The travel of errant vehicles after leaving the carriageway

by D A Lynam and J V Kennedy

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THE TRAVEL OF ERRANT VEHICLES AFTER LEAVING THE CARRIAGEWAY

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by D A Lynam and J V Kennedy

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Executive summary

This report addresses recommendation 6.5b of the Working Group to Review the Standard for the Provision of Nearside Safety Barriers on the Trunk Road Network. This identified the need to understand more about how and where errant vehicles travel after leaving the nearside of the carriageway.
The research has focussed on the factors that influence the travel of the errant vehicles, the relative significance of these factors, and potential ways to address them. Data on errant vehicle travel is needed both in the context of the post Selby action plan, and particularly to inform the risk assessment being developed for the revised standard for vehicle restraint systems.

In the UK, a 3.3m hard shoulder is standard on motorways. A 1m strip is used on both single and dual-carriageway trunk roads; in the latter case where traffic speeds of 70mph are allowed. There is no ‘clear zone’ as such required. Research in UK has therefore been aimed at assessing when it is necessary to provide additional protection.

This requires a model to be developed that allows the costs and benefits to be evaluated more directly for a variety of different roadside conditions. The model being developed by Mouchel/TRL as part of the introduction of risk assessment into road restraint standards provides a basis for this. Models are needed to show how these factors involved combine to reflect overall risk at particular sites.

Data has been collated in this report that will provide the following input to such models

(a) encroachment angles – no evidence is directly available for UK, but US studies suggest that the angle varies with type of run off, and a probability distribution is provided with the majority of run offs being between 5 and 15 degrees

(b) frictional resistance during run off – unbraked run offs over good ground will produce very little deceleration (perhaps 0.1g) but this can increase to 0.5g over loose gravel. Braked runs over loose gravel can produce decelerations of 1g, but over hard ground probably only about half this value.

(c) effect of slope on likelihood of rollover – down slopes greater than 1:3 result in a high likelihood of rollover; even on slopes of 1:4 the scope for driver control over short distances will be limited

(d) severity of injury resulting from hitting different objects – impacts with trees are 50% more likely to result in severe injury than impacts with signs and lampposts; there remains a significant probability of injury after impact with roadside barriers

(e) accident data on the overall outcomes from the combined effect of these factors

Models starting with these values need to be calibrated against accident data from British trunk road sites to demonstrate the validity of their predictions to these sites.

It is concluded that

- The basic methodology exists to make risk assessments at these sites
- Data exists (although mainly from other countries) on the values to be used for the parameters in these models

There is no reason to believe that these values are fundamentally different for British conditions, so the value of further research is in

- The improvement that can be made to the risk estimates for British trunk roads by refining the values used
- Demonstrating the output of the models is consistent with observed accident patterns on trunk roads

1 Introduction

The overall project objective is to address recommendation 6.5b of the Working Group to Review the Standard for the Provision of Nearside Safety Barriers on the Trunk Road Network. This identified the need to understand more about how and where errant vehicles travel after leaving the nearside of the carriageway.

The work required for the first stage of the work is defined in the project brief as:

- Review of relevant existing international and UK research
- Review of relevant injury and non-injury accident statistics and reports

The research will focus on the factors that influence the travel of the errant vehicles, the relative significance of these factors, and potential ways to address them.

Data on errant vehicle travel is needed both in the context of the post Selby action plan, and particularly to inform the risk assessment being developed for the revised standard for vehicle restraint systems. To provide a full picture of the risks involved when vehicles leave the road, data are required on the effect of a variety of factors including

- Slope of ground
- Nature of ground - eg vegetation, firmness, presence of small obstacles
- Vehicle type
- Driver reaction after leaving the road

Although there are plenty of data on the numbers of vehicles leaving the road and involved in injury accidents, it was anticipated at the outset that there would only be limited data available on any details of the path of these vehicles after leaving the road, and the influence of roadside conditions on that path.

2 Sources of information

2.1 Literature review

Warrants for safety barriers requires information on the likelihood of vehicles leaving the road travelling far enough to hit obstacles, with potential resultant injury severity to vehicle occupants and third parties, or damage to structures. But direct data available on vehicle paths and vehicle distances travelled after leaving the carriageway is limited.

Most studies of the subject have collated data on the final location of vehicles that have left the road, and the type of objects hit, but these data mainly relate to US road conditions. More generally models have been developed which have been calibrated against observed numbers of accidents of different severities, and the relative severity of injury according to object hit.

A large number of the studies are also aimed at defining the value of hard shoulders or stabilised areas at the side of roads. The few direct measurements that have been made under experimental conditions have investigated the scope and effectiveness of the use of gravel arrestor beds.

It is useful to look at the development of research separately in the USA, Europe and Australia. The most extensive and longest programme has been in the United States, where AASHTO included advice on design for roadside safety in the 1967 guidelines. Further research led to revision of this in 1974, and subsequently updating in 1977, 1988, 1996 and 2002. Some direct measurement of the distance that errant vehicles reached was made as part of the 1960s studies, but there seems to have been little further direct testing. Subsequent work has focussed more on developing the mathematical modelling predicting accident outcome and comparing this with observed accident data. The principle of a 30ft (9m) clear zone was introduced in the 1967 guidelines and still remains central to US advice.

Road and traffic conditions in Europe vary from those in the US, particularly in terms of traffic flows, driving speeds, and vehicle types, although Swedish roads have more similarity to US roads than roads in many other European countries. In many European countries the scope to provide wide “clear areas” at the roadside is often more limited than in USA due to the higher density of development. Research in Britain, for example, has focussed mainly on the need for safety barriers at higher risk sites, and the value of hard shoulders and hard strips in reducing run off accidents.

Research studies in the Netherlands, Sweden, Finland, France and Germany have also been reviewed. These have focused particularly on the accidents arising from collisions with trees near to the roadside. ETSC (1998) reported that national percentages of fatalities resulting from collisions with roadside objects were 42% (Germany), 31% (France), 24-25% (Finland, Netherlands, and Sweden) compared with 18% in Britain. For countries where data were available, the percentage of fatalities involving collisions with trees were 24% (Germany), 17% (France), 12% (Sweden) compared with 7% in Britain in 2002. Knoflacher et al(1979) claimed that trees were only dangerous when less than 2m from the edge of the carriageway and less than 40m apart along the carriageway. A more comprehensive assessment of the effect on accidents involving collision with trees of the distance of the trees from the roadside has been made in the Netherlands (Schoon, 1997).

Most Australian research has focussed on the value and design of sealed shoulders, but there has recently been a very useful review (McLean, 2002) of the overall development of roadside design standards with a critical assessment of the US research as this appears most relevant to Australian road conditions.

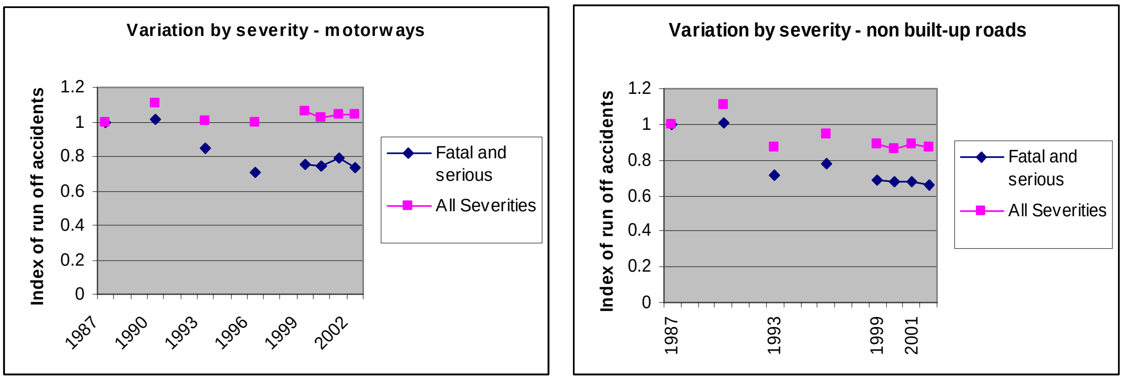
2.2 Accident studies

2.2.1 STATS19 data

National data but information on vehicles leaving the road limited to categorisation of objects hit which has been made since 1987. These categories include a fairly large group described as “other permanent objects” which are not well defined.

