External Vehicle Speed Control

Deliverable D6

Implementation Scenarios

October 1997

Project Partners:
The University of Leeds and The Motor Industry Research Association

Project Funded by the Vehicle Standards and Engineering Division
Department of the Environment, Transport and the Regions

INSTITUTE FOR TRANSPORT STUDIES
DOCUMENT CONTROL INFORMATION

Title	Implementation scenarios
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Reference Number	EVSC–D6
Version Number	1.0
Date	31 October 1997
Distribution	Project
Availability	Restricted
File	C:\External Vehicle Speed Control\Deliverable 6.doc
Authorised	O.M.J. Carsten
Signature	

EXECUTIVE SUMMARY

One application of the new generation of intelligent highways technology, is for the external control of vehicle speeds. This report considers the effectiveness, measured in accident reduction benefits, of various forms of external vehicle speed control (EVSC) and the costs of implementation. The results of this investigation are then compared to the benefits and costs of a more traditional approach, blackspot studies and accident counter-measure programmes. In this respect the report is presented in two distinct parts. The body of the report investigates implementation scenarios for EVSC, by considering the accident reduction potential of EVSC and the costs of various possible systems and subsystems. A report on the second component, the accident reduction measures, has been prepared by the TMS Consultancy and is included as Appendix 1.

In considering the possible implementation scenarios for a system of EVSC the following key questions are asked:

- What is the potential accident reduction that may be achieved by EVSC systems?
- Is it likely that a system of EVSC will provide significant economic benefits that will exceed the cost of implementation, and is therefore worth investigating further?
- Where is additional research required to reduce uncertainty is the estimation of key inputs?
- If an economically attractive system of EVSC is likely to result, what is the set of favoured solutions?

To answer these questions the report considers first the ways in which EVSC may affect traffic speeds and thereby generate accident reductions and economic benefits. The components of possible systems, and sub-systems, are then considered and the costs of the systems established. An economic analysis follows in which the benefits and costs are combined and feasible implementation scenarios are identified on the basis of the resulting benefit cost ratios (B/C).

Having reviewed the literature on the relationship between speed and accidents, in a previous project report (Deliverable D1 June, 1997) this report looks at the possible implementation scenarios for the development of a system of external vehicle speed control (EVSC). In doing so the investigation concerns itself not with the technical issues of implementation but with the safety issues and benefits that may be generated be EVSC. By asking the questions: *Is the system to provide advice or mandatory control?;* and *Is the speed limit data to be simply the current legal speed limits or can it be varied to cover substandard road and weather conditions?;* it is possible to define the level of accident reduction benefits that EVSC may be generated. On the cost side the analysis considers generic types of operating systems and in particular the methods of supplying speed control data to the vehicle and the degree of vehicle retardation that may be provided by the system. The answers to these questions then define a number of potential systems of EVSC.

A review of other studies that seek to quantify the role of speed, and therefore the likely accident reductions related to speed control, has identified two typical approaches. Some studies consider only those accidents in which inappropriate speed is identified as a causal factor while others look at the effect of speed changes on all accident types combined. Neither approach is considered adequate on its own. As speeds are reduced potential benefits arise for all accidents as driver reaction time and evasive action are improved. This will not only reduce the likelihood of an accident occurring but also reduce accident severity so that some injury accidents may become damage only accidents. When considering only those accidents where speed is identified as a causal factor, these benefits are lost. On the other hand considering only the relationship between speed and accidents in general, neglects the fact that EVSC will have a greater impact on speed-related accidents.

Research has indicated that the propensity for speed of individual drivers is related to their personal accident liabilities. On this basis the investigation has considered the way in which different types of EVSC will effect the shape of the distribution of vehicle speeds. Two mechanisms have been defined: *Translation* in which the shape of the speed distribution remains essentially the same but the overall distribution is translated downwards with respect to speed; and *Transformation* in which the speed distribution is truncated, with no vehicles exceeding the speed limit. These two mechanisms respectively represent the effects of an advisory and a mandatory system of EVSC.

The level of accident reduction is then calculated on the basis of the type of speed advice supplied to the driver. In this respect three types of speed limit system are identified. Firstly a system of fixed speed limit categories as at present; secondly a variable system in which the speed limit is a continuous variable and local speed limits may be set to account for poor road geometry and the like; thirdly dynamic speed limits which may account for changing road, weather and visibility conditions.

Combining the two system states, advisory and mandatory, with the three speed limit systems, fixed variable and dynamic, provides six accident reduction scenarios. For each scenario, the accident reductions have been estimated on the basis of a low, best and high estimates of effectiveness. The resulting best estimates of accident reductions are given in the table below.

Estimates of the possible accident reductions from EVSC

System Status	**Speed Limit System**	**Low Estimate (%)**	**Best Estimate (%)**	**High Estimate (%)**
Advisory	Fixed	2.3	9.0	20.9
	Variable	2.3	10.0	21.5
	Dynamic	3.0	12.0	26.5
Mandatory	Fixed	11.0	20.0	31.0
	Variable	12.0	22.0	32.0
	Dynamic	19.3	35.0	49.0
Percentages based upon a total of 23,0376 reported injury accidents in 1995				

Monetary valuations of the expected accident reductions have been calculated using the average accident costs for 1995 and these have then been projected into the future. The predicted accident savings have been established for three growth scenarios. Firstly a projection of the current accident rate and level of travel demand, and then two scenarios which use an extrapolation of the current decreasing trend in accident rates, together with high an low estimates of travel demand. Of these the middle option, that based upon a decreasing accident rate and a higher level of travel demand has been considered as the base case for the analysis.

On the cost side three primary options have been identified: a *Full System* with a mandatory application of speed limits which are supplied to the vehicle speed control system; an *Advisory System* in which speed advice is provided to the driver who retains vehicle speed control and a *Driver Selection System* in which the driver obtains speed limit data from road signs but may choose to activate the vehicle control system to keep the vehicle at, or below, the required speed. Within these primary systems sub options are based upon how the speed limit data is relayed to the vehicle and the means, and therefor the degree of, retardation available to slow vehicles as they pass into a lower speed area.

It must be recognised that the prediction of the future, mass production, costs of what is a developing technology is difficult. Though out the cost analysis, elements of the system have been assigned generic products types. The generic costs have then been estimated for a 1995 base and a 2010 future cost. All costs are however expressed in 1995 £ values.

The options costed are clearly divided into two groups based upon the information supply system. For an autonomous system, termed a CD-ROM system, in which the speed data is help on a digital map inside the vehicle, the major cost is an in-vehicle costs, which would be borne by the vehicle owners. For a beacon based system, the major costs are in developing the beacon network and would be most likely borne by the public sector. Although the latter has a high initial cost it would be cheaper in the longer run. The principal reason for this finding is related to the balance of in-vehicle costs and the number of new vehicles registered each year.

Having considered both the benefits and the costs of the various implementation scenarios, the benefit cost ratio has been established for each option. It is clear from the analysis that an economically attractive system of EVSC is highly likely to be developed. Indeed more than half of the systems investigated have benefit cost ratios in excess of 2.0 and at least five systems have benefit cost ratios greater than 3.0.

In all studies of this type assumptions about the level of future year travel play a significant part in the determination of the benefit cost rations. The quoted benefit-cost ratios assume that, even in the absence of EVSC, a significant reduction will occur in current accident rates albeit combined with increasing travel demand. This reduces the benefits of the scheme below that which would result from a simple projection of current levels of vehicle ownership and the current accident rate. A simple projection of the status quo would increase the benefit and therefore the B/C by 50%. If the accident reductions are applied to an accident base that reflects a lower level of travel, the benefits are reduced by 25%.

The more economically attractive systems have a lower in-vehicle cost and a higher infrastructure costs. However, it is important to remember the distinction between those systems that require high infrastructure investment and therefore funding by central government and those that may be implemented progressively with much of the cost being incorporated into new vehicle purchases.

It has not been possible to calculate a B/C for the Driver Selection System. Under this system speed information is received from road signs, as at present, and drivers input this manually into a vehicle control system. Given that the driver selection system need only achieve 52% of the benefits of a purely advisory system or 26% of the benefits of the mandatory system to achieve a B/C exceeding 2.5 it is potentially a very attractive system. The key issue is the level of compliance, and given that such a system is potentially attractive this will required further research aimed at assessing the likelihood of drivers activating the system.

Systems that include active retardation, those where the vehicles braking system is used to actively reduce speed when a vehicle passes into a lower speed limit, have lower B/Cs than those using passive retardation which is based on the natural deceleration of engine braking. This is because of the higher in-vehicle equipment costs associated with active retardation and the assumption that the full benefits of mandatory speed control will accrue to a system which does not have an active braking system. This remains untested and in view of the significant effect that this assumption may have on the choice of system, further research should be undertaken on this issue.

Although the recommendations have been based upon a "best estimate" of the accident reductions the sensitivity analysis shows extreme variations between the low and high estimates for accident reductions. Even though the variations are high a number of systems produce attractive economic returns even when the lowest estimates of accident reduction are considered. Further research into the behavioural aspects of EVSC are expected to refine the variation in accident reductions.

The more traditional forms of safety measures, blackspot studies and the associated accident reduction projects, generate very high benefits and are typically low cost. Such projects do, by definition, concentrate on addressing problems at sites with severe accident histories. Not surprisingly there is a trend for decreasing benefits with larger schemes. In comparison EVSC will address widespread random accidents which are not the target of the traditional schemes. It should be noted that the general decrease in accident rate has been used when calculating the benefits of EVSC. This downward trend reflects the effectiveness not only of the traditional accident reduction programmes but also of enforcement and road safety education programmes.

The overall conclusion is that significant accident reduction benefits are likely to be generated by EVSC and one or more systems are likely to produce benefit cost ratios that are in excess of 3.0. The final decision on a recommended system will depend upon the cost of the technology used to inclement EVSC. Given the sensitivity of any recommendation to the cost estimates, further refinement of these will be necessary. However this is essentially independent of the next phase of the research, which involves simulator and field studies to refine the driver performance issues.

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Terms and Definitions

ABS	Anti-lock braking system.
Active Retardation	An in-vehicle system that will when necessary apply an active braking force to slow a vehicle to the maximum legal speed if necessary.
Advisory (EVSC) System	A system of EVSC in which speed limit data is transferred to the driver of a vehicle who is responsible for controlling the speed of the vehicle.
B/C	Benefit cost ratio.
Beacon	A dedicated short range communications unit placed at the roadside used to transfer speed limit data to the vehicle.
CD-ROM	A generic term for an autonomous speed limit system based upon a digital map of speed limits held within the vehicle.
COBA	Cost benefit analysis procedures for the economic elevation of highway projects.
DSRC	Dedicated short range communications device.
Dynamic Speed Limit System	A speed limit system which is continuously variable in magnitude, location and temporally. Legally enforceable these speed limits will vary to reflect the prevailing conditions.
ECU	Engine control unit. The electronic system used to manage engine and braking systems.
Fixed Speed Limit System	A speed limit system based upon specified categories e.g. 20, 30, 40, 50, 60 and 70 mph zones which are legally enforceable.
FYRR	First year rate of return, an economic indicator.
GDP	Gross domestic product.
GPS	Global positioning system.
HGV	Heavy goods vehicle.
HMI	Human machine interaction.
LED	Light emitting diode

Mandatory (EVSC) System	A system of EVSC in which speed limit data is transferred to the vehicle which is equipped to limit the maximum speed to the specified speed limit.
NPV	Net present value.
Passive Retardation	Relies upon the “natural” deceleration of a vehicle together with engine braking to decelerate the vehicle to a lower speed limit.
Variable Speed Limit System	A speed limit system which is continuously variable both in magnitude and along the highway alignment. Legally enforceable these do not vary temporally.

1. INTRODUCTION

This report considers the effectiveness, measured in accident reduction benefits, of various forms of external vehicle speed control (EVSC) and the costs of implementation. The results of this investigation are then compared to the benefits and costs of a more traditional approach, blackspot studies and accident counter measure programmes. In this respect the report is presented in two distinct parts. The body of the report looks at the investigates implementation scenarios for EVSC, the costs and benefits of various possible systems and subsystems. A report on the second component, the accident reduction measures, has been prepared by the TMS Consultancy and is included as Appendix 1.

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Throughout the process, generic options are considered in terms of a series of functional categories. Although these are discussed in detail within the appropriate sections they are briefly outlined here.

The investigations into the accident reduction, or benefits, of EVSC have identified a classification of EVSC systems based upon the system status and the type of speed limit data that is provided. To establish the likely accident reductions of EVSC two mechanisms by which EVSC may affect the distribution of vehicle speeds are considered. The accident reductions reported by other studies are identified and discussed together with some further analysis based upon individual accident liabilities. These separate estimates of possible accident reductions are then reviewed and a set of accident reduction estimates (low, best and high) are selected for use in the subsequent analysis.

When considering the technology, and the costs of the EVSC system, a classification system is based on the EVSC system operation with sub-systems being generated through consideration of how various functions, such as the supply of speed data to the vehicle and the type of retardation, are to be implemented. Generic costs for each component are use to determine the cost of implementation.

Combining the accident reduction and system technology options, shown in Figure 1, a range of implementation scenarios are then defined. The subsequent economic analysis, considers issues of progressive implementation, the growth in travel and the current downward trend in accident rates with comments upon the sensitivity of the results to the various assumptions made.

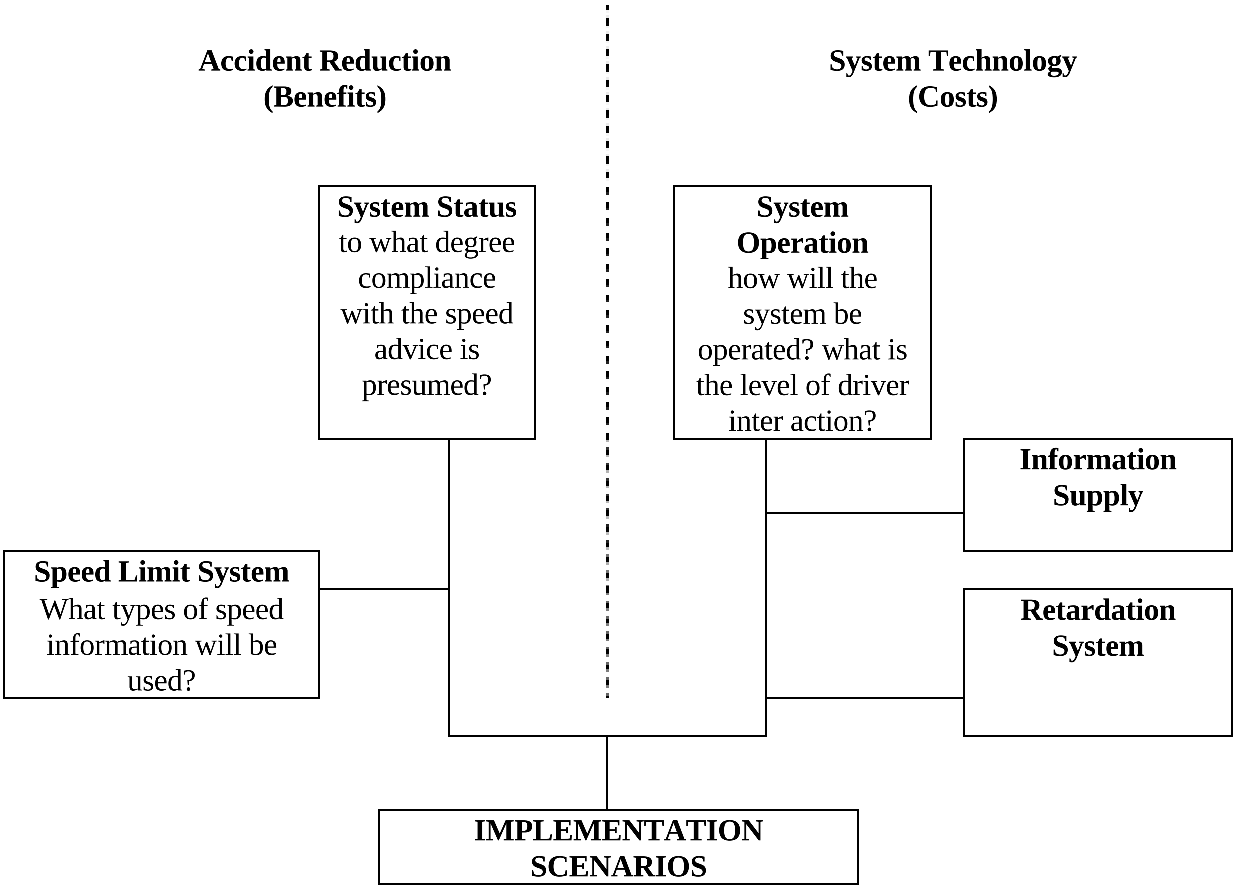


Figure 1: The Classification of EVSC systems

2. CALCULATION OF SAFETY BENEFITS

The negative effects of speed upon safety, both in terms of accident rate and accident severity are well documented. However the safety benefits that may result from external vehicle speed control (EVSC) are less clear and will vary depending upon the:

- status of the system (advisory or mandatory),
- implementation strategies,
- human machine interaction (HMI),
- the degree of driver compliance,
- the level of speed change,
- the introduction of other compensating behaviour.

There is considerable interaction between these factors and the way in which they combine to effect the overall outcome. This may be best illustrated by considering some possible goals for an EVSC system. Two key goals exist:

1. Network wide safety improvement either within the urban network, the rural network or both.

2. Site specific safety improvements at locations where inappropriate speed has been identified as a specific feature and the accidents. These may be fixed conditions such as curves or variable such as changing light or weather conditions.

EVSC may be introduced so that the maximum speed is mandatory and drivers have no choice but to comply. Alternatively EVSC may operate in an advisory capacity simply advising drivers of the current legal limit. Either system may be extended beyond considering only the current regulatory speed to a system where the speed limit is a continuous variable rather than fixed steps, or to a dynamic system which sets more appropriate speeds where local conditions warrant. In terms of vehicle technology, an advanced level EVSC may not only limit the power-train output of the vehicle but actively slow it to the maximum legal speed, or as in the case of a haptic throttle provide progressively more resistance as drivers attempt to exceed the speed limit.

There are also implications for the progressive implementation of the system. For network-wide safety it may be that urban areas are targeted first with coverage being subsequently extended to motorways, rural A roads, B roads and then all remaining roads until the complete network is regulated. Alternatively rural areas or motorways may be treated first. The system may first seek to improve compliance with the current regulatory speed and then be progressively updated to include special sites, blackspots and the like, where the current regulatory speed is inappropriate.

A site-specific system may target locations where more than a predetermined number of speed related accidents have occurred in a given period. Once this coverage has been achieved the threshold may be lowered or the period extended until complete network coverage is obtained.

The choice of goal will effect the choice of infrastructure, cost of implementation and the level of benefits that are likely to derived from the system. Alternatively the choice of infrastructure will suggest the implementation strategy. Two main types of “network” infrastructure appear to be:

1. Beacon-based systems that broadcast to vehicles the local speed requirements; and

2. Electronic map based systems in which the vehicle is located on the road network via GPS and the speed control data is read from the electronic map contained within the vehicle. Since the GPS requires a radio based update correction, the same system may also be used to provide updates in speed control to adjust for local conditions.

These are by no means the only two systems and a number of variants may exist within these. Infrastructure choice will also be affected by the overall goals and implementation strategy. If EVSC is first introduced to enforce the existing speed limits, a beacon based system would appear less appropriate since the bulk of the data is essentially fixed and could be more easily communicated using a map-based system. However if a map-based system were extended to provide variable speed control data it would be necessary to determine how much information would be required to be updated via the GSM before accepting a map based system.

Although at present there may be problems with issues such as data communication rates and other technological factors it must be assumed that in future the hardware required will be smarter, faster and cheaper. At this stage the project is simply concerned with whether the safety, and other benefits of a system of EVSC, are likely to be sufficiently large to warrant further investigation in preparation for the day when the technical issues are more refined.

Clearly a number of trade-offs are involved. The decision as to which types of system are most likely to prove economically attractive is therefore complex. In order to formulate a method by which the safety benefits may be estimated, this section considers firstly the mechanisms by which EVSC will affect vehicle speeds and therefore accidents. Studies into the effects that various traditional traffic management measures have had on speeds, and consequently accidents, are then reviewed, and from these a framework is developed to allow the estimation of the possible accident savings associated with the scenarios for EVSC. The subsequent estimates are then compared with those from other sources.

2.1 HOW BENEFITS WILL ARISE

Although a number of studies into advanced technologies have sought to quantify the benefits of speed control systems, these have typically considered either the effect of speed control on particular accident types or accident reductions based upon an overall reduction in speed. Neither approach is considered satisfactory on its own. Considering only accidents that are clearly speed related ignores the fact that reduced speed allows the driver more reaction and evasion time thus reducing the likelihood of an accident situation arising and increasing the chances of an avoidance action being successful. Reducing speeds will therefore impact upon a wider range of accident types than just those accidents which are clearly related to excessive speed. On the other hand considering only the relationship between accidents and speed does not account for the ability of speed control to impact more severely on accidents that occur at higher speeds. The approach adopted in this study is to consider how EVSC will affect speed and to then relate this to potential accident reductions.

The accident rate on a particular section of highway is the integral of the individual accident liabilities of each driver that passes over the road. Accepting that these personal accident liabilities vary temporally, theoretical arguments and a number of studies link an individual's accident liability with his/her propensity for speed (Finch et. al., 1994). The accident rate is therefore strongly related to the location and shape of the speed distribution. EVSC is expected to modify the distribution of speeds through a combination of two mechanisms:

1. ***Translation*** in which the shape of the distribution remains essentially the same, and

2. ***Transformation*** in which the shape of the distribution is dramatically changed.

