median of major roads, is also included.

1 INTRODUCTION

1.1 Background

Early in 1999, there was a series of accidents involving heavy goods vehicles (HGVs) veering to their offside, impacting safety barriers installed in the median, and entering the opposing carriageway. These are referred to as 'crossover accidents'. Such accidents have caused a number of fatal casualties, and have given rise to this study.

The safety fences (metal) and barriers (concrete) generally installed in the median are known as 'normal' or 'N2' containment. They have been designed to safely contain and redirect errant vehicles of one and a half tonnes in weight, impacting the fence or barrier at one hundred and ten kilometres per hour and at twenty degrees; they were not designed to contain and redirect heavier vehicles. However experience and police files examined as part of this project, have shown that the N2 containment safety barriers can, in some instances, contain these heavier vehicles successfully.

Concern within the Highways Agency about crossover accidents prompted the consideration of replacing normal containment safety fences in the median with fences or barriers of a greater level of containment.

TRL Limited has been commissioned by the Highways Agency to complete a whole life cost-benefit analysis of median safety barriers, and to report on any information which may influence a decision to change the current specified containment level.

1.2 Previous Work

TRL has previously completed two phases to this project, and reports have been produced:

The first phase of the project, TRL unpublished report PR/SE/182/00, examined STATS19 accident data in detail, whilst containing a small amount of information regarding the whole life costs associated with median safety barriers.

Within the second phase, TRL published project report PPR280, the whole life costing section was significantly expanded, and the whole life costing spreadsheet used within this third phase of the project was developed.

1.3 Changes from the Phase II Report

The first significant change between this and the previous phases of the project is that this third phase considers accidents and casualties occurring as a result of an impact between a car, HGV, or another vehicle type and a median barrier. In the previous reports, only accidents involving HGVs were considered. Data have also been collected for accidents in which an object has been struck in the median; this object may be a median safety barrier, but could also be a lighting column, road sign or any other item of roadside furniture.

In addition, this report also identifies a number of other contributory factors which must be considered before changes are made to the type and containment level of median barriers.

This third phase also incorporates the findings from a case study of the M25 Sphere, conducted by Mouchel Parkman. The results from this are incorporated both within the accident statistic considerations, and within the whole life costing analysis of median safety barriers. Further details of this case study are given in Section 2.1 of this report.

1.4 Definitions and abbreviations

Definitions and Abbreviations used within this report can be located in Annex A. In some cases definitions are also included within the main body of the report to aid understanding.

2 SOURCES OF INFORMATION

Within previous phases of this project, much of the whole life costing data have been provided by the "Spon's Civil Engineering and Highway Works Price Book 2002" [1]. Whilst such prices were suitable for comparative purposes, it was felt that in some cases they did not give a true indication of the actual costs associated with safety barriers due to the generalities and assumptions contained within the price lists.

Previous phases of this study have also relied upon test data to estimate the length and cost of repairs following an accident and the time required to affect such repairs. They did not use cost figures which reflect the 'real-world costs'.

It is for these reasons that it was decided to initiate a number of case studies for the third phase of the project, and to include as much 'real-world data' as possible. In order to achieve this, three sectors associated with the UK safety barrier industry were approached for the provision of information; Mouchel Parkman (the Highways Agency Maintaining Agents for the M25 Sphere), the Highways Agency's Regional Agents, and representatives of the UK safety barrier manufacturers (these being Britpave and the Vehicle Restraint Manufacturers' Association – VRMA).

2.1 The Mouchel Parkman Case Study – The M25 Sphere

In order to obtain detailed information relating to accident statistics and whole life costs associated with median safety barriers, one area of the Highways Agency's Network was identified, and pertinent information obtained and analysed. Due to the relatively low usage of concrete barrier on the Highways Agency Network, it was decided that the area of study would be the M25 Sphere (see Figure 1). This contains a large proportion of the concrete barrier installed in the median of Highways Agency roads, in the form of the Vertical Concrete Barrier (VCB) and Higher Vertical Concrete Barrier (HVCB). This sector also contains lengths of Tensioned Corrugated Beam (TCB), Open Box Beam (OBB), and Wire Rope Safety Fence (WRSF). The M25 Sphere is currently maintained by Mouchel Parkman.



Figure 1: The Case Study Area – The M25 Sphere

The case study report supplied by Mouchel Parkman is attached as Annex B, and includes the initial work specification submitted by TRL Ltd.

The information provided within the case study considers the period from 1st January 2002 to 31st December 2002. It is the use of the data within this case study which will provide an insight into the different accident

severities resulting from impacts between vehicles and metal safety fences or concrete safety barriers (see Section 3.2.3).

2.2 Survey of Highways Agency Regional Agents and Barrier Manufacturer Representatives

2.2.1 Background

In addition to the extensive case study of the M25 Sphere, a letter was also distributed to all fourteen of the Highways Agency's regional Traffic Operations Departments, their Agents and their Term Maintenance Contractors. The letter was also sent to Britpave (representatives of UK concrete barrier manufacturers) and a similar letter sent to the Vehicle Restraint Manufacturers' Association - VRMA.

The letters were sent in 2000 and September 2003, and a sample copy is attached to this report as Annex C. The replies received varied in length and detail, and are documented in Annex D.

The more salient points from the replies are as follows:

2.2.2 Use of concrete barriers

- 'The use of concrete barrier for permanent installation on Highways Agency roads is limited'; HA Local Teams 1, 2, 3, 10.
- 'Over 100km of concrete barrier have been constructed in the UK'; Britpave.

2.2.3 Installation costs

- 'The SIAC [concrete barrier manufacturers] cost for installation, mobilisation, demobilisation and other fixed costs associated with a discrete site visit: £45 per m would be valid for any length greater than 1,000 metres, and only in the event of short lengths in isolation where fixed costs become disproportionate to the cost of the actual barrier, would a higher rate be required'; Britpave.

2.2.4 Average cost of repair

Source of Information	No. of repairs	Repair Cost (£)	Cost per repair (£)	Safety Fence Type	Stated Exclusions
HA Area 1	255 per annum	144,000 per annum	564.71	Metal	Traffic Management
HA Area 3	96 per month	124,000 per month	1,291.67	Metal (inc. WRSF)	Preliminary Attendance and Traffic Management
HA Area 8	-	-	1,600	-	-
HA Area 10	2577 in a 16½ month period	1,247,594.57 in a 16½ month period	484.13	Metal	-
			283.64	Single Sided TCB	
			301.68	Double Sided TCB	
			294.53	Single Sided OBB	
			326.46	Double Sided OBB	
			378.45	DROBB	

Table 1: Average cost of repair to safety fencing following an impact

2.2.5 Length of repairs

HA Local Agents within Area 3 reported that for the month of July 2003, there were 96 incidents resulting in damage to the median safety fence. Details of the lengths of repair were as follows:

Length of repair	Number of repairs	Percentage
Up to 10 metres	61	64
10 to 20 metres	17	18
20 to 30 metres	11	11
30 to 40 metres	2	2
40 to 50 metres	1	1
Over 50 metres	4	4
Total	96	100

Table 2: Length of repairs required to safety fencing following an impact

2.2.6 Logistics of repairs

- ‘Repairs are generally carried out within a 7 day period’; HA Local Teams 1, 8, 10.
- ‘The average time to effect the permanent repair from the time of the incident was 4.1 days’; HA Local Team 3.
- ‘Repairs are carried out at night’; HA Local Team 1, 3, 8, 10.
- ‘As term maintenance contractors for the area we install and remove numerous short duration TM schemes on the roads everyday. To meet the requirements of Chapter 8 all TM schemes require a number of signs to be erected in the C/R. To carry this out our operatives have to cross the live carriageway to the C/R and use the gap between the two lines of metal crash barrier as a safe haven. In areas of concrete barrier this safe haven does not usually exist and the operatives are left standing on the edge of the outside lane.’ HA Local Team 3.

2.2.7 Accident Frequency and Severity (metal safety fences only)

Source of Information	No. of injury accidents	Severity of Accidents			Percentage of Accidents (%)		
		Fatal	Serious	Slight	Fatal	Serious	Slight
HA Area 1	286 in 4 years	10	41	235	3.6	14.3	82.1
HA Area 10	558 in 5 years	12	65	481	2.2	11.6	86.2

Table 3: Accident frequency and severity of an impact with a metal safety fence

3 ACCIDENT ANALYSIS

3.1 Accident Data Collection

The data in this section are based on reports sent to the Department for Transport (DfT) by police forces following an accident in which the police have attended and human injury has occurred to one or more persons. The accident report form known as STATS19 is used for such purposes, and this is reproduced in Annex E. The current system of collecting road accident statistics was set up in 1968 [2]. Each year, officers of the 51 police forces in Great Britain complete some 240,000 STATS19 road accident reports. These forms are transferred to magnetic tape and are sent to the DfT at monthly intervals, where they are added to the annual master file.

The most recent accidents considered in this study took place in 2002, due to police reports generally only being released once a verdict has been reached in any court proceedings arising from the accident.

3.1.1 Definition of Accident Severity

Accidents are classed as fatal, serious or slight, depending on the severity of the most seriously injured casualty in the accident:

- *Fatal accident:* One in which at least one person is killed (but excluding confirmed suicides) within 30 days of the occurrence of the accident. [*Killed:* Human casualties who sustained injuries which caused death less than 30 days after the accident].
- *Serious accident:* One in which at least one person is seriously injured but no person (other than a confirmed suicide) is killed. [*Serious injury:* An injury for which a person is detained in hospital as an 'in-patient', or any of the following injuries whether or not they are detained in hospital; fractures, concussion, internal injuries, crushings, burns (excluding friction burns), severe cuts and lacerations, severe general shock requiring medical treatment, injuries causing death 30 or more days after the accident].
- *Slight accident:* One in which at least one person is slightly injured but no person (other than a confirmed suicide) is killed. [*Slight injury:* An injury of a minor character such as sprain, bruise or cut not judged to be severe, or slight shock requiring roadside attention. This definition includes injuries not requiring medical attention].
- Persons who are merely shaken and who have no other injury are not included, unless they receive or appear to need medical treatment.' [3]

3.1.2 Definition of vehicles referred to within this report

3.1.2.1 Cars

Within this study, the definition of a car currently adopted by the DfT (and hence used in the STATS19 reporting structure) has been used:

'Cars:

Small cars are typically between 140 and 150 inches in length, small/medium cars between 155 and 165 inches, medium cars between 170 and 180 inches and large cars over 180 inches.' [3]

3.1.2.2 Heavy Goods Vehicle (HGV)

Research has found that numerous definitions for an HGV exist. In this study, the definition adopted by the DfT (and hence used in the STATS19 reporting structure) has been used:

'Heavy goods vehicles (HGV):

- *Prior to 1994 these were defined as those vehicles over 1.524 tonnes unladen weight and included vehicles with six or more tyres, some four wheel vehicles with extra large bodies and larger rear tyres and tractor units travelling without their usual trailer.*
- *From 1 January 1994 the weight definition changed to those vehicles over 3.5 tonnes maximum permissible gross vehicle weight (gvw).'* [3]

Whilst this is an effective method for limiting the weight of an HGV, the variation in the weight of a vehicle defined as an HGV can be great (ranging from 4 to 38 tonnes in this study). The form of the vehicle can also differ considerably under the current definition of an HGV, from a delivery van to an articulated or rigid vehicle with six or more axles. Such differences can make it difficult to treat all vehicles defined as HGVs in the same manner. This in turn makes it difficult to estimate the effect of a vehicle defined as an 'HGV' impacting a safety fence or barrier.

3.1.2.3 Other Vehicles

Other vehicles are those which are neither defined as a car or an HGV, for example:

- Motorcycles;
- Minibuses, Buses and Coaches;
- Taxis;
- Agricultural Vehicles;
- Light Goods Vehicles (LGV) – Again, as defined by the DfT:
'Prior to 1994 these were defined as those vehicles not over 1.524 tonnes unladen weight. From 1 January 1994 the weight definition changed to those vehicles not over 3.5 tonnes maximum permissible gross vehicle weight. Light vans mainly include vehicles of the van type constructed on a car chassis.' [3]

Whilst it can be seen that the types and weights of vehicles within this category vary considerably, it is felt important to include such vehicles to provide the complete set of accidents occurring. The collection of such data will also allow for percentages and total accident/casualty figures to be calculated.

3.1.3 Searching on the STATS19 database

In order to assess which of the accidents reported through the STATS19 procedure involved a vehicle striking an object in the median and to extract those accidents in which the struck object was a median safety barrier, searches were made on the STATS19 records database. A search can be made for any combination of criteria relating to the information collected on the STATS19 report forms (see Annex E). For the purpose of this report, the following criteria were used between the years 1990 and 2002:

'Accidents on motorways and/or M(A) roads and/or A roads in Great Britain involving at least one vehicle either:

- (a) Impacting and crossing the median or;
- (b) Impacting and remaining either on, or close to the median or;
- (c) Impacting and rebounding from the median.'

The search was completed for accidents involving HGVs only, cars only and 'other vehicles' only. Hence a total of nine data sets were retrieved and analysed.

This search was then repeated but with the additional criterion that the first object struck was a median safety barrier. This then produced an additional nine data sets, and eighteen in total.

3.1.4 Under reporting in the STATS19 database

Whilst the STATS19 database provides information on reported accidents, many potentially reportable road accidents and casualties are not reported to the police and therefore, do not appear in the official annual statistics.

A report by Helen James [4] summarised five UK studies investigating under reporting. Police and hospital, accident and casualty records were compared, and the following Table was reported:

Vehicle occupant	Min-Max % Reported
Fatal	100
Serious	85 - 91
Slight	70 - 82
All injuries	75 - 86

Table 4: Percentage of injuries reported (estimated from hospital-based studies in Great Britain) [4]

In the report (dated 1991), the following observation was made:

'Legally [in Britain], only accidents in which a motor vehicle is involved causing injury to a person other than the driver, and in which exchange of addresses and insurance information has not occurred, must be reported to the police. Thus some accidents are not reported because they do not fall into these requirements, such as single-vehicle accidents where only the driver/rider was injured, or multi-vehicle accidents where names and addresses have been exchanged. Others are not reported because of ignorance of the legal obligation to report, perception that the accident was too trivial, or because the victim did not become aware of their injuries at the scene of the accident.' [4]

In addition, the report also states that:

'Perception of the severity of the injury or accident, and whether it was a road accident, also determined the level of reporting if this was not necessary or was not considered necessary. This meant that rates increased with injury severity and were higher for multi-vehicle compared with single vehicle accidents.' [4]

Whilst it might seem appropriate to adjust the datasets resulting from the STATS19 searches to account for the phenomenon of under reporting, it was decided that, due to the different sources of data being examined the data should remain unaltered to aid comparison.

3.1.5 Outputs from the STATS19 Search

The output of the STATS19 searches was two-fold:

1. A set of data relating to the severity of the *accident*;
2. A set of data relating to the severity of injuries sustained by the casualties involved in those accidents.

These data considered accidents in which one, or more vehicles impacted an object in the median, however it is only the initial contact vehicle which is considered. Subsequent impacts with the median in the same accident are disregarded as they will generally be less severe than the initial impact. Similarly casualties relating to subsequent impacts are also disregarded. This will cause some discrepancies between those data analysed within the previous phases of the project, and those within this third phase.

Both of these data sets are examined in detail in Sections 3.2.1 and 3.2.2, and tabulated in Annexes F to H.

3.2 Accident Data Analysis

Tables summarising the data collected from the STATS19 database can be found in Annexes F and H. These data have been used to provide the graphical representations in Annexes G and I.

