isa - UK
intelligent speed adaptation

Implementation Scenarios

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EXECUTIVE SUMMARY

The Intelligent Speed Adaptation project has carried out a detailed investigation of the behavioural and safety impacts of Intelligent Speed Adaptation, the system which provides in-vehicle information on the speed limit and which can use that information to curtail the possibility of speeding. The central part of the project work was a set of trials of converted cars which were fitted with a voluntary ISA system which, when enabled, governed maximum speed so that drivers could only exceed the limit by a small margin. This system could be overridden by the drivers. A small-scale field trial with a converted truck and test-track trials with a converted motorcycle were also carried out. Other reports summarise the results of the various field trials.

Field trials provide vital information on user behaviour and attitudes with a system. But, on their own, they do not provide an estimate of the overall safety benefits of a system such as ISA, nor on whether the implementation of ISA will provide socio-economic benefits that outweigh the costs of system introduction.

The purpose of this report is to build on the information gathered in the field trials in order to predict the safety impacts of various forms of Intelligent Speed Adaptation (ISA). It also examines hypothetical scenarios for ISA implementation and investigates how those scenarios might affect overall safety gains with ISA. Lastly, it examines ISA from an investment perspective, i.e. assesses the costs and benefits of ISA. The prediction of safety impacts uses relationships between speed and crash risk at various levels of severity taken from a range of UK specific and international literature. These relationships are derived from empirical observations, in the form of before and after studies of risk following changes in the speed and speed distribution of traffic, of cross-sectional studies comparing risk across different locations and case-control studies comparing accident-involved vehicles with matched vehicles in the traffic stream. The investment appraisal for ISA conducted here applies the standard Department for Transport procedure as laid down in the Transport Analysis Guidance (TAG). The benefits of ISA are appraised solely in terms of accidents savings.

Two alternative visions of the future, or scenarios, are examined: a Market Driven Scenario in which drivers choose to adopt ISA and an Authority Driven Scenario with more encouragement of ISA adoption. The scenarios affect not only the rate of ISA adoption but also the mix of ISA systems in the vehicle fleet with “stronger” forms of ISA more prevalent under the Authority Driven scenario.

The potential road accident reduction benefits expected from ISA are estimated by means of an analysis of the impact that ISA has on travel speeds and in particular on the proportion of travel undertaken at higher speeds. This analysis draws on the data collected in the project field trials and then applies that data to the prediction of changes in accident numbers through the application of available speed crash relationships derived from empirical observations. Although there is considerable literature on the impact of speed on accident risk, there are no UK based models that are directly applicable to ISA. Therefore sensitivity tests have been conducted using different sets of models. Three combinations of the available models have been used, in the analysis: the favoured Base Combination, the more optimistic Second Combination and the more conservative Third Combination.

The analysis using the favoured Base Combination of crash reduction models indicates that, over a 60-year period from 2010 to 2070, the Market Driven implementation scenario is expected to reduce fatal accidents by 10% (approximately 15,400 fatal accidents over that 60 year period), serious injury accidents by 6% (96,000 accidents), and slight injury accidents by 3% (336,000 accidents). The same combination of crash reduction models predicts that, over the 60-year period, the Authority Driven implementation scenario is expected to reduce fatal accidents by 26% (approximately 43,300 fatal accidents); serious injury accidents by 21% (330,000 accidents), and slight injury accidents by 12% (1.3 million accidents). Overall, ISA has a considerably greater impact on more severe crashes.

The greatest source of accident reduction benefits occurs on 30 mph roads where the Market Driven implementation scenario is expected to reduce high-severity (fatal and serious injury) accidents by 5%. On those same roads, the Authority Driven scenario is expected to reduce fatal and serious injury accidents by 25% over the 60-year analysis period. The fact that the major savings are on 30 mph roads, closely followed by 40 mph roads, also indicates the potential of ISA to improve the safety of pedestrians and cyclists.

The economic benefit associated with the predicted crash reductions under both the implementation scenarios outweighs the costs, thus justifying the deployment of ISA. The Market Driven implementation scenario is predicted to result in benefit-to cost ratios in the range of range 1.8 to 3.0. The Authority Driven implementation of ISA is expected to produce benefit-to-cost ratios in the range 2.8 to 4.8.

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1. INTRODUCTION

1.1 Objectives of work

The aim of the work reported here has been to examine Intelligent Speed Adaptation from the perspective of a social cost benefit analysis, i.e. to examine whether the potential social benefits from implementing ISA exceed the costs. Such an overall assessment for Great Britain was last performed at a detailed level in 2000 for the final report of the External Vehicle Speed Control (EVSC) Project (Carsten and Tate, 2000). This report updates that work in the light of the large amount of data collected on driver behaviour with a voluntary ISA system in the project's field trials. The work also takes into account more recent accident data, more up-to-date information on system architecture and component costs and newer empirically-based analyses of the relationships between speed choice and crash risk. As an additional enhancement of the EVSC work, implementation of ISA on vehicle other than passenger cars is considered here.

In the EVSC project work on implementation scenarios, different types of ISA were evaluated separately. However, a future in which there is only one kind of ISA, such as adoption of Advisory ISA without any take-up of systems that intervene in vehicle control, is rather improbable. It is much more realistic to envisage a future in which there is a variety of ISA systems on the market. Hence a scenario-based approach has been adopted here, in which there are alternative visions of the future and the rate of adoption of various types of ISA depends on the scenario. It should be made clear that the scenarios chosen are exemplar ones, and that it is possible to envisage alternative ones or mixes of the two different ones that have been proposed here.