These two mechanisms are shown in Figure 2 and Figure 3 respectively. Where advice is being provided to drivers, it is thought that the bulk of the response will be through translation, while a mandatory system that fixes the maximum speed of vehicles will transform the distribution. The estimates for a purely advisory system will provide a lower bound for the benefits of EVSC which may extend though to the full benefits estimated for a mandatory system. A range of combinations is available depending upon the type of system that will operate.

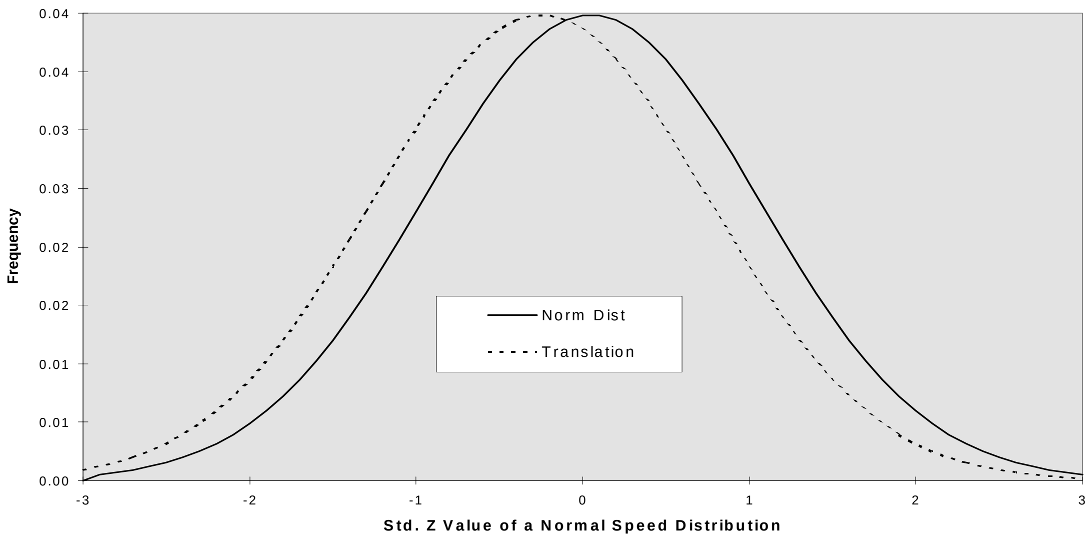


Figure 2 Translation of Speed Distribution

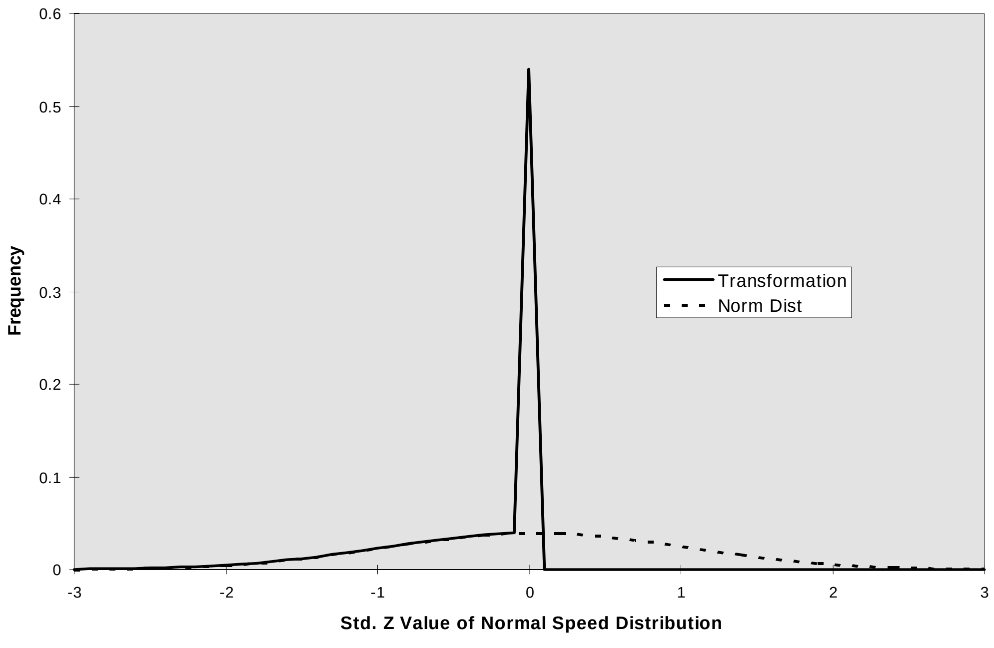


Figure 3 Transformation of Speed Distribution

As well as the split between advisory and mandatory EVSC there is a second split based upon the type of speed information that is input to the system. Three options are available:

- **Fixed** a system that considers only a set of fixed speed limits;
- **Variable** in which the speed limit is a continuous function, thus allowing smooth speed reductions to account for poor geometry and the like;
- **Dynamic** in which the speed limit may change by time of day and to reflect local conditions such as adverse weather, roadwork's and the like.

2.2 CURRENT SPEED REGIME

Before considering the effects of EVSC on speeds it is useful to outline the current pattern of speeds in the United Kingdom. Although the vehicle speeds in Great Britain are monitored (DETR, 1997) the method used is less than satisfactory for the purpose of this study. A large volume of data is collected but the sites are not necessarily chosen at random.

It is also important to note that although the term *mean speed* is used extensively though the associated literature, the definition does from time to time vary. In some studies mean speeds are defined as the mean speed of free, i.e. unimpeded, vehicles travelling on flat straight sections of highway. In other studies the mean speed may be the mean of all vehicles on a variety of highways where the highway geometry may restrict speeds. The data collected in Great Britain contains data of a mixed type. Some speed data is collected at automatic traffic counting sites and may or may not include the effects of traffic volume and geometry while other data may be collected using radar and whether or not the effects of traffic volume are present will depend upon the sampling strategy used. It is however likely that traffic volume effects have reduced the mean speeds to less than the current regulatory speed for some road types. This being the case translation of the speed distribution is unlikely to generate any significant accident reductions since the mean speed is already lower than the regulatory speed (Table 1).

Table 1: Average Traffic Speed by Road Type (source: DETR, 1997)

Speed Measure	Non Urban Roads			Urban Roads	
	Motorways	Dual	Single	40 mph Limit	30 mph Limit
Mean Speed (mph) all Traffic 24 hours	70	68	47	37	33
Percent Cars exceeding:					
Speed Limit	57	49	10	25	72
Limit by 10 mph	19	12	2		
45 mph				8	
35 mph					37

To minimise the effect of traffic volumes it is possible to use the mean speed of traffic in the low flow periods as a more reliable measure of the free mean speed. These are provided in Table 2. Other sources of speed data could include that collected as part of special studies. However since these are typically before-and-after studies of safety treatments, there is a bias toward sites with a safety problem.

Table 2: Average Traffic Speed by Road Type and Time of Day (source: DETR, 1997)

	Mean Speed (mph) all Traffic				
Time of Day	Non Urban Roads			Urban Roads	
	Motorways	Dual	Single	40 mph Limit	30 mph Limit
00:00-04:00	72	67	51		
04:00-06:00	72	68	51		
06:00-07:00	71	69	50	41	37
07:00-08:00	67	69	47	38	34
08:00-09:00	68	70	46	35	31
09:00-10:00	71	69	47	36	33
10:00-11:00	72	69	46	36	33
11:00-16:00	71	69	46	36	33
16:00-17:00	68	68	46	35	32
17:00-18:00	67	68	46	35	32
18:00-19:00	69	69	47	37	33
19:00-22:00	71	69	49	38	34
22:00-24:00	71	67	49		35

3. TRANSLATION OF THE SPEED DISTRIBUTION

In order to separate the effects associated with the translation and transformation of the speed distribution it must be assumed that providing additional advice about speed limits will retain the shape of an existing speed distribution. If this is the case it may be reasonable to use accident relationships that have been derived from studies of speed limit changes or the provision of speed warnings. Studies into the relationship between accident rate and traffic speed generally consider the effect of:

- speed limit on mean speed,
- mean speed on accidents, and
- speed variance on accidents.

An analysis of vehicle speeds (Hauer, 1972) has shown that inter-vehicle conflicts are related to the speed variance. However opinion as to the relationship between mean speed and speed variance has not been fully confirmed by the reviewed reports. One US study (TRB, 1984) established that the reduction of the speed limit from 65 to 55 mph reduced the distribution of highway speeds. The study showed that the standard deviation reduced from 8.5 mph prior to the speed limit change in 1973 to 5.0 mph and stayed at this level until 1981 slowly increasing to 6.0 mph in 1983. Other studies, conclude that the speed variance remained constant after mean speed increases. A US study reported virtually identical standard deviation for the states maintaining the 55 mph limit after 1987 (5.62 mph) and for those that raised the limit to 65 mph (5.48 mph) (Freedman and Williams, 1992).

Australian and New Zealand studies also found that there was no change in speed variance with the increased speed. When in 1987 the speed limit was raised from 100 to 110 km/h on certain roads in Victoria, Australia, the mean speed increased by 4 km/h but no change in speed distributions was noted (RACV, 1990). Similarly, after the speed limit on some of New Zealand highways was raised from 80 to 100 km/h in 1985, mean speed increased from 99.2 to 102.6 km/h but the standard deviation remained constant at 14.1 km/h (MoT, 1986). It should be noted that this study and possibly others consider the mean free vehicles unconstrained by geometry. A further New Zealand study of traffic speeds on curves (Bennett, 1990) suggested that the standard deviation of car speeds increases with increasing mean speed although the relationship ($\sigma = 1.73+0.12\mu$) is at best weak ($R^2 = 0.6$). This result is in part countered by a further US study (Garber and Gadirau, 1988) which found a decrease in speed variance with increased mean speed.

This evidence suggests that speed variance may be independent of the mean travel speed, and if not, the change is not likely to change the shape of the speed distribution enormously. This being the case, it may be that existing relationships, between accidents and mean speed, may be used to provide an estimate of the potential safety benefits.

3.1 THE REDUCTION IN ACCIDENTS WITH REDUCTION IN SPEED

A number of studies have been undertaken to consider the effect of speed limit on accidents. In the main these studies consider either explicitly or implicitly two effects. The first is the relationship between mean speed and the speed limit; the second is the relationship between the mean speed and accidents. In reviewing these studies, it is important to ensure that definition of speed is understood and when predicting likely accident reductions, the different measures, both of which are termed mean speed in the literature, are not mixed.

There exists a body of work indicating that there is a strong correlation between accidents and travel speed. For instance, US studies show that the reduction in mean speed from 65 mph to 57 mph in 1973 was accompanied by 9,100 fewer fatalities (TRB, 1984). Other US studies report increases in fatalities of 20 to 30 per cent after the mean speeds increased from 63.0 to 67.1 mph in 1988 (Freedman and Williams, 1992). It was reported in New Zealand that following an immediate dramatic reduction in operating speeds of 8 to 10 mph in 1973, all casualties in areas designated at 50 mph reduced by 19 per cent, with the reduction in fatal and serious casualties of 29 per cent (Toomath, 1975). There have been several attempts to model the relationship between accidents and mean speed. A generalised model suggested that for every 1 mph rise in the mean traffic speed, the change in accidents rises by about five per cent, although this figure is less than 9.7% estimated for German motorways and the 8-9% proposed as the result of some American studies (Finch et. al., 1994).

The linear relationships described in these studies can only be considered valid over a limited range of data and this has led some researchers to concluded that the relationship between mean speed and percentage change in accidents may be asymptotic rather than linear, that is, the effect of speed reduction on accidents may be subject to some saturation process with the increase limit of 28 per cent and reduction limit of 25 per cent (Finch et al, 1994).

Other researchers suggest non-linear relationships. Speed limit experiments were undertaken in Finland in the 1960's and again from 1973 to 1976. Although the speed limit was only advisory a comprehensive study of the changes in mean speed and accidents was undertaken over a three year period (Salusjärvi, 1988). From that study the following expressions were developed to relate the change in accidents to change in mean speed, Figure 4. The equations are :

$$\Delta O_K = 5.5\Delta v - 1 \qquad R^2 = 0.76$$

$$\Delta O_H = [15(\Delta v)/(\ |\Delta v|\ ).(|\Delta v|)^{1/2})] + 0.8 \qquad R^2 = 0.90$$

Where ΔO_K = % change in accidents
ΔO_H = % change in fatal and injury accidents
Δv = change in mean (free) speed (km/h)

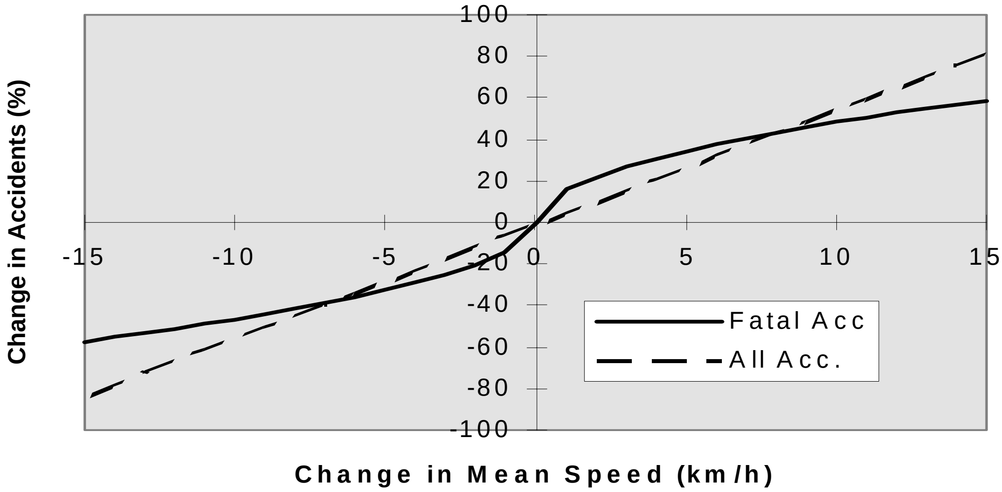


Figure 4: The Relationship between Mean Speed and Accidents (source: Salujavi, 1987)

Although the form of the relationship between change in mean speed and fatal accidents is complex it is possible to make a reasonable linear approximation over the range -10 to +10 mph. The result is a reduction in accidents of 5.6% per km/h reduction in speed. This is in line with values reported in other studies.

When proposing a system of EVSC Várhelyi (1996) used accident speed relationships proposed by Nilsson (1982) :

(Accident rate after) / (Accident rate before) = $(v_a/v_b)^2$

(Injury accident rate after) / (Injury accident rate before) = $(v_a/v_b)^3$

(Fatal accident rate after) / (Fatal accident rate before) = $(v_a/v_b)^4$

Where:

v_a = mean speed in the after case
v_b = mean speed in the before case

This form is potentially attractive since the change in mean speed is treated as a ratio and is therefore more generally applied.

The existence of the saturation level, or a decreasing rate of change might appear because the changes in accident numbers and rates could not be totally ascribed to the changes in travel speeds. Part of the reduction in accidents could be attributed to economic conditions, fuel shortages, improvements in safety due to improved vehicle safety features, safer highways and increased effectiveness of emergency services. The split between the impact of travel speed and other factors is difficult to estimate, although one study concluded that out of 600 fatalities that were studied 400 accidents could be attributed to changes (increases) in mean speed while the remaining were related and 200 to other factors (Baum et al, 1991).

In order to use such expressions it is necessary to predict the changes in mean speed that will result from an advisory system. It is worthwhile noting that while some sources belittle measures that only produce small changes in mean speed, these relationships suggest that a change of 2 mph in mean speed could reduce accidents by as much as 19%.

As an advisory system EVSC could operate in two distinct modes: firstly providing advice on what the current regulatory speed and secondly providing advice on the appropriate speed for a given situation, e.g. for a section of substandard alignment or during adverse conditions such as fog, wet weather or poor light.

3.2 SPEED LIMIT ADVICE

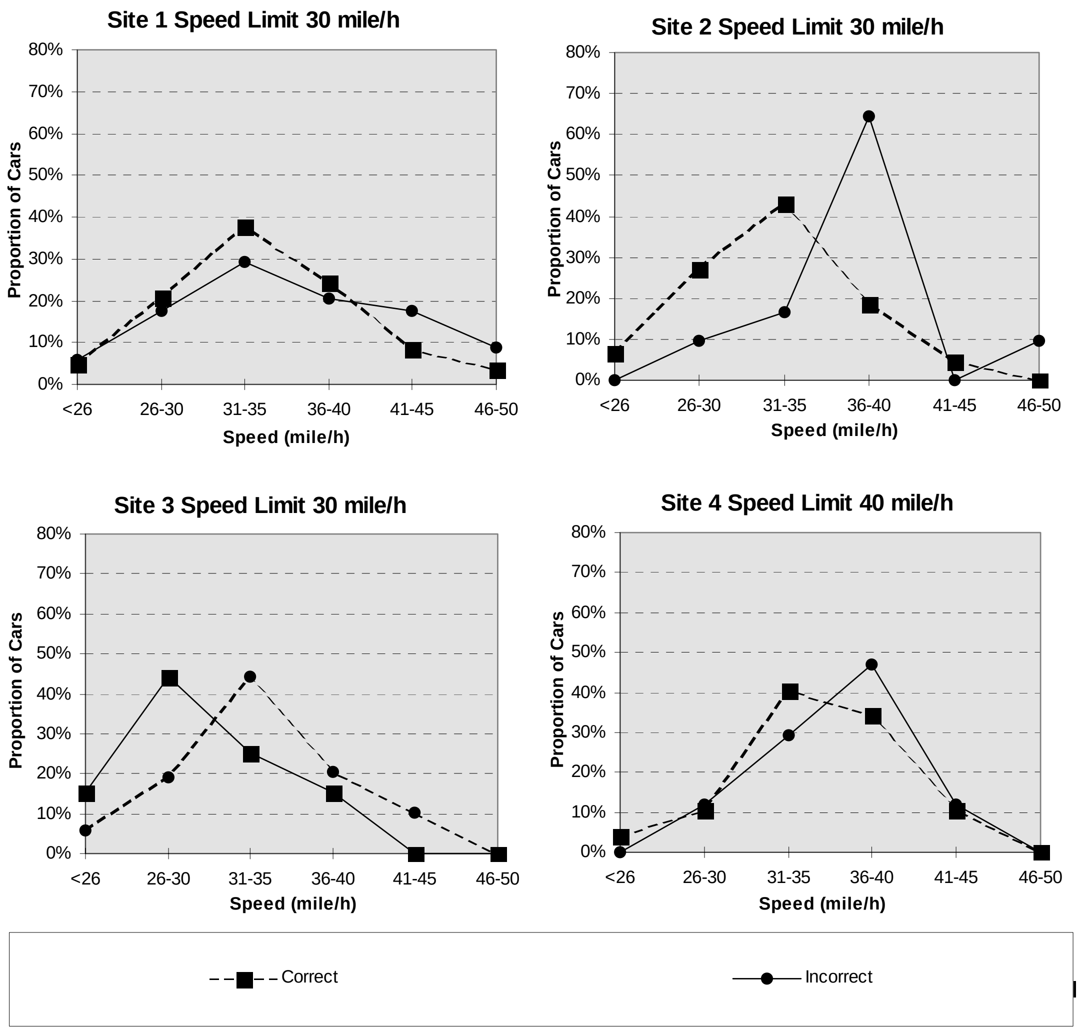


Figure 5: The Effect of Knowledge of the Speed Limit on the Distribution of Vehicle Speeds (source: Cameron, 1980)

When investigating the effect of knowledge of the speed limit on drivers travel speed at four sites (Cameron, 1980), it was found that in 30 and 40 mph speed limits, 26 percent of drivers did not know what the speed limit was. Furthermore the speed distribution for drivers who were unaware of the correct speed limit was higher than that of drivers who were aware of the correct speed limit. The study concluded that the use of repeater speed signs should increase the awareness of the speed limit and subsequently compliance. Although now dated, the results shown in Figure 5 identify a clear difference in the speed distributions of drivers who were aware of what the correct speed limit was and those who did not. Although the original data is unavailable, an analysis of the summary results suggests that, if all drivers were aware of the speed limit, the mean speed of the combined distribution would reduce 3% or approximately 1 mph.

A study into the effect of advisory speed signals on the M4 Motorway (Webb, 1980) found small but significant reductions in the mean speed recorded for light vehicles although no significant change was found for the slower heavy goods vehicles (see Table 3).

Table 3: The reduction in mean traffic speed resulting from the provision of advisory speed signs on the M4 (source: Webb, 1980)

Vehicle Type	Weather	Before Mean Speed (mph)	Percentage Speed Reduction[1] in Before Mean Speed	Corrected Speed Reduction (mph)
Light	Dry	72.1	4.8	3.5
	Wet	70.6	4.9	3.5
Heavy	Dry	55.5	1.5	0.8
	Wet	55.2	2.6	1.4

[1]The actual speed reduction is corrected for changes in speed at the adjacent control sites.

A further study of the effectiveness of motorway advisory speed limit signs on the M1 (Lines, 1981) found that when the speed restriction was set at 50 mph for reasons other than poor visibility the speed reduction for short vehicles was 4 mph (approximately 4%). When the signs were activated due to poor visibility the speed reduction increased to 5 mph (approximately 5%). A number of other studies (Donald and McGann, 1995 and the work of the DSIR referenced by Finch et al, 1994 pp 9) indicate that the impact of speed signs on the proportion of drivers exceeding the speed limit will be significant although changes in the mean may be small and in the order of 2 mph.