As referred to in Section 3.1.3, eighteen data sets have been examined for the purpose of this report. They concern accidents involving a car, HGV or 'other vehicle', impacting an object the median (and in nine data sets, the specific case of a median safety barrier). The impacting vehicle then either crosses the median into the opposite carriageway, rebounds back into the original carriageway, or remains on, or close to the median. These vehicle trajectories are shown in Figure 2 below:

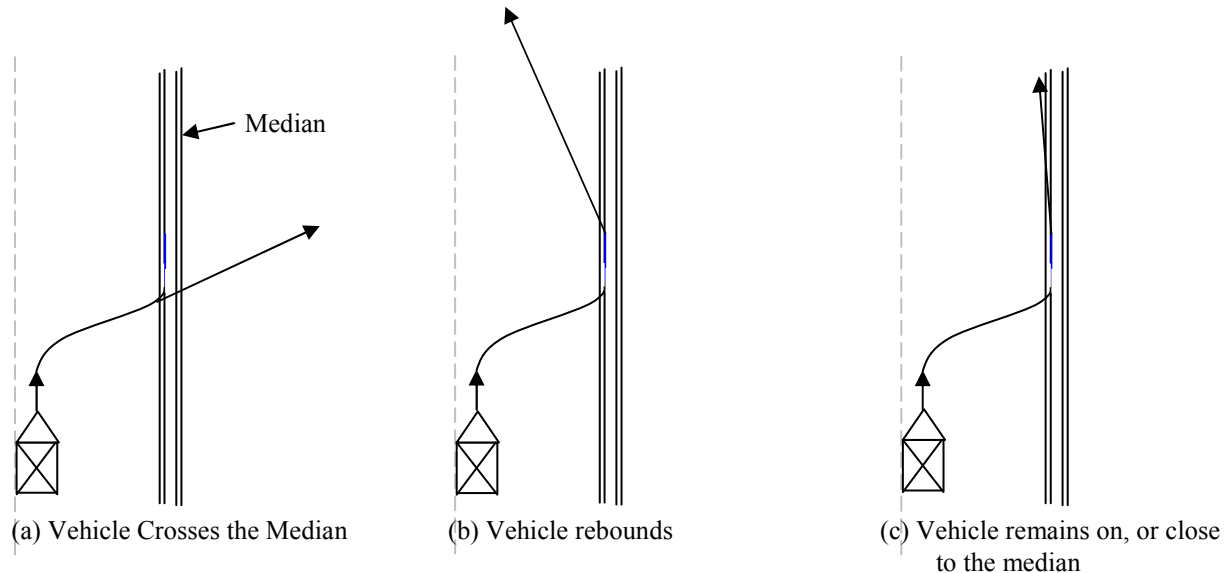


Figure 2: Vehicle trajectories examined within the STATS19 accident data

Accident and casualty data were acquired for the years between 1990 and 2002.

From these STATS19 searches, two distinct types of data have been provided, one relating to accidents, and the second pertaining to the injuries sustained by casualties involved within those accidents. Both data sets will be examined independently, and trends within the two sets compared and contrasted.

3.2.1 Analysis of Accident Statistics

3.2.1.1 Vehicle impacts an object in the median

Within the analysis period of 1990 to 2002, there were, on average:

- 2,179 fatal accidents (1.9%);
- 18,705 serious accidents (16.0%) and
- 96,222 slight accidents (82.2%)

per annum on major roads (motorways and A roads) within Great Britain (see Table F1). This equates to 117,106 accidents per year. These are reported accidents of all types, ranging from the HGV crossover accident on a busy motorway to a pedestrian being struck by a motorcycle on a quiet A road.

Of these 117,106 accidents, there were 2,900 accidents per annum in which an *object* was struck in the median of a major road. This constitutes 2.5% of all of the accidents occurring on the major roads of Great Britain, a small percentage. This object may have been a median safety barrier, lighting column, sign post and any other item of roadside furniture located within the median

Of this subset of 2,900 accidents:

- 91 (3.4%) were reported as being fatal accidents,
- 527 (19.5%) as serious accidents and
- 2282 (78.7%) as slight.

Further breakdown of the 2,900 accidents by their movement following the impact reveals that:

- 957 (33.0%) of the accidents involved a vehicle impacting an object in the median and rebounding;
- 414 (14.3%) of the accidents involved a vehicle impacting an object in the median and crossing over into the opposing carriageway;
- 1,529 (53.7%) of the accidents involved a vehicle impacting an object in the median and being retained on, or close to the median.

These data are tabulated within Table F2, and represented pictorially in Graph G2.

If each of the accident types is then further analysed by its severity, then the following characteristics are identified:

- (1) For accidents in which an object is struck in the median and the vehicle is *rebounded* (total – 957):
 - Those in which one or more casualties received *fatal* injuries: 25 (2.6%);
 - Those in which one or more casualties received *serious* injuries: 154 (16.1%);
 - Those in which one or more casualties received *slight* injuries: 778 (81.3%).
- (2) For accidents in which an object is struck in the median, and the vehicle *crosses through* the median (total – 414):
 - Those in which one or more casualties received *fatal* injuries: 29 (7.0%);
 - Those in which one or more casualties received *serious* injuries: 105 (25.4%);
 - Those in which one or more casualties received *slight* injuries: 280 (67.6%).
- (3) For accidents in which an object is struck in the median, and the vehicle is *retained* in the close vicinity of the median (total – 1,529):
 - Those in which one or more casualties received *fatal* injuries: 37 (2.4%);
 - Those in which one or more casualties received *serious* injuries: 268 (17.5%);
 - Those in which one or more casualties received *slight* injuries: 1,224 (80.1%).

These data are tabulated within Table F2, and represented pictorially in Graphs G3, G4 and G5.

These data show that a cross over accident is less probable than one in which the vehicle is rebounded or retained. However when such a crossover accident does occur, it is almost three times as more likely that a fatal injury will result.

If one compares the accidents in which the vehicle is either rebounded or retained in the median, there is little difference between the two data sets in terms of severity, although it is more probable that a vehicle will be retained close to the median than rebounded. This is unsurprising as current testing requirements specify that for the satisfactory performance of a safety barrier, the test vehicle should remain close to the barrier following an impact, and within the ‘CEN box’.

3.2.1.2 Vehicle impacts a median safety barrier

Within the accident statistics reported above, the object struck may have been a median safety barrier, lighting columns, sign post and any other item of roadside furniture located within the median. This section now examines those accidents in which the object struck was defined by the reporting police officer as a median safety barrier.

Of the 117,106 accidents occurring on major roads within Great Britain per annum, 1,449 involved a vehicle striking a *safety barrier* in the median. This constitutes 1.2% of the total number of accidents, and 50.0% of the accidents in which an object was struck in the median.

Of this subset of 1,449 accidents:

- 34 (2.3%) were reported as being fatal accidents,
- 216 (14.9%) as serious accidents and
- 1199 (82.7%) as slight.

Further breakdown of the 1,449 accidents reveals that:

- 671 (46.3%) of the accidents involved a vehicle impacting a median safety barrier and *rebounding*;
- 82 (5.7%) of the accidents involved a vehicle impacting a median safety barrier and *crossing through* into the opposing carriageway;
- 696 (48.0%) of the accidents involved a vehicle impacting a median safety barrier and being *retained* on, or close to the median.

These data are tabulated within Table F3, and represented pictorially in Graph G6.

It should be noted that these data do not specify the type of safety barrier installed at the accident site (i.e. the containment level and material of the barrier are unknown). It should therefore be emphasised that Britpave state that, to the best of their knowledge, no concrete barriers in the UK has been breached. Hence those accidents within the STAS19 database termed 'vehicle crossed the median' will involve an impact with a steel safety fence, and not a concrete barrier.

If each of the accident types is then further analysed by its severity, the following characteristics are identified:

- (1) For accidents in which a median safety barrier is struck, and the vehicle is *rebounded* (total – 671):
 - Those in which one or more casualties received *fatal* injuries: 15 (2.2%);
 - Those in which one or more casualties received *serious* injuries: 97 (14.5%);
 - Those in which one or more casualties received *slight* injuries: 559 (83.3%).
- (2) For accidents in which a median safety barrier is struck, *and the vehicle crosses through* the median (total – 82):
 - Those in which one or more casualties received *fatal* injuries: 6 (7.3%);
 - Those in which one or more casualties received *serious* injuries: 20 (24.0%);
 - Those in which one or more casualties received *slight* injuries: 56 (68.6%).
- (3) For accidents in which a median safety barrier is struck, and the vehicle is *retained* in the close vicinity of the median (total – 696):
 - Those in which one or more casualties received *fatal* injuries: 13 (1.8%);
 - Those in which one or more casualties received *serious* injuries: 99 (14.3%);
 - Those in which one or more casualties received *slight* injuries: 584 (83.9%).

These data are tabulated within Table F3, and represented pictorially in Graphs G7, G8 and G9.

The data show very similar trends to those seen for accidents in which any object is struck in the median, i.e. whilst the crossover accident is less probable than the other accident types, the resulting casualties are more severe. These data also indicate that both the number and severity of accidents involving a vehicle remaining close to the median barrier or rebounding from it, are very comparable.

Further analysis of the accident data, by the vehicle type, shows that within the 2,900 median barrier accidents occurring each year:

- A car was the errant vehicle in 1,195 cases (82.5%);
- An HGV was involved in 92 accidents (6.4%);
- Other vehicles constituted 161 incidents (11.1%).

These figures must be put into context however, by examining the density of each vehicle type on major roads during the period of the reported accidents. For instance, whilst there are more accidents involving cars, it should be observed that on these roads there is a greater percentage of such vehicles on the road, hence increasing the probability of an accident involving such a vehicle. The data in Table F4 shows that on average, cars constitute 79.4% of the vehicular traffic, HGVs 8.3% and 'other vehicles' 12.2%. This indicates that although there are more accidents involving cars, it is those involving HGVs and other vehicles which constitute a greater percentage of the accidents than their density on the roads.

Table F5, and Graphs G10, G11 and G12 demonstrate that within these vehicle categories, the severity of the accident can be related to the action of the vehicle at the time of the incident. Hence the STAS19 data show that:

- When a car impacts a median safety barrier it is more probable that it will be contained, rather than breach it;
- If the impacting vehicle is an HGV, it is more probable that the vehicle will be retained close to the barrier. It is equally probable that an HGV will cross through a median barrier, than be rebounded by it;
- For accidents involving other vehicles, it is most probable that the vehicle will remain close to the median barrier after impact;
- For impacts by any of the vehicle types, it is more probable that a crossover accident will result in fatal injuries;
- For impacts by cars and HGVs, the highest percentage of serious injuries also results from crossover accidents. The highest number of slight accidents results from those in which the vehicle remains close to the median barrier;
- For impacts by ‘other vehicles’, the highest percentage of serious accidents comes from those in which the vehicle is retained close to the median barrier. Slight accidents are more prevalent with the crossover accident;
- In all accidents, independent of vehicle type or motion after impacting a median safety barrier, as the severity of the accident increases, the number of accidents decreases.

A similar data set for accidents in which any object within the median has been struck is included as Table F6. These data show the same trends as those highlighted above.

An analysis of casualty numbers is given in Section 3.2.2, however it is deemed appropriate to analyse the number of casualties per accident arising from each of the different accident types at this stage. The number of casualties per accident in which an *object* was struck in the median is given in Tables F7 and F8. Similar data are given for accidents in which a median *safety barrier* was struck in Tables F9 and F10.

These data show that the number of casualties per accident is greatest when an ‘other vehicle’ is involved and least when an HGV is involved. This can be explained by the general number of occupants in each vehicle. Whilst the ‘other vehicle’ category incorporates single occupant vehicles such as motorcycles, other more occupant intensive vehicles, such as minibuses, coaches and buses are also incorporated, thus increasing the total number of occupants at the scene of the accident. This in turn will increase the probability that one or more of these persons will become injured. The inverse is also true of the HGV accidents. The number of occupants of an HGV will generally be low when compared of that in a car, bus, coach, etc. and hence the number of casualties per HGV accident is reduced.

It should be noted however that in both accidents with an *object* or with a median *safety barrier*, the highest number of casualties per accident result from crossover accidents, the lowest being those in which the vehicle remains on, or close to, the median. This can be explained by the mechanisms of the different types of accident and the associated risks. These factors are examined Section 5.

3.2.2 Analysis of Casualty Statistics

3.2.2.1 Vehicle impacts an object in the median

A similar analysis to that completed on the accident statistical data shall now be applied to the casualty data. This is to provide a comparison between the two data sets and the highlight similar (and if appropriate) differing trends between the data sets.

Within the analysis period of 1990 to 2002, there were, on average:

- 2,434 fatal casualties arising from the 2,179 fatal accidents;
- 22,974 serious injuries within 18,705 serious accidents and
- 138,908 slight injuries from 96,222 slight accidents

per annum on major roads (motorways and A roads) within Great Britain (see Table H1). This equates to 164,136 casualties per year.

Of these 164,136 casualties, 4,071 resulted from an accident in which an *object* was struck in the median. This constitutes 2.5% of all of the casualties occurring on major roads in Great Britain, a small percentage.

Of this subset of 4,071 casualties,

- 107 (2.6%) were reported as being fatal,
- 676 (16.6%) as serious and
- 3,290 (80.8%) as slight.

Further breakdown of these 4,071 casualties reveals that:

- 1,360 (33.4%) of the casualties resulted from an accident involving a vehicle impacting an object in the median and rebounding;
- 602 (14.8%) of the casualties resulted from an accident involving a vehicle impacting an object in the median and crossing over into the opposing carriageway;
- 2,109 (51.8%) of the casualties resulted from an accident involving a vehicle impacting an object in the median and being retained on, or close to the median.

These data are tabulated within Table H2, and represented pictorially in Graph I2.

When each of the casualties is then further analysed by its severity, the following characteristics are identified:

- (1) For casualties arising from accidents in which an object is struck in the median and the vehicle is *rebounded* (total – 1,360):
 - Number of casualties receiving *fatal* injuries: 29 (2.1%);
 - Number of casualties receiving *serious* injuries: 201 (14.8%);
 - Number of casualties receiving *slight* injuries: 1,130 (83.1%).
- (2) For accidents in which an object is struck in the median, *and the vehicle crosses through* the median (total – 602):
 - Number of casualties receiving *fatal* injuries: 36 (6.0%);
 - Number of casualties receiving *serious* injuries: 144 (23.9%);
 - Number of casualties receiving *slight* injuries: 423 (70.3%).
- (3) For accidents in which an object is struck in the median, and the vehicle is *retained* in the close vicinity of the median (total – 2,109):
 - Number of casualties receiving *fatal* injuries: 42 (2.0%);
 - Number of casualties receiving *serious* injuries: 331 (15.7%);
 - Number of casualties receiving *slight* injuries: 1,737 (82.4%).

These data are tabulated within Table H2, and represented pictorially in Graphs I3, I4 and I5.

As with the data concerning accidents, the casualty statistics also indicate that a cross over accident is less numerous than one in which the vehicle is rebounded or retained. However when such a crossover accident does occur, it is almost three times as more likely that a fatal injury will result.

Again, as with the accident data, these casualty statistics also show that if one compares the accidents in which the vehicle is either rebounded or retained in the median, there is little difference between the two data sets in terms of severity, although it is more probable that a vehicle will be retained close to the median than rebounded.

3.2.2.2 Vehicle impacts a median safety barrier

Within the casualty statistics reported in Section 3.2.2.1, the object struck may have been a median safety barrier, lighting columns, sign post and any other item of roadside furniture located within the median. This section now examines those accidents in which the object struck was defined by the reporting police officer as a median safety barrier.

Of the 164,316 casualties resulting from accidents on major roads within Great Britain, 2,019 involved a vehicle striking a *safety barrier* in the median. This constitutes 1.2% of the total number of casualties, and 49.6% of the accidents in which an object was struck in the median.