The EVSC work showed that, while there are considerable potential benefits from fuel savings with ISA, these were far outweighed by the potential benefits from reduced accident involvement and reduced accident severity. Consequently, the analysis reported here is restricted to the accident-saving potential of ISA.

1.2 System overview

The ISA system envisaged here is an autonomous (in-vehicle) ISA, in which each vehicle uses Global Positioning Systems (GPS) and dead-reckoning, to locate itself on a digital map, held in the vehicle, and reads the appropriate speed limit from that map.

In this report we investigate three system variants, each of which is based on the transfer and use, in various ways, of fixed speed limit information, i.e. the permanent speed limits:

Advisory ISA
Provision of in-vehicle information of current speed limit. The driver controls vehicle road speed in the normal way via brake and accelerator. An auditory signal is given when speed limit is exceeded, or a new speed limit is encountered.

Voluntary ISA
Provision of in-vehicle information of current posted speed limit, which is used by default as a speed limiting value by the vehicle. Drivers can choose to disable the use of this information to cancel the speed limiting function and regain full manual control until a

new speed limit is encountered and/or road speed drops beneath the current speed limit at which point ISA speed limitation resumes.

Mandatory (Non-Overridable) ISA
Provision of in-vehicle information of current posted speed limit, which is used as a speed limiting value by the vehicle. Drivers cannot disable the use of this information to cancel the speed limiting function and regain full manual control.

All of these variants make use of a hypothesised database of posted (static) speed limits. In addition to the three system variants, two scenarios were developed for implementation strategies:

Market Driven
Vehicle owners (and operators) may choose to purchase and fit a commercially available ISA variant, which might be a "SpeedAlert" system, as envisaged by the SpeedAlert project (Ertico, 2005). SpeedAlert is functionally equivalent to Advisory ISA.

Authority Driven
Although this scenario begins with some drivers choosing to equip their vehicles with ISA (as in the Market Driven scenario above), the Government or the EU at some point mandates the fitment of ISA on new vehicles and/or the retro-refitting of existing fleets to accelerate take-up, ensuring high levels of penetration.

While a more detailed description of the implementation strategies and the underlying assumptions is given in section 3, it is important to note that the system variants and implementation strategies considered here are not necessarily independent of each other. Both advisory and voluntary ISA are envisaged in the Market Driven scenario, while the Authority Driven scenario also envisages both systems, although in quite different proportions. The Authority Driven scenario also envisages that the use of ISA on equipped vehicles is eventually made compulsory, i.e. that Voluntary ISA is converted to Mandatory ISA. It should be noted that, under the Authority Driven scenario, the initial assumption is that the mandatory ISA variant would be switched on once 99% of vehicles are fitted with the voluntary system. This is a modelling assumption; earlier enabling of mandatory usage is feasible and is also examined, but it would require more retrofitting to older vehicles. However, this would potentially create an attractive market for vehicles not fitted with the mandatory system, which would be undesirable on safety grounds,

1.3 Analysis outline

The following analysis looks first at the safety benefits of ISA, considering the impact of ISA on the speed profiles on roads with different speed limits, using data collected in the UK ISA field trials. The strengths and weaknesses of a number of alternative speed-crash relationships are then discussed. The speed-crash models are applied to the speed profiles to predict the reduction in all injury crashes associated with the ISA variants.

For the purpose of the analysis here it is assumed ISA will only affect crash risk when at least one vehicle fitted with ISA is involved in an incident. Not all vehicles are capable of being fitted. The potential of an ISA-equipped vehicle to slow down those vehicles following it in the traffic stream has not been investigated in this project and is not counted in the analysis. Thus the assumption that ISA will only affect crash risk for fitted vehicles is a simplification that can be considered conservative. The analysis identifies the crashes involving vehicles that are potentially capable of being fitted with ISA, and future crash levels are predicted, taking into account increases in the volume of travel and the downward trend in crash rate, before discussing the costs associated with ISA implementation.

The vehicle based costs associated with ISA are outlined and the size of the future ISA vehicle fleet is estimated for each year from 2010 until 2070. The fleet penetration of ISA is then determined for each year of the analysis, based on the expected fleet size, scrappage of older vehicles, the number of new vehicles entering the fleet and the two implementation scenarios.

The overall crash reductions associated with the two ISA implementation scenarios are then estimated, based on the future crash levels and the proportion of the fleet fitted with each ISA variant. From the overall injury accident reductions, the expected reduction in fatal, serious and slight injury crashes are derived.

Finally an assessment of the economic benefit of ISA is undertaken. The procedure used follows the guidance issued by the DfT for the appraisal of transport schemes (see http://www.webtag.org.uk/index.htm). TAG Unit 3.5.4, Cost Benefit Analysis, distinguishes between projects with finite lives (i.e. those where there is limited life for component assets such as a bridge with a lifetime of 30 years) and those with indefinite lives. For the latter, the recommendation is to use a 60 year appraisal period. The implementation of ISA falls into this latter category, since the system will continue to deliver benefits indefinitely. The assumed introduction date for ISA is 2010. Hence the analysis is based on the discounted costs and benefits of ISA over the 60 year period 2010 to 2070. The major cost and benefit components are identified and the sensitivity of the resulting benefit cost ratio to changes in these key inputs is investigated.

2. BENEFITS OF ISA

The major potential impact of ISA is on crash risk. There are additional potential impacts also in the form of fuel and emissions savings. The current project has not investigated these. Earlier modelling work in the External Vehicle Speed Control project indicated that there could be substantial monetary value to fuel savings from ISA, but that these were swamped by the safety effects. DfT considers journey time saved through exceeding the speed limit to be a benefit illegally acquired; thus the loss of such time through, for example, speed enforcement is not to be considered in cost benefit analysis. Moreover, recent microsimulation modelling of ISA carried out in the European PROSPER project (Liu et al., 2005) has identified no significant increases in journey time.