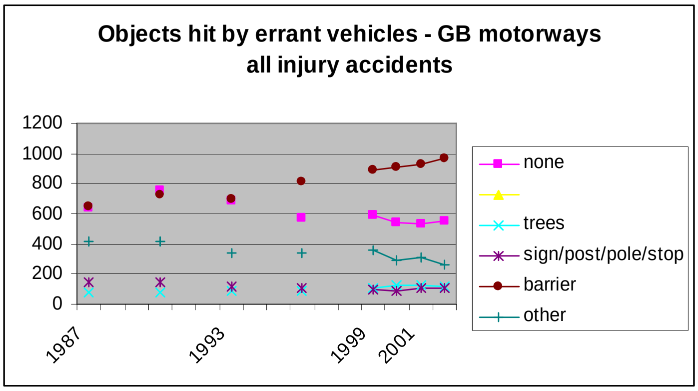
Fig 1 shows how the numbers of vehicles hitting different objects has varied between 1987 and 2002 On motorways, all injury run off accidents remained at a similar level while fatal and serious accidents reduced by about 25% between 1987 and 1996 but have since remained fairly constant. In comparison, there has been a similar reduction in all injury accidents but fatal and serious run off accidents have also reduced by about 10%.

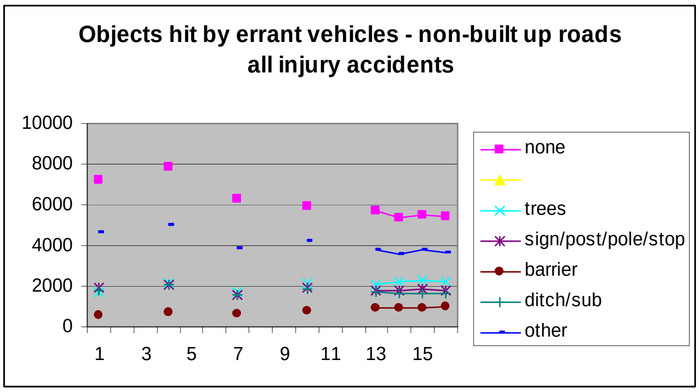
Figure 1 Variation in number of run off accidents between 1987 and 2001



These changes are different for accidents involving hitting different objects, partly reflecting changes in the incidence of these objects over time. Figure 2 shows that accidents involving safety barriers on motorways have increased over this period, probably reflecting the increasing use of barriers, while run off accidents involving no impacts have decreased. The same change is not so apparent on other non built-up roads, although accidents involving no impacts have also decreased on these roads.

Figure 2 Variation in number of different types of run off accidents between 1987 and 2001





Data for trunk roads only (1998 – 2002) shows an annual average total of 4199 single vehicle non-pedestrian accidents, of which 934 were fatal or serious. Of these, 79% resulted in vehicles leaving the carriageway. Of those leaving the carriageway, 63% left on the nearside, 35% on the offside and

2% were going ahead at junctions. Of those leaving the carriageway to the nearside, 42% occurred on motorways, 39% on dual carriageways, 15% on single carriageway roads with 60mph speed limits and 4% on other single carriageway trunk roads. About a third of those on motorways and a sixth of those on dual carriageways involved a collision with the barrier.

The severity of injury resulting from collision with different types of object on different roads is discussed in 3.7.

2.2.2 Fatal accident database

Detailed files of fatal accidents are held at TRL for about 5,350 run off accidents; most of these relate to the period 1987 to 1997. The analysis for this review has been limited to the data available in the IDB. This does not contain any record of how far vehicles travelled off the carriageway or the kind of terrain travelled over. It does include data additional to that in STATS19 on estimates of speed of leaving the carriageway and rates of ejection from the vehicle in this type of incident.

Unpublished research by TRL identified all accidents on motorways and dual-carriageways class ‘A’ roads (all speed limits) in which vehicles left the carriageway and a selection of these, mainly on motorways, was studied in detail. The accidents involving cars and HGVs occurred between 1990 and 1995 and were on motorways only, whilst those involving motorcycles hitting the central barrier were from 1985 onwards and were for both road types. The main conclusions were as follows:

- Objects hit were often on slip roads or on noses
- In some cases, the vehicle hit a safety barrier and then the object and/or got behind the safety barrier
- The object hit was not always recorded accurately in Stats19 e.g. it is not possible to describe multiple objects or embankments
- The term ‘other permanent object’ covers a wide variety of objects and can sometimes be mis-recorded
- In 9 out of 18 single vehicle fatal accidents involving a nearside/offside barrier was hit, it was the ramped end that was hit and two were at ramped ends at noses

2.2.3 CCIS data

This study is retrospective (ie it inspects vehicles after the crash, often at another location) and does not routinely collect accident scene data. The study is designed to correlate car occupant injuries to their causes and thus prioritise the vehicle design changes that will reduce real-world car occupant trauma the most effectively.

When considering crashes where the vehicle left the carriageway there are no searchable variables that can be selected in CCIS to highlight these vehicles. However, some 30% of the crashes CCIS investigates are Single Vehicle Accidents (SVA) and the majority of these involve the car leaving the carriageway and colliding with road side furniture, walls, trees or other objects. Therefore, single vehicle accidents within the CCIS database have been analysed and their characteristics outlined. Multi-vehicle collisions can also result in one or more vehicles leaving the carriageway, but this scenario is less common and is harder to quantify as the information is not routinely recorded electronically. Limited text descriptions are available of the objects hit during the accident and these have been inspected, for vehicles which are coded as hitting a “wide” or “narrow” object.

Some 1,257 of the crashes investigated by CCIS or some 30% (1257/4150) had damage to one vehicle only. The distribution of injury severity was considered and in the CCIS sample, the proportion of Fatal and Serious injury outcome was found to be significantly higher for Multi-Vehicle Accidents (MVA) than Single Vehicle Accidents (SVA), (Chi-square value = 11.360; df = 4; p =0.023). Forty six per cent of these accidents occurred on A roads, and the proportion of these which result in fatal or serious injury is higher than on other roads.

2.2.4 On the Spot Study

To evaluate the size and nature of the problem of *'Errant Vehicles'* using the "On The Spot" (OTS) database it is important to recognise that there are no 'easily' searchable variables that can be selected in OTS Phase 1 to highlight the crashes where vehicles have left the road (this issue has been addressed in Phase 2). However, some 34% (483) of the crashes OTS investigates are Single Vehicle Accidents (SVA) and it is believed that the majority of these involve the car leaving the carriageway and colliding with road side furniture, walls, trees and so on.

This study has simply selected crashes involving only one road user from the OTS database (currently some 708 crashes have been inspected by TRL). Some 83 of these were on trunk roads and the characteristics of these have been analysed. Of these 43 involved the vehicle leaving the road (the remainder involving collision with non-motorised road users).

2.2.5 Linking accident data with HA PMS

An attempt was made to see if trunk road lengths with different hardened strips or shoulders could be identified, with a view to comparing the severity of accidents involving different objects on these different lengths. There is an inventory item within HAPMS which describes the width and construction of the hard shoulder.

Data relating to hard shoulder width were obtained from the Highways Agency's HAPMS database. Each of the 38,000 records included the road name, a section identifier, grid references for the section, the direction, the width of the hard shoulder and the 'chainage' of that sub-section. If the hard shoulder width varied within a section there was more than one record.

Each record related to a sub-section between 1 metre and 4000 metres long. Sub-sections with narrow hard shoulders tended to be relatively short. Attempts were made to group neighbouring sub-sections so that analysis could be performed on longer stretches of road. This was not possible as neighbouring sections could not be identified automatically.

A second approach was tried in Fig 3. Sections with narrow hard-shoulders were plotted (in red) on a road map. These were then overlaid with a plot (in white) of sections of normal or wide hard-shoulder. Stretches of road where the narrow plot had not been obscured by the standard plot could be identified as containing only narrow hard-shoulder. About 10 stretches more than 5 km in length met these criteria. However, close inspection of these sections revealed that the sum of the sub-section lengths from HAPMS fell short of the true road length. It was clear from this (and from discussions with regular users of HAPMS) that the information for hard-shoulder width was incomplete. It is possible that in some areas only stretches of road with narrow hard-shoulder have been added to the database and that the missing sections all have standard hard-shoulder. It was therefore decided that HAPMS would be unlikely to provide sufficient accurate information to compare accident rates according to the hard-shoulder width.

An investigation of substandard hard shoulders on motorways found similar problems. It was estimated that there might be up to 120km of motorway with substandard shoulders but the majority of the sections were only of short length. This seems to be confirmed by Figure 3.

Figure 3. Trial plot of run off accidents by shoulder width

3 Review of information on relevant issues

3.1 Speed of leaving the road

Data on distribution of speeds of vehicles involved in fatal crashes are available from the fatal files database, in the form of an estimated "cruising speed". This is based on evidence at the site – often tyre marks – and therefore in many cases will record speed at the point when the wheels of the vehicle have locked under braking. The estimates from these sources suggest that the average speeds of vehicles at this point is about 60mph on roads with a 70mph speed limit, and 53mph, 52mph and 52 mph respectively on roads with 60mph, 50mph, and 40mph speed limits respectively. The higher speeds on the roads with lower speed limits may reflect a high proportion of vehicles leaving the carriageway when taking bends at excessive speed.