Of this subset of 2,019 casualties,

- 38 (1.9%) were reported as being fatal,
- 274 (13.6%) as serious and
- 1,706 (84.5%) as slight.

Further breakdown of these 2,019 casualties reveals that:

- 947 (46.9%) of the casualties resulted from accidents in which a vehicle impacted a median safety barrier and *rebounded*;
- 120 (5.9%) of the casualties resulted from accidents in which a vehicle impacted a median safety barrier and *crossing through* the median and into the opposing carriageway;
- 952 (47.2%) of the casualties resulted from accidents in which a vehicle impacted a median safety barrier and being *retained* on, or close to the median.

These data are tabulated within Table H3, and represented pictorially in Graph I6.

If each of the accident types is then further analysed by its severity, then the following characteristics are identified:

- (1) For accidents in which a median safety barrier is struck, and the vehicle is *rebounded* (total – 947):
 - Number of casualties receiving *fatal* injuries: 16 (1.7%);
 - Number of casualties receiving *serious* injuries: 124 (13.1%);
 - Number of casualties receiving *slight* injuries: 807 (85.2%).
- (2) For accidents in which a median safety barrier is struck, and the vehicle *crosses through* the median (total – 120):
 - Number of casualties receiving *fatal* injuries: 7 (7.3%);
 - Number of casualties receiving *serious* injuries: 27 (22.5%);
 - Number of casualties receiving *slight* injuries: 86 (71.7%).
- (3) For accidents in which a median safety barrier is struck, and the vehicle is *retained* in the close vicinity of the median (total – 952):
 - Number of casualties receiving *fatal* injuries: 15 (1.6%);
 - Number of casualties receiving *serious* injuries: 123 (12.9%);
 - Number of casualties receiving *slight* injuries: 813 (85.4%).

These data are tabulated within Table H3, and represented pictorially in Graphs I7, I8 and I9.

The data collected can be further analysed by the vehicles in which the casualties were located, this being a car, an HGV or an ‘other vehicle’. This shows that of the 2,019 casualties resulting from an impact with a median safety barrier:

- A car was the errant vehicle causing 1,670 casualties (82.8%);
- An HGV caused 108 casualties (5.3%);
- Other vehicles constituting 240 casualties (11.9%).

As referenced in Section 3.2.1.2, these figures can be put into context by examining the density of vehicles on such roads during the period of such accidents. These show that on average, cars constitute 79.4% of the vehicular traffic, HGVs 8.3% and ‘other vehicles’ 12.2%. Unlike the accident data, this shows that casualties in cars have a greater density than their traffic statistics on the road.

Table H4, and Graphs I10, I11 and I12 demonstrate that within these vehicle categories, the severity of injuries to the casualties can be surmised and related to the action of the vehicle at the time of the incident.

A similar data set for accidents in which any object within the median has been struck is included as Table H5. These data show the **same trends** as those highlighted above for the impacts in which a median safety barrier is struck, **with the following exceptions**:

- For impacts with ‘other vehicles’, it is more probable that a rebound accident will result in fatal injuries;
- For impacts with cars and HGVs, the highest percentage of slight accidents results from those in which the vehicle remains close to the median barrier or is rebounded as these results are close;

- For impacts with ‘other vehicles’, the highest percentage of serious accidents comes from those in which the vehicle is retained, either close to or rebounded from the median barrier. Slight accidents are more prevalent with the crossover accident;
- In all accidents, independent of vehicle type or motion after impacting a median safety barrier, as the severity of the accident increases, the number of accidents decreases

Both of the data sets in Tables H4 and H5 display the same trends as seen in the accident data, analysed in Section 3.2.1.2.

Note that an analysis of the number of casualties injured per accidents is given within Section 3.2.1.2, and hence this exercise is not repeated.

3.2.3 Accident Statistics – The Mouchel Parkman M25 Sphere Case Study

In addition to the statistics for Great Britain provided by the STATS19 database, similar accident and casualty data have been obtained for those accidents occurring within the M25 Sphere Case Study area. These are presented within the case study prepared by Mouchel Parkman (see Annex B) and within Annex J.

The main difference between these data and those presented within STATS19 is that the accident data from the Mouchel Parkman case study define the type of safety barrier (either concrete or steel) impacted during the accident.

Table J1 and Graph J1 show the number of reported *accidents* with median safety barriers within the case study area. The number of *casualties* resulting from these accidents, by severity, is given in Table J2 and Graph J2. Subsequently, the number of casualties per accident is given for the concrete and steel median safety barriers in Table J3.

When the number of accidents and casualties are examined it should be recalled that there are greater lengths of steel median safety barrier than concrete. Hence it is important to remove this biasing of the data by calculating the number of accidents and casualties per metre of median barrier installed, see Table J4. These length data have been provided by Britpave as those reported in the Mouchel report include both verge and median safety barriers.

Firstly, it can be seen from the casualty statistics (Table J2) that the relative percentage of fatal, serious and slight casualties, reflects that seen within the STATS19 data set for Great Britain (Table H3). The data provided by Mouchel Parkman does not detail the movement of the vehicle following the impact with the median safety barrier, and hence detailed comparisons cannot be made.

The number of casualties per accident figures seen within the M25 data (Table J3) also reflects the trends seen in the Great Britain data (Table F8). For metal systems, a casualty per accident value of 1.45 is obtained, and this is within the range of values for accidents involving cars and ‘other vehicles’ in the larger data set. The casualty per accident figure of 1.70 for concrete systems is greater than any of those seen in the Great Britain data. However this is not surprising as the STATS19 data will be dominated by those accidents and casualties resulting from impacts with metal systems due to the relatively low length of median concrete safety barrier installed.

When one examines the figures for the number of casualties and accidents per metre of safety barrier installed (Table J4) it can be seen that:

1. Of the 373 km of median safety barrier installed within the M25 Sphere,
 - Metal safety fences (including wire rope safety fencing) constitute 87.3% of the total length,
 - Concrete safety barriers contribute 12.7%.
2. No fatal casualties have resulted from an impact with a concrete barrier;
3. The number of serious casualties per kilometre is comparable between steel safety fencing and concrete safety barriers;
4. Concrete barriers result in a lower rate of slight casualties and total accidents per kilometre than metal safety fences.

However, it should be noted that some of the sections of the M25 in which concrete barriers are installed are subject to both high traffic volumes and variable (reduced) speed limits, making them some of the slowest sections of motorway in the UK. This may, in turn, reduce the speed, and hence severity of, accidents with concrete safety barriers seen in the Mouchel Parkman case study.

4 ACCIDENT SEVERITY

Full-scale impact testing of safety barriers has been carried out in the UK for over forty years. Such testing has allowed researchers to understand the interaction between vehicles and safety barriers, and to rank the resulting injuries to a theoretical occupant situated within the vehicle. This ranking procedure is achieved through the use of severity indices.

Historically, studies have been carried out to try to correlate these severity indices with ‘real life’ injuries; however no link, to date, has been found. There are currently two programmes of research work being undertaken within Europe which aim to examine this phenomenon, and these being the RISER and ROBUST projects. Their aim is to analyse the injuries resulting from real-life accidents and to try and correlate them to the severity injuries recorded during full-scale impact testing. Within the ROBUST work programme a series of twenty full-scale impact tests are incorporated, with some of the vehicles being fitted with an instrumented dummy. Unfortunately, the results from this work will not be publicised for a number of years.

Within the European domain, three severity index criteria are used to rank the severity of an impact.

4.1 Acceleration Severity Index (ASI)

The acceleration severity index ASI is intended to give a measure of the severity of the vehicle motion for a person seated in the proximity of a point P during an impact.

The index is a function of time, computed using the following equation:

$$ASI(t) = [(\bar{a}_x/\hat{a}_x)^2 + (\bar{a}_y/\hat{a}_y)^2 + (\bar{a}_z/\hat{a}_z)^2]^{1/2} \quad [5]$$

where:

\hat{a}_x , \hat{a}_y and \hat{a}_z are limit values for the components of the acceleration along the body axes x, y and z, with values of 12g, 9g and 10g respectively, and g is the reference for acceleration (9.81 ms^{-2}); \bar{a}_x , \bar{a}_y and \bar{a}_z are the components of the acceleration of a selected point P of the vehicle, averaged over a moving time interval $\delta=50\text{ms}$, so that:

$$\bar{a}_x = \frac{1}{\delta} \int_t^{t+\delta} a_x dt; \quad [5]$$

$$\bar{a}_y = \frac{1}{\delta} \int_t^{t+\delta} a_y dt; \quad [5]$$

$$\bar{a}_z = \frac{1}{\delta} \int_t^{t+\delta} a_z dt. \quad [5]$$

4.2 Theoretical Head Impact Velocity (THIV)

The theoretical head impact velocity (THIV) concept has been developed for assessing occupant impact severity for vehicles involved in collisions with road safety barriers. The occupant is represented by a free moving, unrestrained object (head) that, as the vehicle changes its speed and direction during contact with the safety barrier, continues moving in its original direction until it strikes a surface within the interior of the vehicle. The magnitude of the velocity of the theoretical head impact is considered to be a measure of the vehicle to safety barrier impact severity.

4.3 Post-Impact Head Deceleration (PHD)

After its initial impact, the unrestrained head used within the THIV procedure is assumed to remain in contact with the struck surface during the remainder of the impact period. In so doing it experiences the same levels of acceleration as the vehicle during the remaining contact period and this is known as the Post-Impact Head Deceleration (PHD).

4.4 A Comparison of Severity Indices for Normal and Very High Containment Safety barriers

During the numerous tests completed on safety barriers it has become evident that there is no ‘average’ value for safety barriers of a particular containment level. However in general terms, rigid safety barriers with a lower deflection on impact will have higher severity index values when impacted under the same conditions. This is due to the deflection of the system providing a more gradual deceleration of the vehicle, and hence a less severe impact. Hence, it is reasonable to expect (and it has been seen during testing) that a flexible system with a larger deflection, such as a wire rope safety fence, will have lower severity index values than a rigid concrete parapet.

In general, those safety barriers with a containment level greater than ‘normal’ will deflect less than a normal containment safety barrier when impacted with the small (900kg) vehicle as their rigidity enables them to contain heavier vehicles. Hence it follows that the severity indices for barriers with a ‘high’ or ‘very high’ containment level will be more onerous than those of a normal containment. However it is emphasised that this does not mean that such rigid systems are not ‘safe’. The severity index system is merely a ranking system for products, and no correlation has yet been established to link the severity indices with real life injuries.

Safety barriers with a greater level of containment are less likely to be breached. In the case of median barriers this may, in turn, reduce the number of fatalities occurring on the opposite carriageway. However, if the barriers are of a higher and solid construction, a driver’s visibility of activity on the opposite carriageway will be diminished.

Due to the rigidity of these high or very high containment barriers, it has been seen (through full-scale testing) that there is a general tendency for some vehicles with a higher centre of gravity (such as HGVs) to roll over the barriers if they are not of sufficient height. If such actions were translated onto the highway, this could cause severe problems for vehicles on the opposite carriageway, especially if the HGV were to be transporting a dangerous cargo. Whilst it is preferable for a vehicle to traverse the median on its wheels rather than on its side (as the vehicle is more controllable on its wheels), a greater level of impact energy is required to roll an HGV than for it to breach a deformable safety fence.

Within the M25 Sphere case study area there are two distinct genre of safety barrier installed in the median; metal systems (such as TCB, OBB, wire rope safety fencing and DROBB), and concrete systems (such as VCB and HVCB). Each of these, with the exception of DROBB and HVCB has a designated performance class of ‘normal containment’. Due to testing having been carried out with heavier vehicles, DROBB and HVCB are classified as being ‘higher’ and ‘very high’ containment respectively. These containment levels are detailed below:

Containment Level		Acceptance Tests	Impact Weight (kg)	Impact Speed (kph)	Impact Angle (degrees)	Impacting Vehicle
Normal	N1	TB31	1,500	80	20	Car
	N2	TB32 + TB11	1,500	110	20	Car
Higher	H1	TB42 + TB11	10,000	70	15	Rigid HGV
	H2	TB51 + TB11	13,000	70	20	Bus
	H3	TB61 + TB11	16,000	80	20	Rigid HGV
Very High	H4a	TB71 + TB11	30,000	65	20	Rigid HGV
	H4b	TB81 + TB11	38,000	65	20	Articulated HGV

Note: TB11 test conditions: 900kg, 100kph, 20 degrees, Car.

Table 5: Vehicle Impact Test Criteria [5]

Unfortunately, whilst accident data and injury severity data are recorded by safety barrier genre in the M25 case study, the actual design of the system (such as TCB, OBB etc.) is unknown. Hence no data exists to enable the determination of the severity of injuries resulting from an impact with a higher or very high containment safety barrier installed on the UK Highway. Similarly, these data are unavailable for the normal containment systems.

The only way in which such data could be obtained would be through the analysis of police reports into the accident. In general, these are only prepared in detail for fatal accidents and this would be a very extensive task. Hence the STATS19 data cannot provide information relating to the severity of impact between a vehicle and a safety barrier of a particular containment level.

5 RISK

5.1 Maintenance, accident repairs and replacement of metal and concrete barriers.

There are a number of instances during the whole life of a median barrier when attention will be required from road operatives:

- Initial installation;
- Routine Maintenance;
- Repair (following an impact);
- Removal (at the end of the barrier's life).

During each of these stages, trained operatives may be required to operate on the median barrier during periods in which the roads around them will be trafficked. Although signing, temporary barriers and additional traffic management provisions will be taken to warn road users of the on-coming works, the risk that an operative will be injured is still one which must be considered and quantified.

While assessing this risk, it is important to note a comment from one of the Highways Agency's Local Area 3 Agents (see Annex D) who stated that:

'As term maintenance contractors for the area we install and remove numerous short duration TM schemes on the roads everyday. To meet the requirements of Chapter 8 all TM schemes require a number of signs to be erected in the C/R. To carry this out our operatives have to cross the live carriageway to the C/R and use the gap between the two lines of metal crash barrier as a safe haven. In areas of concrete barrier this safe haven does not usually exist and the operatives are left standing on the edge of the outside lane.

As I am sure you are aware the high-speed roads to which this applies are already a high risk place of work and we believe the use of concrete barriers would significantly increase these risks still further. We trust this will be taken into consideration during your analysis.'

However, one should recall that due to the reduced number of repairs and routine maintenance required for concrete systems (as shown in the Mouchel Parkman case study), the probability of an operator being on-site is significantly reduced.

5.2 Risks Associated with different levels of median containment

As well as risks to those conducting works on the Highway, risks to the travelling public must also be considered.

There are five scenarios in which a vehicle can interact with the median (and/or roadside furniture installed in the median) when it leaves the carriageway on the offside if no counter action is taken by the driver of an errant vehicle:

1. No roadside furniture installed, and the vehicle crosses the median into the opposing carriageway;
2. Roadside furniture installed, the vehicle does not strike the roadside furniture, and crosses the median into the opposing carriageway;
3. Roadside furniture installed, the vehicle strikes the roadside furniture, but still crosses the median into the opposing carriageway;
4. Roadside furniture installed, the vehicle strikes the roadside furniture, and is redirected back into the original carriageway;
5. Roadside furniture installed, the vehicle strikes the roadside furniture and is retained at, or close to, the median.

It should be noted that in addition to safety barriers, the term roadside furniture equally applies to lighting columns, matrix signals, sign posts, bridge piers etc.

The following Table assesses the levels of Risk associated with each of these scenarios, and estimates the effect of altering the containment level of the median barrier. The same number of accidents is assumed in each case. An explanation of some of the thought processes used is contained in the text following the Table.