This analysis of benefits will focus solely on the crash reduction that will be achieved by ISA. The magnitude of these benefits is dependent on:

- the impact that ISA has on speed choices of drivers, and the crash risk reduction associated with changes in speed profiles,
- the volume of travel in future years, and the crash risk consequences associated with that travel both with and without ISA.

2.1 Impact of ISA on speeds and crashes

2.1.1 Impact of ISA on speed

Over the past three years the impact of Voluntary ISA on driving behaviour has been assessed in a series of four on-road trials in which drivers used one of twenty ISA capable vehicles for a period of 6 months each. Four of those six months were with the ISA activated. The trials, the details of which can be found in the report from this project entitled “Overall Field Trial Results”, have provided a wealth of information on a range of drivers responses to ISA, including the distribution of drivers' speed choices, under normal driving conditions, both with and without voluntary ISA. The trials covered some 12,119 person days of driving over which the subjects travelled 570,661 km. This section of the report uses summary data from these trials, to predict the impact of ISA on drivers’ speed profiles.

2.1.1.1 Comparing baseline speeds with Vehicle Speeds Great Britain

The ISA trials were undertaken in Leeds, a predominantly urban area, and Leicestershire, a more rural area with a number of small towns and villages. Participants in the trials included both private motorists and fleet driving. Each six-month trial was divided into three phases. During the first month of the trial (Phase 1), ISA was inactive and the vehicle operated as a normal car. The voluntary ISA was then activated during the four months of Phase 2, and switched off for the final month, which was defined as Phase 3.

Figure 1 below compares the speed distributions of the subject drivers in the baseline (non-ISA) case against speed distribution data published in Vehicle Speeds Great Britain (DfT, 2006a).

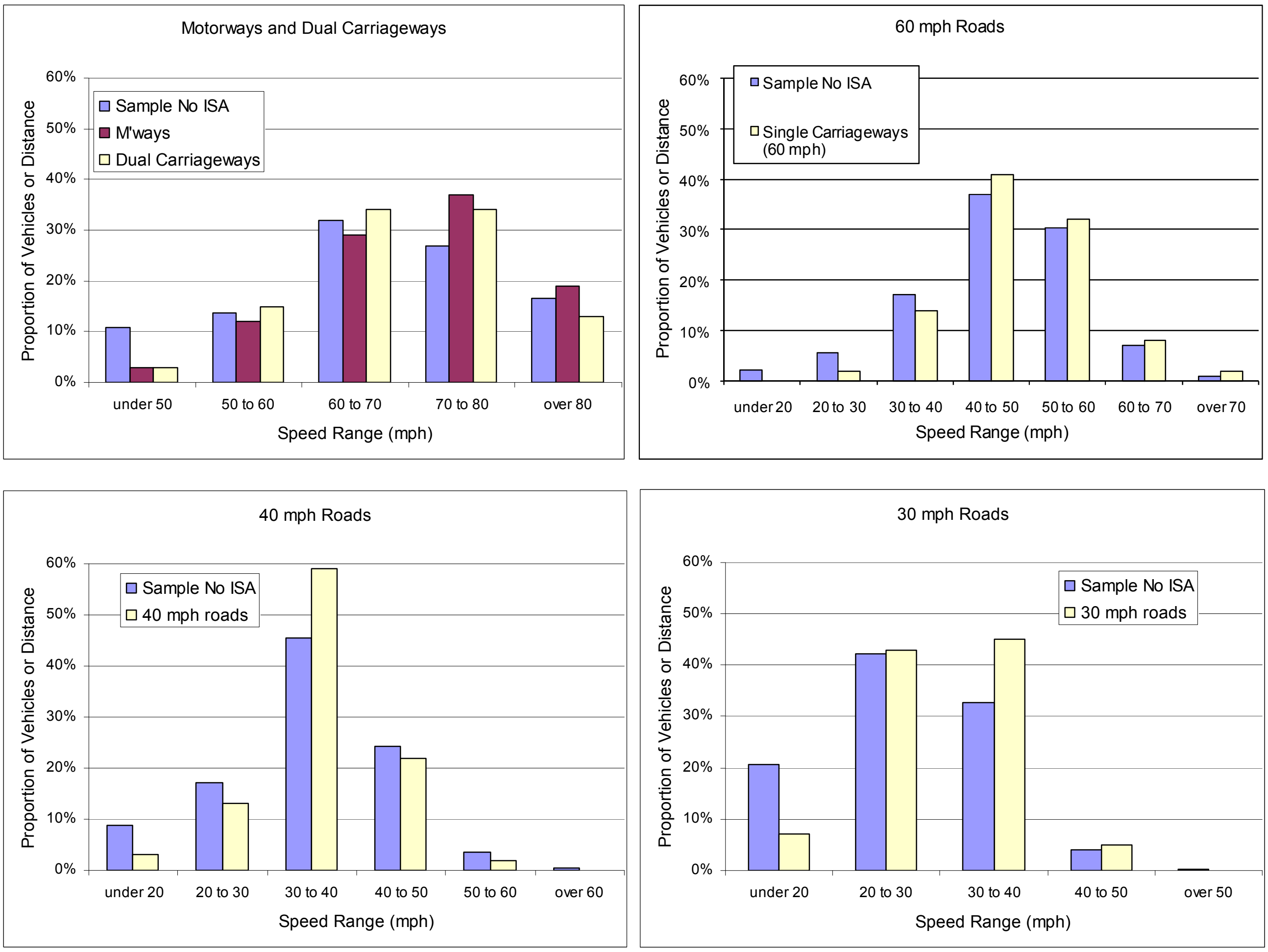


Figure 1: Comparison of non-ISA speed distribution by road type with data from Vehicle Speeds Great Britain 2005

The speed distributions, and means speeds (see Table 1), from the no-ISA sample are generally similar to those reported in Vehicle Speeds Great Britain. That there are no gross differences suggests that the speed choices of the drivers who participated in the ISA field trials are not dramatically different from the speed choices of the wider driving population. Exact correspondence is not to be expected, since the baseline (non-ISA) data is the proportion of distance travelled by the trial participants in each speed band, whereas Vehicle Speeds Great Britain is based on the proportion of the car fleet that passed a particular location travelling within a particular speed band.