On the higher speed roads, there is very little variation in the estimated "cruising speeds" between those leaving the road on the nearside, offside or through central reservation.

3.2 Angle of departure from the road

Most measurements of vehicle encroachment have been based on the final locations of accident involved vehicles. For these vehicles, the encroachment distance, typically measured as the distance at right angles to the edge of the carriageway, is the combined result of the angle at which the vehicle left the road, the effect of any driver intervention that modifies the vehicle path, and the distance travelled by the vehicle along this path.

Tests of safety barrier performance are usually done with an angle of impact of 20 degrees. Barrier design is aimed at stopping the vehicle from passing through the barrier, and subsequently redirecting the vehicle along the barrier face. As the angle of impact increases, this outcome is harder to achieve. The test angle has been chosen therefore to cover the majority of the situations in which vehicles leave the road and represents the maximum angle at which the barrier will definitely restrain the vehicle.

In practice, vehicles will leave the road at a range of angles depending on the events immediately prior to leaving the road. For example, a vehicle may be involved in a collision, may swerve before it leaves the road, or the driver may over-correct and end up on the other side of the road. If none of these happen, a simple point mass model for vehicles travelling along a circular arc gives the maximum angle at which it can leave the road (depending on the speed of travel, the distance from the edge of the carriageway and the coefficient of friction). As the vehicle's encroachment speed increases, the maximum encroachment angle decreases and these low values have been used in a number of encroachment models.

Earlier researchers assumed an angle of 20 degrees for encroachment models but this has subsequently been reduced as data from on road accidents was investigated.

The distribution of encroachment angles obtained by Hutchinson and Kennedy (quoted in Glennon, 2002) are shown in Table 1 below.

Table 1 Distribution of encroachment angles (Hutchinson and Kennedy 1966)

Angle (degrees)	5	10	15	20	30
Cumulative percent	25	60	75	85	95

The average angle of departure from Hutchinson and Kennedy data is 11 degrees. A similar figure (12 degrees) was quoted by Ehrola (1981) although it was again stressed that this was an average of a wide range of departure angles for individual vehicles.

Sicking and Ross (1986) assumed a probability of encroachment angles varying with speed, combining data from Hutchinson and Kennedy with that for Cooper (1980), shown in Table 2. The highest probability band for all speeds is between 5 and 15 degrees which is consistent with Table 1. However it has been pointed out (Mak and Sicking, 2003) that this data is based mostly on collisions with utility poles, which commonly run alongside rural roads, and that lower speeds will tend to be under-reported.

Table 2 Distribution of encroachment angles assumed in Sicking and Ross

Angle (degrees)	5	15	25	35	45	90
Cumulative percent	10	55	83	94	98	100

The US model developed in SR214 used an angle of 6.1 degrees. By contrast, the US 1996 AASHTO model (ROADSIDE) assumes an angle of departure of about 10 degrees at a design speed of 120kph for the hazard module, with a distribution of angles used to determine the distribution of lateral extent. The latest 2002 AASHTO model (RSAP) uses a distribution of angles based on Mak et al (1986) and related studies.

On GB roads, it is estimated (DfT, 2000) that perhaps 16% of encroaching drivers are asleep and would therefore leave the road at a shallow angle. Data from fatal accident files show that in about half of these, the errant vehicle had hit another vehicle before leaving the road; these vehicles are likely to have left at higher than average angles.

3.3 Encroachment rate and distance travelled from the road

3.3.1 Observations of encroachment

The encroachment rate has been estimated by a number of authors in the US

Hutchinson and Kennedy (quoted e.g. in Sicking and Ross) - data from observations of tyre tracks on snow-covered medians of rural interstate highways in Illinois (70mph roads)

Cooper (quoted e.g. in Sicking and Ross) – data from observations of tyre tracks on grass verges on 2-lane and 4-lane Canadian roads with lower speeds (80-100kph),although Sicking and Ross claim that the presence of hard shoulders disguises the proportion of short distance encroachments in Cooper’s data.

Calcote et al (1985) (quoted in Mak and Sicking, 2003) used time-lapse video photography on urban freeways. An overwhelming majority of the encroachments recorded involved vehicles moving slowly off the roadway for some distance and then returning into the traffic stream without any sudden changes in trajectory, thought to be due to drivers being fatigued or distracted, or possibly responding to traffic conditions.

In Europe, Ehrola (1981) investigating incidents where vehicles ran off the road in Finland during the period 1971 to 1975 found that in more than half the cases the vehicle had come to rest in the open ditch beside the road, while 1 vehicle in 10 had travelled as far as 12m from the edge of the road. About 6 out of every 10 vehicles running off the road in fatal accidents had overturned and 3 out of every 4 had collided with a roadside obstacle.

Information for Finland was updated by a study by Hautala, 1996 (quoted in SAFESTAR, 1997). This suggested that over half of the accidents hit objects less than 3m from the edge of the road, and 88% less than 7m from the road edge.

3.3.2 *Comparative accident studies of encroachment distance*

The main data sources for lateral encroachment distances of vehicles following run-off are again in the US. Examples are:

Zegeer and Parker (1984) investigated the effect of offset on accident frequency with utility poles and found a rapid decrease in frequency with offset

Zegeer et al (1988) investigated variation in accident rate by average roadside recovery distance (i.e. distance from running lanes that is basically flat, unobstructed and smooth within which there is a reasonable opportunity for safe recovery of an out-of-control vehicle). A recovery distance of 10 feet was associated with a reduction in related accidents of 25% and a distance of 20 feet with a reduction of 50%. The results are summarised in Table 3.

Table 3 Estimated changes in accident rate as recovery distance increase (Zegeer et al)

Distance m	1.5	2.5	3.1	3.7	4.6	6.2
Accident rate reduction %	13	21	25	29	35	44

Knuiman et al (1993) found that median accident rates and severity decline rapidly when the median width exceeds about 25 feet (7.6m).

Wright and Robertson (quoted in Mak and Sicking, 2003) analysed 300 single-vehicle, fixed-object fatal accidents in Georgia in an attempt to determine encroachment rates at bends and on gradients by comparing the characteristics of the accident sites with controls 1 mile upstream of the accident sites. Bends were significantly over-represented at the fatal accident sites, with the outside of the bend accounting for 70% of the fatal crashes on bends. Downhill gradients of 2% or more were also found to have some effect.

Klassen (2003) reported German studies which compared run off accidents rates for roads with different clearance distances on either side. These suggested the following reductions in accident numbers might be obtained from varying the clear zone widths – 26% from adding a 3m clear zone, 30-48% from extending a 1.3m clear width to 5m clear width, and 60% from extending a 1m clear width to 8.6m.

Studies in the Netherlands in the 1980s (reported in Schoon, 1997) looked at accidents on road sections lined with rows of trees at various distances from the edge of vehicle running lane. The ratio of the number of accidents involving trees to the number of accidents not involving trees was taken as a proxy for the distance that vehicles travelled into the roadside. The results are shown in 3.3.3.

3.3.3 *Modelled encroachment distances*

The results of the US studies during the 1970s and 1980s are summarised in a comparison of exponential, linear and sinusoidal distributions in SR214 (TRB, 1987). These produce similar estimates over most of the range of interest (Table 4). One of the main difference is in the estimate of run offs only travelling a short distance off the road, for which true rates are very difficult to establish.

Table 4. Comparison of lateral travel distribution models (SR214)

Encroachments per mile per year with flow of 6000 vehicle per day					
	Lateral distance encroached (m)				
Type of curve fitted	1	2	4	6	8
Exponential	6.8	5.1	3	1.8	1.2
Straight line	6.1	5.3	3.7	2.0	1.0
Sinusoidal	6.2	5.5	3.8	2.0	1.0

Schoon (1997) modelled the ratio of accidents involving trees as a proportion of all accidents, as a function of distance of trees from the road, for motorways and two lane rural roads in the Netherlands. The results are summarised in Table 5.