Accident Type	Severity of impact between errant vehicle and barrier	Level of Risk to those on the same carriageway	Level of Risk to those on the opposite carriageway
1	N/A	Low	High
2	N/A	Low	High
3	Medium	Low	High/Medium
4	Medium/High	Medium	Low
5	High	Medium	Low

Table 6: Level of risk associated with Median Barrier Impacts

If the level of median barrier containment were to be increased, then it is probable that accidents of type 1, 2, and 3 would reduce, whilst those of types 4 and 5 would increase.

The levels of risk were estimated through consideration of the following contributory factors:

Reaction times – The drivers of vehicles on the same carriageway as the errant vehicle will have a longer time to react to the movement of the errant vehicle as they will be able to see it ahead of them and react accordingly (either by changing direction, braking and/or engaging hazard warning lights on their vehicle to warn following drivers). Vehicles impacting with each other will also be travelling in the same direction; hence the transfer of momentum from one vehicle to another will be gradual.

In the case of a crossover accident, it is likely that the drivers of vehicles on the opposite carriageway will have much less time to react to the movement of the errant vehicle and, due to the differing directions in travel, the transfer of momentum will be greater (hence a high risk level).

Impact conditions – As has been seen through the application of full-scale testing, the impact speed and angle, and the type and model of vehicle can effect the interaction between a safety barrier and a vehicle. For example, the higher centre of gravity of an HGV will make it more probable that it will roll-over the top of a barrier if it is low and rigid, whilst its weight and speed will give it enough energy to breach a safety barrier of normal containment. In addition, the faster the impact speed, and greater the impact angle, the higher the impacting energy and hence, the higher the level of containment required to contain the vehicle.

The level of risk to those involved in the accident will also depend on the compatibility between the vehicle in which they are travelling, and others participating in the accident. For example, a car being struck by an errant HGV will provide a greater level of risk to the car driver. If the same car driver were to be struck by a motorcycle, then the greater level of risk would befall the motorcyclist.

Deceleration of vehicle – The injuries sustained by vehicle occupants during an impact will be greatly determined by the magnitude and direction of vehicle deceleration. Whilst safety systems within the vehicles, such as airbags and seat belts pre-tensioning devices, may reduce the levels of deceleration within a vehicle, they may not be sufficient to eradicate injuries within an accident. In some instances, due to the oblique angle of impact associated with safety barrier accidents, some of these safety devices may not be triggered by the impact. Whilst it is thought that the threshold levels for impact severity assessed by indices such as THIV, ASI and PHD are survivable, the levels to which these relate to injuries in ‘real-world’ accidents is unknown. Never the less it is reasonable to assume that the lower the index, the lower the potential injury.

There are a number of additional factors which will have an effect on the risk levels associated with an accident. These are outlined below:

Traffic Flow – As detailed in a later example (in Figure 3), there may be some instances when one type of accident may result in fewer casualties than another due to traffic flow. For example, if the carriageway on which an errant vehicle is travelling has heavy traffic, and the opposite carriageway has no traffic, a crossover accident may result in fewer casualties than one in which the vehicle were contained and redirected. However, if the errant vehicle is alone on the carriageway, and the opposite carriageway is carrying heavy traffic, the inverse would apply.

Visibility – Lighting and weather conditions are two additional factors which may affect the risks associated with impacts with a median safety barrier. If other road users cannot see either that there is an errant vehicle ahead and/or that a vehicle may encroach into their travelling path, appropriate avoiding actions will not be taken, or be taken too late. This has the effect of reducing the reaction time available to take avoiding actions. Whilst weather and lighting conditions are not examined in specific detail within this report, they are important factors to recall when examining accident statistics.

Whilst the Risk levels outlined in Table 6 take into account many of the contributory factors mentioned above, they do not consider the severity statistics seen in Section 3.2.2. To summarise, these showed that accidents in which a vehicle crosses through the median safety barrier result in over three times as many fatal casualties than those accidents in which a vehicle is contained and redirected, or retained close to the median. Accidents in which a vehicle retained close to the median occur more frequently than those in which the vehicle is rebounded, although the severity of the accidents is similar.

5.3 Containment and Traffic Conditions

Consideration should be given to the possibility that the selection of one type of vehicle containment level over another could, in some circumstances, increase the risk to road users. A hypothetical example of such a situation is given below:

Figure 3 shows a simple, single HGV scenario. The HGV is travelling along the carriageway with roadworks ahead. As a result of the roadworks, traffic ahead has slowed on the carriageway and congestion is developing. The driver of the HGV has not anticipated this, and hence brakes sharply, and swerves to the offside to avoid the queuing traffic. The HGV strikes a very high containment safety fence or barrier in the median and is contained and redirected in accordance with CEN validation tests [5]. The HGV is however, redirected towards the queuing traffic, increasing the probability of impact with other vehicles and hence, of casualties. The traffic on the opposite carriageway was light and free moving at the time of the accident. Therefore the number of casualties may have been lower had the HGV been allowed to cross the median and enter the opposite carriageway, as other drivers may have had enough time to recognise and assess the danger, and take appropriate avoidance action.

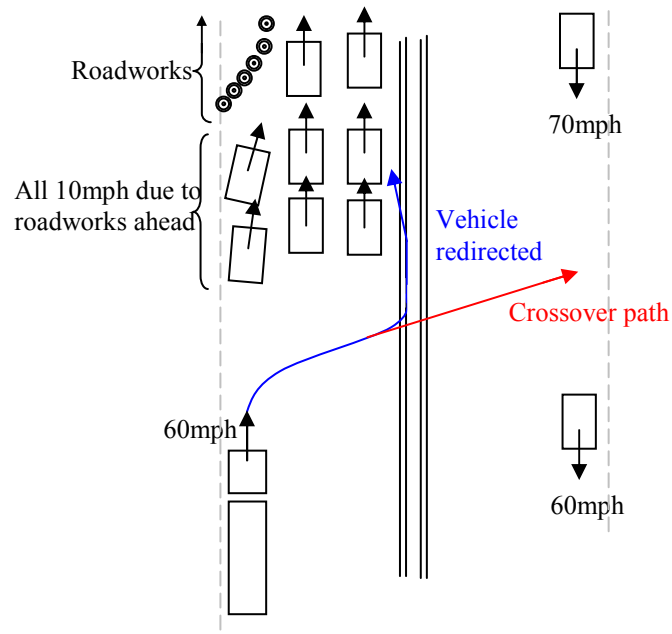


Figure 3: Hypothetical Example of a Single HGV Crossover Scenario where allowing a crossover may reduce the probability of casualties

To help in the avoidance of this hypothetical example, it is reasonable to expect that warning signs would have been placed sufficiently in front of the roadworks to warn the HGV driver of the roadworks ahead. However for this example, it is assumed that either the HGV driver has chosen to disregard these signs, or that the traffic congestion is sufficiently long in length that the road signs have not yet begun, or that the driver has been distracted.

6 ACCESS THROUGH MEDIAN BARRIERS

During the whole life of a median safety barrier, there may be occasions when legitimate access through the barrier is required. For example, if an incident were to occur between two Junctions of a motorway and the road is impassable, it may be necessary for the emergency services to initiate the deconstruction of the median barrier to enable vehicles to U-turn across the median, and exit the road at the previous junction, speeding up the clearance time for the accident, and reducing delays to other road users. Additionally, the emergency services may require access through the median barrier in order to reach an accident and provide medical assistance.

Whilst this action can be quite speedily effected with a metal safety fence, where concrete barriers exist, the use of removable/movable/demountable sections of barrier would be necessary, or a detour around the barrier would be required.

An alternative solution to this would be the use of maintenance crossing points, i.e. designated gaps in the safety barrier to allow. However current Highways Agency requirements state that:

'Maintenance Crossing Points

4.30 To facilitate contra-flow traffic flows during Maintenance Renewal Schemes, it may be necessary to establish Maintenance Crossing Points (MCPs) across the central reserve and thereby create gaps in the safety barrier. The length of an MCP can be in excess of 100m and the end terminations of the existing safety barrier installation, at any such gap, must satisfy the Performance Class requirements detailed in Chapter 8 of this IRRRS

4.31 On completion of the works, any MCP gap(s) must be closed by re-installing the original safety barrier(s) or a replacement system of an equivalent Performance Class and Working Width to that which was taken down to enable the MCP to be constructed. Any 'above ground' elements of the temporary end termination(s) of the safety barrier shall be removed.' [6]

This policy results from a number of serious accidents at such points in the road infrastructure. Due to this, the inclusion of such crossing points is not encouraged and consultation should be undertaken at the design stage with the Emergency Services.

As a result, consideration should be given to accessibility considerations when deciding upon which design of median barrier to install.

7 THE WHOLE LIFE COSTING OF STEEL AND CONCRETE BARRIERS

7.1 Whole Life Costing – Introduction

It is widely believed that the initial installation costs associated with higher containment and, in particular, concrete safety barrier are greater than those for their steel counterparts. However, it is equally understood, and publicised that the maintenance and other whole life costs associated with such barriers are generally lower. However, the whole life costs associated with metal and concrete median barriers have not, to the author's current knowledge, been compared. The aim of this section of the report is to combine the findings from the accident statistics given within Section 3.2 of this report with those from Mouchel Parkman's case study report of the M25 Sphere.

Whilst any discussion to alter the containment level of median safety barriers should not rely exclusively on monetary concerns, they will have a part to play in such decisions.

Additional factors such as traffic delay and disruption costs are also incorporated into the whole life cost study, as these will be factors which require consideration during safety fence and barrier installation, maintenance, repair and removal at the end of the system's service life.

7.2 Whole Life Costing - Background

Whole life costing (WLC) provides a method by which alternative solutions to a problem can be compared, in financial terms, over the total life of a structure. Whilst the basis of WLC is relatively simple, the assignment of values to some of the variables involved can be more difficult.

The basis of WLC is that all costs associated with a solution to a problem, over its total life, can be added together to represent a total or 'whole life' cost for that solution. Future costs can be normalised to a present value using the following formula:

$$\text{Present Value} = \frac{C}{(1+r)^t} \quad [7]$$

where:

C is the cost at current prices

r is the test discount rate

t is the time in years to when the cost is incurred

Once the whole life cost has been calculated, it can then be used to compare different solutions (for example the replacement of normal containment safety fences and barriers in the central reserve with those of a higher or very high containment level). Reduced maintenance frequency and/or improved performance under impact may justify any extra first cost.

To carry out the whole life costing for a possible solution, the following information is required: first cost, test discount rate, frequency and cost of maintenance, and the proposed service life of the structure.

7.2.1 First Cost

These are the initial installation costs for a green field site which, in the case of safety fences and barriers, will include materials, labour and plant costs. These will also include traffic management and traffic delay costs associated with the installation of the fences or barriers.

Costs for the relocation of services (such as lighting columns, signs, and communications cables) have not been included, as these considerations can be extremely site-specific and would be very difficult to incorporate into the assessment of more general WLCs. It is generally thought that these costs would be higher for concrete barrier installations due to the foundations required for this type of safety barrier.

In addition, the resurfacing of a carriageway could not be carried out if a concrete barrier were installed without first stripping the carriageway to, at least, the base course level. This cost has, again, not been included as it may be site specific, but it would not be applicable to metal safety fence installations as intervention testing of non proprietary systems has shown the addition of the 100mm overlay to have no detrimental effect on the performance of the safety fence.

7.2.2 Test Discount Rates

The test discount rate represents the fact that money not spent now could be invested (or at least not borrowed), and would therefore be worth more in the future.

In the UK, the test discount rate recommended by the Treasury in its publication, 'The Green Book: Appraisal and Evaluation in Central Government, July 2002' is 3.5% [8]. Hence this test discount rate has been used in the WLC analysis.

Due to the long-term nature of WLC, the final cost figures calculated cannot be considered as absolute values, and must be used for comparative purposes only.

7.2.3 Frequency and Cost of Maintenance

It is possible to estimate the maintenance and repair costs associated with typical normal containment and higher or very high containment safety fences and barriers. Metal safety fences are designed to deform in order to contain and redirect an errant vehicle, and hence any impact with such a fence will generally require a level of repair, and/or maintenance. Damage to the rigid higher or very high containment concrete barriers will generally be less, and in some cases zero, as such systems are designed not to deflect when impacted. This has been shown during controlled full-scale impact testing and within the M25 Sphere case study.

In addition to the repairs and maintenance required by safety fences and barriers after impact, consideration has also been given to the detailed maintenance and inspection of safety barriers. Within the WLC, detailed inspection frequencies have been timetabled in accordance with the requirements of the Trunk Road Maintenance Manual, Volume 2, Section 1.13.2 and Table 1.1.2 which states that:

*'Detailed inspections of all steel and wire rope **safety fences** shall be carried out at intervals of 2 years in respect of mounting height, surface protection treatment and structural condition.'*
*'Detailed inspections of **concrete barriers** shall be carried out at intervals of 2 years in respect of height and structural condition.'* [9]

Costs for this routine maintenance have been taken from the Mouchel Parkman case study of the safety fences and barriers installed on the M25.

Once the maintenance strategy for the fences or barriers has been decided, the likely disruption costs incurred then need to be addressed. The Department for Transport has developed a computer model (QUEUES AND DELAYS AT ROADWORKS - QUADRO) to calculate the delay costs incurred when disrupting traffic. These costs, and any associated traffic management costs, can often overwhelm the cost of maintenance procedures. Such costs will be incurred during maintenance work and during the installation, repair and removal of the safety fence or barrier.

Prediction of the cost and frequency of maintenance following an impact will require engineering judgement. Hence, estimations of the frequency with which a safety fence or barrier in the median of a major road will be impacted, and the resulting length of damage will have to be made.

The length of accident damage will, obviously, depend on the circumstances of the accident. For example, an HGV striking a normal containment safety fence or barrier at twenty degrees and at ninety-five kilometres per hour will generally cause a greater length of damage than a small car (such as a Ford Fiesta) impacting at the same speed and angle. This is because in the case of the HGV impact, the impact parameters are greater than those for which the normal containment safety fence or barrier is designed. The interaction between the vehicle and the safety fence or barrier will also play a part in the length of accident damage, and hence this will depend on the type of vehicle striking the barrier (e.g. a car or an HGV) and the angle at which the impact occurs.

The length of accident damage can be estimated through the results of controlled full-scale impact tests and through information obtained from police fatal files. However, such police files have shown that tensioned corrugated beam (TCB) constitutes the majority of the safety barrier in the median, and hence information on the in-service performance of other types of fence or barrier is limited. Where possible, data shall also be extracted from the M25 Sphere case study report.

7.2.4 The Predicted Service Life of Median Safety Barriers

If costing is to be carried out over the service life of the safety fence or barrier then by implication, this should be defined. Factors that may influence this decision are:

- Type of safety fence or barrier;
- Quality of materials, manufacture and installation;
- In-use conditions;
- The external environment;
- Maintenance conditions.

These factors can either increase or decrease the standard service life to give a 'predicted service life'.

Within this study, the predicted service life for the barrier has been extrapolated from Volume 1 of the Specification for Highways Works, Series 400. This states that:

'401 Performance Criteria for Safety Fences and Safety Barriers:

Durability:

2. Safety fences and barriers shall comply with the following durability criteria:

(i) All components of a safety fence shall be designed to achieve a serviceable life of not less than 20 years and for concrete barriers 50 years, except for Temporary Vertical Concrete Safety Barriers where the nominal service life shall be not less than 10 years.' [10]

As a result, a predicted service life of 50 years has been used for concrete safety barriers, and 25 years for metal safety fences. The longer working life of 25 years for safety fences has been used as experience has shown (and data exists to demonstrate) that this may be a more appropriate estimate than the 20 years stated.