Table 1: Mean speed comparison

	Speed Limit (mph)					
	20	**30**	**40**	**50**	**60**	**70**
Baseline (No ISA) speeds	19	27	35	43	46	67
Vehicle Speeds Great Britain speeds		30	36		49	69 Dual 71 M'way

While the speeds recorded in the ISA field trials are generally lower than those reported in Vehicle Speeds Great Britain 2005, this is likely to reflect the site selection protocols for the latter, which seek to minimise the impact of congestion. The monitoring sites that provide data for Vehicle Speeds Great Britain are:

"*generally situated away from junctions, hills or sharp bends, at locations where traffic is likely to be free flowing and not near speed cameras. Thus, in principle, they provide information on the speeds at which drivers choose to travel when their behaviour is not constrained by congestion or other road conditions*." (DfT, 2006a, page 5)

It is therefore to be expected that the mean speeds recorded in Vehicle Speeds Great Britain will be higher than those recorded by drivers taking part in the ISA trials, and it appears reasonable to conclude that the Baseline (No ISA) speed profiles from the trials are reasonably typical of average conditions in Great Britain.

However, the sample of subjects selected for the ISA trials is unlikely to be truly representative of the driving population as the intention in the trials was to obtain a reasonably balanced sample of drivers categorised on the basis of:

- Gender
- Age
- Fleet drivers and private motorists and
- Behavioural indicators regarding their intentions towards speed violations

While differences within the sample in drivers' speed choices, some of which were statistically significant, were identified (see "Overall Field Trial Results" report), the practical significance of these differences for safety prediction is considered to be minimal.

Using the data from these recent trials, it is possible to develop mean speed profiles that show the impact of Voluntary (overridable) ISA on drivers travelling on roads with different speed limits (20 mph, 30 mph, 40 mph, 50 mph, 60 mph, and 70 mph). It is also possible to use the time when drivers had the ISA enabled, i.e. not overridden, as a surrogate for a Mandatory ISA, i.e. one that cannot be overridden. Admittedly, this is not a perfect assumption. The times when ISA was left on by the drivers may not be fully representative of all the times when ISA was available to them, since they would have been more likely to leave ISA enabled when traffic conditions kept them below the speed limit. Thus there is likely to be an underestimate of the speed impact, and hence safety impact, of a true Mandatory system. The alternative is to use the speed data reported annually in Vehicle Speeds in Great Britain to impute the impact of Mandatory ISA, supposing that all excess speed will be eliminated by the ISA system. This was the procedure used in the External Vehicle Speed Control project. However, this procedure has its own problems, in that the sites chosen for speed monitoring are deliberately selected to be free flowing. Thus they are not representative of the road system in general. Because the sites selected tend to be high speed, using them to calculate the impact of a Mandatory ISA would tend to exaggerate the speed and safety effects of ISA. Overall, it has been considered preferable to use real observed data as opposed to employing imputation on non-representative data and thus to be conservative in the estimation..

A set of speed profiles from the ISA trials are shown in Figures 2 through 5, depicting speed on 30 mph roads. Similar plots for other speed limits are shown in Appendix A. In each case, the speed limit is shown with a solid line. Apart from the distribution for Advisory ISA (shown in Figure 3), these are all plots of the recorded data. Advisory ISA was not tested in the trials, and accordingly the distribution for that version of ISA has been calculated, using a methodology that is discussed in section 2.1.2 below.