Table 5. Ratio of tree accidents and distance vehicle travelled into clear zone (Schoon)

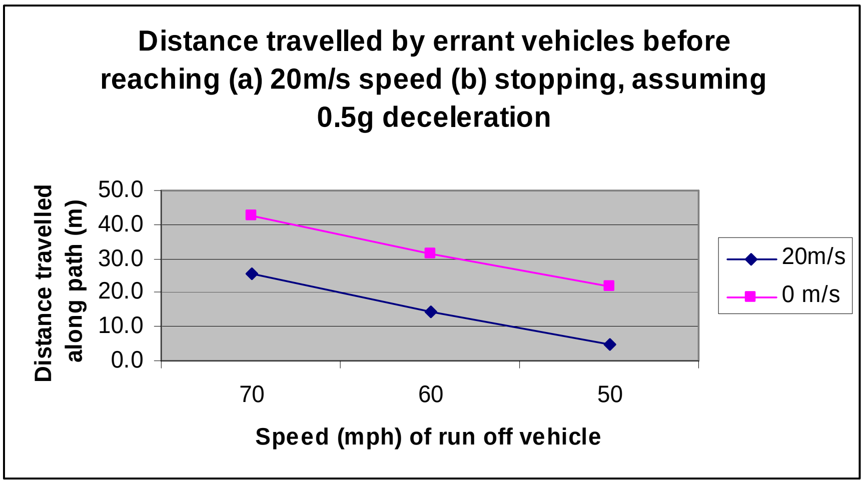
Ratio of tree accidents to other accidents					
	Width of zone free of obstacles (ie distance to tree line) (m)				
Type of road	2	4	6	8	10
Regional two lane AADT >5000	0.18	0.09	0.045		
Federal two lane AADT 5-10,000	0.285	0.18	0.12	0.075	0.05
Motorways AADT>30,000		0.17	0.14	0.115	0.095

Schoon suggested that a ratio of 0.1 (ie a maximum of 10% of accidents being associated with collision with trees might be assumed as an acceptable threshold. On this base acceptable obstacle free zones would 3.5m (regional two lane road), 7m (federal two way road, and 10m (motorway). But no reason is given for the choice of 10% as an acceptable ratio.

3.3.4 Estimates based on mechanical equations

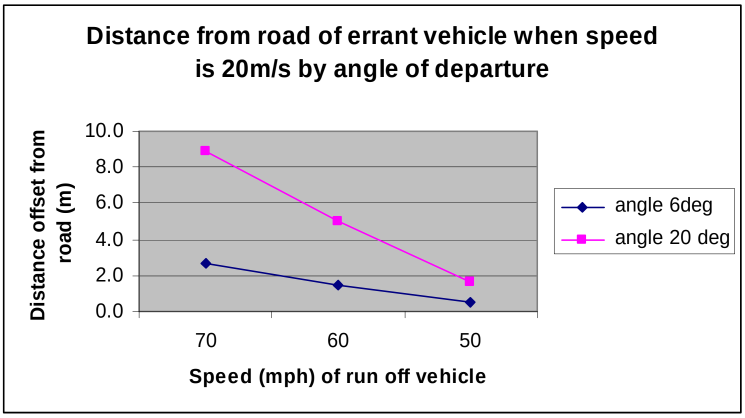
Basic calculations can be made of the distances that vehicles are likely to travel when leaving the road as a function of initial vehicle speed and deceleration. The latter will depend on the friction provided by the ground over which the vehicle travels, and the extent of any braking by the driver. Figure 4 shows the distances reached with different initial speeds, assuming a deceleration equivalent to 0.5g (4.55 m/s/s). Distances are shown for the vehicle coming completely to rest, and also for the vehicle speed reducing to 60kph (20m/s); the latter is the speed at which a car which has a good NCAP rating can be expected to protect its occupants from fatal injury.

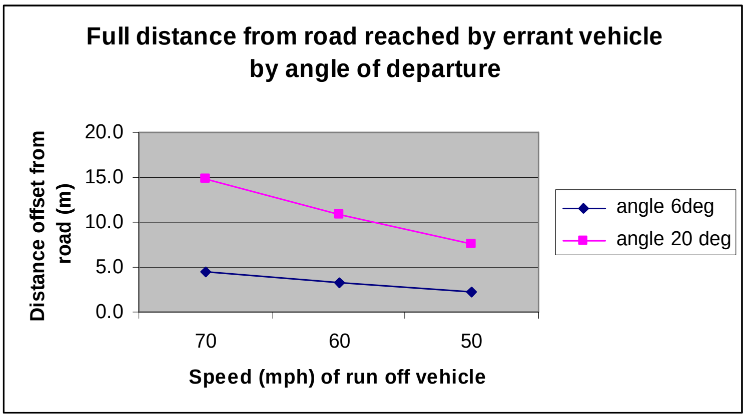
Figure 4 Distance travelled by errant vehicles along their path



For any particular assumption of initial speed and deceleration, the distance that the vehicle will encroach into the roadside area will depend on the angle at which it leaves the road. Figure 5 shows these encroachment distances for different angles, again based on the two "final" speeds used above.

Figure 5 Example of variation in encroachment distance by angle of departure and final vehicle speed





For situations where the main risk arises to the car occupants, the distance of interest will be that required to bring the vehicle within an impact speed of 20m/s. Where there is additional risk of impact with third parties or of reaching a road, railway or water hazard after leaving the road, the distance required to bring the vehicle to a standstill is likely to be of more relevance.

3.3.5 Data from On The Spot investigations

Of the 83 single vehicle incidents on trunk roads in the TRL database, 9 of them involve vehicles which did not leave the running area of the road – most involving either cars that roll within the carriageway or motorcycle riders that come off their bike within the carriageway.

Of the remainder, 31 (42%) involved vehicles which hit the safety barrier but were contained within the carriageway area; 23 of these were on motorways and 8 on A roads. Of these, 25 (81%) did not result in injury. Of the 3 serious injury accidents of this type, two involved motorcyclists and one a vehicle which travelled across the carriageway, hitting barriers on both sides of the road.

For the 43 incidents for which vehicles left the carriageway, the distribution of the distances (offset at right angles from the carriageway) that vehicles ended up is shown in Table 5. For the motorways, these distances are measured from the back of the hard shoulder.

Table 5. Encroachment by errant vehicles (OTS sample)

Road	Speed limit	Distance from edge of carriageway (m) – excluding hard shoulder										
		1	2	3	4	5	6	7	8	9	10	>10
M	70	6	4	1		2	2		3		2	5
A	70	1	1	1		1			1			1
A	60	1	2			1					1	
A	<60	1	1		1	1					1	1

Detail of the individual conditions affecting each of these incidents is given in Appendix 1. Of the vehicles encroaching more than 5m on single carriageway trunk roads, one was the result of brake failure, one went straight ahead at roundabouts, and one left the road on the nearside and rolled into a ditch. Of the two vehicles encroaching more than 5m on dual carriageway trunk roads, one crossed a central reservation and rolled over and the other went straight ahead at a roundabout. Of the 5 motorway incidents where vehicles encroached more than 10m beyond the hard shoulder, one travelled at excessive speed crossed to the far side of the central reserve, one spun at a roundabout and another spun after drifting to far to the right in the outside lane, one was an HGV driver who fell asleep, and the fifth a motorcyclist. Of the five motorway incidents involving encroachment to 8 and 10m beyond the hard shoulder, three involved vehicles which first hit the offside barrier, one was a fatigued HGV driver, and in the fifth the vehicle spun down a slope.

These detailed examples suggest that most of the cases involving higher encroachment distances are likely to involve either driver fatigue or vehicles which leave the road at high angles due to swerving or spinning within the carriageway.

3.3.6 Travel of vehicles during impact tests

Recent impact tests at TRL on different diameter steel circular hollow section posts have provided some information on the travel of vehicles after these impacts. Impact of a Ford Fiesta on an 89mm diameter sign post at 100kph resulted in the sign post being bent to the ground as the vehicle passed over it, and the vehicle was brought to rest by a catch net some 69m beyond the site of the post. In a similar test with a 114mm diameter post the rear of the vehicle was pitched in the air, but the vehicle continued and spun round to face the direction from which it had come before coming to rest approximately 17m beyond the original position of the sign post. In a lower speed test (35kph) with the smaller diameter post the post was again bent over as the vehicle passed over it, but the vehicle stopped with the front of the vehicle approximately 4.6m beyond the sign post.

The injury level sustained with the 114mm diameter post was not considered acceptable, and on the basis of the other two tests it was recommended that sign posts should not exceed 88.9mm diameter and 3.2mm wall thickness.

3.4 Information on factors affecting resistance to travel

Mak and Sicking (2003) assert that although some vehicles do undoubtedly slow down during ran-off-road accidents, accident data do not reflect any significant variation within the first 6 m from the edge of the carriageway. Other authors have assumed a fixed deceleration rate of 0.4g (3.7 m/sec^2). The deceleration rate corresponding to the Highway Code braking values is about 0.7g. However, it is likely that some drivers, for example, those who fall asleep, do not attempt to brake their vehicles at all, but these are also likely to leave the road at very shallow angles and therefore have further to travel before reaching obstacles at a given distance from the roadside.