Due to the fact that one service life is twice that of the other, the vehicle restraint installed in the median will require replacement after a period of 50 years, no matter whether a metal safety fence or concrete safety barrier was installed in the first instance.

7.3 The Whole Life Costing Worksheet

To estimate the whole life costs associated with a number of different common safety fence and barrier types, a worksheet was developed (in Excel format). Cells highlighted in yellow on the worksheet indicate values which can be altered, and which have been obtained from a third party (e.g. the Spon's Price Book, a safety manufacturer or the M25 Sphere case study report).

Sheets from the worksheet are reproduced in Annex K.

In order to calculate the WLC associated with median safety barriers, the following information was collected:

7.3.1 Initial Installation Cost (Annex K, Table K1)

Most installation costs used in the whole life assessment have been provided by UK industry representatives (i.e. Britpave and the VRMA). In each case, only prices received from the relevant authority have been used (i.e. concrete barrier costs from Britpave and metal fence costs from the VRMA).

In addition, some initial installation costs have been sourced from the Highway Works section of the "Spon's Civil Engineering and Highway Works Price Book 2002" [1]. Some concern has been raised that whilst such prices are appropriate for comparative purposes (such as is required for this report), the prices in the reference are traditionally a little high. Hence to validate these claims (or otherwise), a comparison between costs received from industry, and those in the price book are given in Annex L, Table L. The Table shows that while the Price Book costs are a little high in some areas, they are also low in others. Hence overall, the prices are suitable for use within the whole life costing exercise. This Table also highlights the differences that can arise in quotation from different companies. It should also be noted that in many cases, the monetary amount quoted by a particular contractor could differ according to the length of works undertaken and it is for this reason that the lengths quoted for are noted underneath Table L.

The initial installation costs quoted include the cost of materials, labour and plant, but not the delivery of the parts to site as this could vary greatly depending on the location of, and access to, the works site.

The quantity of materials required for the construction of each length of safety fence or barrier has been calculated in accordance with Drawings available in the Highway Construction Details [11]. For TCB and OBB, both two parallel rows of single sided safety fence and double sided configurations are considered.

It is assumed that the original carriageway meets all the requirements of a straight dual, three-lane motorway with a relatively flat, grassed central reserve. The definition used for a 'straight' road in the context of this report is that quoted in the Spon's Price Book, i.e. that the road is curved and 'exceeding a 120m radius' [1]. Curves with a radius tighter than this would incur additional costs due to the difficulties arising during the installation. In a more general sense, the definition of a straight road is usually that quoted in TD19/85, i.e. those roads with a radius greater than or equal to 850m [12].

It is also assumed that no safety fence or barrier currently exists at the site and hence there is no need to connect into an existing system through a transition arrangement. The cost associated with end terminals is, therefore, included in the calculations. It is also assumed that the Spon's Price Book definition of a 'terminal' includes all parts specified under the phrase 'terminal' in the HCD Drawings (i.e. they include the angled beam and concrete haunch in the case of steel fences, and tapered concrete terminals (to Drawing SB/23 [11]) for concrete barriers). Intermediate and end anchorages are included in the whole life cost calculations for the wire rope safety fence.

Inclusions:

The costs associated with surfacing the median and the provision of additional drainage for concrete barriers have been included as these may introduce significant cost differences between concrete safety barriers and steel safety fences.

Exclusions:

Costs for the relocation of services (such as lighting columns, signs, and communications cables) and the stripping of the carriageway during resurfacing work have not been included, as these considerations can be extremely site-specific and would be very difficult to incorporate into the assessment of more general WLC. These could be an addition cost for to the initial installation costs associated with concrete barrier systems.

UK Industry representatives and the Spon's Price Book have also estimated the time required to install the elements of the safety systems, and hence the period of time required for traffic management and subsequent traffic delay costs can be calculated for each type of fence or barrier. For such costs, a working day of 24 hours is assumed for simplicity.

7.3.2 Traffic Management Costs (Annex K, Table K2)

Cost information regarding the hiring of traffic management equipment was requested from a number of UK traffic management companies. The only quote received was from Class One Traffic Management. Hence this means that unlike the initial installation costs, these prices have not been compared to quotations from similar companies to assess how closely they reflect prices throughout the industry.

Whilst costs for Temporary Vertical Concrete Barriers (TVCB) and VarioGuard (a temporary metal fence) have been received, it is the TVCB costs which have been used when estimating traffic management costs. This is due to the need to remain consistent with the style of temporary vehicle restraint employed, as including calculations for both TVCB and VarioGuard may complicate the issue. As can be seen in Annex K, Table K2, the costs associated with the use of TVCB and VarioGuard are comparable.

It is assumed that the TVCB quoted for is designed for a speed limit of 110kph (i.e. it is of the TVCB (110) designation), and hence there is no requirement for a reduction in speed limit from 110kph (70mph) to 80 kph (50mph) throughout the works. This would cause additional complications when attempting to calculate QUADRO traffic delay costs associated with the works.

The layout of the temporary barriers has been costed so as to be in accordance with the requirements of HA Document IAN 24: 'Use of Temporary Safety Barriers at Road Works' [13]. This requires that 'in addition to the work zone, 39m of temporary safety barrier is required before the works and 21m beyond the end of the works'.

The traffic management costs also include an allowance for the provision of cones and signage before the works, these being in accordance with Chapter 8 of the Traffic Signs Manual [14].

7.3.3 Maintenance Costs (Annex K, Table K5)

There are three types of maintenance cost which will be incurred during the whole life of the median safety barrier:

(i) Routine Maintenance

This concerns the more frequent (i.e. daily or weekly) 'drive-by' inspection of safety fences and barriers that will identify areas requiring attention from maintenance crews. Such a task will incur similar costs for the different types of fence or barrier and hence, has not been included in the whole life costing exercise. In addition, the inspection of the restraint systems will not be the sole task of the 'drive-by' inspections and hence, assigning a cost to this particular exercise would be difficult. This cost would also be relatively small when compared to other areas associated with the process of whole life costing, and the other areas of maintenance.

(ii) Detailed Maintenance

These are the costs necessary to maintain the performance characteristics of the safety fence or barrier for any reason other than a vehicular impact (for example checking and if necessary, re-tensioning of metal tensioned systems and assessing the structural integrity of a barrier system).

Mouchel state in their case study report of the M25 Sphere that:

'Re-tensioning of metal safety barriers is carried out under static traffic management layouts. Near side work is carried out within either hard shoulder, or lane one closures. The closures are affected purely for this function. Central reservation re-tensioning is carried out within single or double lane closures. Seventy to eighty percent of this work is undertaken within planned closures for other maintenance works, with the balance requiring additional closures. A number of exit/entry slip require total closures with diversion routes to carry out maintenance works', i.e.

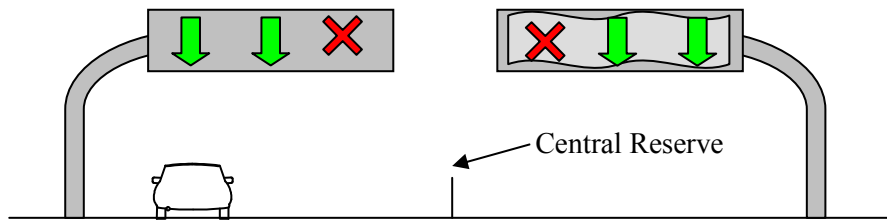


Figure 4: Lane Closures Due to Maintenance Work in the Median

As stated in Section 7.2.3, the detailed maintenance frequencies are taken from the Trunk Road Maintenance Manual, Volume 2, Section 1.13.2 and Table 1.1.2 [9].

From the details given within the Mouchel case study, the cost for the routine inspection and retensioning of metal safety fencing systems is included within a Lump Sum activity, i.e. contractors are paid a Lump sum at the start of the year for the carrying out of such tasks. It is for this reason that the visual inspection, detailed inspection, retensioning, painting etc. of the safety fencing is not categorised separately from the other maintenance activities.

Within the whole life costing spreadsheets it is assumed that this detailed maintenance will take place using cones and hence, the cost to install temporary safety barriers is not considered necessary. It is also assumed that that:

For tensioned metal systems the works will take two hours and hence this equates to a detailed maintenance 'cost' of £288 (from Mouchel Parkman's contract rates) + £5 (for the hire of the cones) + twice the QUADRO cost for that year.

For untensioned metal systems the works will take one and a half hours and hence this equates to a detailed maintenance 'cost' of £200 (estimated) + £4 (for the hire of the cones) + one and a half the QUADRO cost for that year.

For concrete systems, the works will take one hour and hence this equates to a detailed maintenance 'cost' of £50 (estimated) + £2.50 (for the hire of the cones) + the QUADRO cost for that year.

(iii) Repairs Maintenance

Refer to Section 7.3.5.

7.3.4 Traffic Delay Costs (Annex K, Table K5)

The DfT has developed a computer model (QUEUES AND DELAYS AT ROADWORKS - QUADRO) to calculate the delay costs incurred when disrupting traffic. These costs, and any associated traffic management costs can often overwhelm the cost of the maintenance procedures.

Such traffic delay costs have been included in the whole life costing for the disruption caused during the installation, repair (following an accident) and removal of the safety fence or barrier system. They have not been included for the time required to clear the carriageways of vehicles and debris following an accident as this will depend greatly on the accident and the number of vehicles involved.

Due to the predicted change in traffic flow from year zero to year fifty (the whole life cost period), it can be seen on the WLC worksheet that the associated hourly QUADRO costs increase yearly during the whole life of the fence or barrier.

These costs are incorporated into the WLC via equations in the WLC Worksheet. The equation calculates the total amount of time required for each of the works, and multiplies this by the QUADRO cost per hour. These costs are then added to the parts and traffic management costs to give the costs shown in the 'Additional Cost of Works' and 'Cost of Repair' columns in Table K5 (see Appendix K).

The Mouchel case study demonstrates the differences in QUADRO costs arising due to the time of day at which repairs and maintenance are affected and the road section upon which the repairs are being carried out:

Reference	7.3.4.1.1.1 Location	Road Standard	Period of Repair	Works Duration	Road User Costs (£)
1	J17 - J18 clockwise	D3M	Night	6 hours	317
2	J24 - J25 clockwise	D3M	Night	6 hours	660
3	J15 - J16 clockwise	D4M	Night	6 hours	442
4	J24 - J25 clockwise	D3M	AM Peak	2 hours	63,443
5	J15 - J16 clockwise	D4M	AM Peak	2 hours	70,187

Table 7: The effect of the time of day and repair location on QUADRO costs

These data assume:

- Maintenance carried out in 2004
- Discount rate of 3.5% (as recommended by the HM Treasury's Green Book [15]);
- Period of temporary traffic management – Night: 22.00 to 04.00 (6 hours) or AM Peak: 07.00 to 09.00 (2 hours) on a weekday;
- Works area in the centre of a junction to junction link on a standard motorway;
- Works defined with standard lanes, accident/incident rates and site capacities;
- No route diversion in place (maximum queuing delay of 30 minutes defined).

The case study summarises that:

‘The current standard maintenance approach in which works take place at night during low traffic flows is seen to result in very low road user costs, principally because the available capacity is less than traffic demand.

However, when some maintenance does take place at times of higher traffic flow, appreciable delays are incurred by motorists resulting in high road user costs, calculated to be at least **£60,000** for the 2-hour period evaluated, whether on D3M or D4M sections of motorway. This is primarily because demand flow exceeds available capacity through the works.’

7.3.5 Repair Costs (Annex K, Table K3)

All of the data used within this section originates from that provided from the Mouchel case study of the M25 Sphere and from the damage seen within full-scale impact tests.

This reports that between 1st January 2002 and 31st December 2002 there were the following number of incidents and repairs to safety barrier installed within the M25 Sphere (see Annex B, Table 1.2):

Location	Concrete		Metal		Totals	
	Incidents	Repairs	Incidents	Repairs	Incidents	Repairs
Nearside barrier repairs	14	0	873	873	887	873
Median barrier repairs	36	0	784	784	820	784
Other*	0	0	*	652	*	652
Totals	50	0	1657	2309	1707	2309

* Due to the nature/severity of the incident some damage to the safety barriers is recorded on the Pinnacle system (a Network information database) under other symptoms such as Total closures, fatalities, oil spill etc. This has been taken into consideration and accounted for in the above Table under ‘Other’ repairs.

Table 8: The number of repairs required to safety barriers on the M25 Orbital Motorway, 2002.

The most noticeable fact is that of the 36 impacts against the median concrete barriers, no remedial repair works have been required to the concrete safety barriers. The Mouchel report states that:

‘The concrete barrier systems within M25 Sphere have to-date only suffered superficial, cosmetic damage. We [Mouchel] cannot comment on time taken to repair this system, as the need has not arisen.’

The report goes on to comment that:

‘The VCBs require minimal maintenance and generally only require inspection after being struck by vehicles. Road user costs for these barriers may be considered to be negligible.’

This may also imply that the number of reported incidents with concrete barriers is higher than for metal systems as damage to the concrete barrier would be less noticeable than that occurring with a metal safety fence.

In addition, the report also states that the cost for repairs to metal safety fencing in 2002 was **£2,856,242.00**. In addition a yearly lump sum of **£93,781.38** applies for the maintenance of the metal safety fences. This includes yearly traffic management, yearly call out charges and the retensioning of the fences on a two yearly basis. This equates to a total of **£2,950,023.38** per annum for the repairs required to the metal safety fences, on average **£1,277.62** per repair. It is this latter figure which will be used when calculating the whole life costs associated with steel median barriers.

With regard to the processes employed to affect a repair, Mouchel state in their case study report that:

‘The TCB and OBB barriers require inspection and usually repairs after vehicle impact. Repairs take place within a few days of the damage being incurred and take place during weekday nights (generally between 22:00 and 04:30) and involve temporary traffic management (TTM) being applied to both carriageways using cones. Two lanes are closed in the primary direction (the side on which damage occurred) and one lane in the secondary direction’, i.e.

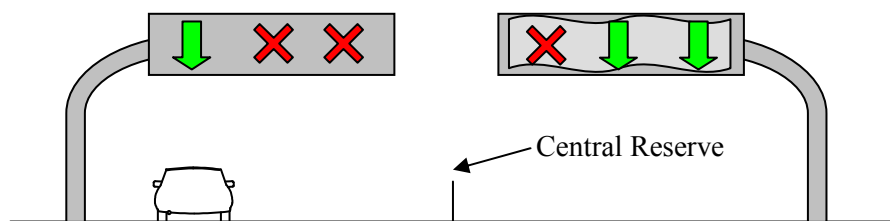


Figure 5: Lane Closures Due to Repair Work in the Median (Accident on left hand carriageway)

‘Speed restrictions of 50mph are signed and the coning normally extends over 1.8 km. In certain instances the damaged incurred or the location may represent a particular hazard and repairs need to be undertaken at other times of day.’

Within the Whole Life Costing spreadsheet, the following repair costs have been used, and are derived from factoring expected damage from car and HGV impacts and factoring these costs to account for the proportion of each type of vehicle having an impact with a median safety barrier.

	Duration of repairs (hrs)	Cost of TM	Cost of Replacement Parts
WRSF	0.4669	£12,124.19	£219.82
DSTCB	3.53478	£12,650.50	£1,231.59
DSOBB	3.3439	£11,659.45	£1,184.03
Slipformed VCB	0.01842	£10,008.15	£414.45
Slipformed HVCB	0.02763	£10,008.22	£2,302.50
2 rows of SSTCB	1.0483	£12,621.64	£444.06
2 rows of SSOBB	0.953	£11,640.28	£532.57
2 rows of DROBB	0.70194	£10,168.24	£282.91
Dutch Step Barrier	0.01842	£10,008.15	£414.45

Table 9: Repair costs used within the Whole Life Costing Worksheet

The same figures have been used whether the vehicle was retained, rebounded or crossed over the median as it is felt that these costs will be similar for metal safety fence systems. For concrete systems, it is assumed that the barrier will only require repair after a crossover accident.