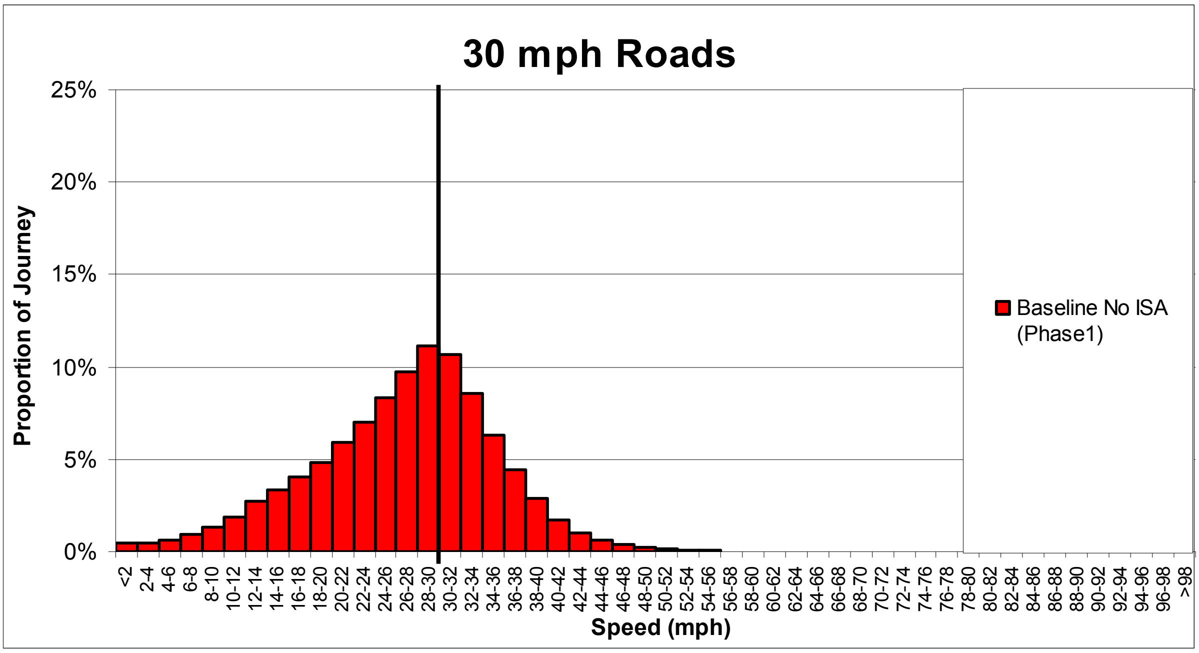


Figure 2: Proportion of distance travelled by driving speed in baseline situation on 30 mph roads