3.3 SPECIFIC SITUATIONS

One application of EVSC would involve a dynamic system which would provide drivers with information on the appropriate speed for various conditions. Three situations have been identified associated with:

- road geometry, in particular curves with poor geometry and or high accident rates;
- lighting, darkness;
- weather/pavement surface condition.

3.3.1 Geometry

Of all non-two-wheeled vehicles involved in accidents, 8.4% were involved in accidents of the type “going ahead on bend”. This category of movement is the third highest behind “going ahead other” at 49% and “ turning right or waiting to” at 13.1% of all non-two-wheeled vehicles (DOT, 1996a). In order to reduce the instances of curve related accidents EVSC may be used to provide advice on the appropriate speed at which to negotiate substandard curves. Studies have identified that the accident rate for curves on rural roads is strongly related to the differences between the speed environment approaching a curve and the design speed of the curve (Jackett, 1992; Koorey and Tate, 1997).

Koorey and Tate used road geometry data to calculate the average and minimum advisory speed for each 200 metre segment of approximately 6000 km of rural two lane highway. A strong relationship was found relating accident rate to the difference between the approach speed environment, taken as the average speed over the preceding 1000m, and the minimum speed within the 200 metre section under consideration. The study also looked at the accident rates for three severity classes, Fatal, Serious and Minor Injury accident but found that the differences were minor.

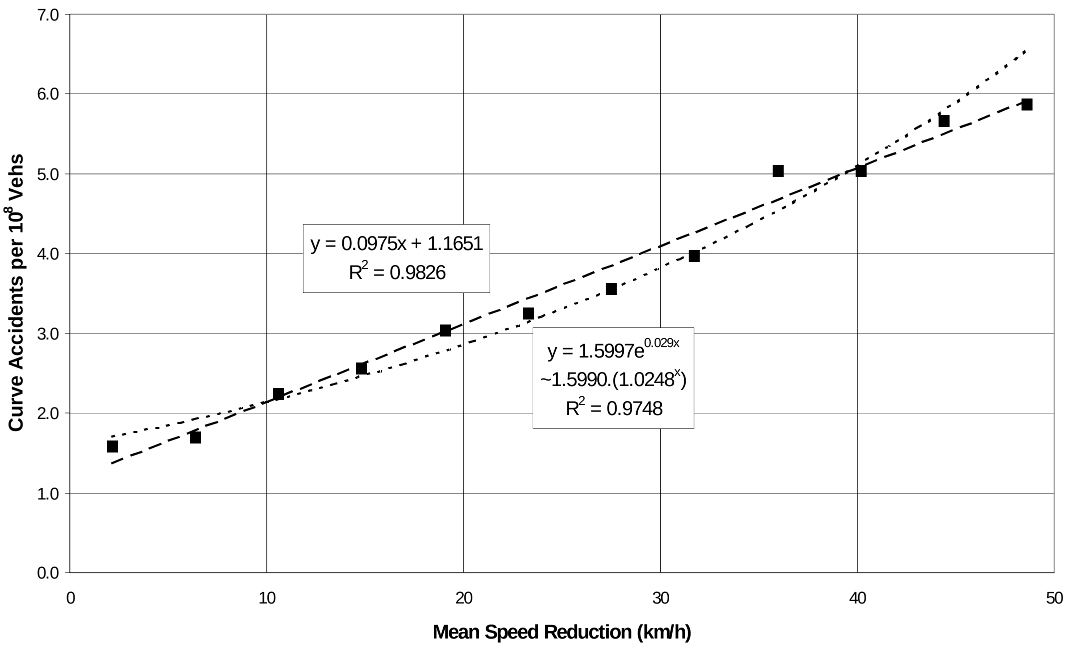


Figure 6: The relationship between speed reduction (Approach speed environment - segment speed) and accidents (source: Koorey and Tate, 1997)

The resulting relationship, Figure 6, clearly shows the effect on accidents rate of in-appropriate speed decisions. The conclusion is that the accident rate will increase by 2.5% for every 1 km/h increase in difference between the approach speed environment and the negotiating speed of a section of road.

Clearly the provision of appropriate advice, if accepted by drivers would have a significant impact on these types of accidents. If the EVSC is providing advisory information then the level of safety benefits will be related to the degree to which drivers are prepared to accept the advice provided by the system. A study into the effectiveness of advisory speed signs on curves (Rutley, 1972) found significant accidents savings in one of the three counties where the trial was undertaken, but no significant change in the other two counties. An interesting aspect of the trial was that the advisory speed was in some cases higher than the mean traffic speed at the site. The result was a rise in the mean speed at these sites, something that appears to have been viewed as an adverse effect. For all but the 30 mph advisory speeds significant changes in mean speed occurred in the direction of the advice given (Table 4).

Table 4: The effect of advisory speed signs on bends (source: Rutley, 1972)

Advised Speed	Number of Bends[1]	Mean Speed (mph)			t-test value	level of significance
		Before Advisory Speed Sign Erected	1 Year After Advisory Speed Sign Erected	Change		
15	5	19.2	18.1	-1.1	6.37	<0.001
20	5	21.2	19.9	-1.3	5.87	<0.001
25	13	25.4	26.2	+0.8	2.39	<0.02 >0.01
30	20	30.4	29.9	-0.5	0.92	Not Significant
35	18	32.7	33.3	+0.6	<0.001	<0.001
40	6	33.8	37.0	+3.2	10.41	<0.001
45	4	37.8	41.1	+3.3	7.97	<0.001

[1]each direction treated separately

What is of interest is the degree to which drivers "take up" the advice of the speed signs. Figure 7 shows the relationship between the change in mean speed and the difference between the mean speed prior to erection of the advisory speed plate and advisory speed. In this case the drivers appear to "take up" approximately 40% of the advice. That is they adjust their speed by 40% of the amount that they have been advised to. In the absence of information about the distribution of curve speed values in the roading network it can only be suggested that if drivers are advised of the correct speed of all curves the accident type "going ahead on bend" may be reduced by 40%.

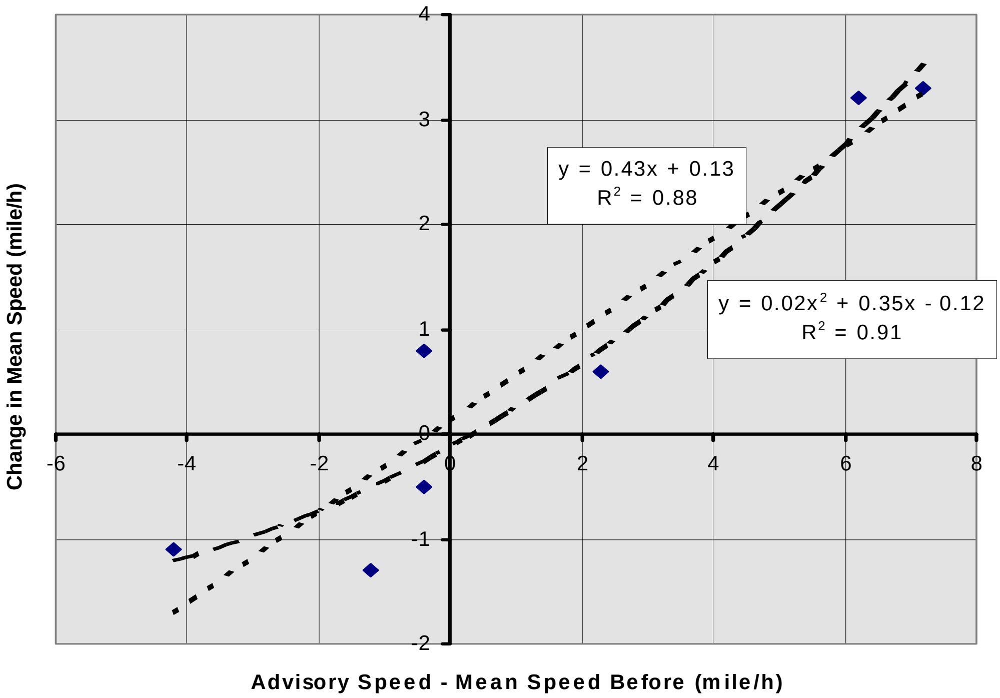


Figure 7: The relationship between speed advice and change in speed

In order to apply these results to the UK situation, it is necessary to have a distribution of the speed drop between successive curves. Such information is not available in a form suitable for use in this study, however as an indication of the potential benefits of advisory speed information an analysis has been undertaken of the summary data used by Koorey and Tate (1997) which is given in Table

5. If an advisory form of EVSC were implemented and the take-up of the advice was 40% the reduction in curve related accidents for this data set would be 10%. If a mandatory system of EVSC were able to limit the difference between the "approach" speed and that required to negotiate a particular segment of road to less than 5 km/h the expected reduction would be 30%. On this basis and assuming that under an advisory system there would be a maximum take-up of approximately 80%, the upper bound of the expected accident reduction would be 20%. It should be noted that this reduction applies only to curves which are not in keeping with the surrounding alignment. As such it does not account for the fact that the lower the overall speed environment of a piece of road, the higher the accident rate. The adjustment should therefore be added to any reduction in the overall accident rate which is achieved by encouraging vehicles to travel at speeds more appropriate for the section of road under consideration.

Table 5: The relationship between curve speed reduction and accidents (adapted from Koorey and Tate, 1997)

Speed Reduction km/h	**Number of Curve Related Vehicle Accidents 1990-1991 (per 200 metre road segment)**			**Vehicles Traversing (200m section)**
	Fatal	Serious Injury	Minor Injury	$x10^6$
0	107	287	571	51351
5	9	35	74	3090
10	14	36	70	2978
15	24	47	67	2563
20	13	29	62	2315
25	11	31	55	1884
30	5	19	31	1225
35	5	15	40	920
40	5	12	17	413
45	2	11	19	222
50	0	2	6	154
55	0	2	4	72
Grand Total	195	526	1016	67187
All speed drops limited to ≤ 5 km/h	140 (72%)	376 (71%)	747 (74%)	

3.3.2 Light Conditions

When driving at night the key constraint is the headlight distance which typically equates to a design speed of 90 km/h (Austroads, 1993), although traffic speeds during the hours of darkness are typically higher than those during daytime hours, possibly reflecting the reduced levels of traffic congestion. No research into the effectiveness of speed advice to aid night-time driving has been located. However the scope for speed reductions is considered limited as only unlit dual carriageways would be affected since the average night-time speed on single carriageways is less then the 56 mph (90 km/h) advisory speed. If it is assumed that the ratio of mean speed to speed limit is between 1.02 and 1.08, the likely speed reduction would be between 6 and 10 mph. On this basis it is assumed that the speed reduction would lie between 0 (no change) and 6 mph (assuming a 40% "take-up"). Within this range the best estimate is thought to be a reduction in speed of 4 mph.

3.3.3 Weather/Surface Conditions

Studies into the effectiveness of speed advice as a means off reducing accidents in which adverse weather or road conditions have been identified are limited. One application of advisory speed technology has been to reduce fog related accidents Although fog has been identified as being present in less than 3% of accidents recorded in the STATS 19 database such accidents may be significantly reduced by EVSC. More importantly studies into the effectiveness of fog warnings may be used as an indication of the benefits that may accrue when drivers are advised of wet or slippery surfaces the accident set, and therefore the potential benefits are likely to be far greater.

Although a number of studies have investigated the effect of fog on vehicle speeds only a few have considered the potential of advisory speed signs to reduce either traffic speeds or accidents. Indeed separating the effect of the advice from the condition is difficult. In Oregon a total speed reduction of around 15 km/h was achieved through advisory speed signing. It was noted by the researchers that *" it was not possible to determine what percentage of the reduction was due to fog and what was due to the sign"* (George et al, 1979 referenced in Brisbane, 1996). Separation of the two effects is difficult. One study into fog advisory speed signs on the M25 (Cooper and Sawyer, 1993) identified a speed reduction of approximately 1.8 mph with the system. Unfortunately the before and after speeds are not recorded in the report. It is however identified that for the warning signs to be activated visibility at the site needed to fall below 100 metres. Although UK studies found that speeds did not tend to reduce until visibility dropped below 250m (White and Jeffery, 1980) this finding has been contradicted by other more recent studies.

An Australian study found that speeds reduced by 11 km/h (Brisbane, 1992) down to a visibility of 250 m identifying that drivers have already made some adjustment for the observed effects. This would tend to reduce the before speed measures. In a study of the advisory speed limits on the M1 (Lines, 1981) it was found that when the advisory speed limits were activated for reasons of poor visibility the speed reduction was approximately 1 mph greater than when the sign was activated for other reasons. In field trials of a fog advisory system in Australia (Brisbane, 1996) the speed reduction was related not only to the presence of a fog warning sign but also to the level of visibility through the fog. A fixed fog warning was found to reduce speeds by approximately 5 km/h while a variable message sign providing speed advice achieved speed reductions of up to 15 km/h although the average reduction over the range of daytime fog visibility was 7 km/h. It is also interesting to note that the study considered night-time as well as dawn and dusk periods separately. The speed drop that resulted from the provision of advisory speed information was 30% to 50% of that recorded in the daytime, since before speeds had already reduced significantly.

It would appear that speed reductions of between 2 and 5 mph may be achieved by providing suitable warnings with realistic advisory speeds. Inside this range a best estimate is judged to be 4 mph.

3.4 SUMMARY OF TRANSLATION EFFECTS

A number of studies have produced linear models which seek to predict reductions in injury accidents ranging from 3.75% to 9.7% for each 1 mph reduction in mean speed. Within this range a reduction of 5% of injury accidents per 1 mph reduction in mean speed appears to be commonly accepted. However some studies support a non-linear reduction and the existence of a saturation level for accident reductions of 25% has been proposed by some research. The range of speed reductions considered in the research is relatively narrow and for most a linear relationship, with bounds should, be sufficient for predicting the likely accident benefits of EVSC. Of the non-linear models those proposed by Nilsson (1982) are favoured due to the ease of calculation. It should be noted that the majority of studies were undertaken on non-urban rural roads with higher speed limits. Just how applicable these reductions are in an urban situation may be questioned but in the absence of any other data the relationships of Table 6 will be adopted.

Table 6: Predicted Accident Savings From Translations of the Speed Distribution

<table>
<tr><th>Accident Type</th><th>Severity</th><th>Movement /Type</th><th>Estimated Reduction</th><th>Low</th><th>High</th><th>Source</th></tr>
<tr><td rowspan="2">All</td><td rowspan="2">All Injury</td><td rowspan="2">All</td><td>5%</td><td>3.75%</td><td>9.7</td><td rowspan="2">A variety of studies included in Finch et. Al.</td></tr>
<tr><td colspan="3">per mph change in mean speed max reduction 25%</td></tr>
<tr><td>All</td><td>Injury</td><td>All</td><td colspan="3">$(V_{before}/V_{after})^3=(A_{before}/A_{after})$</td><td>Nilsson</td></tr>
<tr><td>Non Built Up</td><td>All Injury</td><td>Curve Related</td><td>10%</td><td>0%</td><td>20%</td><td>Koorey and Tate with Rutley</td></tr>
</table>

The level of speed reduction that may be achieved will depend upon the extent to which drivers accept the advice they are given. Although the number of studies is limited it appears reasonable to expect that improved speed limit advice will reduce mean speeds by around 1 mph (3%) while for motorways the figure is in the order of 3 – 4 mph (3.5%–4%). Where advice is given for a specific situation the best available estimate would appear to be that a “take up” rate of 40% may be expected. Simply reducing the advisory speed to compensate for a lack of take-up will reduce the overall credibility of any advice. Studies into the effectiveness of speed advice technology to reduce accidents in which adverse weather conditions feature are limited. It has therefore been assumed that the speed reductions similar to those generated by fog warning systems will occur. This being the case reductions of 1–2 mph, over and above any other reductions, are proposed. The summary speed changes proposed for use in this current study are set out in Table 7.

Table 7: Predicted Speed Reductions

Application	Situation	Speed Reduction			Source
		Estimated Reduction	Low	High	
Speed Limit Advice	Non-Built-Up	4% 4 mph	3% 3 mph	5% 5 mph	Webb, 1980; Lines, 1981
	Built-Up	3% 1 mph	0% 0	4% 2 mph	Cameron, 1980
Darkness	Unlit Dual Carriageway	4 mph	0 mph	5 mph	
Adverse Weather	Non-Built-Up	2 mph	4 mph	5 mph	Cooper and Sawyer, 1993; Lines, 1981; Brisbane, 1992 and, 1996

Combining the accident and speed relationships of Table 6 with the expected speed reductions of Table 7 provides a number of estimates of the likely accident reductions from an advisory EVSC system. These are given in Table 8 and the values selected for use in the calculation of safety benefits have been identified.

Table 8: Accident reductions recommended for the evaluation of EVSC

Application	Situation	Case	Estimated Accident Reduction (%)		
			Low	"BEST"	High
Speed Limit Advice	Non-Built-Up All Reported Injury Accidents	Linear relationships 5% per mph 3.75% per mph 9.7% per mph Non-Linear (Nilsson) **SELECTED VALUES**	 15 11.3 18.8 8.7 **8.7**	 20 15 25 11.5 **17.5**	 25 [1] 25[1] 25[1] 14.3 **25[1]**
	Built-Up All Reported Injury Accidents	Linear relationships 5% per mph 3.75% per mph 9.7% per mph Non-Linear (Nilsson) **SELECTED VALUES**	 3.8 0 7.5 0 **0**	 5 0 10 8.7 **6.5**	 9.7 0 19.4 11.5 **19.4**
Curve Related	Non-Built-Up All Injury	**SELECTED VALUES**	**0**	**10**	**20**
Darkness	Unlit Dual Carriageway All Injury Accidents	Linear relationships 5% per mph 3.75% per mph 9.7% per mph 3 Non Linear (Nilsson)[2] **SELECTED VALUES**	 0 0 0 0 **0**	 20 15 39 16.6 **20**	 25 18.8 48.5 20.5 **48.5**
Adverse Weather	Non-Built-Up All Injury Accidents	Linear relationships 5% per mph 3.75% per mph 9.7% per mph **SELECTED VALUES**	 10 7.5 19.4 **7.5**	 20 15 3.8 **20**	 25 18.8 48.5 **48.5**

[1]maximum reduction capped at 25%
[2]assumes mean night-time speed on dual carriageways is 68 mph

4. TRANSFORMATION OF THE SPEED DISTRIBUTION

The translation of the speed distribution, as discussed in Section 3, is essentially a movement in the mean speed. However the question is raised, *Is the mean the most appropriate measure to be dealing with?* There is considerable evidence to suggest that drivers that travel either excessively faster or slower than the mean speed have higher accident liabilities (Finch et. al., 1994). The effect of a mandatory form of EVSC will be to dramatically transform the speed distribution such that no driver can exceed the given speed limit. It is unlikely that any of the relationships based upon simple translations of an essentially normal speed distribution will be able to predict the likely accident savings. It is therefore necessary to consider the accident liability of different drivers with respect to their locations within the speed distribution. Furthermore the transformation of the speed distribution should consider the rural and urban situations separately due to the different accident types in the two areas.

4.1 RURAL SITUATIONS

Some research has been undertaken into the profile of drivers who are more likely to be involved in accidents (Parker et. al., 1995). This work has identified that those drivers who exhibit a tendency to commit traffic violations, and in particular those involving excessive speed, are more likely to be involved in an accident. In terms of quantifying the relationship between individual accident liability and the propensity for speed the key studies in this area were undertaken before the mid 1970's (Solomon, 1964; Munden, 1967; Hauer, 1970; West and Dunn, 1971). Each study identified that a U shaped relationship such that drivers travelling faster or slower than the mean speed had significantly higher accident rates than drivers travelling close to the mean or median speed. These studies formed the basis of the arguments for the setting of speed limits.

Two studies of particular are of interest, a UK study by Munden (1967) and a US study by West and Dunn (1971). In each of these studies the researchers collected field data about speed and accidents, whereas Solomon used self-reported speeds, and the study by Hauer is a theoretical analysis of the relationship between individual vehicle speeds and the level of vehicle interaction within the traffic stream.

West and Dunn used a monitored highway to collect vehicle trajectory data which was used to detect accidents and obtain the speeds of the vehicle involved. The accident rate (accidents/ million vehicle miles) is given for speed differences from the mean for five speed bands. As shown in Figure 8, it is possible to construct a reasonable relationship using the mid interval points of the study and the origin. Forcing the function though the origin is required to avoid a small negative accident rate in the area of the origin. Clearly the assumption of a zero accident rate at zero speed difference is also questionable and is discussed in more detail below. Although the mean speed is not provided, a speed distribution may be constructed by assuming that speeds are normally distributed with a standard deviation of 9 mph.