3.4.1 Slope and vegetation

The gradient of the slope of the side of the road affects run off

- By modifying the distance that vehicles will travel by increasing or decreasing the rate of acceleration
- By increasing the likelihood that drivers will lose control of the vehicles and they will roll over

Zegeer et al (1988) developed models showing the effect of side slopes on the single vehicle accident rate on two-lane rural roads, analysing accident data from 1777 miles of rural roadway. The model developed from these data suggested that single vehicle accident rates increased by 30% as downward slopes increased from 1:7 to 1:3. There was very little difference for slopes with gradients of 1:2 and 1:3. Both Allaire et al (1996) and Lee et al (1999) agree that the number and severity of run off accidents are reduced significantly in US by flattening side slopes. Wolford and Sicking (1996) investigated the need for safety barriers at embankments and produced a graph indicating when a barrier would be cost effective as a function of traffic flow – generally when the side slope was 2:1 or steeper, except on very low flow roads

Schoon (1997) gives examples from US encroachment models showing vehicles running off a 6omph design speed road onto a slope of 1:6 requiring a clear zone of 9m, while the same vehicle on a slope of 1:4 would require a clear zone of 13.5m. He quotes work by Schoon and van der Pol involving twelve full scale tests on slopes with gradients of 1:2.2 and 1:4. This showed that on descending slopes the radius of curvature at the top of the slope was of great importance in preventing the wheels of the vehicle from leaving the ground. He suggests that the radius of curvature should be no less than 9m and preferably 12m. With a gradient of 1:4 the vehicle stays in good contact with the ground, but steering manoeuvres are not helpful in gaining control. A gradient of at least 1:5 and a slope height of 5m is necessary if the driver is to get the vehicle under control on the slope. When the slope height was less (2m) a gradient of at least 1:6 was required. On ascending slopes the authors suggested that the radius of curvature had to be at least 4m, and that a gradient of 1:2 or gentler would be acceptable.

Schoon also quotes US encroachment models as suggesting that slopes with downward gradients of 1:4 and flatter are recoverable. Hedman (1990) similarly recommends slopes of 1:4 or flatter for Swedish roads. More recently in Sweden, the SNRA have proposed profiles for their roadside which have an initial downward gradient of 1:6, followed by a flat width and then an upward gradient of 1:2. Part of the aim of this design is to channel the vehicles along the flat area parallel to the road between the downward and upward slopes.

There is relatively little information available about the effect of vegetation or ground condition on vehicle behaviour, other than that which can be inferred from tests of arrestor beds. One exception is the early work by Laker (1966a) which investigated the option of using thick vegetation as a barrier to vehicle penetration across the hard shoulder. Tests were made of cars impacting a 20ft thick 6 year old hedge of rosa japonica. The tests showed that the vehicles were retarded at about 0.45g. Cars impacting the hedge at 90 degrees at a speed of 19mph and at 20 degrees at a speed of 32mph both passed completely through the hedge. A third car impacting at 10degrees with a speed of 29mph came to a halt after travelling 54 feet (about 17m) within the hedge.

Data from the small OTS sample suggests that two thirds of vehicle leaving the road had travelled over earth or grass, and most of the rest through shrubbery vegetation; less than 3% ran over hard ground.

3.4.2 Studies of arrestor beds

Tests (Laker 1966b; Jehu and Laker 1969) have indicated that average decelerations of about 0.45g for unbraked vehicles and 1g for braked vehicles could be achieved when cars are driven into beds of gravel. These tests indicated that deceleration was independent of vehicle entry speed, but later research by Cocks and Goodram (1982) concluded that deceleration rate reaches a maximum at about 50kph and decreases with entry speeds above this figure.

Higher decelerations were achieved with smooth rounded gravel than with angular gravel; gravel should be 5-10mm diameter.

Vehicle mass has little effect on the decelerations achieved but Cocks and Goodram concluded that axle and tyre configuration did have an effect, with a large articulated vehicle with tandem axles on both prime mover and trailer having a lower deceleration than a single axle rigid truck.

Laker (1971) also tested the effect of side entry into arrestor beds. Compared with end on entry decelerations of about 0.5g, decelerations after side entry of about 0.3g were achieved. There was very little steering ability available whilst the vehicles were in the gravel bed.

3.5 Rollovers

The likelihood of rollover and the resulting injury is influenced by many factors, for example prior impacts (especially with a barrier), slopes, ditches, and impact with obstacles while rolling. The occurrence and outcome are therefore difficult to predict.

Viner (1995a, 1995b) reported that rollover was the leading cause of run-off-road fatalities in the US, accounting for one third of fatalities on rural roads. They were most common on 2 lane rural roads, particularly on bends. Frequently the vehicle was skidding before it left the carriageway – this was less likely to be the case for vehicles hitting a fixed object. Typical causes of roll-over were a steep side slope (1:1 or greater) or a ditch with near vertical sidewall. Whether or not roll-over occurred appeared to be strongly dependent on crash speed.

Pickups and utility vehicles were overrepresented in rollover fatalities compared with those hitting objects off the carriageway, and small cars were more likely to be involved in rollover accidents than large cars.

Viner quotes data from both Hall and Zadoor (1980) and Terhune (1991) as showing that about a quarter of fatal rollover cases involved overturn on the opposite of the road from the initial departure.

Hautala (quoted in SAFESTAR, 1997) shows that for run off accidents in Finland between 1991 and 1995

- In about a fifth of the accidents the vehicle rolled around the vertical axis either once or several times
- In about a third of the accidents the vehicle rolled about the horizontal axis
- In about a third of accidents the vehicle did not roll at all

In the CCIS sample, 43% of the vehicles had been involved in rollover. Of these about half only involved rollover, and half involved rollover and impact with an obstacle. Of the latter group, 80% rolled after impact, 16% before impact, and 4% between impacts.

3.6 Outcome where safety barrier present

In Britain, 16 (31%) out of 51 fatal accidents involving single vehicles on motorways in 2002 were recorded as having involved a collision with a safety barrier. This is about 9% of all fatal accidents on motorways. The proportion of motorway accidents involving collision with a barrier resulting in serious and slight injury accidents were somewhat higher at 37% and 51% respectively. These represented 13% and 11% respectively of all motorway accidents of these severities.

In comparison, Schoon (1997) reported that the percentage of fatalities involving collision with safety barriers, as a proportion of all motorway fatalities, was about 20% in the Netherlands, in Belgium, and in Denmark. In the Netherlands about half of these died from collision with the barrier in the primary phase of the incident, whilst half died as a result of colliding with barrier in the secondary phase. Schoon also refers to McCarthy (1987) who looked at barrier involvement in 81 reconstructed accidents and concluded that in 70% of these the vehicle sustained a secondary impact after smooth redirection following the initial impact with the barrier.

The OTS sample analysed contained 23 incidents on motorways and 10 on trunk A roads where vehicles hit safety barriers and were contained within the carriageway after the impact. Of these, 20 of the motorway incidents and 7 of the A road incidents resulted in no injury and would not have been reported as injury accidents. In addition a further 7 incidents on motorways and 1 on an A road involved barriers being hit and the vehicle leaving the carriageway. Most of these again resulted in no injury, with 2 of the motorway incidents being slight injury accidents and the A road incident resulting in serious injury through impact with a nearside wooden fence after clipping the barrier on the offside. Both of the accidents where motorcyclists hit the barrier but were contained within the carriageway resulted in serious injury.

The data from the fatal accident files showed that occupants involved in a collision where vehicles hit a barrier were much more likely to be ejected, than those where vehicles left the road without contacting a barrier. For those either hitting the central barrier and rebounding or the offside barrier and rebounding, some 22% suffered full ejection from the vehicle. For those hitting the nearside barrier and rebounding the proportion was 15%. In comparison, for those leaving the carriageway either to the nearside or offside, without rebounding from the barrier, the proportion with an occupant fully ejected from the vehicle was only 7%. It is probable that the greater proportion of ejections after hitting the barrier is the result of subsequent rollover which is more likely to result in a fatal outcome.

3.7 Driver response

3.7.1 Influence of hardened shoulders

Many authors (Crowley 1973; Rinde et al 1977; Zegeer and Perkins 1980; Rogness et al 1981; McLean 1996; Ogden 1997) have identified that accidents can be reduced by adding or widening shoulders on the roadside. Crowley claimed substantial (50%) reductions from 2.5m shoulders on 7.3m roads. Ehrola (1981) concluded that the rate of vehicles leaving the road in Finland in the early 1970s reduced by 10-20% for every additional metre of hard shoulder provided. He noted that the rate was particularly high with asphalt surfaced roads with a hard shoulder of gravel, although he does not say what mechanism causes the increased rate.

Zegeer and other US authors have suggested rather lower benefits, although acknowledging that cost benefit ratios can be high where there are relatively high run off accident rates. In more recent years, McLean (2002) has claimed that potential reduction rates in Australia are higher than some of the US estimates, and Ogden estimates a potential reduction of 43%.