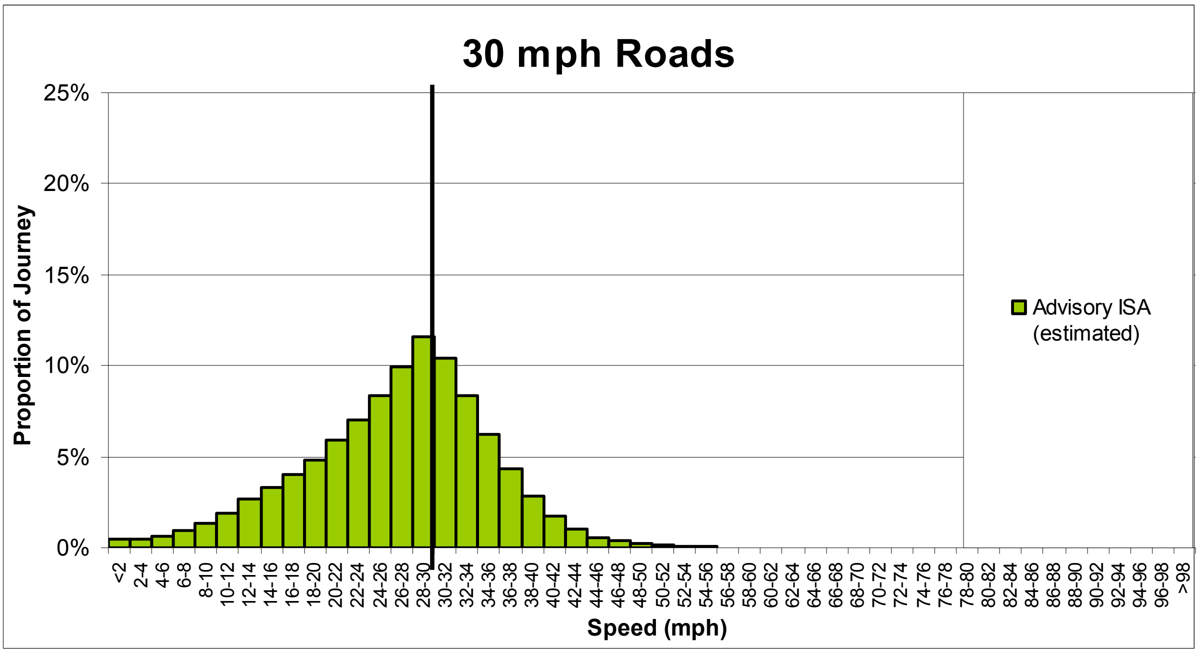


Figure 3: Proportion of distance travelled by driving speed with Advisory ISA

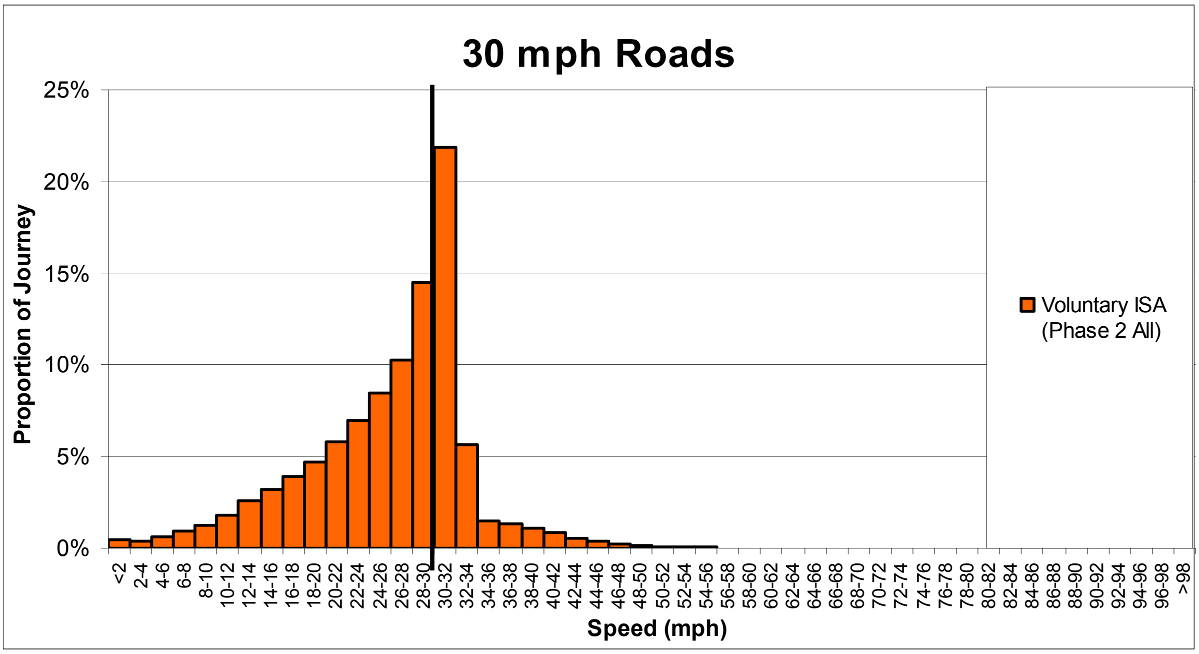


Figure 4: Proportion of distance travelled by driving speed with Voluntary ISA

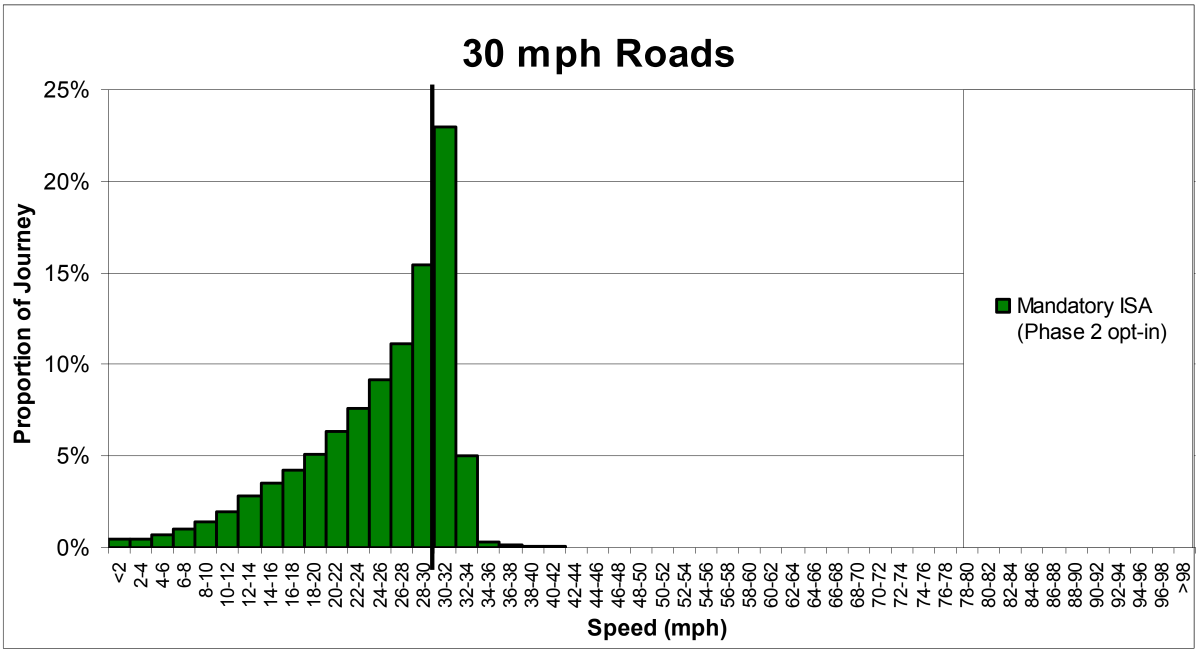


Figure 5: Proportion of distance travelled by driving speed with "Mandatory" ISA

The driving with Voluntary ISA, depicted in Figure 4 covers all the driving during Phase 2 of the trials when the ISA system was enabled. It can be seen that speeding was very much reduced, but not eliminated completely — drivers could override the system when they so desired. As discussed above, data for "Mandatory" ISA (as shown in Figure 5) is derived from driving with ISA when there has been no activation of the opt-out feature of the tested system. It can be seen that, even with the ISA system active, there was a certain amount of over-speeding, although the large peak around the limit is evident. The control unit had a certain amount of hysteresis or variability around the set limit. It would allow a small amount of speeding before it reacted to slow the vehicle down. Thus it allowed those choosing to accept speed limitation to exceed the speed limit by around 3 mph, and up to 5 mph on steep downhill grades. This was a prototype system and it is expected that such issues would either not apply, or be minimised, in a production system. Here again, the effects of real-life ISA, introduced in the future, may be larger than the results observed in the field trials.

The combined impact of over-speeding and the use of speed profile data aggregated in bins of 2 mph has resulted in a larger than expected section of tail close to the speed limit boundary. However, no adjustments have been made to the data to account for any improved system performance in the future.

2.1.2 Estimating the impact of Advisory ISA

The recent trials did not specifically test an Advisory ISA. In order to estimate the impact of Advisory ISA, the findings of two recent sets of investigations have been applied — PROSPER studies (Varhelyi et al., 2006) undertaken in Debrecen (Hungary) and Mataro (Spain), and the French project LAVIA (Ehrlich et al., 2006).

The PROSPER trials investigated the impact of an Advisory ISA system as well as one with an active throttle pedal, a system which was analogous to but not quite as intrusive or intervening as the Voluntary ISA system tested in the UK (Varhelyi et al., 2006). In each of the trials there were twenty participants, each of whom drove an initial month with no ISA, followed by two months with ISA (split between the two ISA variants) and a final month again with no ISA. The mean speeds of driving on roads with different speed limits are reported for Debrecen (Hungary), where the system was trialled on 50 km/h roads, and Mataro (Spain) where a range of roads with different speed limits was studied.