7.3.6 Accident Costs (Annex K, Table K5)

In addition to the repair costs associated with an accident, other accident costs will be incurred. These are taken from the DfT's Highways Economic Note No.1: 2001 [16]. This gives estimates for the total value for the prevention of road casualties and road accidents in Great Britain for 2001. It is stated in the Note that:

'these do not represent actual costs incurred as the result of road accidents. They are the cost-benefit values and represent the benefits which would be obtained by prevention of road accidents.' [16]

The Note goes on to explain that:

'It is to be noted that the value of prevention of an injury accident is greater than the value of the corresponding casualty, e.g. value of preventing a fatal accident is greater than the value of a fatality for two reasons. The first is that an injury accident is classified according to the most severe casualty but will on average involve more than one casualty...The second reason is that there are some costs which are part of the valuation of an injury accident but which are not specific to casualties. These are:

- *costs of damage to vehicles and property*
- *costs of police and the administrative costs of accident insurance.'* [16]

Thus, in accordance with the figures in the Highways Economic Note 2001, the following values have been used for casualty (Table 10) and accident (Table 11) costs:

				£ June 2001
Injury Severity	Lost Output	Medical and Ambulance	Human Costs	Total
Fatal	410,540	700	783,000	1,194,240
Serious	15,810	9,580	108,800	134,190
Slight	1,670	710	7,970	10,350

Table 10: Average Value of Prevention per *casualty* by severity and element of cost [16]

Accident Severity	Cost Element						£ June 2001	
	Casualty Related Costs			Accident Related Costs			Total	Total minus Damage
Lost output	Medical & Ambulance	Human Costs	Police Costs	Insurance Admin.	Damage to Property			
Fatal	453,080	4,910	897,580	1,390	220	8,140	1,365,310	1,357,170
Serious	18,660	11,180	126,950	190	1401	3,730	160,850	157,120
Slight	2,220	940	10,560	40	80	2,190	16,030	13,840
All injury	10,740	2,410	38,910	80	90	2,480	54,710	52,230
Damage only				3	40	1,380	1,420	40

Table 11: Average Value of Prevention per *accident* by severity and element of cost [16]

It can be seen within Table 11 that the 'damage to property' value has been subtracted from the total. This is to avoid double-accounting when actual repair costs are included in the whole life costing for the median barrier.

An item of accident cost not included in the whole life costing exercise is that associated with structural consequences. In the case of safety fences and barriers, they are positioned to protect road users from exceptional local hazards. If the vehicle strikes this hazard there is a possibility that the hazard itself may be damaged (i.e. the report does not include costs associated with the financial and societal consequences of an HGV striking a bridge pier causing the bridge to collapse). In each case, repair work will need to take place to rectify the damage and this will incur costs. It is these costs which have not been considered as part of the WLC exercise, due to their complex and incident specific nature.

7.3.7 Removal Costs (Annex K, Table K4)

The removal costs for metal and concrete safety barriers have been provided by the VRMA and Britpave respectively.

Traffic management and traffic delay costs have also been incorporated into this part of the calculation, as they will be incurred during this time.

7.3.8 Whole Life Costs (Annex K, Table K5)

This combines the individual costs and calculates the whole life cost of safety fences and barriers over a 50 year period. This includes the initial installation, any subsequent repairs, maintenance and removal, and the associated traffic management and traffic delay costs. Accident costs have also been incorporated into the calculations.

7.4 Summary of the Information used to calculate the WLCs.

It is assumed that the original carriageway meets all the requirements of a straight dual, three-lane motorway with a relatively flat, grassed central reserve. The definition of a 'straight' road is as detailed in Section 3.3.1.

It is also assumed that no safety fence or barrier currently exists at the site and hence there is no need to connect into an existing system. The cost associated with two end terminals are, therefore, included in the calculations. Intermediate and end anchorages are included in the whole life cost calculations for wire rope safety fence.

Costs for the relocation of services (such as lighting columns, signs, and communications cables) have not been included, as these considerations can be extremely site-specific and would be very difficult to incorporate into the assessment of more general WLC. These could be investigated on a case study basis, and the commencement of this work is one of the recommendations from this report.

However, the costs associated with surfacing the central reserve and the provision of additional drainage for concrete barriers have been included as these may introduce cost differences between concrete safety barriers and steel safety fences.

A sample length of 1000m was selected as some of the quotes sent by contractors were based on such a length, and hence selecting the same length would increase consistency in the pricing. Due to the post spacing being different between some of the safety fences, the lengths constructed will only approximate to 1000m and will not be exact.

It is also assumed that HGVs contribute 8.3% of the traffic on the road. This is taken from DfT's Traffic data for 2000 where HGVs contribute 8.3% of all motor vehicles on major roads (See Appendix J).

Two analyses have been performed with regard to the whole life costs associated with median barriers. Firstly an analysis performed using the accident rates data attained from the STATS19 data analysis, and the costs from UK Industry representatives and the SPON's Price Book [1], and a second based partly on the SPONS data, but also incorporating data received from within the Mouchel Parkman case study of the M25 Sphere.

7.4.1 STATS19 Accident Rate Analysis

It is also estimated that the average annual daily two-way flow (AADT) of traffic is 67,046. This value is the average flow of the M25 between Junctions 17 and 18, as received by Mouchel Parkman in the case study report.

The WLC worksheet was used to calculate the cost associated with safety fences and barriers at damaging strike intervals of once every five, ten, fifteen or twenty years, and if they were not struck at all during their whole life. This was completed over a whole life period of fifty years. The results are shown in Annex M.

7.4.2 Rate of Damaging Accidents and Repairs

The calculations have shown that if no damaging impacts occur on a 1000m length of median safety fence or barrier during its whole life, then the associated whole life costs are as outlined below (see Annex M, Tables M1 to 3):

	WLC if no damaging impacts during a whole life of 50 years	
WRSF (2.4m post spacing)	£454,795	Metal Safety Fences
D/S TCB (3.2m post spacing)	£431,867	
D/S OBB (2.4m post spacing)	£453,805	
2 rows of S/S TCB (3.2m post spacing)	£473,403	
2 rows of S/S OBB (2.4m post spacing)	£524,754	
2 rows of DROBB (2.4m post spacing)	£570,623	
Slipformed VCB	£395,903	Concrete Safety Barriers
Slipformed HVCB	£630,626	
Dutch Step Barrier	£363,704	

Table 12: Costs incurred for 1km of median safety fence or barrier if it is undamaged during a whole life of 50 years.

Table 12 shows that the whole life cost associated with higher vertical concrete barriers (HVCB) is greater than that for metal safety fences. However, the Table also shows that the whole life costs of the H2 containment Dutch Step Barrier and the vertical concrete barriers (VCB) is less than that for metal systems. This is primarily due to the fact that within the 50 year whole life period a metal safety fence will need to be installed twice, and removed twice. In contrast, due to its assumed longer serviceable life, the concrete system only requires installation once, and removal once. In addition to the installation and removal costs themselves, costs will also be incurred for traffic management and traffic delay costs related to these on-site activities. General maintenance of the concrete barriers is also considered to be less than that required for the metal safety fences.

It should be re-emphasised at this point that the whole life cost of the concrete systems do not include costs associated with the relocation of services. These could greatly increase the initial installation costs associated with these barriers.

7.4.3 Rate of Fatal Casualties and Associated Accident Costs

Controlled full-scale impact tests have shown that flexible metal safety fences will require repair after any vehicular impact. Repairs to rigid concrete barriers are not required for the generally superficial and non-structural damage caused by impacts, and this has been seen within the M25 Sphere case study; of the 30 accidents between a vehicle and a concrete barrier, no repairs have been required following the accident.

Within this and subsequent sections, the costs associated with these repairs are incorporated into the whole life cost calculations.

A value of £1,357,170 has been used as the accident cost associated with a fatal accident with the values for serious and slight accidents being £157,120 and £13,840 respectively (refer to Section 7.3.6)

As a result, the costs resulting from an accident will far outweigh the initial installation costs, especially if a fatal casualty has occurred.

One factor which will also be incorporated into WLC calculations is the severity of the accidents with median safety barriers. The STATS19 database has, for example, shown that within accidents in which the vehicle is rebounded 2.2% of the accidents were classed as 'fatal', as opposed to 1.8% in accidents where a vehicle was contained and redirected, and 2.2% where the vehicle crossed the median.

7.4.4 Summary of Whole Life Costs

The whole life costs have been calculated separately for the three types of accident analysed within the STATS19 data, i.e. the vehicle was rebounded, retained or crossed the median.

Factors discussed in Sections 7.3.1 to 7.3.7 have been taken into account during the calculation of the WLCs. The values are summarised in Annex M.

The following explanations detail how these whole life costs were calculated:

Column 1 – Number of accidents during Whole Life: It is first assumed that the safety fence or barrier is not struck during its whole life. The exercise is then repeated with five, ten, fifteen or twenty strikes during the whole life (i.e. approximately once every ten, five, three or two years).

Columns 2 to 4 – Estimated Number of Injuries (by severity): STATS19 data (refer to Section 3.2.1.1) have been used to estimate the number of fatal, serious and slight accidents which may occur during the fifty-year whole life period, for example, the data have shown that for rebound accidents (which are more likely to occur with safety barriers of higher or very high containment classification):

- 2.2% can be classed as fatal;
- 14.5% can be classed as serious;
- 83.3% can be classed as slight.

The STATS19 data have also shown that for accidents in which a vehicle crosses the median (which are more likely to occur with safety barriers of normal containment classification):

- 7.3% can be classed as fatal;
- 24.0% can be classed as serious;
- 68.6% can be classed as slight.

Finally, the STATS19 data also indicate that for accidents in which the vehicle is retained on, or close to the median (which could equally occur with lighter vehicle striking a normal containment safety barrier, or a heavier vehicle striking a higher or very high containment barrier):

- 1.8% can be classed as fatal;
- 14.3% can be classed as serious;
- 83.9% can be classed as slight.

From these figures, the number of accidents occurring in each severity class can be calculated by multiplying the total number of accidents by these percentages.

Columns 5 to 7- Accident Cost: The accident cost can be approximated by multiplying the estimated number of accidents (from columns 2 to 4) by the cost data from Section 7.3.4.

Column 8 – Average Accident Cost: This column calculates the average accident cost using the values derived from columns 5 to 7.

Column 9 – Number of repairs required during the Whole Life: Each impact with a metal safety fence will require repair to some extent. This may not be true for every impact with a concrete safety barrier. Both of these factors have been shown in controlled full-scale impact tests, and within Mouchel Parkman's case study of the M25 Sphere. Column 9 uses the information in the test reports and the case study data to predict the number of repairs which will be required on the 1000m length of safety fence or barrier if it is struck five, ten, fifteen or twenty times during the whole life of fifty years.

Column 10 – Total Whole Life Cost: This figure is derived from the WLC worksheet, with the number of repairs and accidents being distributed equally throughout the fifty year period (See Annex K, Table K5). The figures quoted are 'present value' figures (see Section 7.2) and hence the costs will vary according to the year in which they occur. For example, a £1000 cost in year zero will appear as a £21 cost after fifty years. This emphasises the need to equally spread the repair and accident costs throughout the whole life of the safety barrier. The figures are repeated in Table 13 for clarity.

Vehicle Manoeuvre: Vehicle Rebounded by Barrier					
Safety Barrier Type	Total Whole Life Cost for 50 years – 1km Length (in £s)				
	0	5	10	15	20
WRSF (2.4m p/s)	£454,795	£670,868	£852,815	£1,052,715	£1,211,829
D/S TCB (3.2m p/s)	£431,867	£654,119	£841,397	£1,047,078	£1,210,948
D/S OBB (2.4m p/s)	£453,805	£673,013	£857,720	£1,060,581	£1,222,198
2 rows of S/S TCB (3.2m p/s)	£473,403	£691,860	£875,838	£1,077,957	£1,238,865
2 rows of S/S OBB (2.4m p/s)	£524,754	£740,635	£922,442	£1,122,175	£1,281,182
2 rows of DROBB (2.4m p/s)	£570,623	£782,296	£960,549	£1,156,384	£1,312,275
Slipformed VCB	£395,903	£576,881	£729,260	£896,684	£1,029,927
Slipformed HVCB	£630,626	£811,604	£963,983	£1,131,407	£1,264,651
Dutch Step Barrier	£363,704	£544,682	£697,061	£864,485	£997,729

Vehicle Manoeuvre: Vehicle Breaches the Median Barrier					
Safety Barrier Type	Total Whole Life Cost for 50 years – 1km Length (in £s)				
	0	5	10	15	20
WRSF (2.4m p/s)	£454,795	£902,437	£1,279,359	£1,693,486	£2,023,092
D/S TCB (3.2m p/s)	£431,867	£885,688	£1,267,941	£1,687,849	£2,022,211
D/S OBB (2.4m p/s)	£453,805	£904,583	£1,284,265	£1,701,352	£2,033,461
2 rows of S/S TCB (3.2m p/s)	£473,403	£923,429	£1,302,383	£1,718,728	£2,050,128
2 rows of S/S OBB (2.4m p/s)	£524,754	£972,205	£1,348,986	£1,762,946	£2,092,445
2 rows of DROBB (2.4m p/s)	£570,623	£1,013,866	£1,387,093	£1,797,155	£2,123,538
Slipformed VCB	£395,903	£837,857	£1,209,970	£1,618,825	£1,944,213
Slipformed HVCB	£630,626	£1,077,912	£1,454,515	£1,868,303	£2,197,618
Dutch Step Barrier	£363,704	£805,659	£1,177,774	£1,586,630	£1,912,019

Vehicle Manoeuvre: Vehicle Retained Close to the Barrier					
Safety Barrier Type	Total Whole Life Cost for 50 years – 1km Length (in £s)				
	0	5	10	15	20
WRSF (2.4m p/s)	£454,795	£654,905	£823,411	£1,008,544	£1,155,905
D/S TCB (3.2m p/s)	£431,867	£638,156	£811,993	£1,002,906	£1,155,024
D/S OBB (2.4m p/s)	£453,805	£657,050	£828,317	£1,016,410	£1,166,274
2 rows of S/S TCB (3.2m p/s)	£473,403	£675,897	£846,435	£1,033,785	£1,182,941
2 rows of S/S OBB (2.4m p/s)	£524,754	£724,672	£893,038	£1,078,004	£1,225,258
2 rows of DROBB (2.4m p/s)	£570,623	£766,333	£931,145	£1,112,213	£1,256,351
Slipformed VCB	£395,903	£560,918	£699,856	£852,515	£974,005
Slipformed HVCB	£630,626	£795,641	£934,579	£1,087,236	£1,208,727
Dutch Step Barrier	£363,704	£528,719	£667,657	£820,314	£941,806

Table 13: Summary of the WLC for 1km of the common types of median safety fences and barriers for a whole life of 50 years

The values in Table 13 show that in each scenario the whole life cost value of HVCB is greater than for the other steel safety fences and concrete safety barriers.

However, the Table also shows that the whole life cost associated with HVCB becomes more comparable with the cost of metal systems as the number of accidents with the vehicle restraint increases. This is not surprising given the lower repair frequency and costs associated with the HVCB system. Indeed if 10 or more rebound or retained vehicle accidents occur on the one kilometre length of barrier over its 50 year life, the HVCB is more financially viable than two rows of DROBB. In addition, if 17 or more such accidents occur, the HVCB is then more viable than the use of two rows of single sided OBB. This is shown in Graphs M1 to M3.