Several Australian authors have also pointed out the potential value of sealing unsealed shoulders on Australian roads; this was first noted by Armour in 1984, and Ogden (1992) and Corben (1997) has claimed potential accident reductions of 43% and 32% respectively.

In UK, hard shoulders are standard on motorways and interest has centred more around the value of metre strips on dual and single carriageways. Simpson and Brown (1988) reported data showing that roads with these strips were associated with accident rates some 20% lower than those without strips. Walmsley and Summersgill (1998) concluded that roads with hard shoulder were 16-18% safer than roads without. Their data suggests that this reduction is higher (up to 25%) on dual carriageways and probably less than 10% on single carriageways. It also suggests that the reductions are mainly in accidents that would otherwise result in slight injury.

A further measure aimed at reducing run off accidents associated with fatigue involves the use of hard shoulder rumble strips. Garder and Alexander (1994) reviewing the use of such strips in 34 US states concluded that continuous strips could reduce accidents by 20-50%.

3.7.2 Role of fatigue, alcohol and excessive speed

Department for Transport (2000) estimates that up to 20% of accidents on motorways may involve driver fatigue. These accidents are typified by vehicles leaving the road at a relatively shallow angle with little or no driver intervention to brake or change the vehicle path.

The small sample of OTS cases analysed identified 2 out of the 25 incidents where vehicles left a motorway as being fatigue related; the vehicles in these cases encroached 8m and 15m from the motorway. One case of excessive speed (80mph) was\also identified. Eight of the 18 incidents where vehicles left non-motorway trunk roads were at roundabouts, with several indicating inappropriate speed.

ETSC (1998) reported that 46% of the collisions with trees in France involved drivers affected by alcohol. In Germany high speed and alcohol, and in Finland, high speed, were associated with large proportions of run off accidents.

Kim and Li (1997) report for Hawaii that drivers involved in single vehicle accidents are less likely to be wearing seat belts, and are more likely to have accidents involving excessive speed, alcohol and drug use, and to occur in late evening or early morning.

3.8 Object hit and injury severity

3.8.1 Objects most often hit

Data from STATS19 for British trunk roads (Table 6) shows that on motorways crash barriers are the most likely object to be hit, while on dual and single carriageway high speed trunk roads “other permanent object” are recorded most often. The proportion of collisions involving trees varies from 10% on motorways to 18% single carriageway roads. These proportions reflect the number of each type of object present as well as their proximity to the road.

Table 6. Proportion of objects recorded as hit in accidents on trunk roads (1998-2002)

Percentage of all nearside run off accidents for each road type by object hit			
Object hit	Motorway	Dual carriageway	Single (60mph)
None	20	19	19
Central crash barrier	3	3	-
Entered ditch	9	12	14
Lamp post	4	12	6
Nearside/offside crash barrier	31	13	3
Other permanent object	19	16	30
Road sign/traffic signals	4	11	8
Telegraph/electricity pole	0	1	3
Trees	10	14	18

3.8.2 Proportion of injury accidents that are fatal by object hit

Data from STATS19 for the trunk road network over the period 1999-2002 is shown in Table 7 to illustrate the proportion of fatal accidents associated with each type of object and road type . These proportions will reflect the types of objects hit on these roads and their position in the highway, so this does not necessarily give a direct comparison of there aggressiveness. But the pattern shows some consistent features, with trees being associated with the highest proportion of fatal accidents per collision on all three road types, and the overall fatal accident proportions being similar on all three road types. For comparison, data are also present from a US study (Zegeer et al, 1988); trees again show a relatively high proportion of fatal accidents, but collision with culverts are also very severe.

Table 7. Proportion of accident by severity and object hit

	STATS19			Zegeer et al	
Object hit	Percent of all injury accidents that are fatal			% fatal of all injury	% injury of all incidents
	Motorway	Dual	Single rural		
Roll over – no object hit				3.2	57
All objects	3.4	3.2	3.3	2.2	41
Median barrier	4.3	0.7			
Ditch	3.3	4.0	1.4		
Lamppost	6.9	3.3	3.0		
NS/OS barrier	2.6	2.7		2.4	39
Other permanent	4.4	3.2	2.3		
Signs/signals	4.2	2.9	4.1	1.8	34
Tree	5.1	5.4	8.5	5.2	53
Pole			2.4	2.4	47
Fence				2.0	35
Culvert				5.4	60

Data from the TRL fatal accident database shows that of the vehicles leaving the road (and not rebounding) about half (54%) had hit another vehicle before leaving the road. Of this 54%, 36% had been in collision with a car, 10% with a PSV or HGV, 4% with light goods vehicles and 4% with a motorcycle.

3.8.3 Proportion of all run off incidents that are injury accidents by object hit

No data are routinely collected in Britain on non-injury accidents. However some data are available from the OTS sample where the investigators are called out without knowing the severity of the accident. In the small sample of run off incidents about40% to which the team responded were recorded as injury accidents.

Studies of run off accidents in US have used databases in which non-injury accidents are recorded. The accident reporting and injury coding system is different from that in Britain, but most authors (Mak and Mason, Griffin) quoted 45-50% of these accidents as involving injury. Zegeer et al (1988) report severity in relation to object hit as shown in Table 7. Incidents involving rollover have a higher proportion of injury accidents than those only involving impact while among the latter group, the highest proportion of injuries is to those in collision with trees and culverts. These patterns are consistent with the pattern of fatal accidents described above although the relative differences in proportions are not so large.

3.8.4 *Relative severity factors*

The data given in Tables 6 and 7 could be used to produce an indication of the relative influence of different objects on the severity of injury likely to result, based on the average severity in each group, which roughly equates to the severity of impact with a lamppost. Table 8 provides an example of the potential outcome. It should be noted that the level of injury at which an injury accident is reported in US is different from that in Britain.

Table 8. Potential comparative aggressiveness factors for collisions with different objects

Kerb	Guard-rail	“Safe” guard-rail end	Small signpost Parapet rail?	Lighting column	Culvert	Utility pole	Tree Large signpost	Bridge pier
Based on injury accidents per collision (US data)								
0.1	0.30	0.40	0.6	1.0	1.3	1.4	1.6	2.0
Based on fatalities per injury accident (US data)								
	1.1		0.8			1.1	2.4	
Based on fatalities per injury accident (STATS19 GB data)								
	0.8		0.85	1.0			1.5	

3.8.5 *Severity outcome by speed of impact*

From US data, Mak and Mason suggested there was a 50% chance of injury in pole impact with impact speed as low as 6mph (with US vehicles and occupant protection) and chance increase dramatically at speeds above 30mph.

There is very little British data on which to define the severity of injury likely to result from different impact speeds (for an object of average aggressiveness), but an estimate could be compiled for GB (Table 9), based on the following assumptions

- No fatals below 10m/s
- No serious below 5m/s
- Proportions in each severity group increase with V squared
- Average proportions in GB data relate to collision speed of 20m/s

Table 9 Estimate of effect of vehicle speed at impact on injury severity

Speed m/s	% Fatal	% Serious injury	% Slight injury
5	0	1	99
10	1	5	94
15	2	12	86
20	4	20	76
25	6	31	63
30	9	45	46

As part of the CCIS analysis an estimate is made of the Equivalent Tests Speed (ETS) that reflects the speed of impact of the vehicle with the obstacle. For the sample of vehicles evaluated, the median

ETS for frontal impact was about 15 m/s, and for side impact 12 m/s. That suggests the average GB severity proportions might be associated with rather lower speeds than assumed in Table 9.

3.8.6 Obstacle spacing, safety barrier gaps and the effect of ramped ends

Proctor (1997) attempting to estimate the numbers of accidents involving ramped ends suggested that up to 10-15% of accidents involving barriers on motorways might fall into this category; rather more than half of these were with exit slip nosings. A survey of a sample of southern and midland motorways suggested that over 60% of exit slips had ramped ends. From his study, Proctor recommended that a minimum gap between adjacent sections of safety fence should be 150m, and that existing gaps of 80m or less should be infilled during routine maintenance.

In unpublished research by TRL, it was assumed the potential likelihood of injury from hitting a ramped end on the nearside of the road was equivalent to that defined in US data in Table 8 as “guardrail – safety end”. This suggests the likelihood of injury to be a third or less of that associated with an impact with a large diameter signpost. Using encroachment theory with data from US roads, It was estimated that the number of injury accidents per ramped end might be 1 in every 300 years. Comparing the costs and benefits of safety fencing, it was also estimated that the minimum gap in safety fencing should be at least 50m. Schoon (1998) stated that French Standards suggest a minimum gap of 100m in safety fencing on the verge.