The speed reduction factors for each PROSPER trial are shown in Figure 6. The relative reductions for the Advisory and active throttle pedal systems from the PROSPER Mataro study have been used to estimate the likely speed reduction factors of an Advisory ISA system in the UK. In section 2.1.3 these changes in mean speed are used to assess and check the crash reduction potential of the UK Advisory ISA.

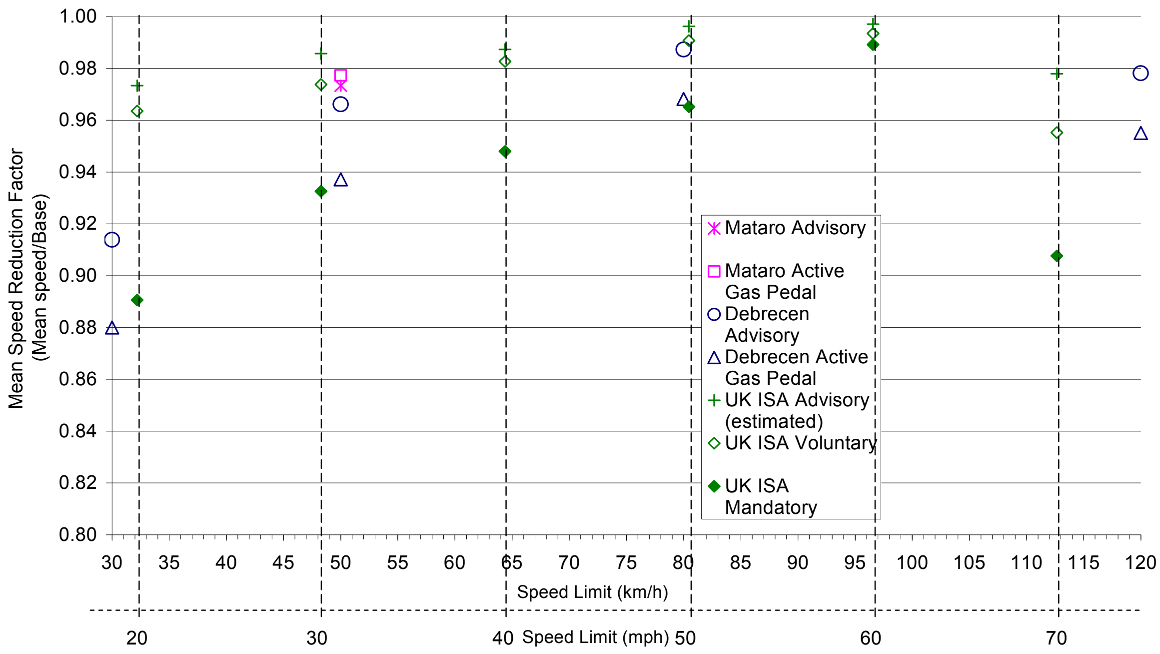


Figure 6: Impact of ISA variants on mean speed (Varhelyi et al., 2006; and the UK ISA trials)

The second study used to assess the likely impact of UK Advisory ISA is the LAVIA project. LAVIA investigated the impact of Advisory and Voluntary ISA on the proportion of journey time exceeding the speed limit on roads with different speed limits. There were 90 participants, who drove 79 days with no ISA, 70 days with an Advisory ISA and 143 days with a Voluntary (overridable) ISA.

The relative reduction in proportion of time spent exceeding the speed limit, achieved by the Advisory ISA relative to Voluntary ISA in LAVIA, has been applied to the UK Voluntary ISA, e.g. in LAVIA the Voluntary ISA reduced the proportion of time spent exceeding the speed limit on 50 km/h roads from 12.9% to 11.1%, a reduction factor of 0.86. In the UK ISA trials, the speed limit was exceeded during 37% percent of driving without ISA in the pre-ISA period, but dropped to 34% under Voluntary ISA, a reduction factor of 0.92. In LAVIA the Advisory ISA reduced the proportion of time spent exceeding the speed limit from 12.9% to 12.5% which is 22.22% of the reduction achieved by the LAVIA Voluntary ISA system. Applying the same relative shift to the UK ISA we would expect an Advisory ISA system to result in 36.4% of driving to be in excess of the speed limit. The results of this exercise are presented in Figure 7 which provides details of the multiplicative factors for the reduction in the proportion of speeding.