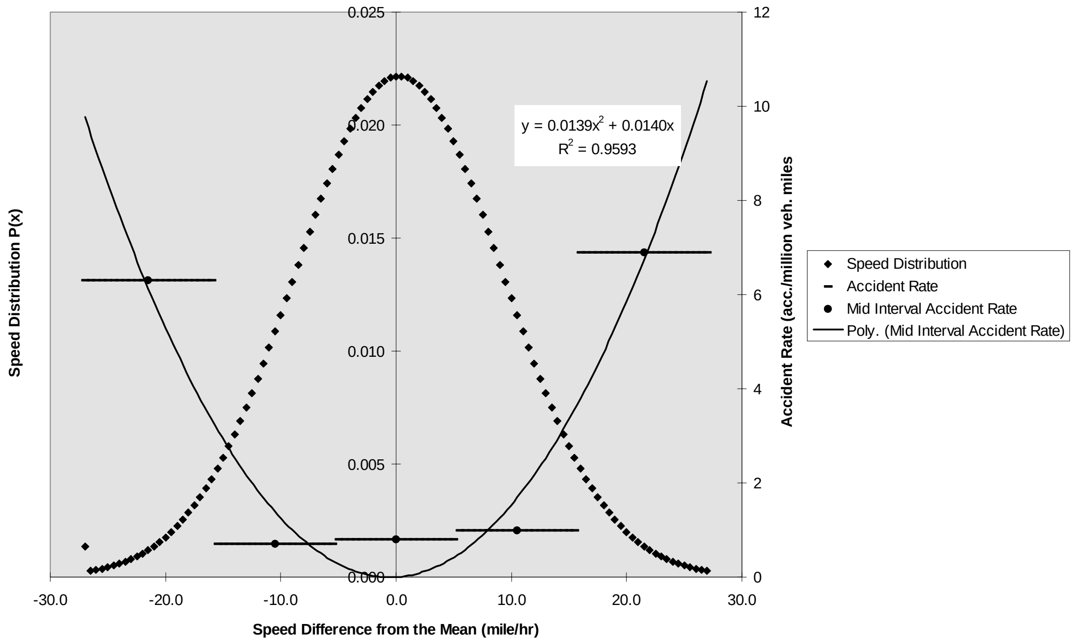


Figure 8: The relationship between speed variance and accident rate (adapted from West and Dunn, 1971)

It is then possible to apply the accident rate equation to the speed distribution. The area under the resulting graph is the number of accidents without EVSC. Using the modified speed distribution of EVSC, it is possible to calculate the area under the curve or accidents with EVSC in place (Figure 9). The difference in area is then the expected reduction in accidents.

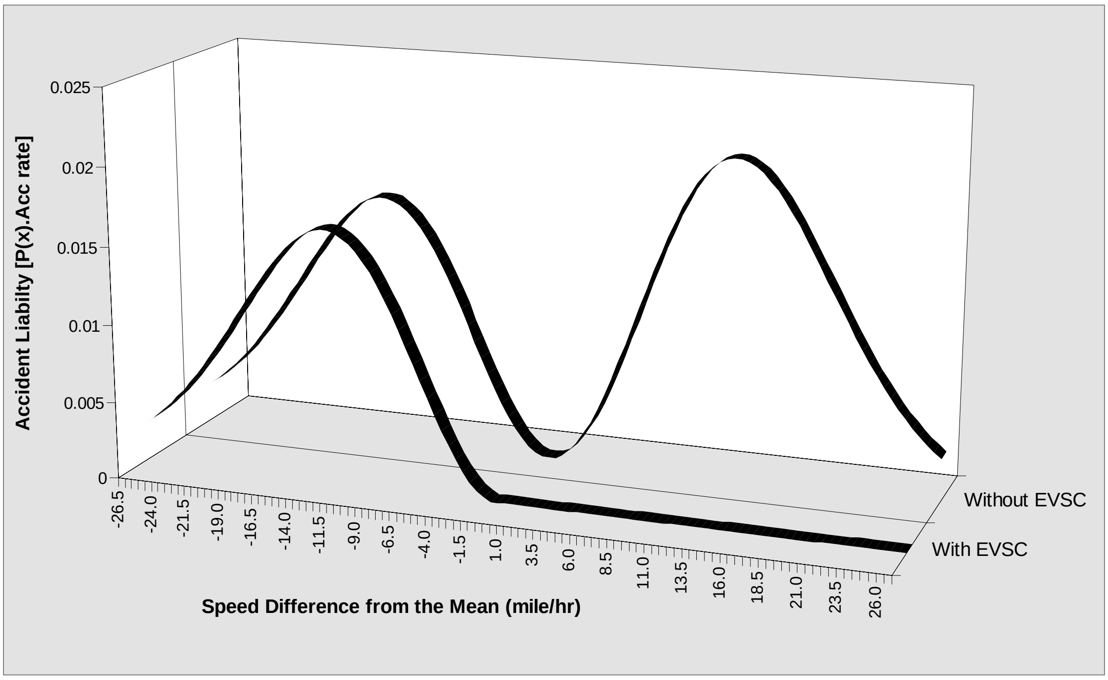


Figure 9: The calculation of an accident reduction resulting from a change in the speed distribution

The analysis has been performed using both the continuous function fitted in Figure 8 and the interval data. The predicted accident reductions are 56% and 23% respectively. The reduction is sensitive to any assumptions about the minimum accident rate i.e. the accident rate of vehicles travelling at the mean speed. Although the function fitted in Figure 8 is forced through the origin the lowest accident rate recorded in the study is 0.8 accidents per million vehicle miles. This is for vehicles travelling at the mean speed forcing the regression function though the point (0,0.8) results in a predicted accident saving of 31%, with little reduction in the strength of the relationship (R^2 = 0.91).

A similar type of analysis has been performed on the results collected by Munden. In that study the registration plate data and the speed of vehicles were recorded for a sample of vehicles travelling on Class 1 and 2 roads in Berkshire and Buckinghamshire. The registration data were subsequently matched with the Police accident data records for that area to determine the proportion of vehicles in each speed band that were involved in accidents. More than 13,000 recordings were undertaken at 10 sites.

Vehicle speeds were reported in terms of a speed ratio between the speed of the subject vehicle and the mean of the speeds of the four vehicles preceding and following the subject vehicle. The speed ratios were then adjusted to account for inter site variations and the standardised speed ratios (SSR) which resulted were used in the analysis. Figure 10 identifies that the accident risk is roughly U shaped and that the distribution of SSR is also approximately normally distributed. Although it is possible to fit parabolic relationships to this data, a better result is obtained by grouping the data and plotting this against the z statistic for an equivalent normal distribution, Figure 11**.**

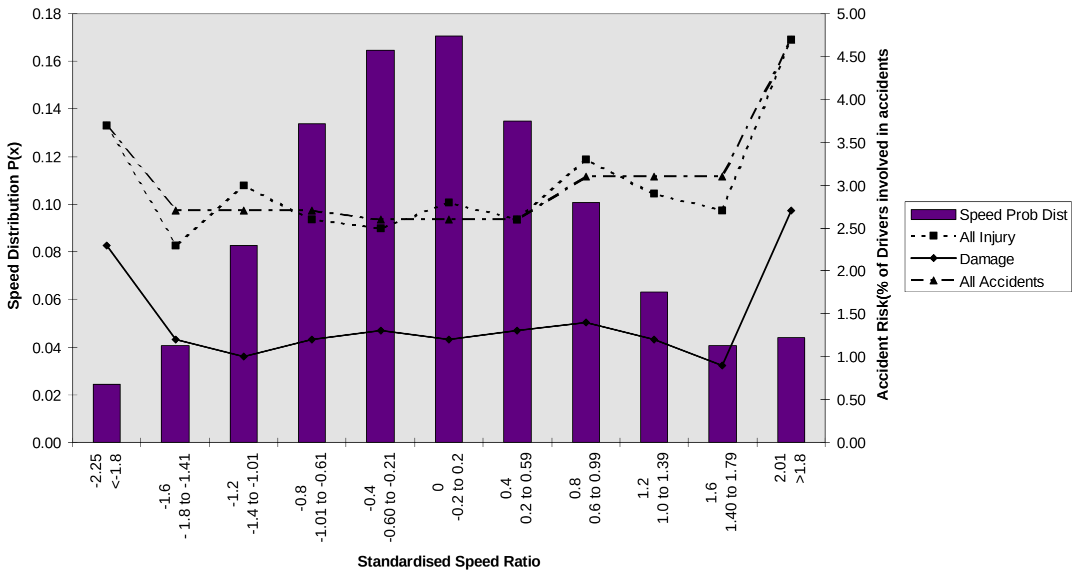


Figure 10: The relationship between Speed Ratio and accident risk (source: Munden, 1967)

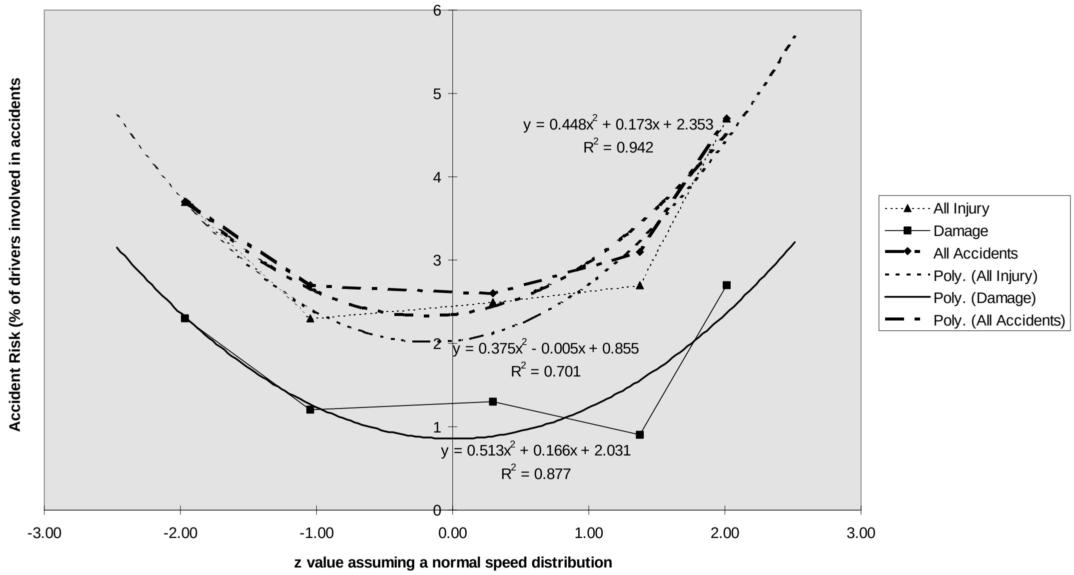


Figure 11: The relationship between speed variance and accident risk (adapted from Munden, 1967)

In the same manner as above it is possible to combine the distribution of vehicle speeds and the accident risk both with and without EVSC. The resulting reductions are 15%, 13% and 11% for All Injury, Damage Only and All Accidents.

Although the summary analyses are not directly comparable it can be seen that the accident reductions derived from the data of Munden are considerably lower than those predicted from the analysis of the West and Dunn data. A number of reason may account for this. Firstly there is Munden's use of the standardised speed ratio which considers only the relationship between the subject vehicle and the eight adjacent vehicles. Secondly the accident data used in the analysis is only that for the surrounding county and the analysis excludes vehicles seen more than once. Thirdly the measure of accident risk is the percentage of vehicles observed that were involved in an accident over the two-year period from which the accident data were drawn. West and Dunn consider accident rate calculated on a vehicle distance basis. Finally Munden assumesthat the same driver was driving the vehicle in the same "state" during the study period 1960 to 1962 and the accident data used preceded the field surveys so that any vehicle that was "written off" in a accident in the period 1960-61 could not be surveyed in the speed surveys of 1962. It is also possible, although the data is not available to confirm this, that the range of speeds encountered by Munden was much narrower since the survey were undertaken on some commuter routes during peak periods.

Given that in the West and Dunn study the actual vehicle speed prior to the accident is used, more credence may be given to that study when considering the likely accident benefits to be derived from a transformation of the speed distribution using EVSC. Given the narrower speed band and the likelihood that local commuter traffic was surveyed by Munden and in view of the lower level of accident reductions that result, it is proposed that accident reductions derived from the analysis of the Munden data will be used for roads in built-up areas.

4.2 SPECIFIC SITUATIONS

Under a dynamic and mandatory system, it is in theory possible to eliminate almost all accidents simply by setting the speed limits so low that drivers may avoid or recover from most accident situations. Although this is clearly extreme, it does identify the potential for continuous adjustments to be made to the system. Unlike the advisory system there is far less need to consider whether the set limits are within a range that drivers believe to be credible. It may therefore be claimed that 100% of accidents that result from causes such as excessive or inappropriate speed may be saved. Although such an assumption may provide an upper bound of the system benefits the determination of cause or even contributory factors from the STATS 19 data is at best haphazard. For this reason a number of researchers have undertaken in-depth studies into subsets of the accident data. Unfortunately there is little commonality between the approaches and definitions. The key issue is ensuring that the accident categories used are "exclusive" and may therefore be added together when considering different accident systems of EVSC.

The order in which the various factors are applied is important as it reflects the different types of study used. There is essentially a two stage process involving translation and then truncation of the speed distribution. The effect of variable or dynamic speeds limits results in a translation effect that lowers the mean speed. To then consider the effect of a mandatory EVSC system the translated speed distribution is subsequently transformed. It could, however, be argued that the provision of advice will narrow the speed distribution so that the subsequent truncation would slightly over estimate the final accident reduction. To estimate the degree to which this may occur is a refinement beyond the bounds of the data.

4.2.1 GEOMETRY

As identified in Section 3.3.1 above, it is difficult to predict the degree of accident reduction that may result from the adoption of more appropriate speeds on bends. Since the accident rate varies with curvature it is necessary to have data on the road geometry. Since such data is not currently available in a useable form, for the United Kingdom, overseas data has been used (Koorey and Tate, 1997). It was estimated, in Section 3.3.1**,** that providing speed advice so that the mean speed of an approaching vehicle stream would be within 5 km/h of the negotiating speed of the curve could generate an accident reduction of 30%. Although differences in the approach speeds are accounted for, the effect of the overall alignment remains unaccounted for. If it is assumed that under the mandatory form of variable EVSC, vehicle streams travel at speeds which are in keeping with the geometry at all times, the effect would be similar to travelling on an alignment with a high relative design speed. If the accident rate for those segment with advisory speeds greater then 100 km/h is used as the base accident rate, i.e. 7.5 accidents per 10^8 veh.km, a 41% reduction in geometry based injury accidents may be assumed. If the most favourable base rate, 3.5 accidents per 10^8 veh.km is assumed a 74% reduction is estimated.

It may be argued that the roads with the lowest accident rate in Great Britain, the motorways, are heavily congested. As a consequence the accident rate for motorways will be higher than would be the case if only geometry related accidents were considered. However, repeating the analysis using a minimum accident rate of 10 injury accidents per 100 million vehicle kilometres (DOT, 1996b) and applying this to all non-built-up roads and motorways the overall accident reduction is 41%. This is comprised of no change for motorways, a 62% reduction for non-built-up A roads, and a 77% reduction on other non-built-up roads. Excluding motorways the reduction for non-built-up roads is 68%. The latter is considered to be the most appropriate value.

4.2.2 ADVERSE WEATHER/SURFACE AND LIGHT CONDITIONS

No data has been found that gives explicit estimates of the likely accident reductions that would result from dynamic speed advice to control speeds under such conditions. Those accidents occurring under conditions of adverse weather and road surface conditions account for 30% of accidents total accidents and are therefore an important potential benefit source for dynamic speed control. A number of researchers have considered the relative risk of driving under adverse conditions Table 9.

Table 9: Relative risk levels in different road and weather conditions compared to dry road/daylight conditions (Taken from Várhelyi, 1996, p 50)

Condition	Accident Rate number of acc./vehicle km)	Source
Dry Road surface daylight	1	
Wet road	1.5 1.1	Sabey (1973) Carlsson (1976)
Slippery Road	5 9	Carlsson (1976) Schandersson (1986)
Darkness	1.3 to 2.0	Brüde et al (1980:a/b)
Rain	1.5 to 2.0	Schandersson (1986)
Snow	1.5 to 5.0	Schandersson (1986)

An accident reduction may be estimated if it assumed that the dynamic speed control will reduce the accident rate to the daytime rate. No data is available specifically for fog related accidents. However fog related accident account for less than 3% of all accidents and may be approximated by the Rain and Wet Road reductions. The category 'Slippery road surface' may indicate ice but in the STATS 19 ice and snow are combined as a single surface condition. It is proposed that the following reductions be used in the subsequent analysis:

Darkness	23% to 50%
Rain and wet road	10% to 50%
Snow	33% to 80%.

4.3 URBAN AREAS

In urban areas the effect of vehicle speed on pedestrian accidents has been the subject of numerous studies. Of particular importance are the studies that relate the vehicle speed on impact to the probability of pedestrian death, Figure 12 (Pasanen and Salmivaara, 1993). Using much the same approach as was adopted for the rural situation it is possible to estimate possible reductions in the pedestrian fatality rate that may result from a transformation of the speed distribution. It is however necessary to relate the impact speed to the travel speed of the vehicle and identify that, as the travel speeds decrease under EVSC, the ability to avoid accidents will be improved. In a study of 168 pedestrian accidents in Adelaide (Anderson et. al., 1995) it was found that in 55% of the accidents drivers had attempted some evasive action, typically braking, before impact. That study, together with others, identifies that not only are the consequences of impact likely to reduce with a reduction in travel speed, so are the number of incidents. To account for such effects a conditional probability to account for the reduction in the likelihood of an impact occurring may be added to the expression. The modification considers a pedestrian entering a random gap in the traffic stream and given particular values of reaction time and deceleration rates the likelihood of being struck and the speed at impact.

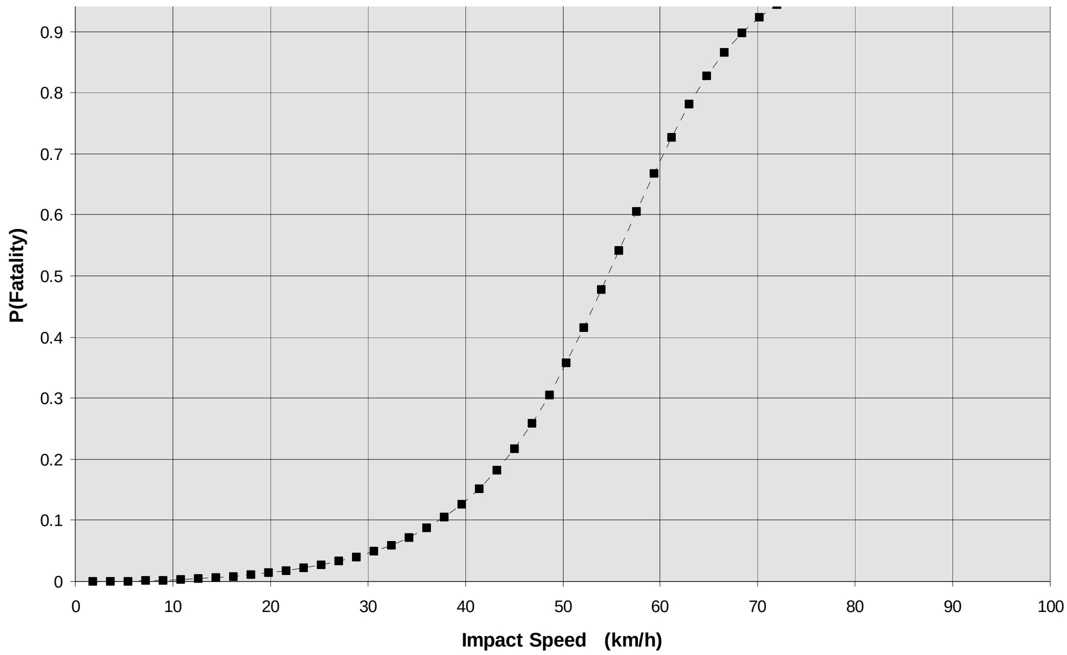


Figure 12: The relationship between vehicle speed at impact and the probability of a pedestrian fatality (taken from Pasanen and Salmivaara, 1993)

Unlike the rural situation, where research has linked the likelihood of an accident with an individuals deviation from the mean speed, the probability of a fatality is related to the absolute speed. Given that it is typically the free vehicles that are involved in pedestrian accidents (Pasanen and Salmivaara, 1993) we are interested in the profile of urban free speeds. Estimates of these are discussed in Section 1.2.1**.** Assuming a mean free urban speeds of 37 mph and 41 mph in areas having 30 mph and 40 mph regulatory speed, respectively, it is possible to estimate the reduction in pedestrian fatalities that might occur from a transformation of the urban speed distributions. The reductions in pedestrian fatalities are estimated to be 20% and 26% for the 30 mph and 40 mph speed limits respectively.

The above analysis deals solely with pedestrian accidents. In the absence of any other data on individual accident liability and speed it is difficult to derive a reduction for other accident types. The only alternative is to use the relationships collected on non-urban roads. The more conservative relationships derived from the data of Munden (1967) are therefore proposed to represent non-pedestrian accidents on Built-up roads while the pedestrian fatality relationship has been extended to cover all pedestrian accidents.

4.4 SUMMARY OF TRANSFORMATION EFFECTS

The values of Table 10 summarise the expected reduction in various accident rates that may be expected to occur from a transformations of the speed distribution that would result from a mandatory form of EVSC that enforces the posted speed limit. When considering the likely reduction in pedestrian fatalities a distinction was made between the reductions for roads with 30 mph and 40 mph speed limits. However in terms of an implementation strategy it is considered that the roads in built-up areas are better classified as A roads and other. A single set of values of for the expected reduction in fatalities on Built-up roads has been derived using the ratio of all accidents for each road type to calculated a weighted mean reduction.