3.8.7 Spinning, rollovers and vehicle orientation

Mak and Sicking (2003) report on an earlier study of vehicle orientations at impact, based on an accident study involving utility poles, lighting columns and sign supports. They note that vehicle orientation at impact can have an important effect on the severity of many types of run-off accidents, including breakaway supports, guardrail terminals, and barriers.

Viner (1995) states that slope rollovers result in more severe injury than the average run of road accidents, accounting for 26% of all run off fatalities although they only make up 15% of these crashes. But rollovers which include collision with an object have the highest severity, accounting for 25% of run off fatalities, but only 5% of crashes. These outcomes will be affected by US seat belt wearing rates and may not be similar in UK. Viner (quoting data from Terhune, 1991) reports that in US the pre-crash orientation of vehicles is different for vehicles involved in slope rollover and vehicles hitting fixed objects. For the former, 71% are in a lateral skid, 10% tracking, 9% spinning and 7% in a frontal skid. For the latter, 46% are tracking, 24% in a frontal skid, 14% a lateral skid, and 5% spinning.

Although CCIS data suggest that injury severity for rollover without impact is lower than with impact, the average overall severity from all rollovers (38% fatal and serious) is still lower than for impacts (45%). For collisions without rollover, 60% are to front of car (40% fatal and serious), 15% to left side (55% fatal and serious), and 20% to right side (57% fatal and serious).

4 Linking the information into a model

Various aspects interact to determine where vehicles finally travel to and the likely injury outcome.

Models of this interaction typically follow the form developed in the US including

Probability of encroachment beyond traffic lane

Lateral encroachment distribution

Severity index of obstacles within potential encroachment area

4.1 Model relationships

4.1.1 Fixed objects

Edwards (1968), quoted in Zegeer et al (1988), developed the first encroachment probability based model for lighting columns on freeways, based on the Hutchinson and Kennedy data. This model was extended by Glennon (1974) to other objects on rural 2 lane and multilane roads and was the first to use the hazard envelope approach shown in Figure 6. All these models were applicable to a single vehicle type, an average encroachment angle and a straight line path.

Zegeer and Parker (1984) obtained an empirical formula for objects hitting utility poles:

$$\text{Acc/mile/year} = [9.84 \times 10^{-8}\ \text{ADT} + 0.0354\ \text{DENSITY} / (\text{OFFSET})^{0.6}] - 0.04$$

where ADT is the average daily traffic flow

DENSITY is the number of utility poles per mile

OFFSET is the distance in feet from the carriageway

Miaou (1997) developed regression models for vehicle accidents as a function of flow and geometric design variables.

Appendix F of SR214 (TRB, 1987) gives an encroachment model developed from work by Zegeer et al (1986). The model has the following general form.

Expected number of accidents involving a specific hazard =

Expected no. of encroachments on section containing hazard x

Probability that, given an encroachment, impact is possible x

Probability that, given an encroachment in potential impact area, collision will occur x

Probability that, given a collision, severity will result in an accident

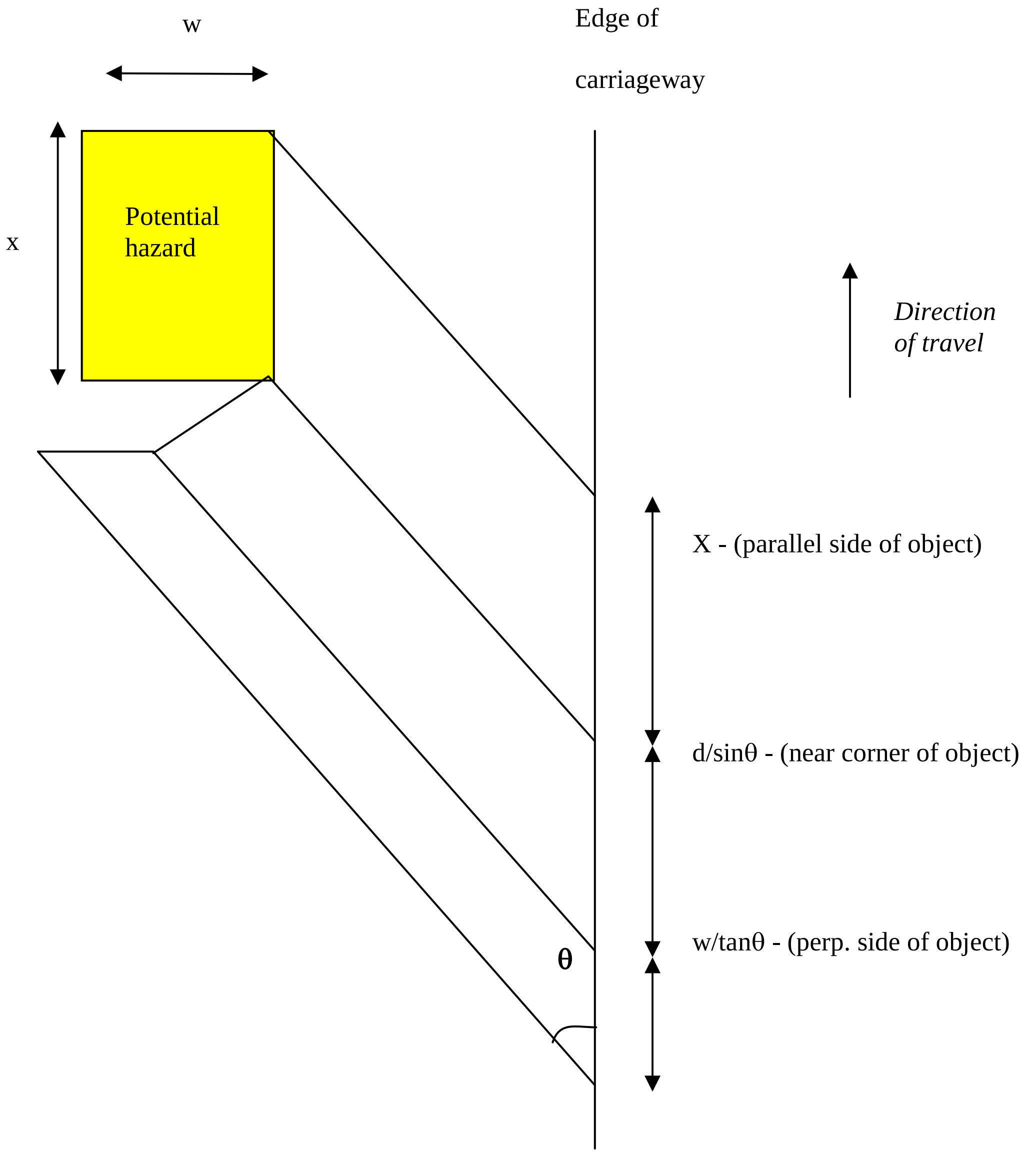
The expected number of encroachments was assumed to be a function of AADT (no account being taken of curvature or lane width).

The probability that, given an encroachment, an impact is possible was obtained from the effective length of the hazard. This is shown in Figure 6 and depends on the angle of departure, the length and width of the object, and the width of the encroaching vehicle. The departure angle was assumed to be 6.1 degrees nearside and 11.5 degrees offside (based on a circle of 1000 ft diameter).

The probability that, given an encroachment in the potential impact area, a collision will occur is the probability that the vehicle will continue beyond a lateral distance y if not impeded by a prior collision and control is not regained.

Estimates of accidents per collision are given for a number of objects.

Figure 6: Envelope of potential hazard, based on trace of left front corner of vehicle



θ	Angle of departure
w	Width of object hit
x	length of object hit
d/sinθ	Effective width of hitting vehicle
w/tanθ	Effective width of object hit

4.1.2 *Embankments*

A log linear regression model for single vehicle accident rates on two-lane rural highways was developed by Zegeer et al (1988):

$$AS = 793.58\ (1.91)^{SS}\ (0.845)^{W}\ (0.974)^{RECC}\ (0.99994)^{ADT}\ (0.908)^{SW}$$

where AS is the single vehicle accident rate (accidents per 100 million vehicle-miles)

SW is the total shoulder width (paved and unpaved), in feet

W is the lane width in feet

RECC is the median roadside recovery distance

SS is 1 if the side slope is 3:1 or steeper and 0 otherwise

A second model allowed for more detailed data on side slopes. This showed little difference between gradients of 3:1 compared with those of 2:1 and steeper, but beyond this, flatter side slopes were associated with a reduction in single vehicle accident rates.

On UK motorways, unpublished TRL research found that the single vehicle accident rate on embankments without a safety barrier was about 60% higher than at other cross-sections (level verge, safety barrier, cutting and parapet), which were all similar.