In addition, the slipformed Dutch Step barrier and VCB have the lowest whole life cost over the 50 year period even if the barrier is breached. From experience through testing, and from the case study of the M25 Sphere, it

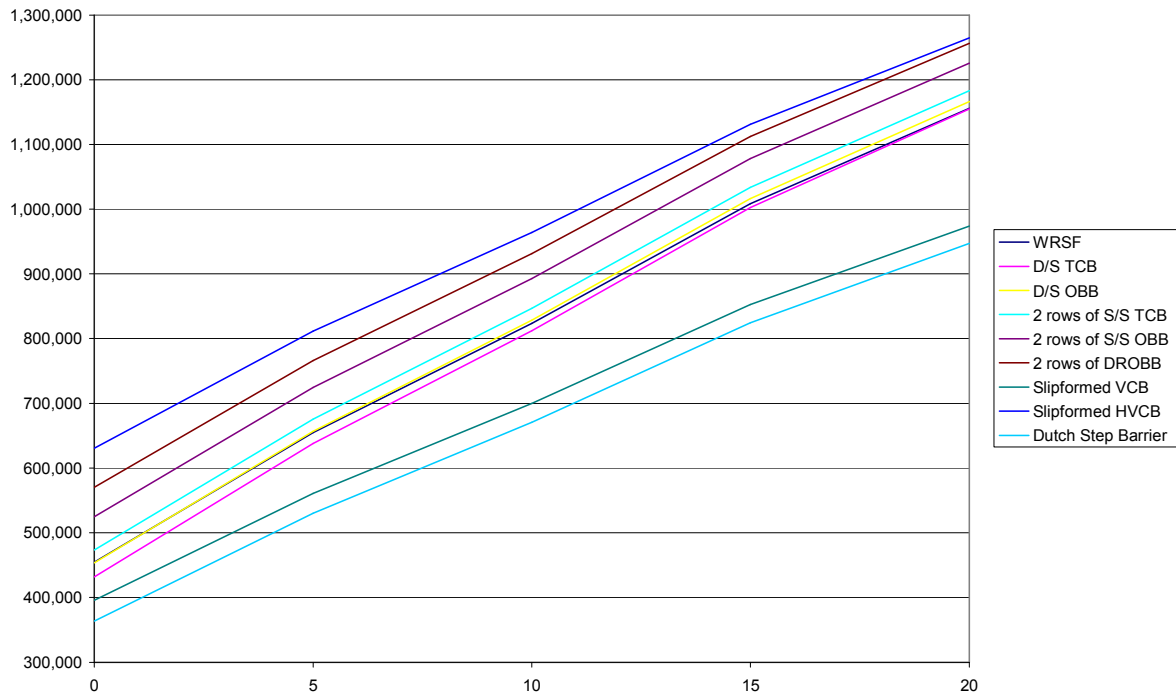
is felt unlikely that any breaches of the VCB or HVCB would occur during the life of the barrier, although this probability is increased in areas of higher HGV traffic. The more likely trajectory for a crossover-type accident would be for the HGV to roll over the top of the barrier. This has been seen during full-scale testing, but not within the M25 Sphere case study.

To compare the whole life costs in a general sense may be slightly misleading as different vehicle types will interact with the median barrier in different ways. Instead, one should examine the more probable vehicle reactions if the median barrier were impacted (see Table 14). In some cases, it may be likely that one of two situations may arise, and in which case, an estimate of the likely proportions of such accidents has been made. It is felt that although the VCB system has only been tested to an N2 containment level, its performance during testing would imply a similar performance characteristic as the Dutch Step Barrier.

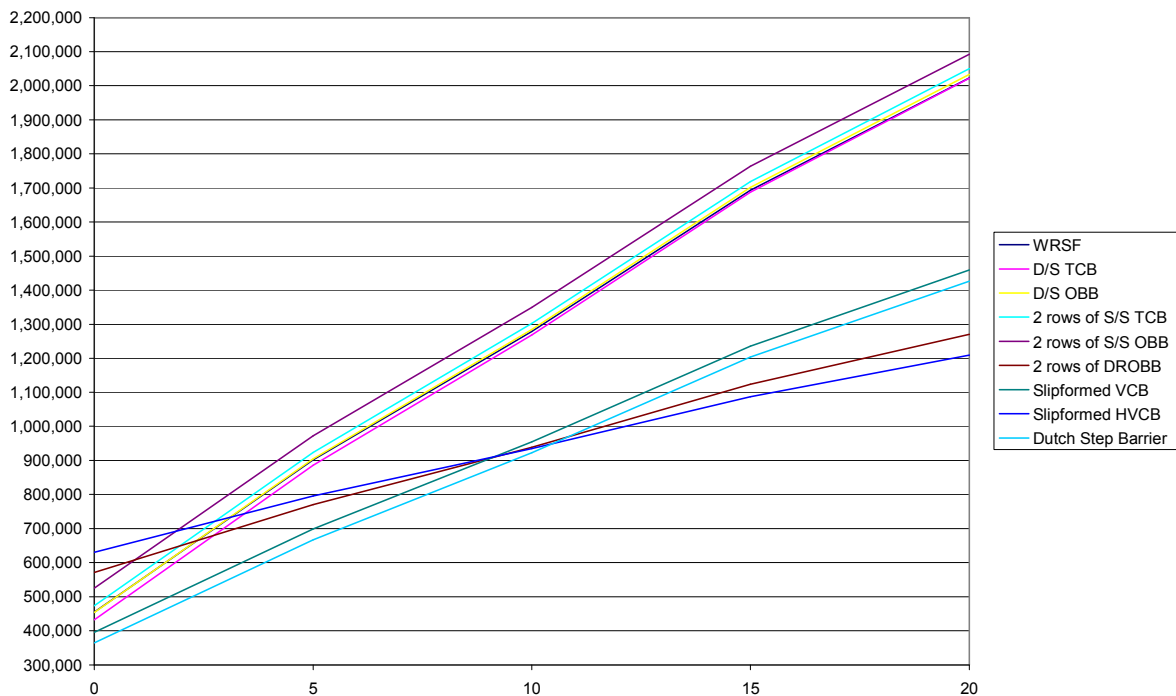
Safety Barrier Type	Impacting Vehicle	Probable Outcome	Total Whole Life Cost for 50 years – 1km Length (in £s)				
			0	5	10	15	20
WRSF	Car	Retained	454,795	654,905	823,411	1,008,544	1,155,905
D/S TCB	Car	Retained	431,867	638,156	811,993	1,002,906	1,155,024
D/S OBB	Car	Retained	453,805	657,050	828,317	1,016,410	1,166,274
2 rows of S/S TCB	Car	Retained	473,403	675,897	846,435	1,033,785	1,182,941
2 rows of S/S OBB	Car	Retained	524,754	724,672	893,038	1,078,004	1,225,258
2 rows of DROBB	Car	Retained	570,623	766,333	931,145	1,112,213	1,256,351
Slipformed VCB	Car	Retained	395,903	560,918	699,856	852,515	974,005
Slipformed HVCB	Car	Rebounded	630,626	811,604	963,983	1,131,407	1,264,651
Dutch Step Barrier	Car	90% Retained, 10% Rebounded	363,704	530,315	670,597	824,731	947,398
WRSF	HGV	Crossover	454,795	902,437	1,279,359	1,693,486	2,023,092
D/S TCB	HGV	Crossover	431,867	885,688	1,267,941	1,687,849	2,022,211
D/S OBB	HGV	Crossover	453,805	904,583	1,284,265	1,701,352	2,033,461
2 rows of S/S TCB	HGV	Crossover	473,403	923,429	1,302,383	1,718,728	2,050,128
2 rows of S/S OBB	HGV	Crossover	524,754	972,205	1,348,986	1,762,946	2,092,445
2 rows of DROBB	HGV	75% Retained, 25% Rebounded	570,623	770,324	938,496	1,123,256	1,270,332
Slipformed VCB	HGV	50% Retained, 50% Crossover	395,903	699,388	954,913	1,235,670	1,459,109
Slipformed HVCB	HGV	Retained	630,626	795,641	934,579	1,087,236	1,208,727
Dutch Step Barrier	HGV	50% Retained, 50% Crossover	363,704	667,189	922,716	1,203,472	1,426,913

Table 14: Whole Life Costs associated with most probably vehicle reaction to barrier impact

The resulting graphs, by vehicle type are as follows:



Graph 1: Whole Life Costs Associated with Accidents in which a Car is the errant vehicle



Graph 2: Whole Life Costs Associated with Accidents in which a HGV is the errant vehicle.

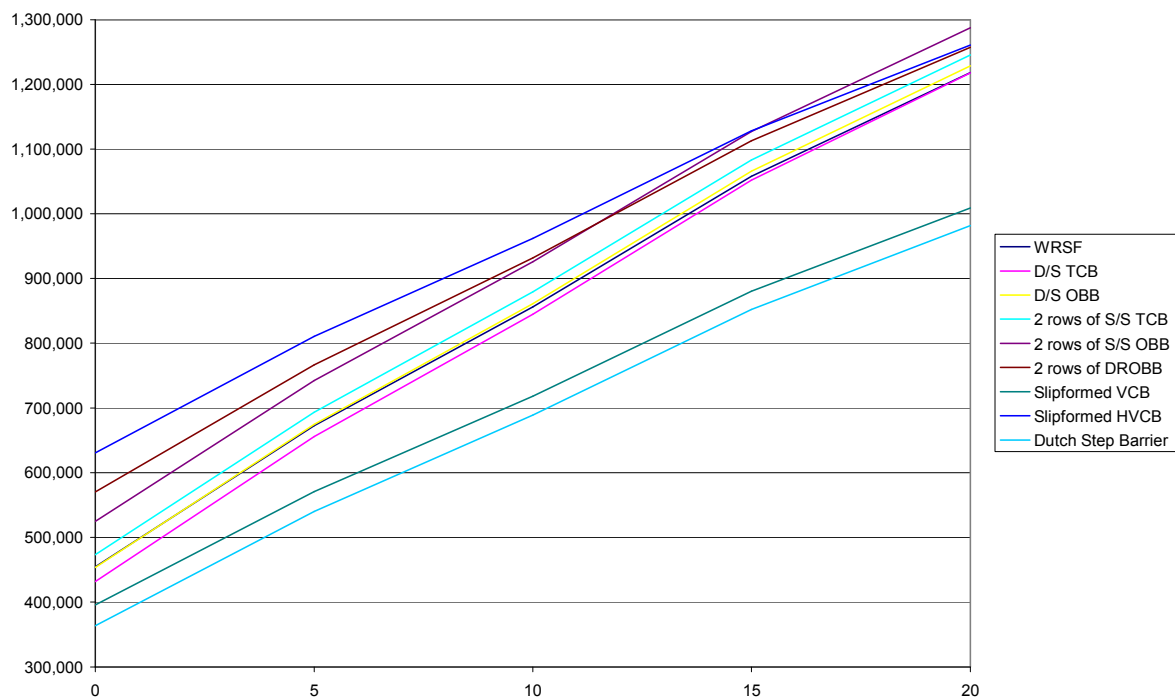
Graphs 1 and 2 indicate that whilst the use of slipformed HVCB may not be economically viable in areas where they are predominately struck by cars, significant savings could be made if such barriers were introduced in areas where there are high densities of HGVs. This is partly due to the reduced accident costs resulting from rebound and retained vehicle accidents when compared to those in which a vehicle crosses the median. This shows the dominance of the accident costs. These greatly outweigh all of the other costs associated with a median barrier system during its whole life. As a result, the gradient of the lines in Graphs 1 and 2 are highly dependant on the accident rates derived from historical STATS19 data and subsequently used in Table 14.

It is therefore emphasised that the findings from Graphs 1 and 2 are only applicable if the accident rate and severity remain consistent with the average figures for the past twelve years of STATS19 accident data.

Hence, the introduction of safety fences and barriers with a greater level of containment may be economically viable in areas where the probability of three HGV accidents on a 1km length of median safety barrier, in a fifty year period, is high. This is shown in Graph 2 by the intersection of the whole life costs for HVCB and normal containment median barriers being at around this value. This could be an area with a high volume of HGVs and/or a history of such accidents.

This could be determined retrospectively (through accident records) or proactively (by examining the traffic flows on particular roads, and identifying those roads with a higher population of HGV traffic).

In addition to examining the Whole Life Costs for each vehicle type individually, knowing the probability of vehicles striking a median barrier, one can incorporate these probabilities into the calculations, and recalculate the whole life costs. Hence, we have seen in Section 3.2.1.2 that of those incidents in which a median barrier accident occurred, 82.5% of the accidents involved a car, and 6.4% involved an HGV. (The remaining 11.1% is attributable to 'other vehicles'). If one incorporates the relative proportion of cars and HGVs involved in the accidents, the whole life cost figures are summarised as follows. Graph 3 therefore demonstrates the most probable whole life costs for median barriers installed on UK roads (assuming accident rates and proportionality of car to HGV accidents remains similar to that currently seen in the STATS19 data).



Graph 3: Whole Life Costs incorporating the proportion of Car and HGV accident rates.

This graph demonstrates that both the Dutch Step and Vertical Concrete Barriers have the lowest whole life costs. This is due to a number of factors:

- Lower accident costs as a result of reducing crossover accidents (which generally have a higher fatal and serious injury rate, and hence accident cost);
- No repairs generally being required following an impact;
- Lower routine maintenance costs;
- Longer working life, and hence no need to replace the system after 25 years;
- Reduced initial installation costs due to reduced installation times, and hence resulting traffic management and traffic delay costs (which can exceed the installation costs themselves)

It should be noted that the Dutch Step Barrier offers H2 containment, and hence, this increase in containment is provided with a reduced whole life cost.

The graph also shows that the introduction of a very high containment safety barrier would only be cost effective if there were 15 accidents occurring on the 1km length of median barrier in its 50 year life. However, this report has not examined costs associated with structural consequences (i.e. the costs associated with damage to the item of roadside furniture being protected [for example a bridge pier]). In such cases, these structural consequences may be sufficiently high that the use of a very high containment safety barrier would be warranted.

The graph also shows that the use of an intermediate (H1 containment) steel system (i.e. DROBB) would only be economically viable on a length of 1 km safety fence experiencing 11 accidents during its whole life.

Double sided TCB is seen to be the least expensive metal safety fence system, slightly cheaper than wire rope safety fence.