Table 10: Predicted Accident Savings From Transformation of the Speed Distribution

Accident Type	Severity	Movement/Type	Estimated Reduction	Low	High	Source
Non Built Up Roads	All Accidents	All	31%	23%	56%	West and Dunn (re-visited)
Non Built Up Roads	All Injury	All	15%	10% [1]	20% [1]	Munden (re-visited)
SELECTED VALUES Non Built Up Roads	All Injury	All	**31%**	**10%**	**56%**	
Non Built Up Roads	All Injury	Geometry based single carriageway	**41%** **68%**	**30%**	**74%**	Tate and Koorey, 1997 Using M'way Acc. rate
		Darkness	**37%** [2]	**23%**	**50%**	Várhelyi, 1996
		Rain and wet road	**30%** [2]	**10%**	**50%**	
		Snow	**57%** [2]	**33%**	**80%**	
Built Up Roads 30 mph	Fatality	Pedestrian	20%	13% [1]	27% [1]	Pasanen and Salmivaara (assumed mean speed 37 mph)
Built Up Roads 40 mph	Fatality	Pedestrian	26%	17% [1]	35% [1]	Pasanen and Salmivaara (assumed mean speed 41 mph)
SELECTED VALUES All Built Up Roads	All Injury	Pedestrian	**21%**	**13.5%** [3]	**28%**	
All Built Up Roads	All Injury	Non Pedestrian	**15%**	**10%** [1]	**20%** [1]	Munden (re-visited)

[1]High and Low estimates assumed at ±1/3
[2]Best estimate taken as middle of range.
[3]Mean weighted by length highway designated as 30 mph and 40 mph

5. ACCIDENT REDUCTIONS

5.1 ADVISORY SYSTEM

Under an advisory system the accident savings for each of the three types of speed information are added together so that the accident reduction for speed limit advice is first calculated for each of the built-up and non-built-up road types. The additional benefits of curve warnings are then added in to provide the benefits for a variable system and finally a further reduction is made for dark and adverse accidents which will be addressed by a dynamic system. The accident reduction estimates for advisory speed advice are given in Table 11. These estimates are based on predicted reductions of Table 8 and the number of injury accidents for each road classification (DOT, 199b Table 14a). The accident costs have been developed using the All Injury costs for 1995 (DOT, 1996b Table 1k).

Table 11: Predicted Accident Reductions for an Advisory EVSC system using Fixed Speed Limits

Road Class	Low Est	Best Est	High Est
A Roads (Non Built Up)	2,901	5,836	8,337
Other Non Built Up Roads	1,732	3,484	4,977
All Motorways	643	1,294	1,848
A Roads (Built Up)	–	4,809	14,352
Other Built Up Roads	–	6,223	18,573
Total Accident Reduction	5,276	21,645	48,086
As a % of Total Accidents (230,376)	2.3%	9%	20.9%

To estimate the further reduction in accidents that may result from an advisory system with variable speed limits the reduction in curve related accidents is required. Within STATS 19, movement codes are associated with vehicles rather than combinations of vehicles or on a per accident basis. Further more the codes *going ahead on bend left/right* are also used for describing junction based accidents. However a recent study of rural single carriageway accidents has identified that 65% of such accidents occurred away from junctions and that 29% involved one or more vehicle *going ahead on bend*. The accident reductions calculated for the speed limit advice were subtracted from the total accidents prior to calculating the expected accident reductions for a variable speed limit, which are given in Table 12. Although this was undertaken to minimise the effects of double counting a comparison between these results and those calculated using the total accidents showed a differences of less than 2%.

Table 12: Predicted Accident reductions for an Advisory EVSC System using Variable Speed Limits

Road Class	Low Est	Best Est	High Est
A Roads (Non Built Up)	2,901	6,354	9,280
Other Non Built Up Roads	1,732	3,793	5,540
All Motorways	643	1,294	1,848
A Roads (Built Up)	–	4,809	14,352
Other Built Up Roads	–	6,223	18,573
Total Accident Reduction	5,276	22,473	49,592
As a % of Total Accidents (230,376)	2.3%	10%	21.5%

To establish the likely accident reductions for a dynamic system, Table 14, the accidents affected by a variable speed limit system are first deducted and the additional benefits for a dynamic system are then calculated for the remaining accidents. There were 1058 accidents during the hours of darkness on roads with a 70 mph limit in which the street lighting was either not present or not operating. Of these 950 were on motorways and a further 8868 accidents occurred under similar conditions on roads with a 60 mph speed limit in place. These represent 12.9% of all motorway accidents and 16.9% of accidents on all non-built-up roads. In this case the check of under or double counting, applying the accident reductions cumulatively to each road type, resulted in differences of <5%. The effects of all types of adverse weather have been combined and applied only to accidents in non-built-up areas, where traffic speeds are higher. The proportion of accidents occurring during adverse weather has been taken from Table 14a of Road Accidents Great Britain (DOT, 1996b).

Table 13: Predicted Accident Reductions for an Advisory EVSC System using Dynamic Speed Limits

Road Class	Low Est	Best Est	High Est
A Roads (Non Built Up)	3,860	9,457	15,753
Other Non Built Up Roads	2,304	5,646	9,404
All Motorways	805	1,831	3,001
A Roads (Built Up)	–	4,809	14,352
Other Built Up Roads	–	6,223	18,573
Total Accident Reduction	6,970	27,966	61,083
As a % of Total Accidents (230,376)	3.0%	12%	26.5%

5.2 MANDATORY

The speed reduction relationships for road geometry, weather and lighting effects are constructed using existing relationships. So rather than establishing the accident reductions of the Fixed, Variable and Dynamic speed limit systems in a cumulative manner, each is calculated separately. The specific components of accident savings are first deducted and then the overall accident reductions associated with the transformation of the speed distribution is calculated. Therefore the accident reductions for a Fixed Speed limit system, Table 14, are based upon a transformation of the speed distribution alone.

Table 14: Predicted Accident reductions for a Mandatory EVSC System with Fixed Speed Limits

Road Class		Low Est	Best Est	High Est
A Roads (Non Built Up)		3,335	10,338	18,674
Other Non Built Up Roads		1,991	6,171	11,148
All Motorways		739	2,292	4,140
A Roads (Built Up)	Non Ped.	5,438	8,157	10,875
Other Built Up Roads	Non Ped	7,037	10,555	14,073
A Roads (Built Up)	Pedestrian	2,647	4,117	5,489
Other Built Up Roads	Pedestrian	3,425	5,327	7,103
Total Accident Reduction		24,610	46,956	71,503
As a % of Total Accidents	230,376	11%	20%	31%

To assess the accident reductions associated with a Variable speed limits system the accident benefits associated with speeds more appropriate for a given geometry are first calculated. The overall reduction that results from the transformation of the speed distribution is then applied to produce the predicted accident reductions of Table 15.

Table 15: Predicted Accident Reductions for a Mandatory EVSC system using Variable Speed Limits

Road Class		Low Est	Best Est	High Est
A Roads (Non Built Up)		5,032	12,116	20,721
Other Non Built Up Roads		3,004	7,233	12,370
All Motorways		739	2,292	4,140
A Roads (Built Up)	Non Ped.	5,438	8,157	10,875
Other Built Up Roads	Non Ped	7,037	10,555	14,073
A Roads (Built Up)	Pedestrian	2,647	4,117	5,489
Other Built Up Roads	Pedestrian	3,425	5,327	7,103
Total Accident Reduction		27,321	49,796	74,771
As a % of Total Accidents	230,376	12%	22%	32%

Using a procedure similar to that used to construct Table 15, the accident reductions available to a Dynamic system are calculated by first establishing the reduction in accidents associated with weather and light conditions. The accident reduction associated with road geometry is then applied and finally the overall reduction for the speed limit transformation is applied to give the predicted reductions of Table 16.

Table 16: Predicted Accident Reductions for a Mandatory EVSC system using Dynamic Speed Limits

Road Class		Low Est	Best Est	High Est
A Roads (Non Built Up)		8,446	17,365	25,398
Other Non Built Up Roads		5,042	10,366	15,162
All Motorways		1,423	3,346	5,141
A Roads (Built Up)	Non Ped.	10,219	17,284	23,679
Other Built Up Roads	Non Ped	13,223	22,366	30,642
A Roads (Built Up)	Pedestrian	2,647	4,117	5,489
Other Built Up Roads	Pedestrian	3,425	5,327	7,103
Total Accident Reduction		44,424	80,171	112,615
As a % of Total Accidents	230,376	19.3%	35%	49%

6. A COMPARISON WITH OTHER STUDIES

6.1 A REVIEW OF OTHER STUDIES

As identified earlier, the role of new technologies in addressing road safety issues is a relatively recent development. As such very few studies have been undertaken. This section looks at three such studies, one Swedish and two from the United Kingdom. The accident reductions predicted by, or used in these studies, are then compared with the finding of this current study.

6.1.1 SWEDEN (Várhelyi, 1996)

A study of the potential benefits of EVSC was undertaken in Sweden (Várhelyi, 1996). Although the technology of the proposed system is essentially that required for a Mandatory System the study considered the effect of speed distribution translation only. No account has been taken for the changing shape of the speed distribution, and the accident reductions are based on the equation of Nilsson (1982):

$$(V_{after}/V_{before})^3 = A_{after}/A_{before}$$

Where:

V is the mean traffic speed **before** and **after** implementing EVSC

A is the number of traffic accidents involving injury **before** and **after** implementing EVSC.

The study used measured traffic speeds for a variety of speed limits and road conditions; daylight and darkness, as well as dry road, wet road, and slippery road conditions. The overall reduction in injury accidents was considered to be 15%, if the mean traffic speed was reduced to the speed limit. A further analysis of a dynamic system that could reduce speeds depending upon road conditions was also undertaken. The maximum mean traffic speed was reduced between 7% and 17% of the legal speed limit for wet conditions and between 30% and 50% for slippery road conditions. For darkness, the reductions varied by road type from 3% for motorways to 53% for non-motorway roads with 110 km/h speed limits. The range is thought to reflect the level of highway lighting and potential for hazards. The dynamic analysis resulted in accident reduction predictions of 19% and 34% for the high and low speed scenarios.

Although the study considers the effect of speed on accident rates under different road conditions it does not consider the change in the speed distribution that EVSC would bring about. An unspecified post analysis adjustment, to account for a transformation of the speed distribution, has been made and the resulting accident reduction of a mandatory dynamic system was between 20% and 40%.

6.1.2 UK TRL

Two separate studies have been undertaken in the United Kingdom by Transport Research Laboratory. With an emphasis on the infrastructure and technological requirements of such systems the first report (Perrett and Stevens, 1996), looks broadly at the benefits and costs of a wide range of transport telematics and considers automatic speed control as just one of a number of options. The second report (Broughton and Markey, 1996) looks specifically at the way in which common accident groups may benefit from new transport technologies.

Road Transport Telematics Study (Perrett and Stevens, 1996)

The study adopted an accident reduction sourced from the EUREKA funded project PROMETHEUS. The estimate was that under a full dynamic speed control, that is, a system which is capable of varying speeds to suit specific situations, 16% of accidents would be saved. The report then reduced that amount by 50%, since the proposed system is not universally dynamic and then further reductions provide for the incomplete implementation over the vehicle fleet. Under full implementation of a set of fixed legal speed limits the accident reduction was 8% of all accidents. The study also considered the cost savings from reduced enforcement and from a reduction in investment in engineering measures designed to combat speed. The report clearly identifies that there is a lack of data from which to establish these "other" benefits. However, given that the overall accident savings amounted to 94% of the total benefits predicted, there appears little advantage in refining these areas.

In-Vehicle Technology Study (Broughton and Markey, 1996)

In an investigation into the ways in which in-car equipment may help drivers avoid accidents (Broughton and Markey, 1996) a sample of 1112 fatal and 1548 non-fatal accidents were studied. Data on the fatal accidents was obtained from the Department of Transport fatal accident database while the non-fatal accidents were obtained from insurance records held by General Accident. The study sought to identify the factors that precipitated and caused accidents. Based upon a cross tabulation of the precipitating and cause factors, the seven most common accident clusters, essentially homogenous groups, were identified. These are provided in Table 17.

Table 17: Analysis of causal factors in accidents (taken from Broughton and Markey, 1996)

Cluster	Type	Precipitating Factor		Cause Factor
1	Fatal	Driver loses control		driving too fast
2	Fatal	Driver loses control		lack of judgement
3	Fatal	Pedestrian Fails to give way to driver		Pedestrian Fails to give way to driver
4	Non Fatal	Driver hits object in carriageway	***Because of***	distraction
5	Non Fatal	Driver hits object in carriageway		failure to judge other drivers speed
6	Non Fatal	Driver hits object in carriageway		driver loses control due to snow and ice
7	Non Fatal	Driver hits object in carriageway		excessive speed

It is not clear from the report how the complement to Cluster 3, that is, a pedestrian accident where the driver was essentially at fault, has been treated. It may have been allocated a precipitating factor *Driver failed to yield* if the accident was associated with a pedestrian crossing or possibly *Driver hits object in carriageway.* Of the latter group those involving pedestrians accounted for 26% of fatal accidents but none of the non-fatal accidents. The principal causes of Fatal *Driver hits object in* *carriage* way were excess speed, 42% occurrences and *looked but did not see*, 20%. As a result these accidents did not feature in the top seven clusters.

Each cluster involved one precipitating factor (P) and one cause factor (C) although cause factors were described as either primary, or secondary. A cause factor is termed primary if the Precipitating Factor would *very probably* not have occurred if it (the cause factor) had not been present. If that was not the case it was considered a secondary factor. Accident savings would result if an in-car aid was able to remove, or nullify the cause factor. The calculation of the potential safety benefits from an in-car aid were then based on three levels of effectiveness:

Level 1	$N_0.(N_1+N_2+N_3)/100$	All accidents with precipitating factor P and any cause code of type N would be avoided
Level 2	$N_0.(N_1+N_2)/100$	Only accidents with precipitating factor P and a primary cause code of type N would be avoided
Level 3	$N_0.(N_1)/100$	Only accidents with precipitating factor P and a sole cause code of type N would be avoided

N_0 = percentage of accidents with Precipitating Factor P and Cause Factor C
N_1 = percentage of accidents involving P where C is the sole Causation Factor
N_2 = percentage of accidents involving P where C is the primary Causation Factor but others exist
N3 = percentage of accidents involving P where C is a secondary Causation Factor

From this basis the researchers calculated the potential accident benefits of various type of in-car technology. These are outlined in Table 18. Of the predicted savings those in *Cluster 1 Driver loses control because of excessive speed* and Cluster 7 *Driver Hits Object because of excessive speed* are of relevance to this project.

Table 18: Accident reductions (adapted from Broughton and Markey, 1996)

Cluster	**Proportions of Causation Factors**				**Accident Reductions**			
	N_0	N_1	N_2	N_3	Accident Type	Level 1	Level 2	Level 3
1	45.8	4.8	33.2	15.8	All Fatal	24.6%	17.4%	2.2%
2	45.8	1.0	3.8	18.5	All Fatal	10.7%	2.2%	0.4%
3	Problem was defined as pedestrian based and not amenable to most in-car technologies							
4	44.9	27	2.4	2.9	Non Fatal	14.5%	13.2%	12.1%
5								
6	25.5	39.8	4.3	0.9	Non Fatal	11.5%	11.2%	10.1%
7	Considered to be of the same order as Clusters 4 and 5							

The implementation of EVSC was therefore predicted to reduce reported injury accidents by between 2.4 and 35.0%. Although the common accident clusters represent the most significant groups of accidents which may be addressed using in-vehicle technology it should be noted that the classification *"other"* which contains a significant proportion of accidents may of which may also benefit from a reduction in speed. The minimum reduction of 2.4% is considered to be unrealistically low when compared to the accident reductions that have been report as resulting from changes in the speed limit and mean speeds.

6.2 SUMMARY OF OTHER STUDIES

In order to establish the likely benefits of EVSC the studies reviewed have considered either a:

- simple translation of the speed distribution in which existing relationships between the change in accidents the change in mean speed, or
- set of accidents which have been identified as being directly related to speed.

In each case the method adopted ignores an area of potential benefit. The simple translation ignores the fact that EVSC will, except in an advisory mode, impact more effectively upon the higher end of the speed distribution. On the other hand limiting the analysis to only those accidents which are clearly related to speed neglects the fact that reduced vehicle speeds will reduce the instance and severity of all accidents.

Within the wide range of predicted savings are two key variants. The first is a system that replicates the current regulatory speeds, while the second is a dynamic system that allows more appropriate speeds to be set. The summary values are presented in Table 19.

Table 19: Comparisons with other studies

System Type	Accident Reduction	Assumption	Source	Equivalent Savings from This Study		
				Low	Best	High
Advisory Fixed	15%	Translation	Várhelyi, 1996	2.3	9.0	20.9
Advisory Dynamic including weather and darkness	19-34%	Translation with a factor to cover a transformation		3.0	12.0	26.5
Mandatory Dynamic	20%-40%	Approximation of Transformation		19.0	35.0	49.0
Mandatory Dynamic	2.5-35%	Addressing Speed Related Accidents	Broughton and Markey, 1996	19.0	35.0	49.0
Mandatory Fixed	8%		Perrett and Stevens, 1996	11.0	20.0	31.0
Mandatory Dynamic	16%			19.0	35.0	49.0

As shown in Table 19 the different studies have produced quite different results. The studies of Várhelyi assumed an advisory type system in which the mean speed is reduced to the legal speed. The big difference between Várhelyi and the present study, results from the low accident reductions we predicted for urban areas. In the low estimate a nil speed and accident reduction was used in urban areas. This is because the mean speeds reported in these areas are already below the speed limit. Indeed in almost all cases the speed reductions used by Várhelyi are much larger than those used in this study. It is also interesting to note that the upper bound of accident reductions produced by Várhelyi‘s advice based system are similar to those generated by Broughton and Markey, however their system would be a mandatory dynamic system. Várhelyi‘s final estimate for a mandatory dynamic system is remarkably similar to the findings of this present research. This provides us with some confidence, since the two studies although similar are essentially independent of each other. The study by Perrett and Stevens suggests benefits that are approximately half those of the other studies. This is certainly the result of the coarse accident assessment employed by Perrett and Stevens.

7. COSTS

Technical issues associated with system components and the derivation of system costs are provided in Deliverable 4 of this project. In terms of defining the possible implementation scenarios the key issues associated with system costs are the:

- form of the system,
- unit costs,
- reducing cost associated with mass production, and the
- integration of EVSC with other technologies to reduce costs.

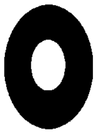
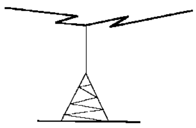
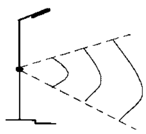
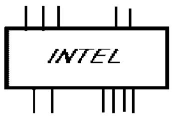
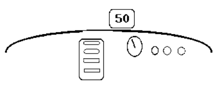
7.1 FORM OF THE SYSTEM

Three basic system types have been defined to cover the range of costs and driver interaction levels:

- **Full System** which is capable of implementing mandatory speed control with speed advice from an external source;
- **Driver Selection System** in which drivers selects the appropriate driving speed and the in-vehicle technology implements that decision;
- **Advisory System** which provides speed advice from an external source but requires the driver to implement the appropriate action.

Within each system a number of sub options are possible. These relate to the way in which speed advice is transferred to the vehicle, and the degree of retardation if speeds in excess of the specified limit are detected. The latter being an important issue for dynamic speed information which could be less effective if the vehicle is not actively slowed. The components of the systems are shown in Table 20 while the systems are sketched in Figure 13, Figure 14, and Figure 15.

Table 20: Definition of the components of a EVSC system

COMPONENT	DESCRIPTION	COST ISSUES
	**CD ROM SYSTEM** Containing digital road map and GPS vehicle location system. Will read fixed speeds from map.	• £ per disk • £ per reader • £ to re write/replace system update and maintenance • £ per GPS locator • Does unit life = vehicle life
	**UPDATE BROADCAST** Broadcasts on GSM or similar will update "roadmap"data. Could include local conditions and network changes	• £ per vehicle receiver including interface to CD ROM and GPS • Will existing broadcast units be used • Cost per broadcast unit • What is the coverage, how many will be needed • Annual operating cost per broadcast unit
	**ROADSIDE BEACON** Roadside beacons broadcast up to date speed data to vehicles approaching.	• £ per in-vehicle receiver • cost per beacon including power • number per location (are they bi directional and multi lane) • how many locations • expected life • special maintenance
	**ON-BOARD UNIT** Receives speed data and implements action based upon logic to ensure conflicts with other systems do not occur	• £ per in-vehicle unit assuming interface with likely common in-vehicle technologies ABS eng management system etc Options • Input from external data source • Driver operated speed selection system
	**POWERTRAIN RETARDATION** Vehicle is slowed through limiting powertrain output. essentially a passive system.	• £ per unit Options • within engine management system Can we assume all vehicle will have the same system or at least one that costs the same?
	**ACTIVE BRAKING** Vehicle is slowed using an active braking system via an ABS or similar system	• £ per unit assuming implemented only with powertrain retardation system Can we assume all vehicle will have the same system or at least one that costs the same?
	**HMI** Driver advice system. Will provide advice on what the current speed settings are OR in the case of the advisory system may warn drivers of excess speed	• £ per unit Options • Simple visual • Visual with Simple audible
	**DRIVER** Will be allowed to choose speed (a lower speed) as required. For the Driver Selection system the driver will set the speed value manually but for the advisory system will make all speed choice decisions	

FULL SYSTEM

Updatable data received from external infrastructure
Speed control is automatic and compliance is mandatory.
Drivers are informed of system performance

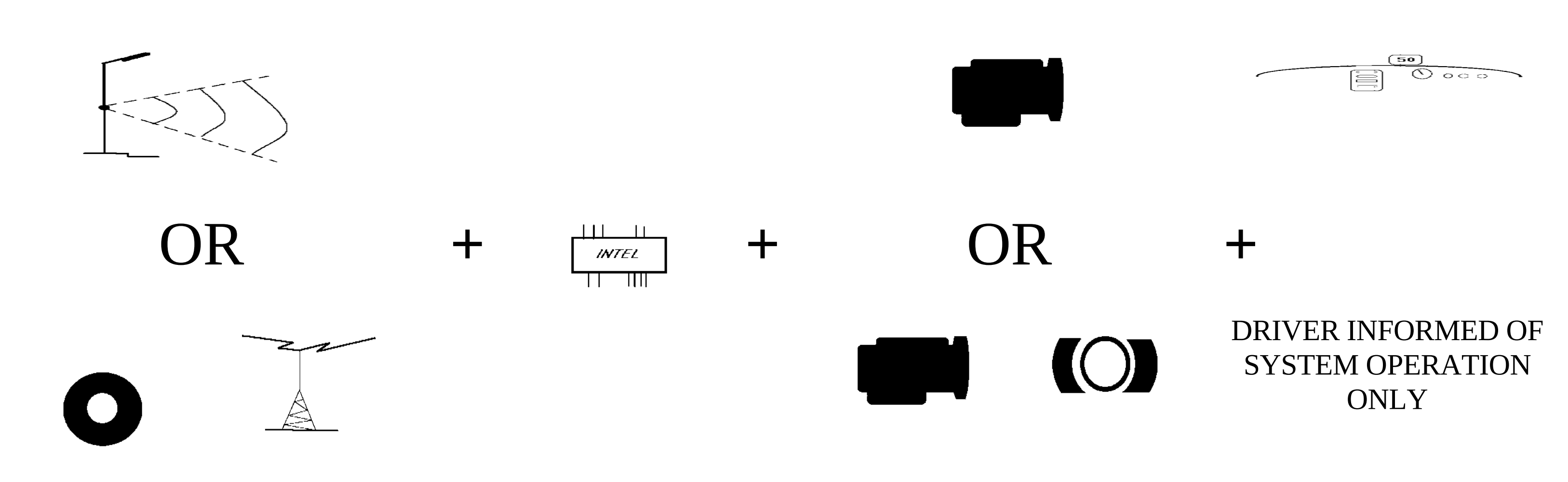


Figure 13: Concept diagram for a Full EVSC system

DRIVER SELECTION SYSTEM (using signs)

Drivers choose their maximum travel speed (from pre-set options).