4.2 Software

Two different versions of cost/benefit encroachment software have been developed in the US in the 1996 and 2002 versions of the AASHTO Barrier Guides – ROADSIDE and RSAP. Both allow for traffic growth and include a cost-benefit analysis.

The same general approach is being used in the risk assessment procedure being developed by Mouchel Parkman /TRL for use within a revised standard for vehicle restraint systems.

4.2.1 *ROADSIDE*

ROADSIDE is partially based on the earlier encroachment models outlined in Section 4.1. It assumes a fixed encroachment rate of 0.0003 nearside encroachments per year per km per AADT and that encroachments vary linearly with flow. The distribution of lateral extent is based on a maximum lateral encroachment and a sinusoidal distribution:

$$\text{Probability } (Y > Yd) = 0.5 + 0.5 \cos(\pi\, Y_d / Y_m)$$

where Y is the lateral extent of the encroachment

Y_m is the maximum calculated lateral extent of the encroachment

Y_d is the lateral distance from the edge of the travelled way

The maximum extent of the encroachment depends on the design speed of the road and the traffic mix up to an absolute maximum of 45m.

The hazard module uses an average value for the encroachment angle which varies slightly with design speed from 10 to 13 degrees, with higher angles corresponding to lower design speeds. The distribution of the lateral extent of encroachment is based on a range of design speeds, traffic mixes and encroachment angles, a constant deceleration rate of 3.66 m/sec/sec (0.4g) and a straight path.

Parameters affecting the run-off rate are:

- Design speed of road
- Type of road – dual or single carriageway
- Traffic flow (vehicle mix assumed) in vehicles per day

- Dimensions of object
- Lateral offset of object
- Swath width of vehicle
- Type of object hit (leading to a severity index)
- Side slope and type of intervening ground (leading to an equivalent lateral displacement)
- Hilliness of road – multiplicative factor of up to 2 on steep downhill sections
- Bendiness of road – multiplicative factor of up to 2 on inside of sharp bend, up to 4 on outside

In SR214 (TRB, 1987) the swath width was taken to be the actual width of the front of the vehicle (approximately 2m), whereas in ROADSIDE, it was taken to be 3.6m to allow for skidding. ROADSIDE does not take into account vehicle orientation.

A Severity Index on a scale from 0 to 10, with 0 representing no injury or property damage and 10 representing a fatality in 95% of cases and injury in the remaining 5%, is given for all types of object hit, according to the design speed of the road.

4.2.2 RSAP

RSAP (Roadside Safety Analysis Program) has 4 modules:

- Encroachment
- Crash prediction
- Severity prediction
- Benefit/cost

The lateral extent of encroachment is based on Cooper encroachment data, modified to allow for run-off where there are paved shoulders - encroachment rates are multiplied by 2.466 for 2-lane undivided highways and by 1.878 for multilane divided highways. Encroachment rates are multiplied by 0.6 to account for the lack of distinction between controlled and uncontrolled encroachments. The program includes 12 vehicle types.

Accident prediction is stochastic using a Monte Carlo process with a minimum of 10,000 encroachments simulated. Speed, encroachment angle and vehicle orientation are taken from Mak, Sicking and Ross (1986). There is a weighting system to ensure rare events are represented.

The program is applied to homogeneous sections of road i.e. with constant flow and geometry. It can predict for both sides of the road and for the median.

Severity prediction is based on:

- impact speed (currently taken to be the same as encroachment speed)
- impact angle
- vehicle orientation for individual object types
- impact performance of features such as safety barriers (which will deflect light vehicles with low impact angles back onto the carriageway)

The Severity Index is calculated from a linear regression function of lateral impact speed based on real data; it assumes that zero severity results from zero impact speed except where there is a sharp drop e.g. at the edge of a paved shoulder.

5 Summary

Most of the studies that have been described above have been aimed at establishing the extent of clear zones that should be provided to minimise the number of severe injuries from roadside run off accidents. From the US work there is a general consensus that clear zone widths of the order of 10m are needed on high speed roads to achieve high levels of safety. At the same time it is recognised that while these would be justified in cost benefit terms on free ways, clear zone increases may only be justified at specific high risk sites on other roads. In Sweden, Hedman (1990) recommends clear zones of at least 7-11m for high speed roads, and 4.5m to 7m for lower speeds. Similar distances are recommended by Dutch work (Schoon 1997, SAFESTAR 2000).

In Australia, several authors have suggested that there can be considerable reduction in risk from rather lesser clear zone widths. Fox (1979), quoted by ETSC, suggested that clear zones of at least 2m and preferably 3m would significantly reduce injury consequences. Ogden (1996), quoted by ETSC, suggested that increasing recovery distances from 1.5m to 6m on Australian roads would reduce injury accidents by 13-44%, although less on curves. McLean (2002) re-examining US data suggests that a large proportion of the benefits could be obtained with clear zones of 6m.

In the UK, a 3.3m hard shoulder has been standard on motorways although the number of substandard sections allowed is increasing. A 1m strip is used on both single and dual-carriageway trunk roads, where traffic speeds of 70mph are allowed. There is no 'clear zone' as such. The focus in UK has therefore been more towards assessing when it is necessary to provide additional protection.

- This requires a model to be developed that allows this need to be evaluated more directly for a variety of different roadside conditions. The model being developed by Mouchel Parkman/TRL as part of the introduction of risk assessment into road restraint standards provides a basis for this.

Data from this report provides the following input to such models

(f) encroachment angles – no evidence is directly available for UK, but US studies suggest that the angle varies with type of run off, and a probability distribution is provided with the majority of run offs being between 5 and 15 degrees

(g) frictional resistance during run off – unbraked run offs over good ground will produce very little deceleration (perhaps 0.1g) but this can increase to 0.5g over loose gravel. Braked runs over loose gravel can produce decelerations of 1g, but over hard ground probably only about half this value.

(h) effect of slope on likelihood of rollover – down slopes greater than 1:3 result in a high likelihood of rollover; even on slopes of 1:4 the scope for driver control over short distances will be limited

(i) severity of injury resulting from hitting different objects – impacts with trees are 50% more likely to result in severe injury than impacts with signs and lampposts; there remains a significant probability of injury after impact with roadside barriers

(j) accident data on the overall outcomes from the combined effect of these factors

Models are needed to show how these factors combine to reflect overall risk at particular sites. These need to be calibrated against accident data from British trunk road sites to demonstrate the validity of their predictions to these sites.

It is concluded that

- The basic methodology exists to make risk assessments at these sites

- Data exists (although mainly from other countries) on the values to be used for the parameters in these models

There is no reason to believe that these values are fundamentally different for British conditions, so the value of further research is in

- The improvement that can be made to the risk estimates by refining the values used
- Demonstrating the output of the models is consistent with observed accident patterns on trunk roads

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Appendix A. Examples of run off accidents from On The Spot database

Road type	Speed limit	Distance from road (m) **	Direction left road	Slope	Object hit *	Injury severity	Details
Motorway	70	4	L	0	7	SL	
				0	1	NI	
				0	2	NI	
				0	12	NI	
				0	12	NI	
				-	13	NI	
		5		0	6	SL	Slip road
				0	2+5	NI	Slip road
				0	5	NI	Slip road
				0	none	NI	Controlled move to h s
		6		0	1	NI	Bridge parapet
		8		-	1 os	NI	
				-	2+5	NI	
		9		-	5	SL	Alcohol related
				-	5	SL	
		11		-	1os +2	SL	
				+	1os+5	NI	
				0	3	NI	HGV - fatigue
		13		-	1os+1	SL	
				-	2	NI	Spun
		>13		-	6	SE	RAB spun, rolled
		18		-	2	SL	HGV driver asleep
				0	none	SL	m/c
				-	2	NI	
		19	R	0	1	NI	Cross reserve
A road DC	70	1	R	0	7	NI	
		2	L	-	2	SL	Rolled
		3	R	0	11	NI	
		5	L	0	1os+3	SE	
		8	R	0	none	SL	Across reserve
		15	Ahead	0	9	SL	

A road	60	1	R	0	6	SL	Across reserve
		2	L L	0 0	6 5	NI NI	RAB exit RAB exit
		5	Ahead	0	2	NI	RAB approach
		10	L	0	2	NI	rolled
A road	40/30	1	L	0	7	?	Slip road island
		2	L	0	6	SL	RAB entry – alcohol
		4	L	0	8	NI	RAB exit
		5	L	0	11	NI	RAB exit
		10	Ahead	0	None	SL	RAB approach
		50	L	0	10+3	NI	Brake failure

* Key for object hit ** measured from edge of running lane RAB = roundabout

1. barrier
2. ditch
3. wooden fence
4. debris in carriageway
5. tree
6. lamp post
7. sign post
8. metal fence
9. stream
10. electricity junction box
11. vegetation
12. other
13. earth bank