8 CONCLUSIONS

8.1 Accident Statistics (Refer to Section 3.2.1)

- Within the STATS19 analysis period of 1990 to 2002, there were, on average 117,106 accidents per annum on major roads (motorways and A roads) within Great Britain (Refer to Section 3.2.1.1).
- Of these 117,106 accidents, there were 2,900 accidents in which an *object* was struck in the median. This constitutes 2.5% of all of the accidents occurring on the major roads of Great Britain, a small percentage. This object may have been a median safety barrier, lighting column, sign post and any other item of roadside furniture located within the median (Refer to Section 3.2.1.1).
- The accident data show that a cross over accident is less probable than one in which the vehicle is rebounded or retained. However when such a crossover accident does occur, it is almost three times as more likely that a fatal injury will result (Refer to Section 3.2.1.1).
- If one compares the accidents in which the vehicle is either rebounded or retained in the median, there is little difference between the two data sets in terms of severity, although it is more probable that a vehicle will be retained close to the median than rebounded (Refer to Section 3.2.1.1).
- Of the 117,106 accidents occurring on major roads within Great Britain per annum, 1,449 involved a vehicle striking a *safety barrier* in the median. This constitutes 1.2% of the total number of accidents, and 50.0% of the accidents in which an object was struck in the median (Refer to Section 3.2.1.2).
- Of this subset of 1,449 accidents, 34 (2.3%) were reported as being fatal accidents, 216 (14.9%) as serious accidents and 1,199 (82.7%) as slight (Refer to Section 3.2.1.2).
- The data show very similar trends to those seen for accidents in which any object is struck in the median, i.e. whilst the crossover accident is less probable than the other accident types, the resulting casualties are more severe (Refer to Section 3.2.1.2).
- The accident data have shown that:
 1. When a car impacts a median safety barrier (either of metal or concrete construction) it is more probable that it will be contained, rather than breach it (Britpave state that, to the best of their knowledge, no concrete barriers in the UK has been breached);
 2. If the impacting vehicle is an HGV, it is more probable that the vehicle will be retained close to the barrier. It is equally probable that an HGV will cross through a median barrier, than be rebounded by it;
 3. For accidents involving other vehicles, it is most probable that the vehicle will remain close to the median barrier after impact;
 4. For impacts by any of the vehicle types, it is more probable that a crossover accident will result in fatal injuries;
 5. For impacts by cars and HGVs, the highest percentage of serious injuries also results from crossover accidents. The highest number of slight accidents results from those in which the vehicle remains close to the median barrier;
 6. For impacts by 'other vehicles', the highest percentage of serious accidents comes from those in which the vehicle is retained close to the median barrier. Slight accidents are more prevalent with the crossover accident;
 7. In all accidents, independent of vehicle type or motion after impacting a median safety barrier, as the severity of the accident increases, the number of accidents decreases (Refer to Section 3.2.1.2).
- The number of casualties per accident is greatest when an 'other vehicle' is involved and least when an HGV is involved. This can be explained by the general number of occupants in each vehicle (Refer to Section 3.2.1.2).
- The highest number of casualties per accident result from crossover accidents, the lowest being those in which the vehicle remains on, or close to, the median (Refer to Section 3.2.1.2).

8.2 Casualty Analysis (Refer to Section 3.2.2)

- Within the STATS19 analysis period of 1990 to 2002, there were, on average 164,136 casualties per annum on major roads (motorways and A roads) within Great Britain (Refer to Section 3.2.2.1).
- Of these 164,136 casualties, 4,071 resulted from an accident in which an *object* was struck in the median. This constitutes 2.5% of all of the casualties occurring on major roads in Great Britain (Refer to Section 3.2.2.1).
- As with the data concerning accidents, the casualty statistics also indicate that a cross over accident is less numerous than one in which the vehicle is rebounded or retained. However when such a crossover accident does occur, it is almost three times as more likely that a fatal injury will result (Refer to Section 3.2.2.1).
- Again, as with the accident data, these casualty statistics also show that if one compares the accidents in which the vehicle is either rebounded or retained in the median, there is little difference between the two data sets in terms of severity, although it is more probable that a vehicle will be retained close to the median than rebounded (Refer to Section 3.2.2.1).
- Of the 164,316 casualties resulting from accidents on major roads within Great Britain, 2,019 involved a vehicle striking a *safety barrier* in the median. This constitutes 1.2% of the total number of casualties, and 49.6% of the accidents in which an object was struck in the median (Refer to Section 3.2.2.2).
- Of this subset of 2,019 casualties, 38 (1.9%) were reported as being fatal, 274 (13.6%) as serious and 1,706 (84.5%) as slight (Refer to Section 3.2.2.2).
- These data show the **same trends** as those highlighted above for the impacts in which a median safety barrier is struck, with the **following exceptions**:
 1. For impacts with ‘other vehicles’, it is more probable that a rebound accident will result in fatal injuries;
 2. For impacts with cars and HGVs, the highest percentage of slight accidents results from those in which the vehicle remains close to the median barrier or is rebounded as these results are close;
 3. For impacts with ‘other vehicles’, the highest percentage of serious accidents comes from those in which the vehicle is retained, either close to or rebounded from the median barrier. Slight accidents are more prevalent with the crossover accident;
 4. In all accidents, independent of vehicle type or motion after impacting a median safety barrier, as the severity of the accident increases, the number of accidents decreases (Refer to Section 3.2.2.2).

8.3 Accident Statistics – Mouchel Case Study (Refer to Section 3.2.3)

- The M25 Sphere case study shows that:
 1. Of the 373 km of median safety barrier installed within the M25 Sphere,
 - Metal safety fences (including wire rope safety fencing) constitute 87.3% of the total length,
 - Concrete safety barriers contribute 12.7%.
 2. No fatal casualties have resulted from an impact with a concrete barrier;
 3. The number of serious casualties per kilometre is comparable between steel safety fencing and concrete safety barriers;
 4. Concrete barriers also result in a lower rate for slight casualties and total accidents per kilometre than metal safety fences.However, it should be noted that some of the sections of the M25 in which concrete barriers are installed are subject to both high traffic volumes and variable (reduced) speed limits, making them some of the slowest sections of motorway in the UK. This may, in turn, reduce the speed, and hence severity of, accidents with concrete safety barriers seen in the Mouchel Parkman case study (Refer to Section 3.2.3).

8.4 Factors to Consider when Specifying Containment

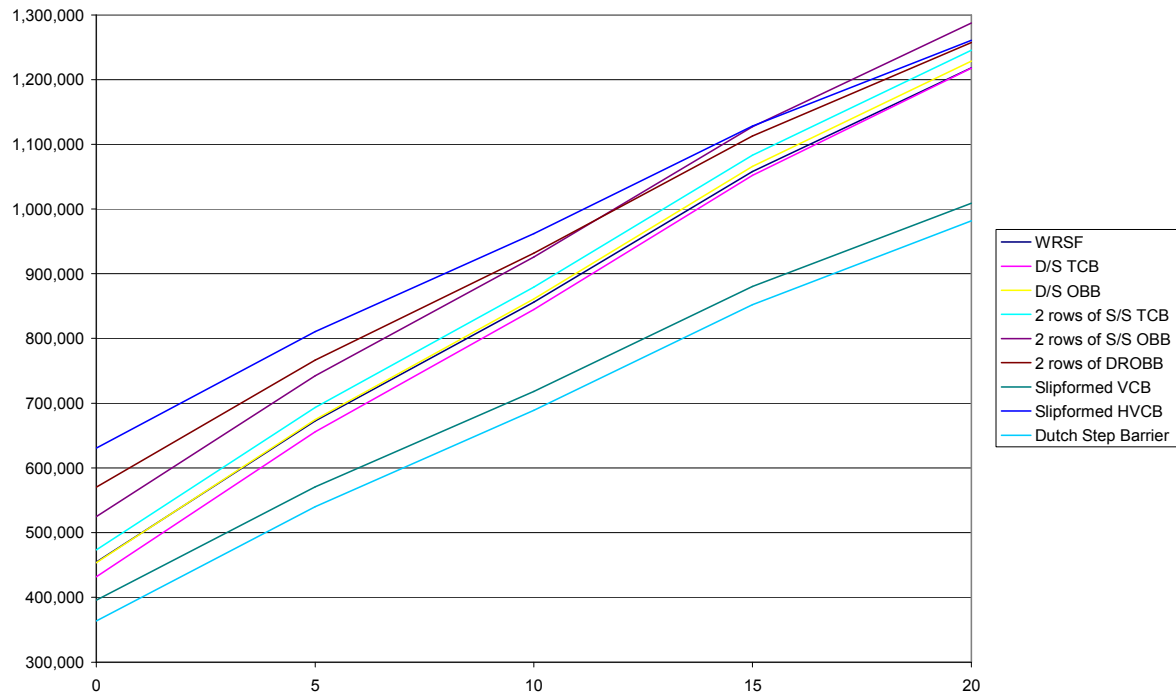
- Those safety barriers with a containment level greater than ‘normal’ will deflect less than a normal containment safety barrier when impacted with the small (900kg) vehicle as their rigidity enables them to contain heavier vehicles. Hence it follows that the severity indices (such as ASI, THIV and PHD) for safety barriers with a ‘high’ or ‘very high’ containment level will be more onerous than those of normal containment (Refer to Section 4.4).
- Safety barriers with a greater level of containment are less likely to be breached. In the case of central reserve safety barriers this may, in turn, reduce the number of fatalities occurring on the opposite carriageway. However, if the barriers are of a higher and solid construction, a driver’s visibility of activity on the opposite carriageway will be diminished (Refer to Section 4.4).
- European studies such as the RISER and ROBUST projects are currently being carried out to try to correlate these severity indices with ‘real life’ injuries; however no link, to date, has been found (Refer to Section 4).
- Due to the rigidity of these high or very high containment barriers, it has been seen through full-scale testing that there is a general tendency for some vehicles with a higher centre of gravity (such as HGVs) to roll over the barriers if they are not of sufficient height. Whilst it is preferable for a vehicle to traverse the median on its wheels rather than on its side (as the vehicle is more controllable on its wheels), a greater level of impact energy is required to roll an HGV than for it to breach a deformable safety fence. (Refer to Section 4.4).
- Factors contributing to risks during an impact with a median safety barrier include reaction times, impact conditions, deceleration of the vehicles, traffic flow, and visibility (Refer to Section 5.2).
- Consideration should be given to the possibility that the selection of one type of vehicle containment level over another could, in some circumstances, increase the risk to road users (Refer to Section 5.3).
- During the life of a median safety barrier, there may be occasions which arise when legitimate access through the barrier is required. Whilst this action can be quite speedily effected with a metal safety fence, where concrete barriers exist, the use of removable/movable/demountable sections of barrier would be necessary, or a detour around the barrier would be required (Refer to Section 6).

8.5 Whole Life Costing (Refer to Section 7)

- A predicted service life of 50 years has been used for concrete safety barriers, and 25 years for metal safety fences (Refer to Section 7.2.4).
- **Inclusions in the whole life costing exercise:** (Refer to Section 7.3)
 1. Initial installation, including surfacing the median and the provision of additional drainage for concrete barriers;
 2. Routine Maintenance (for values refer to 7.3.3);
 3. Repair following an accident (for values refer to 7.3.5);
 4. Removal and reinstallation at the end of the barrier's serviceable life;
 5. Traffic management due to installation, removal and/or repair;
 6. Traffic delay costs due to installation, removal and/or repair.
- **Exclusions to the whole life costing exercise:** (Refer to Section 7.3)
 1. Costs for the relocation of services (such as lighting columns, signs, and communications cables) and the stripping of the carriageway during resurfacing work. These considerations can be extremely site-specific and would be very difficult to incorporate into the assessment of more general WLC. These could add large amounts to the initial installation costs associated with concrete barrier systems.
 2. Structural consequences i.e. the costs associated with damage to the hazard being protected by the barrier.
- Of the 36 median barrier impacts against the concrete barriers within the M25 Sphere case study, no remedial repair works have been required to the concrete safety barriers. Road user costs for these barriers may be considered to be negligible. (Refer to Section 7.3.5)
- The WLC calculations have shown that if no damaging impacts occur on the 1km length of safety barrier during its whole life, then the associated costs are as follows (Refer to Section 7.4.2):

	WLC if no damaging impacts during a whole life of 50 years	
WRSF (2.4m post spacing)	£454,795	} Metal Safety Fences
D/S TCB (3.2m post spacing)	£431,867	
D/S OBB (2.4m post spacing)	£453,805	
2 rows of S/S TCB (3.2m post spacing)	£473,403	
2 rows of S/S OBB (2.4m post spacing)	£524,754	
2 rows of DROBB (2.4m post spacing)	£570,623	
Slipformed VCB	£395,903	} Concrete Safety Barriers
Slipformed HVCB	£630,626	
Dutch Step Barrier	£363,704	

- However, if factors such as accident rates, repairs, accident compensation and likely vehicle reaction to the barrier and the relative percentage of Car and HGV traffic are also incorporated, the WLCs for 1km of safety fence or barrier more closely resemble the following (Refer to Section 7.4.4):



- This graph demonstrates that both the Dutch Step and Vertical Concrete Barriers have the lowest whole life costs. (Refer to Section 7.4.4)
- This is due to a number of factors:
 - Lower accident costs as a result of reducing crossover accidents (which generally have a higher fatal and serious injury rate, and hence accident cost)
 - No repairs generally being required following an impact
 - Lower routine maintenance costs
 - Longer working life, and hence no need to replace the system after 25 years
 - Reduced initial installation costs due to reduced installation times, and hence resulting traffic management and traffic delay costs (which can exceed the installation costs themselves)
(Refer to Section 7.4.4)
- It should be noted that the Dutch Step Barrier offers H2 containment, and hence, this increase in containment is seemingly provided with a reduced whole life cost. (Refer to Section 7.4.4)
- The graph also shows that the introduction of a very high containment safety barrier would only be cost effective if there were 15 accidents occurring on the 1km length of median barrier in its 50 year life. However, this report has not examined costs associated with structural consequences (i.e. the costs associated with damage to the item of roadside furniture being protected [for example a bridge pier]). In such cases, these structural consequences may be sufficiently high that the use of a very high containment safety barrier would be warranted. (Refer to Section 7.4.4)
- The graph also shows that the use of an intermediate (H1 containment) steel system (i.e. DROBB) would only be economically viable on a length of 1 km safety fence experiencing 11 accidents during its whole life. (Refer to Section 7.4.4)
- A graph showing the whole life costs for accidents involving HGVs only indicates that very high containment median safety barriers may be economically viable if 3 HGV accidents occur on a 1km length of barrier during a working life of fifty years. (Refer to Section 7.4.4)
- Double sided TCB is seen to be the least expensive metal safety fence system, slightly cheaper than wire rope safety fence (Refer to Section 7.4.4)

9 RECOMMENDATIONS AND IMPLEMENTATION

There are areas in the study which have been omitted due to their complexity, and other topics which have arisen as requiring further investigation during the study. It is therefore recommended that the following items of work (listed in order of priority) are examined before further conclusions regarding the suitability of increasing the containment capability of safety fences and barriers in the median can be made.

- Initiate a study to identify lengths of major road with a high percentage of HGVs or HGV crossover accidents.

As stated in the conclusions, the WLC spreadsheet has shown that the use of very high containment safety barrier in the central reserve becomes more viable where the probability of it being struck by an HGV is high. Such lengths of road could be determined either retrospectively (by examining accident records and plotting the accident sites) or proactively (by examining the traffic flows on particular roads, and identifying those roads with a higher population of traffic over 3.5 tonnes). Once areas of HGV population are found which greatly exceeds the DfT average of 8.3% of all traffic, the associated cost of installing median barriers of greater containment in those areas could then be calculated.

- Initiate a series of case studies investigating the costs associated with structural consequences resulting from HGV accidents in the central reserve of major roads.

Another item of cost not included in the whole life costing exercise is that associated with structural consequences. Within the accident costs, monetary amounts have been allocated solely on the number and severity of casualties involved in an accident. In the case of safety fences and barriers, they are positioned to protect road users from exceptional local hazards. If the vehicle strikes this hazard there is a possibility that the hazard itself may be damaged (for example, an HGV strikes a bridge pier causing the bridge to collapse, or an HGV striking a lighting column). In each case, repair work will need to take place to rectify the damage to the structure and this will incur costs. It is these costs which have not been considered as part of the WLC exercise, due to their complex and site specific nature.

- Initiate a series of case studies investigating the costs associated with relocating services in the central reserve.

The main area of cost not included in the whole life costing exercise was a study into the financial penalties associated with relocating services in the central reserve (such as lighting columns, signs, drains and communications cables). This was due to the very site-specific nature of such works and hence, this is likely to be a complex investigation. However, if it were felt necessary, such an investigation could be undertaken as a case study, and carried out in conjunction with maintenance agents such as Mouchel Parkman.

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