Speed control is automatic although compliance is not mandatory.
Drivers are informed of system performance

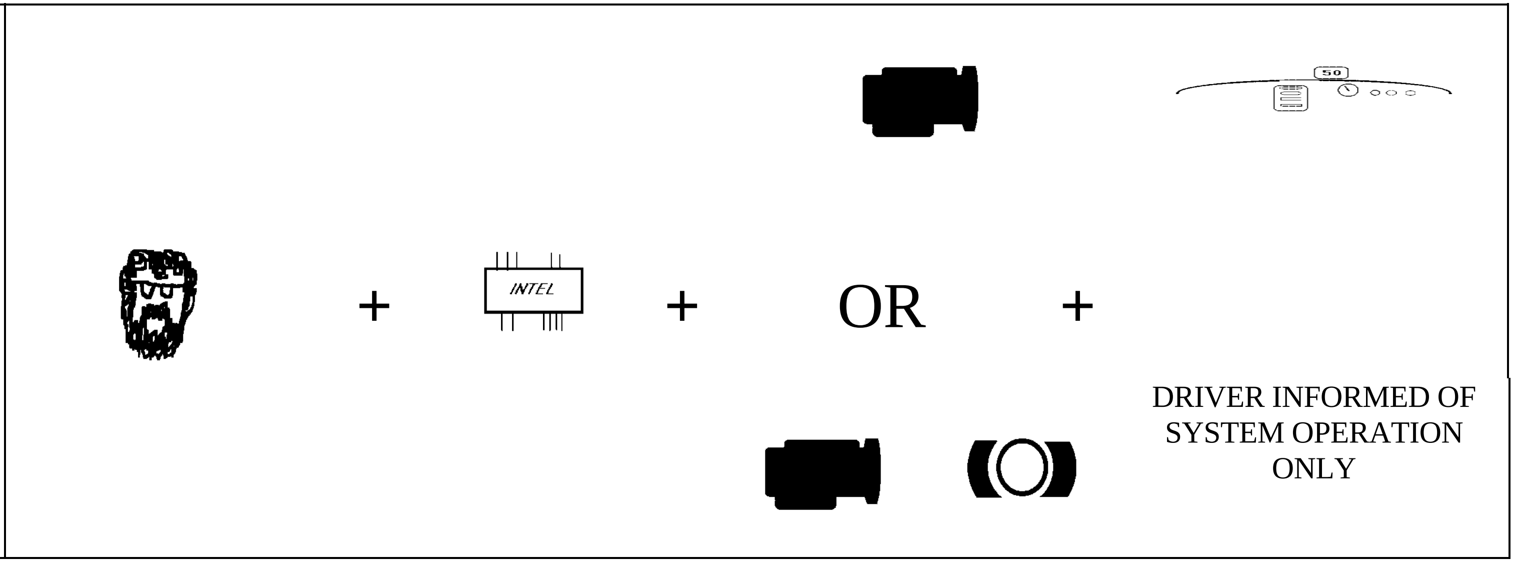


Figure 14: Concept diagram for a Driver Selection system of EVSC

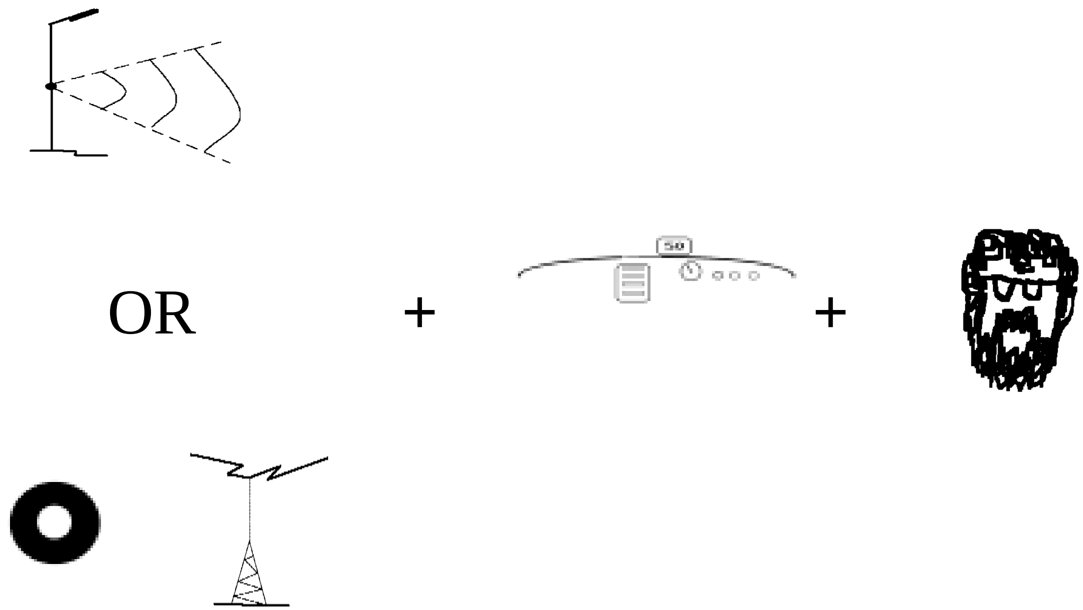
ADVISORY SYSTEM Updatable data received from external infrastructure Drivers are informed of speed limit and choose speed	

Figure 15: Concept diagram for an Advisory EVSC system

7.2 UNIT COSTS

Although three types of EVSC systems are proposed it can be seen from Figure 13, Figure 14, and Figure 15 that a number of sub-systems are defined, principally in terms of the variations in the supply of information, and the method of retardation.

A number of different products or technologies may fulfil the requirements of each element in the sub-systems. This combined with the uncertainties inherent in estimating the future costs of new technology has lead us to consider generic costs for each element rather than create a multitude of sub-options that are specific to a particular type of unit. In discussing the costs of these systems it is useful to identify three main areas:

- Information Supply,
- System Control and the
- Human Machine Interaction system.

The options available in each of these areas together with the assumptions used to develop the cost estimates are discussed below.

7.2.1 INFORMATION SUPPLY OPTIONS

Three mechanisms by which speed limit advice may be transmitted to the vehicle/driver are available. The first is the current system of using road signs to advise the driver of the speed limit. This method would be used under the driver selection system. The other two systems represent different ends of the supply scale. One being infrastructure based, the other being essentially an autonomous system. While other options such as electronic nails may be available these will generally lie within this range.

Beacon Based System

Under this system roadside beacons, termed dedicated short range communication (DSRC) units, would "broadcast" the electronic speed limits required for the local area. The speed limit would remain current until updated by a subsequent signal.

The system would comprise a beacon set, including power supply, and an in-vehicle receiver. The system would also require control and monitoring centres. For a dynamic system some form of sensor and local logic to vary the speed limit for local conditions using some pre-set logic is needed.

If a beacon based information distribution and collection, is a potential component of an EVSC control network, then this would necessarily require major installation to the UK road network and therefore by any standards considerable. Although pilot system such as the Road Traffic Advisor are currently being trialed, only a relatively small number of units have been produced so far, and price information is still currently confidential. Estimated unit costs are given in Table 21.

Table 21: Unit Costs for a Beacon based system (1995£)

Item	Now	2010
Receiver	25	5
DSRC per	30,000	750
DSRC beacon power for 12 months	50	50
Number required per location*	2+	2+
Maintenance cost per year per beacon	50	50

It is assumed that:

- the beacons are uni-directional and will cover up to 2 lanes but not three lanes with any accuracy or reliability;
- special beacon gantries will not be required and that existing infrastructure such as poles, bridges and existing sign gantries will be used;
- the average beacon life is in excess of the analysis period and that the maintenance costs include an allowance for replacement of premature failures.
- the beacons network will be partially intelligent in that it will perform some detection functions for the dynamic system.

The number of beacons will be based upon the number of speed changes in the road network. Although this data is not readily available two methods have been used to estimate the frequency of speed changes in the network. Firstly a review of the West Yorkshire maintenance inventory database suggests that there is one speed sign for each 0.867 km of road. If it is assumed that the signs are located on each side of the road then the average spacing is one sign per 1.7 km. The second estimate is based upon a limited survey of sections of A and B roads. This provided a mean value of one speed change location every 4.2 km and a likely range of between one per 3 to 8 km. This compares well with another study (Perrett and Stevens, 1996) which assumed a speed change every 5 km.

Using the assumption that speed changes are located on average every 5 km on the 363809 km of non-motorway network (DOT, 1996b Table 3.17) a total of 72,762 bi- directional locations would require beacons. For the motorway network it could be assumed that beacons would be required at each junction on and off ramp. This would be approximately 2800 single direction locations. This amounts to a total of approximately 148,500 uni-directional locations. If a dynamic system which allows speed limits to reflect local road conditions is assumed, it could be expected that a beacon is required every one to two kilometres. This would ensure locally specific information is provided and allow for transitions of speeds. This would require approximately 367,000 beacons.

Without data on the number of substandard curves, or other locations that may warrant a fixed speed limit less than the current regulatory speed, it is not possible to establish how many beacons would be required by a variable system. An average of the Fixed and the Dynamic systems has therefore been used. This would give approximately 257,000 uni-directional locations. The total cost for the proposed beacon network is given in Table 22.

Table 22: **Cost of the beacon network (1995£M)**

EVSC System	Number of Uni directional Beacons	1995	2005	2010	Annual Power and Maintenance
Fixed	148,500	4,455.0	1,559.3	111.38	14.9
Variable	257,000	7,710.0	2,698.6	192.75	25.7
Dynamic	367,000	11,101.0	3,853.6	275.25	36.7

If beacons were the basis for the supply of other services as the primary reason and justification for their installation (such as RTA) then the EVSC functionality would only be a proportional additional service cost.

One criticism of beacon based systems is that they have proved relatively unreliable to date. It is therefore proposed that an allowance be made to replace 10% of the beacons each year following completion of the system. The cost of a replacement beacon being half of the initial installation cost.

CD-ROM Based System

This is an essentially autonomous system where an in-vehicle storage device, such as a CD-ROM, contains a digital map of the road network with the speed limits identified. A vehicle navigation system with a global positioning system (GPS), inertial gyroscopes and dead reckoning capability will position the vehicle on the digital map and the relevant speed data will be read from the map. Such maps are expected to be updated and issued annually as part of the vehicle licensing procedures. Between revisions update data would be broadcast using an existing cellular based system. These broadcasts would also be used to provide dynamic speed limit data.

The costs of an in-vehicle data storage based system with updates from a cellular type communications network are considered in Table 23.

Table 23: Unit Costs for a CD-ROM based system (1995£)

Item	Now	2010
Construct Digital Map	8-12M	8-12M
Disks with datamap each	50	5
Reader Unit	600	100
GPS + gyroscope + dead reckoning sensors	900	300
Update system information	2.25M	2.25M
Update in-vehicle disk maps per vehicle per year	50	5
Broadcast unit*	nil	nil
Coverage and number of transmitters**	n/a	n/a
Additional costs on Vehicle receiver	50	5

* We would anticipate that this would employ the existing network, and not require additional hardware.

** This is not an issue with use of the established network.

The key issue is the cost of creating the digital map. This is difficult to establish since much of the information sought is commercially sensitive to the current map producers. The values used in the other UK study (Perrett and Stevens, 1997) have been compared to those derived from "first principles". The study by Perrett and Stevens estimated the cost of establishing a navigation database at £25M. Although the basis of this estimate is not detailed, this is equivalent to between 850 and 1250 person years of work or roughly 13 - 20 person per county for one year to construct the database which would cover the 366,999 kilometres of road in Great Britain (DOT, 1996b). However a number of commercial organisations have already digitised the trunk road network. The addition and checking of speed changes would be an arduous task but assuming that each road was driven to determine the actual speed limits a further 20 persons would be required to complete this in one year. Even if another 2-4 staff were required to digitise the sections of outstanding road network, and the estimate were inclusive of additional administrative structures and the establishment of a distribution network the estimate of £28M is considered high. This is especially so given that much of the road network has already been digitised.

Assuming that some 200 people are involved and that labour represents 50% of the total project cost the set-up cost would be in the order of £8M to £12M. This cost would provide both the fixed and variable speed limit maps. However a dynamic system would require additional roadside monitoring infrastructure to determine local conditions such as ice, fog or weather. If sensors are situated at key locations, approximately 5 km apart on the principal road network, and cost £1000 each this would add approximately £34M to the system costs.

For the in-vehicle technology, route guidance and driver information systems which include a complete navigation system including digital maps GPS with gyroscopes and a dead reckoning system are currently available for around £3000. This price may be used to check the overall level of cost although it must be recognised that such systems are based upon recouping costs over a small level of market penetration.

An annual maintenance cost of £8M has been estimated by Perrett and Stevens (1997) to cover the updating of the digital road maps and presumably the costs of distribution. This estimate represents between 4 and 6 persons per county per year. This is considered to be an upper estimate and based upon 75 full time staff nation-wide the annual maintenance cost of both the fixed and variable systems would be £2.25M. For the purpose of this study the value has been doubled for a dynamic network to cover the management of the sensor and speed limit modification systems that would be required. It is envisaged that the system used to provide temporary variations would simply identify whether a speed limit change would be temporary or permanent. The latter changes would then be accumulated and distributed as a system update. It is assumed that the in-vehicle data is updated annually with a new disk map being supplied as part of the licensing requirements.

The broadcasting of update information would be a continuos process since disk updates would not be issued at a specific time but throughout the year. Although the annual costs account for the administration of this system it does not include an item for the transmission of the broadcasts. It assumed that these will be essentially “free transmissions” using the current infrastructure, or the future equivalent.

7.2.2 SYSTEM CONTROL

System control considers the management and implementation of speed control and consists of an on-board control unit and the retardation system. The on-board control unit is the means of providing EVSC functionality together with an integrated logic to co-ordinate the EVSC with other vehicle functions. Such functions may be undertaken by a new dedicated unit or incorporated into an existing electronic control unit (ECU). Clearly, as more sophisticated engine management and braking systems are increasingly available, this function will be integrated into the existing engine management system /electronic control unit. Although the cost of developing a separate unit has been estimated (Table 24) it is expected that with the implementation of EVSC, advanced engine management systems will become standard production items, and a degree of shared functionality would result. Therefore an average present cost of £300 is proposed reducing to £10 for 2010.

Table 24: Unit costs of On board control Unit (1995£)

Item	**Now**	**2010**
Cost per unit (separate controller)	500	50
Cost per unit (integrated with existing vehicle ECU)	75	10
Driver operated speed selection system*	–	–

* This is dealt with in the section on HMI below.

The costs for two systems of retardation are considered in Table 25. These are passive retardation though engine management and general deceleration and active retardation though the braking system. For passive retardation the costs of the components will be broadly similar for all vehicles if the implementation was via the ECU, i.e., virtually no additional hardware, only the cost to program the additional code into the ECU. This would not be the case, in our view, if additional hardware is employed for the active retardation system. Therefore the costs may vary markedly between passenger cars and commercial vehicles. Costs below are based on passenger cars, and may be ten times larger for HGVs and buses. However since these vehicles comprise approximately 2.5% of the vehicle fleet the distinction in costs is well within the bounds of the estimates and no further adjustment to the costs has been made.

Table 25: Unit costs for retardation systems

Item	Now	2010
Passive retardation only via ECU control	50	5
Active retardation including traction control and ABS actuators	1000	300

The cost of an active braking system assumes that traction control and ABS actuators are required solely for EVSC. It is however likely that by 2010 all vehicles will be fitted with this technology. Reducing the 2010 cost of this item from £300 per item to £100 reduces the cost of systems involving active braking considerably. Furthermore it is assumed that any active retardation will only be available on vehicles with fully functional ECUs. The estimates therefore include only updating the ECU software not providing a separate ECU unit.

7.2.3 HMI

Once again it is difficult to fully rationalise a truly "additional" system for EVSC. The design of the vehicle HMI should seek to integrate all information display and control elements into a whole solution. If speed limit data was required to be displayed then it would ideally be within a display functionality present within the vehicle. For example, highlighting in some way the local speed limit on the speedometer dial via a circle of LEDs or similar mechanism. Therefore the additional costs are likely to be marginal if this is done. The same comments would apply to control of EVSC by switches. This may be done by including this into existing controls thereby making additional costs, shown in Table 26, are minimal.

Table 26: Unit Costs of HMI (1995£)

Item	Now	2010
Simple visual and/or auditory displays	1	1
Driver self selected system controls	5	5

7.2.4 SUMMARY OF SYSTEM COSTS

For each of the system identified above it is possible to establish the systems costs in terms of an initial establishment cost to set up the system and an annual cost. These costs, presented in Table 27, are for both the current estimate year 1995 and for the future year 2010. Linear interpolation is used to establish the costs in any intermediate year. The estimated costs for 2010 will be used for all subsequent years. Although this approach represents the reduction of manufacturing costs with respect to time and massed production costs have not been reduced to reflect the possibility of shared use by other telematics applications.

Table 27: EVSC System Costs

<table>
<tr><th rowspan="2">SYSTEM</th><th colspan="2">Sub Options</th><th>Cost per Vehicle</th><th colspan="3">Establishment Cost 1995£M

(2010 costs in 1995£M)</th><th colspan="3">Annual Cost 1995£M

(2010 costs in 1995£M)</th></tr>
<tr><th>Information</th><th>Retardation</th><th>1995£</th><th>Fixed</th><th>Variable</th><th>Dynamic</th><th>Fixed</th><th>Variable</th><th>Dynamic</th></tr>
<tr><td rowspan="2">Full</td><td rowspan="2">Beacon</td><td>Passive</td><td>380
(60)</td><td>4455.0</td><td>7710.0</td><td>11101.0</td><td>14.9</td><td>25.7</td><td>36.7</td></tr>
<tr><td colspan="7"></td><td colspan="3">+10% beacon replacement</td></tr>
<tr><td></td><td></td><td>Active</td><td>1000
(120)</td><td>(111.4)</td><td>(192.8)</td><td>(275.3)</td><td>(14.9)</td><td>(25.7)</td><td>(36.7)</td></tr>
<tr><td colspan="7"></td><td colspan="3">+10% beacon replacement</td></tr>
<tr><td></td><td>CD ROM</td><td>Passive</td><td>1950
(470)</td><td>8.0</td><td>12.0</td><td>46.0</td><td>2.3+£50/v.</td><td>2.3+£50/v.</td><td>4.5+£50/v.</td></tr>
<tr><td></td><td></td><td>Active</td><td>2580
(520)</td><td>(8.0)</td><td>(12.0)</td><td>(46.0)</td><td>(2.3+£5/v.)</td><td>(2.3+£5/v.)</td><td>(4.5+£5/v.)</td></tr>
<tr><td>Driver Selection</td><td>Nil</td><td>Passive</td><td>360
(60)</td><td colspan="3">NIL</td><td colspan="3">NIL</td></tr>
<tr><td></td><td></td><td>Active</td><td>1080
(120)</td><td colspan="3">NIL</td><td colspan="3">NIL</td></tr>
<tr><td>Advisory</td><td>Beacon</td><td>Nil</td><td>30

(10)</td><td colspan="6">Costs for Construction and Maintenance are as per the Beacon based systems above.</td></tr>
<tr><td></td><td>CD ROM</td><td>Nil</td><td>1600

(410)</td><td colspan="6">Costs for Construction and Maintenance are as per the CD ROM based systems above</td></tr>
</table>

8. ECONOMIC EVALUATION

8.1 GENERAL APPROACH

Up until this point the benefits and costs of EVSC have been treated separately. Within each stream, benefits and costs a number of options have been identified as shown in Figure 16. It is now necessary to establish the Net Present Value (NPV) of both the benefits and the costs and calculate the benefit cost ratio (B/C) in order to select a set of favoured implementation scenarios.

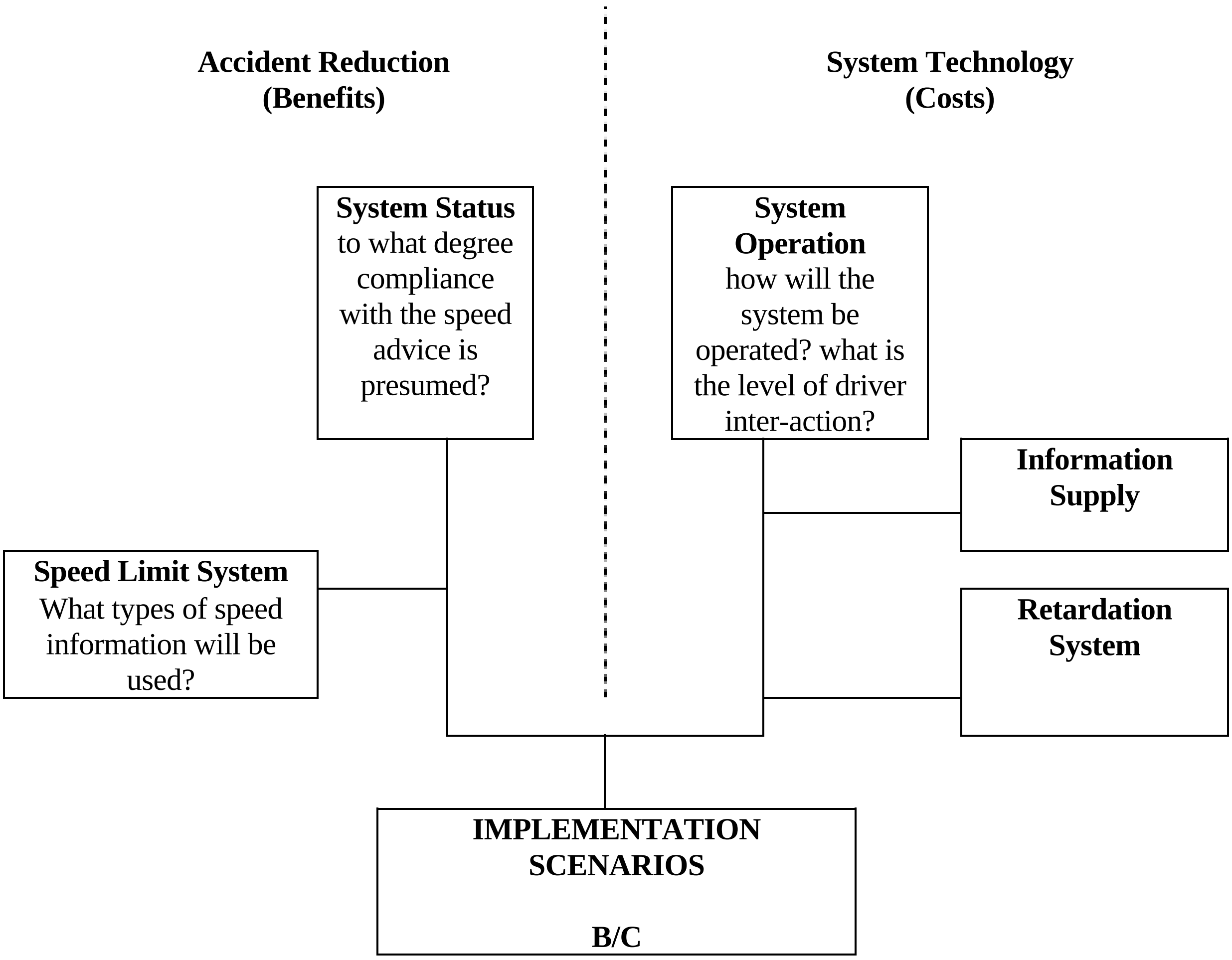


Figure 16: Analysis Framework

The number of possible combinations and permutations based upon the combinations of accident reduction and system technology classifications is obviously large. However some of possible combinations are impractical e.g. a full system EVSC system with active (or passive braking) which is supplied with only advisory speed data. The feasible implementation scenarios are detailed in Table 28.

Table 28: Feasible EVSC Implementation scenarios

SYSTEM TECHNOLOGY		FULL SYSTEM				ADVISORY		DRIVER SELECTION	
Information Supply		Beacon		CD-ROM		Beacon	CD-Rom	na	na
Retardation System		Active	Passive	Active	Passive	na	na	Active	Passive
SYSTEM STATUS	Speed Limit System								
ADVISORY	Fixed	✗	✗	✗	✗	✓	✓	✗	✗
	Variable	✗	✗	✗	✗	✓	✓	✗	✗
	Dynamic	✗	✗	✗	✗	✓	✓	✗	✗
MANDATORY	Fixed	✓	✓	✓	✓	✗	✗	?	?
	Variable	✓	✓	✓	✓	✗	✗	?	?
	Dynamic	✓	✓	✓	✓	✗	✗	?	?

In Table 28 the Driver Selection options are marked with ?. Although these are feasible implementation scenarios the distinction is made because no benefits have been calculated for such a system, and for that reason these options are treated separately when it comes to determining whether these scenarios are economically attractive.

8.2 ECONOMIC ASSUMPTIONS

In the process of economic evaluation the net present values (NPV) of benefits and costs are calculated. To do this the benefits and costs that occur in each year are established. In this study the benefits calculated in terms of the 1995 accident reductions are projected into the future using a series of growth assumptions. The costs stream is based on the timetable of implementation and the estimated costs of defined in Section 7.2.4. The annual values for the costs and benefits are then discounted to base year sums, and the ratio of benefits divided by costs, is calculated.

The economic evaluation has been undertaken using the following assumptions. The accident reduction benefits for 1995 are presented in Section 5 above. For ease of calculation, the monetary value of the 1995 accident benefits has been calculated using the unit costs for All Injury Accidents, disagreggated by road type (DOT, 1996a). These benefits have been estimated for each future year based upon a projections of accident rates and the volume of travel, with the level of benefits accruing to the system being proportional to the market penetration of EVSC systems.

The base year for the analysis is 2000 and all values are expressed in terms of 1995£ with a 30-year analysis period and a 6% discount rate. No residual values are assumed at the end of the analysis period. The programme for the implementation would see development of the infrastructure (be it creation of the beacons, digital maps, in-car technology), from 2000 to 2005 and progressive implementation of technology into new vehicles from 2005. Infrastructure maintenance begins at 2005 while system updates for the CD Rom based system begin in 2006. This timetable differs from that proposed in Deliverable 4 where it is expected that an initial decision would be made following completion of this project in 2000. It is then expected that a consultation phase of 5 years would be required before an implementation strategy was introduced, so that progressive implementation would begin in 2010. The programme used in economic evaluation effectively neglects the 5 years of consultation. Since the analysis period is limited to 30 years this approach allows a reasonable period over which benefits may be accrued, while at the same time retaining a decision point in the “near future”. This reduces the degree to which future growth parameters require extrapolation. If the base year were extended to 2005 the effect would be to reduce the costs slightly.

A sensitivity analysis has considered the effect of different projections for vehicle kilometres of travel, and therefore accidents, estimates of the future monetary value of accident savings as well as the variation in the accident reductions for the options as discussed in Section 5.

8.2.1 Accident Projections

The prediction of accident rates into the future is at best uncertain. Accidents are related to the number of vehicles and drivers active in each year together with the distance driven by each which is in turn related to the prevailing economic climate. In addition there are reductions due to the effectiveness of accident reduction measures, education and enforcement measures. These effects are shown in Figure 17 which plots the annual accident numbers from 1926 to 1995.

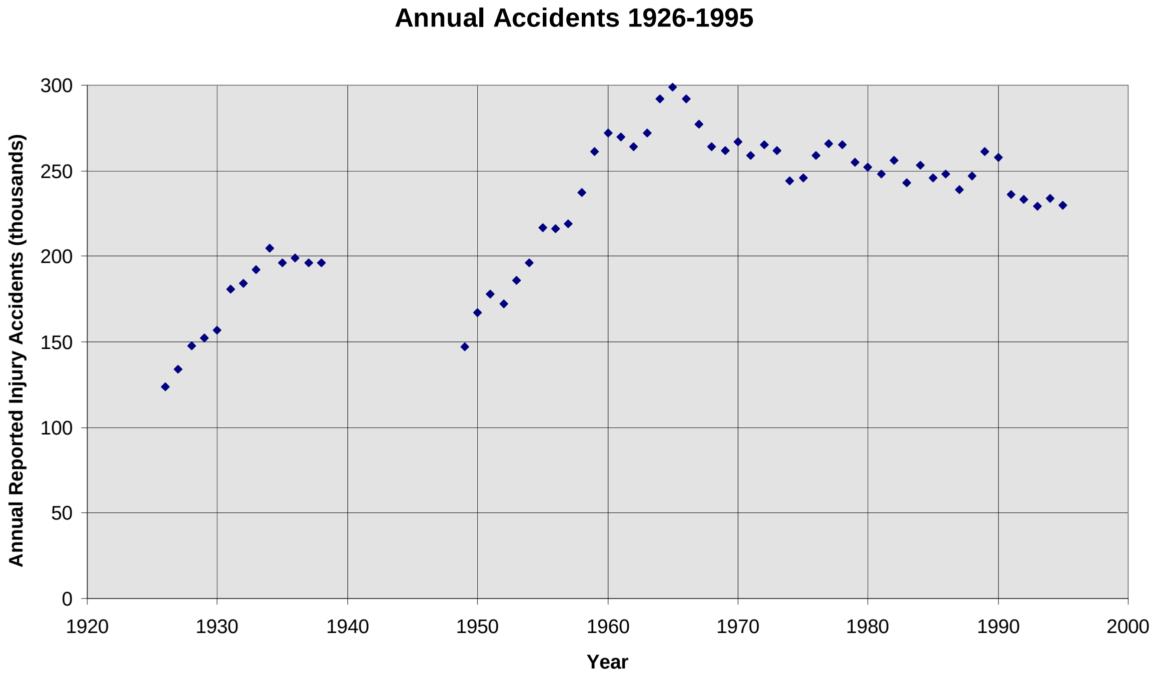


Figure 17: Annual Accidents (source: DOT, 1996b)

Although it is possible to establish a simple linear relationship to extrapolate the accident trend over the last 30 years it is not strong and the prediction of a future relationship is at best poor. It is however possible to establish a reasonable relationship between accidents per 10^8 vehicle kilometres travelled Figure 18. This may then be related to the predicted volume of travel in future years (DOT, 1996b) in Table 29. Extrapolating the accident rate allows the analysis to explicitly consider the reduction in accident rate that results from initiatives such as accident studies, blackspot treatments education and enforcement measures.

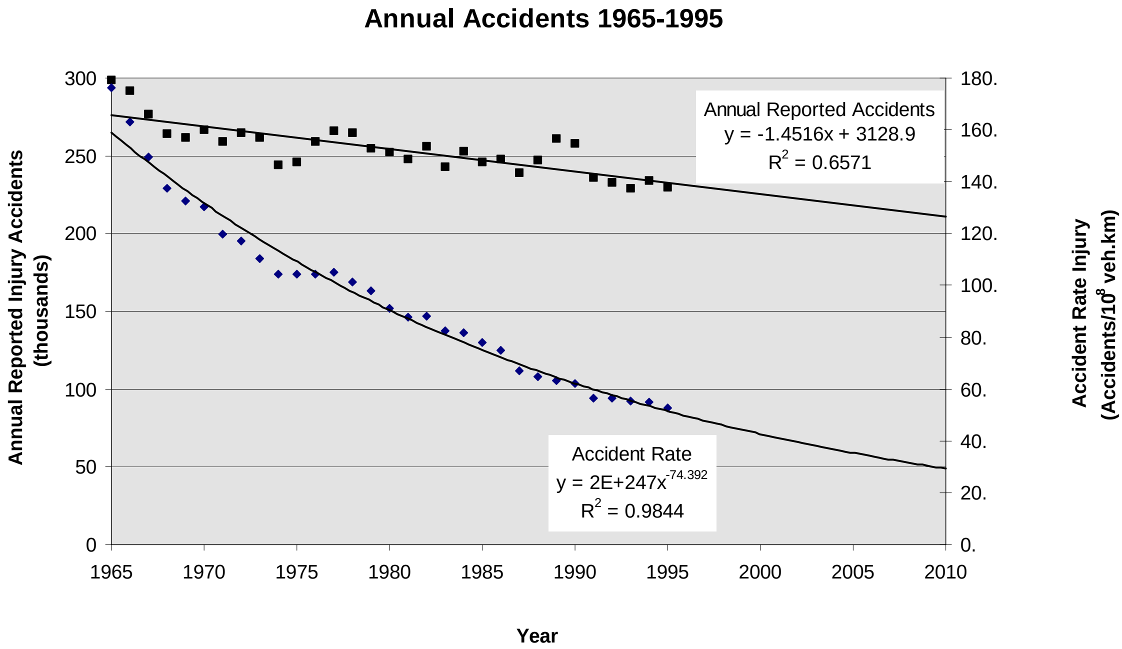


Figure 18: Annual Accidents and accident rates 1965 to 1995 (source: DOT, 1996b)

Table 29: Accident Trends (adapted from Transport Statistics Great Britain, 1996 Table 4.8).

	Index of Travel : Vehicle Kilometres 1995=100								
Year	1985	1990	1995	2000	2005	2010	2015	2020	2025
Actual/Low	71	95	100	109	118	127	136	145	155
High				115	129	114	158	173	187
	Accident Trends								
Actual/Expected Accident Rate (acc/10^8 veh km)	77.9	56.6	52.8	42.7	35.4	29.3	24.3	20.1	16.7
Accident Rate Index 1995=100	147.5	107.2	100	80.9	67.1	55.5	46.0	38.1	31.6
Accident Index Index of Travel x Accident Rate Index 1995=100	104.7	101.8	100	88.2 93.0	79.2 86.6	70.5 63.3	62.6 72.7	55.2 65.9	50.0 59.1

It should be noted however, that even though an exponential model has been fitted, the predicted reductions in accidents are large and may not account fully for the decreasing returns that may be expected from current programmes. For this reason three accident growth scenarios have been identified. These involve no change in current accident numbers, and a high and low accident reductions as shown in Table 33.

8.2.2 FLEET SIZE

It is proposed that EVSC would be introduced by providing the technology in new vehicles with the possibility that at some point in time retro refitting of all vehicles would be undertaken. Although little data on the age profile of the vehicle fleet is readily available it is considered to be relatively stable and may for this study be translated into the future without adjustment. The cumulative distribution of vehicle ages for the car body vehicle stock in 1994 (Balmforth, 1997) is shown in Figure 19.

The age profile for heavy goods vehicles is somewhat different to that of cars with more older vehicles. The characteristics of the car fleet has been used to define the fleet overall since it represents approximately 85% of the national stock as shown in Table 30. It can be seen that if natural renewal were to be used to implement EVSC approximately 40% of the fleet would be fitted with the technology after 5 years and 80% after 10 years. It is assumed that the benefits of the new technology will accrue in direct proportion to the level of market penetration.

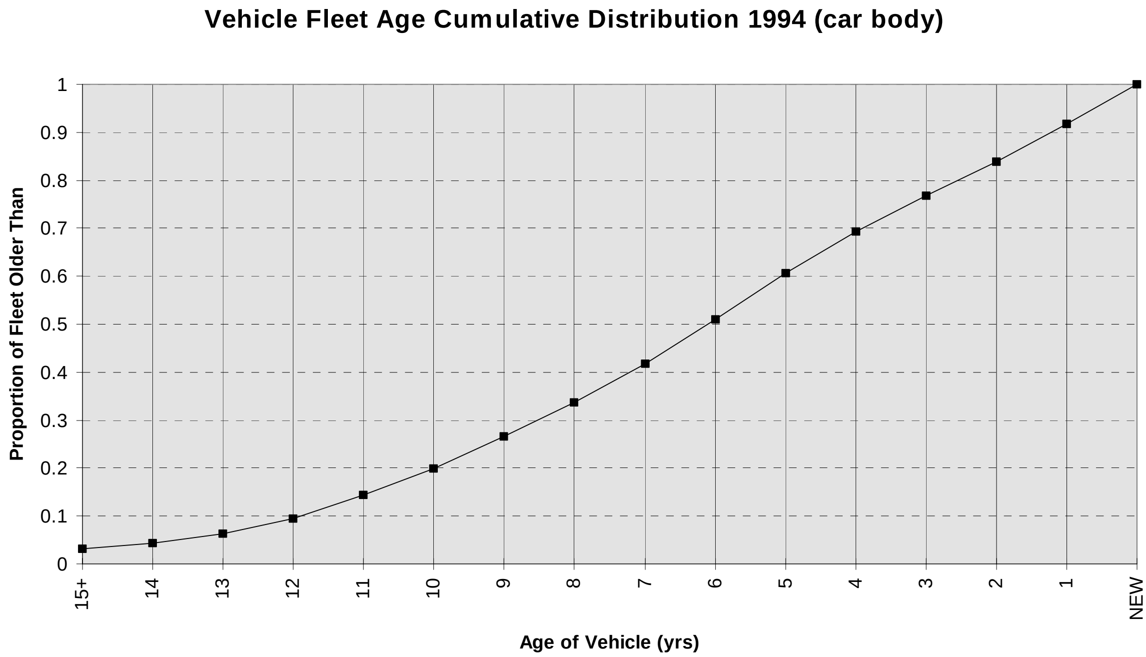


Figure 19: Age profile of the car fleet in 1994 (source: Balmforth, 1997)

Table 30: Vehicles to which EVSC technology may be fitted 1995 (DOT, 1996b)

Type	Private and Light Goods		Buses	Goods Vehicles	Other Vehicles	Crown and exempt	TOTAL
	Body Car	Other					
Number	20505k	2217k	74	421k	44k	1169k	24430k
Proportion	83.9%	9.1%	0.3%	1.7%	0.2%	4.8%	

The expected number of vehicles for future years has also been established using projections for growth in the number of cars in future years (DOT, 1996b Table 4.8). These growth projections have been applied to the EVSC fleet as a whole is shown in Figure 20. For this purpose the vehicle fleet is defined as all vehicles excluding motorcycles and other two-wheeled vehicles, and special machines (DOT, 1996b Table 3.1).

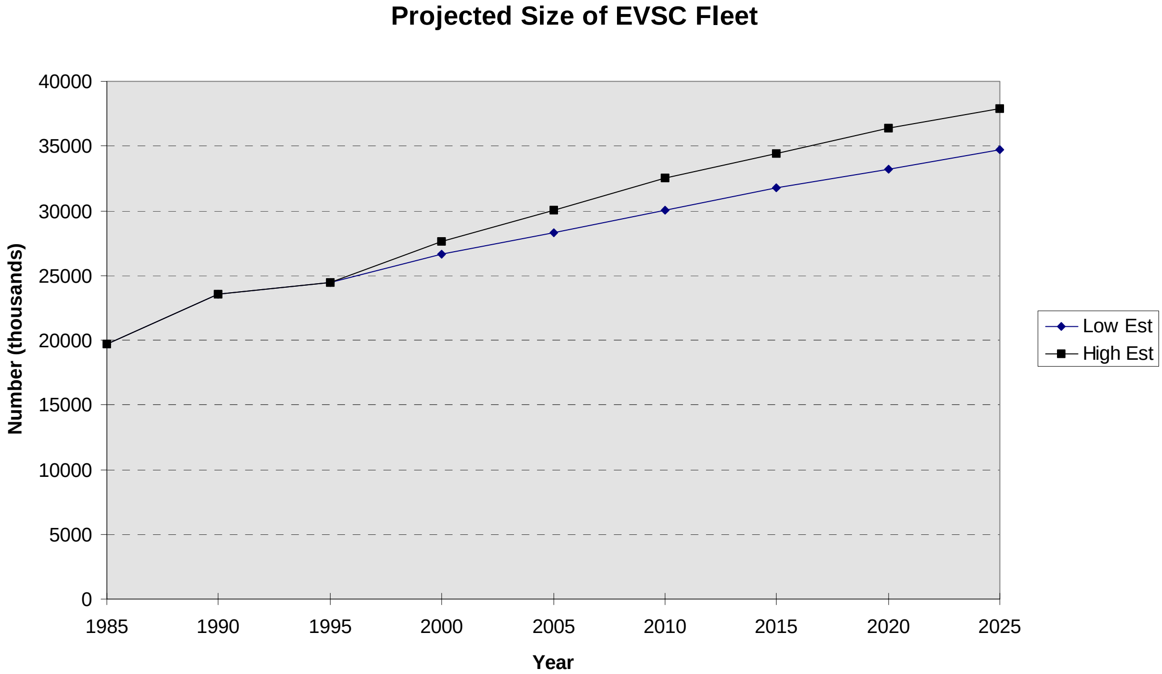


Figure 20: Projections of vehicle fleet size

For technical reasons it is unlikely that a mandatory EVSC system, that includes engine management and braking technologies, may be retro refitted to vehicles. It is therefore expected that the EVSC will be implemented progressively as vehicles are added to the fleet at a rate of 2.333 million new vehicle registrations per year, i.e. the average for the period 1986-1996 (DOT, 1997).

8.3 RESULTS OF COST BENEFIT ANALYSIS

8.3.1 BENEFITS

The benefits of the three main systems are outlined in Table 31. These are based upon the assumption of higher levels of car ownership **(**DOT, 1997e**)** and consequently a lesser level of accident reduction from the status quo. To maintain consistency the analysis uses the higher rates of increase in Gross Domestic Product (GDP) specified in COBA (DOT, 1996c). If the lower estimate of increase GDP is assumed the benefits fall by 25%.

If a more optimistic approach is taken, by which car ownership is low, the total accident reductions are lower the benefits of Table 31 are reduced by 10%. However if the current level of car ownership and current accident rates (the status quo), is simply projected into the future the projected benefits increase by 51.3%.

Table 31: Net Present Value of the Accident Reduction Benefits of EVSC (1995£M)

Accident Reduction	Advisory System			Mandatory System		
	Fixed	Variable	Dynamic	Fixed	Variable	Dynamic
Low estimate	3,026.5	3,026.5	4,004.6	8,615.2	10,219.3	16,786.2
Best estimate	9,143.2	9,633.3	12,804.0	18,582.3	20,263.0	31,489.7
High estimate	17,815.9	18,707.1	25,335.6	29,878.6	31,813.0	44,811.8

In terms of choosing between system it can be seen that the level of benefits achieved by the variable system is not significantly greater than that of a fixed system. It is suspected that this is a product of the assumption that a variable system may only assist to reduce a limited number of lost control type accidents. This was principally due to the lack of data on geometry deficiencies in the highway network and it may well be that the incremental affect has been underestimated and the benefits may be closer to those estimated for the fully dynamic system.

8.3.2 COSTS

The NPV costs for each type of system are presented in Table 32. The total costs for each system include the implementation cost to progressively introduce the technology into the vehicle fleet; an infrastructure cost for the development of the system; a annual maintenance cost and a cost for updating information. The analysis has identified two distinctly different cost streams for the different systems used to provide information to vehicles. The beacon based system which involves high infrastructure and maintenance costs but low in-vehicle and update costs, while the opposite applies to the CD ROM based system.

The estimation of the future costs of what are currently fledgling technologies is at best difficult and some sensitivity assessment is necessary. Doubling the 2010 cost estimate for the beacons has little effect, increasing the costs by between 1% and 4% . Increasing the cost of the beacon receiver unit by £5, in 2010, increase the costs approximately 5% more. It has been found that halving the 2010 estimate of in-vehicle costs for the CD ROM based unit reduces the NPV of the system costs by 45% for the Advisory System. For the Mandatory System and reductions are 40% and 21% for the Passive and Active Retardation Systems respectively. It is clear that the system costs are very sensitive to the cost of in-vehicle components. This is not surprising since it has been estimated that each year 2.33 million vehicles enter the fleet. It is for this reason the Driver Selection System appears very attractive with the lowest costs in each category.

Table 32: Net Present Value of Costs (1995£M)

System Type	Infrastructure	Retardation	Fixed	Variable	Dynamic
Advice	Beacon	Nil	2,386.6	3,933.6	5,540.8
Advice	CD	Nil	12,666.5	12,669.9	12,719.1
Full	Beacon	Passive	4,050.8	5,597.7	7,204.9
Full	Beacon	Active	6,370.8	7,917.8	9,525.0
Full	CD	Passive	14,550.5	14,553.8	14,603.1
Full	CD	Active	16,666.9	16,670.3	17,719.5
Driver selection	Nil	Passive	1,900.1	1,900.1	1,900.1
Driver selection	Nil	Active	4,381.7	4,381.7	4,381.7

Clearly a beacon based system provides the lesser cost option for providing in-vehicle information. However it should be noted that the infrastructure cost of a beacon based system would be borne by the highway authorities, while the in-vehicle costs of a CD ROM based system would be borne by the vehicle owners.

8.4 BENEFIT COST RATIOS

The benefit cost ratio is defined as the Net Present Value of benefits divided by the Net Present Value of the costs. In terms of this study the benefits considered are solely those associated with accident reductions. The costs are only those associated with the provision of a stand alone system.

When considering the benefits of EVSC six system types were defined. These related to whether or not the EVSC was Advisory or Mandatory. Inside each category are three further divisions that depend upon the amount of speed information supplied to drivers. These are the Fixed, Variable, and Dynamic speed limit systems. On the cost side three types of implementation have been considered; the Full System of autonomous control, an Advice System and a system of Driver Selection. For each a cost estimate has been developed assuming Fixed, Variable and Dynamic Speed Limit systems. For each feasible combination the B/C ratio for calculated under the assumptions of Low, Best, and High estimates of accident reduction are given in Table 33.

Table 33: Summary of Benefit Cost Ratios

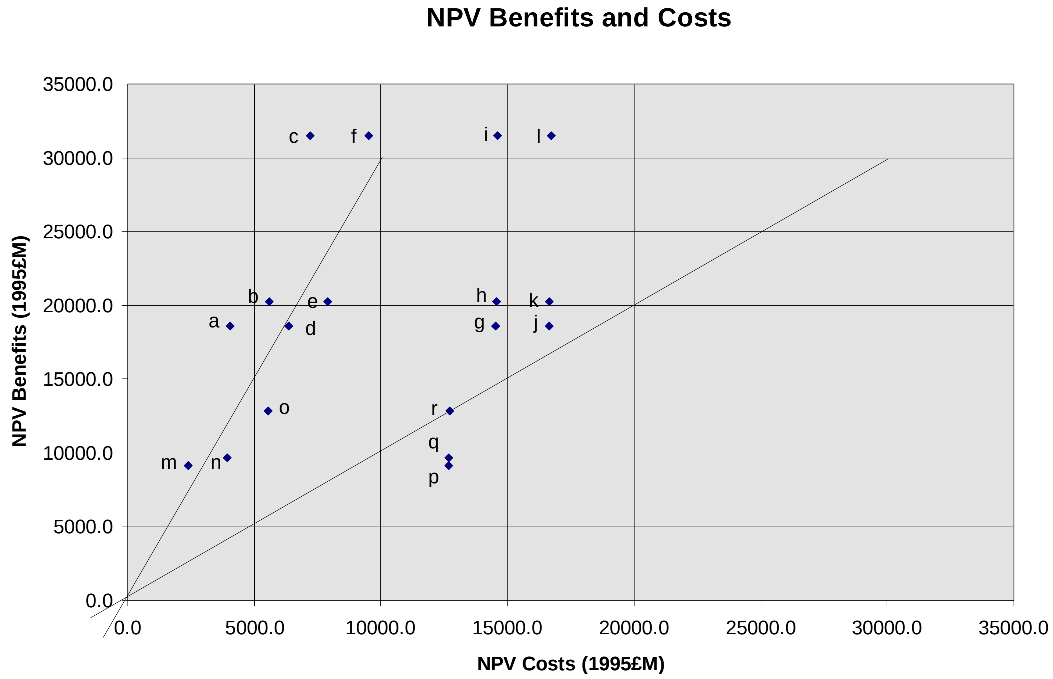
System	Sub-System	Low Estimate	Best Estimate	High Estimate
Mandatory	Beacon/ passive/ fixed Beacon/ passive/ variable Beacon/ passive/ dynamic	2.1 1.8 2.3	4.6 3.6 4.4	7.4 5.7 6.2
	Beacon/ active/ fixed Beacon/ active/ variable Beacon/ active/ dynamic	1.4 1.3 1.8	2.9 2.6 3.3	4.7 4.0 4.7
	CD/ passive/ fixed CD/ passive/ variable CD/ passive/ dynamic	0.6 0.7 1.1	1.3 1.4 2.2	2.1 2.2 3.1
	CD/ active/ fixed CD/ active/ variable CD/ active/ dynamic	0.5 0.6 1.0	1.1 1.2 1.9	1.8 1.9 2.7
Advisory	Advice/ beacon/ fixed Advice/ beacon/ variable Advice/ beacon/ dynamic	1.3 0.8 0.7	3.8 2.4 2.3	7.5 4.8 4.6
	Advice/ CD/ fixed Advice/ CD/ variable Advice/ CD/ dynamic	0.2 0.2 0.3	0.7 0.8 1.0	1.4 1.5 2.0

Notes:

- Mandatory sub-systems are coded in terms of Information supply/ Retardation system/ Speed Limit system.
- Advisory sub-systems are coded in terms of Advice/ Information supply/ Speed Limit system.
- Information supply: Beacon – beacon supplied information, CD – an in-vehicle digital map system
- Retardation system: Active – active braking system, Passive – a system of engine braking and natural deceleration
- Speed Limit: Fixed – fixed speed limits, Variable – variable speed limits, Dynamic – dynamic speed limits

When plotting the NPV benefits against NPV Costs, Figure 21,the slope of a line from any point to the origin is the B/C. The slope of a line between any two points represents the incremental, or staged, B/C. In Figure 21 lines representing B/C's of 1.0 and 3.0 have been marked. It can be seen that at least 5 systems are expected to provide B/C ratios in excess of 3.0. While more than half the systems have B/Cs greater than 2.0 only two systems have B/Cs less than 1.0.

From Figure 21 it can be seen that the benefits of providing a Variable speed limit data (points b,e,h and k) rather than a Fixed speed limit data are small. This is because the accident analysis is restricted by the information available on the potential accident savings. This restriction has little effect when selecting between a Fixed, Variable or Dynamic systems based on CD-ROM technology since the additional cost is marginal. It may however affect the selection of the most appropriate Beacon based system.



FULL SYSTEM						
Retardation	Passive Retardation			Active Retardation		
System	Fixed	Variable	Dynamic	Fixed	Variable	Dynamic
Beacon	**a**	**b**	**c**	**d**	**e**	**f**
CD	**g**	**h**	**i**	**j**	**k**	**l**
ADVISORY SYSTEM (no retardation system)						
Information	Beacon Based			CD-ROM Based		
	m	**n**	**o**	**p**	**q**	**r**

Figure 21: Net Present Values of Costs and Benefits

The above analysis considers only the Best Estimates of the likely accident reductions for each system. Systems a to f are Beacon based and the pair a-d, b-e, and c-f, show the difference between a Passive and Active retardation systems. For these points and the equivalent pairs g-j, h-k, and i-l for the CD ROM based system, the no increase in benefits is predicted through the use of active breaking. This is due to the assumption that the full benefits of a mandatory speed limit will accrue to both options. This is unlikely to be so, and further research into effects of passive rather than active retardation will be required. As shown in Table 10 to Table 16**,** the expected accident reductions vary considerably depending upon the assumptions made, Figure 22 and Figure 23 show the range of B/Cs for the Mandatory and Advisory systems respectively. It is worthwhile noting that for many options the adoption of a low accident reduction estimate still produces a worthwhile project.

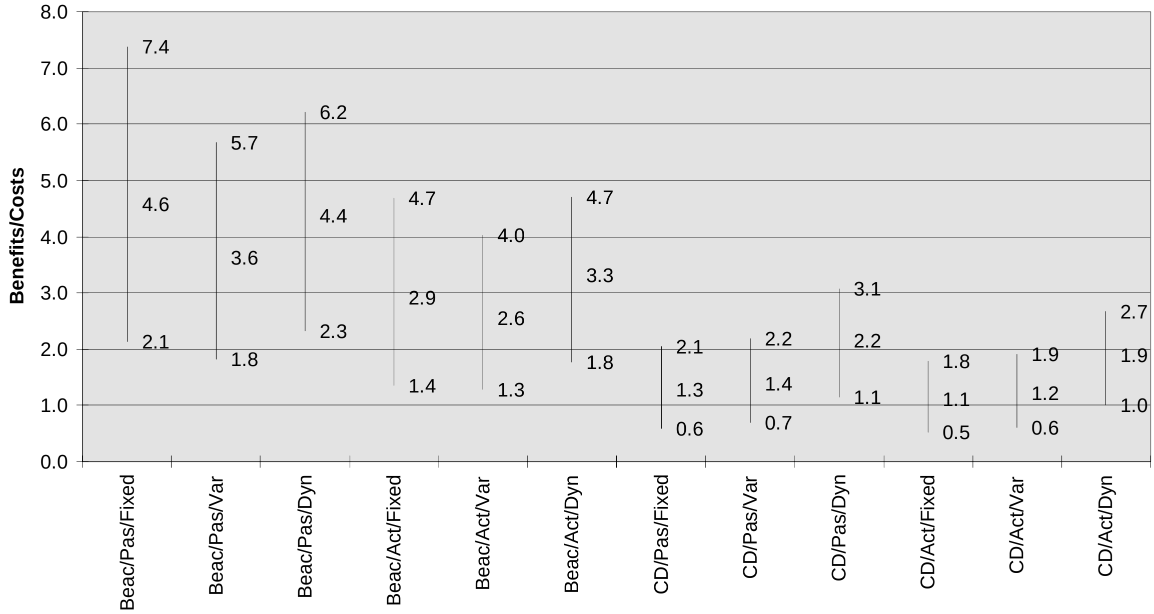


Figure 22: Benefit Cost Ratios of Mandatory EVSC Systems

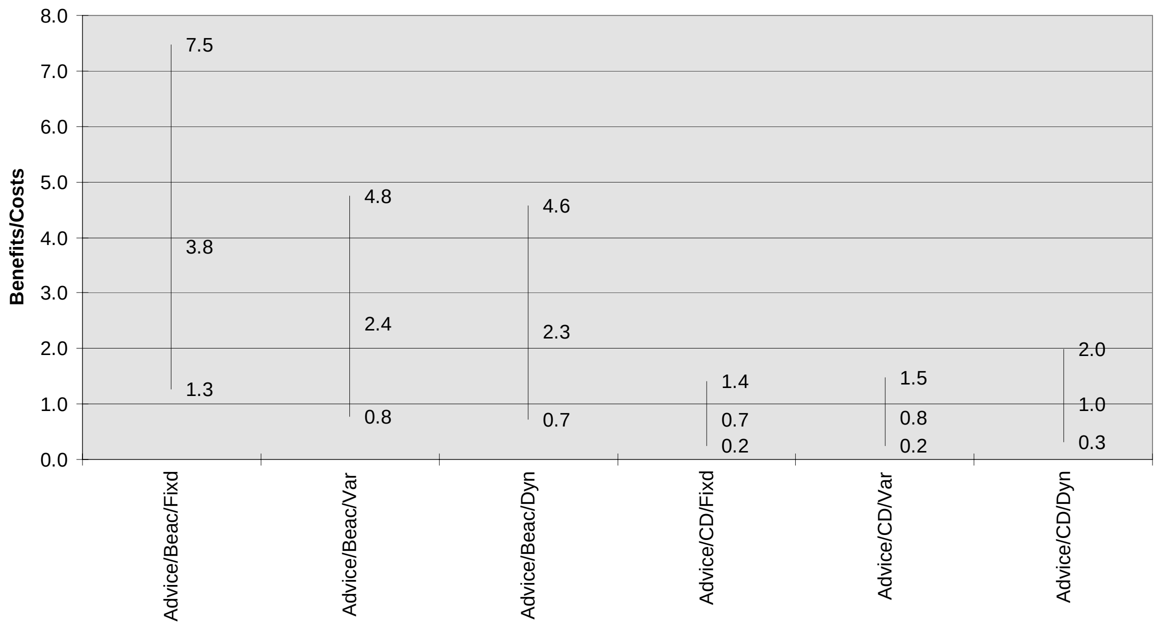


Figure 23: Benefit Cost Ratios of Advisory EVSC Systems

While Figure 22 and Figure 23 show clearly the sensitivity of the B/C ratio, to assumptions about the level of accident reductions changes in system costs are not included. As discussed in Section 7.2.4 the system costs are most sensitive to the cost of in-vehicle equipment. A 50% reduction in the 2010 cost of the in-vehicle equipment to operate a CD-ROM system reduces the overall cost by approximately 40% and would then raise the B/C accordingly.

The above analysis has dealt solely with those systems for which both the benefits and costs have been estimated. However the benefits of a Driver Selection system have not been estimated. This is because no data is available as to the level of compliance, nor whether those drivers who do not choose to activate the system are those with higher personal accident liabilities. To assess whether this system warrants further consideration a pragmatic approach has been taken. The question is asked *"What proportion of the Fixed Speed Limit benefits would need to be gained for the system to be worthwhile?"* Based upon the answers to this question, Table 34, it is concluded that the system should be investigated further to establish the likely level of driver use.

Table 34: The likely B/C for a specific proportion of Fixed Speed Limit Benefits .

Retardation System	Proportion of System Benefits	Expected Benefit Cost Ratio		
		Low Est	Best Est	High Est
Passive	50% Advisory	0.8	2.4	4.7
Active	50% Advisory	0.3	1.0	2.0
Passive	25% Mandatory	1.1	2.4	3.9
Active	25% Mandatory	0.5	1.1	1.7

9. TRADITIONAL ACCIDENT REDUCTION MEASURES

A separate report into the performance of so called traditional accident reduction measures has been completed by the TMS Consultancy Limited. The report (included as Appendix A) reviews a total of 510 schemes which sought to reduce accidents at identified blackspot locations. The schemes were classified into three categories depending upon the type of remedial measures and accidents that these were expected to address. The key indicators of performance were the accident reduction, average cost and first year rate of return (FYRR), a measure of economic performance.

Typically such schemes are low cost, for example the average cost of 30 schemes in which road markings and signs were used to reduce loss of control accidents was <£1000. The average accident reduction from these schemes was 46% and with such low costs a FYRR of 2264% is not surprising. These schemes are very effective at reducing accidents at locations which have, by definition, and abnormally high accident rate. There is however a trend of decreasing returns as shown in Figure 24.

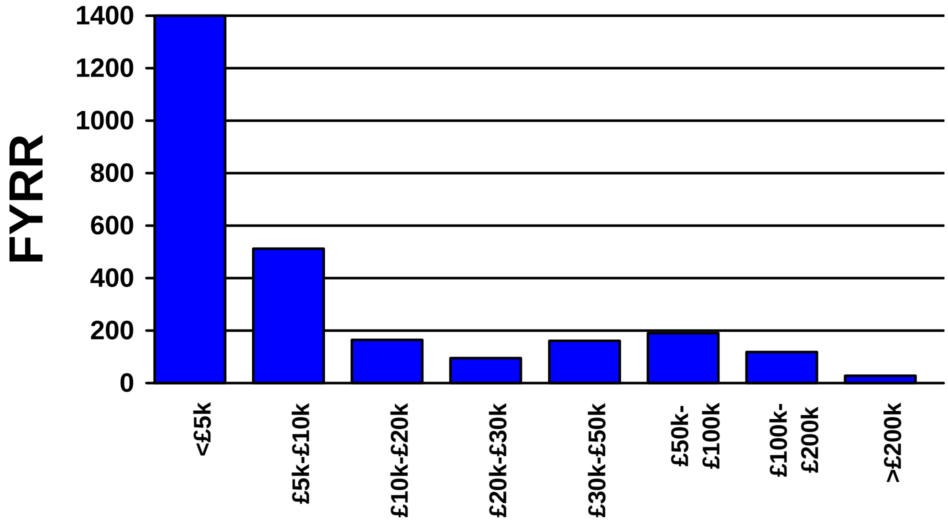


Figure 24: The economic performance of accident reduction projects against cost

The effectiveness of accident remedial measures together with education and enforcement programmes has been incorporated into the analysis. The decreasing accident rate of Figure 18 and Table 29 reflects these programmes. This approach has been adopted since it is not possible to separate out the separate effects of these programmes nor to obtain reliable cost estimates. The assessment of the benefits of EVSC is therefore conservative because any attempt to account for the benefits of not having to proceed with accident remedial measures would provide a cost saving and yield a higher base accident rate against which the EVSC benefits would be calculated.

10. CONCLUSIONS

The objective of this study is to consider the possible means by which a system of EVSC might be implemented, and to estimate the economic benefits and costs of such a systems. In doing so it is recognised that the prediction of the future, mass production, cost of what are currently fledgling systems is difficult as is the estimation of the accident reductions from systems which are radically different to the traditional safety measures. The results of the study will answer the following key questions:

- What are the likely accident reductions that may be achieved by EVSC?
- Is it likely that a system of EVSC will provide significant economic benefits that will exceed the cost of implementation, and is therefore worth investigating further?
- Identify those area where additional research is required to reduce uncertainty is the estimation of key inputs?
- Having identified that an economically attractive system of EVSC is likely to result, to establish a set of favoured solutions?

It is clear that an economically attractive system of EVSC is highly likely to be developed. Indeed more than half of the systems investigated have benefit cost ratios in excess of 2.0 and at least five systems have benefit cost ratios greater than 3.0.

All studies of this type are haunted by problems in predicting the future growth in traffic, and in the case of this study, accident trends. The quoted benefit cost ratios assume a significant reduction in current accident rates albeit combined with increasing travel demand. Bearing this in mind further attempts to refine future travel demand and accident rate projections are not considered worth while. A simple projection of current levels of vehicle ownership and the current accident rate would increase the benefit and therefore the B/C by 50%.

It has not been possible to calculate a B/C for the Driver Selection System. Under this system speed information is received from road signs, as at present, and drivers input this manually into a vehicle control system. Given that the system need only achieve 52% of the benefits of a purely advisory system or 26% of the benefits of the mandatory system to achieve a B/C exceeding 2.5; the key issue is the level of compliance. Given that such a system is potentially attractive this will required further research aimed at assessing the likelihood of drivers activating the system.

Systems that use active retardation have lower B/Cs than those using passive retardation. This is because of the higher in-vehicle equipment costs associated with active retardation and the assumption that the full benefits of mandatory speed control will accrue to this system which does not have an active braking system. This is remains untested and given the significant effect that this assumption may have on the choice of system further research should be undertaken on this issue.

Although the recommendations have been based upon a “best estimate” of the accident reductions the sensitivity analysis shows extreme variations between the low and high estimates for accident reductions. One key area is the effects of a transformation of the speed distribution under a dynamic system. Given the limited number of dated studies upon which this element is based, some research into individual accident liabilities would be worthwhile to reduce the range of the predicted benefit cost ratios.

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