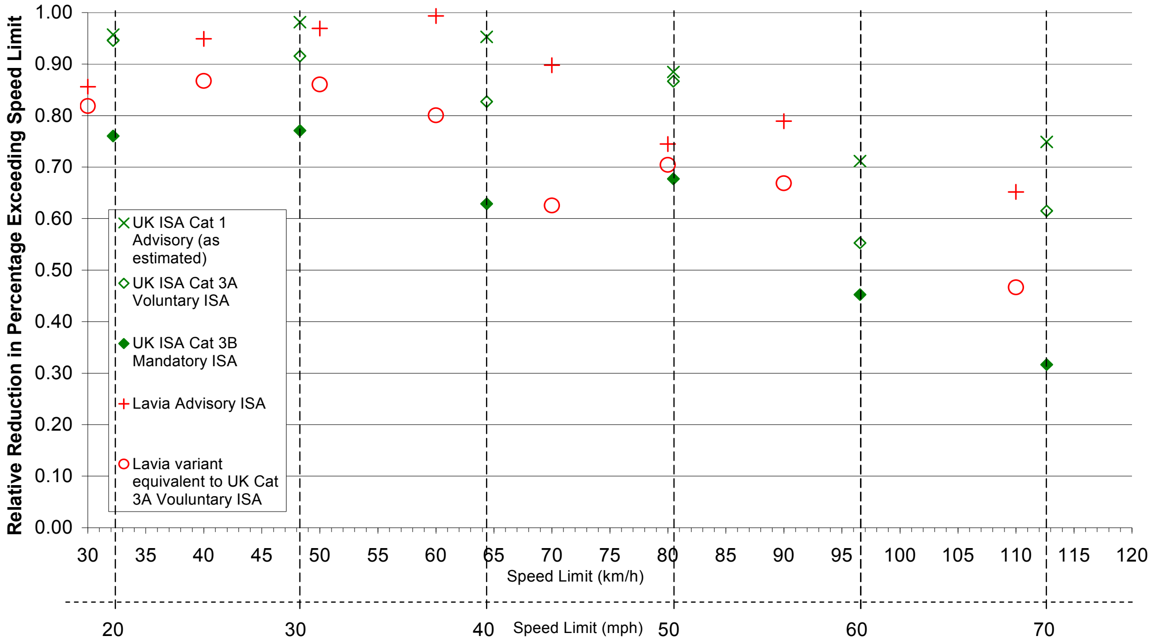


Figure 7: Impact of ISA variants on proportion of journey time exceeding speed limit (source Erhlich et al., 2006, and UK ISA trial data)

Of the two sets of studies, LAVIA is considered the more reliable, since the systems tested are in general terms more similar to those studied in the UK. Furthermore the LAVIA trials involved prolonged use of ISA in everyday driving, while many other studies (e.g. Comte, 2001; Paatalo et al., 2001) have involved driving on a specific route. In these cases the characteristics of the route will have a major impact on the speed profiles.

The reductions in the proportion of drivers exceeding the speed limit reported in LAVIA have been used to estimate the expected reductions in the total proportion of driving at speeds exceeding the speed limit under UK Advisory ISA. The proportion of travel in each 2 mph speed bin above the speed limit has been uniformly reduced, according to LAVIA, and the differences reallocated to the speed bin immediately below the speed limit. So even though the UK ISA trials employed only a Voluntary ISA, it is possible to predict the impact of all three ISA variants. Table 2 summarises the various data sources that have been used to estimate the speed reductions with ISA. Graphs of the resulting speed profiles for each system are shown in Appendix A.

Table 2: Basis of speed reduction predictions

Case	Basis of Analysis
Base: No ISA	Speed distributions from Phase 1 (no ISA) of the UK ISA trial
Advisory ISA system	Apply the proportional reductions of Ehrlich et al. (2006). This factor is applied to the speed distributions obtained from Phase 1 of the UK voluntary ISA trial.
Voluntary ISA system	All data from Phase 2 of the trial
Mandatory ISA	Data from the non-overridden component of Phase 2 driving in the trials

2.1.3 Impact of ISA on crashes

2.1.3.1 Introduction

There has been a large body of work using empirical methods to determine the relationship between speed and crash risk. Studies have employed a variety of methodologies to collect and analyse their data. A recent summary of the literature can be found in Aarts and van Schagen (2006). Methods applied to acquire the data for analysing and modelling the relationship between speed and the risk of an accident or injury include before and after studies which look at risk changes following an intervention which has altered traffic speed, cross-sectional studies which compare the risk of similar roads with different speed profiles and case-control studies comparing the pre-crash speeds of accident-involved vehicles with the speeds of vehicles randomly selected from the traffic stream. Elvik et al (2004) carried out a meta-analysis of a large number of studies from across the world to investigate the form of the relationship between traffic speed and risk of an accident or injury at various levels of severity. They identified 175 studies as being relevant and used 98 in the meta-analysis. The other 77 studies were not used because they did not report all the data that was required for the meta-analysis. This provides an indication of the sheer number of published studies.

Given the different methodologies used in data collection, the different environments in which the data have been collected and the variety of analytical methods applied to the observed and collected data, it is not surprising that individual studies differ on the precise relationship between speed and crash risk. However, there is broad consensus about the fact that traffic speed or the travel speed of the individual driver is a very major determinant of crash and injury risk, about the fact that risk goes down when speed is reduced and goes up when speed is changed upwards and about the relationship between speed and risk being causal.

Elvik et al. (2004) conclude that the relationship between speed and risk is unequivocal. They conclude (pp. iii–iv):

1. There is a very strong statistical relationship between speed and road safety. It is difficult to think of any other risk factor that has a more powerful impact on accidents or injuries than speed.
2. The statistical relationship between speed and road safety is very consistent. When speed goes down, the number of accidents or injured road users also goes down in 95% of the cases. When speed goes up, the number of accidents

or injured road users goes up in 71% of the cases. While it may to some extent be possible to offset the impacts of higher speed by introducing other road safety measures, a reduction in speed will almost always improve road safety.
3. The causal direction between speed and road safety is clear. Most of the evidence reviewed in this report comes from before-and-after studies, in which there can be no doubt about the fact that the cause comes before the effect in time.
4. The relationship between speed and road safety holds up when potentially confounding factors are controlled for. There is no evidence of a weaker relationship between speed and road safety in well-controlled studies than in less well-controlled studies.
5. There is a clear dose-response relationship between changes in speed and changes in road safety. The larger the change in speed, the larger the impact on accidents or accident victims.
6. The relationship between speed and road safety appears to hold universally and is not influenced by, for example, the country in which it has been evaluated, when it was evaluated or the type of traffic environment in which it was evaluated.
7. The relationship between speed and road safety can be explained in terms of elementary laws of physics. These laws of physics determine the stopping distance of a vehicle and the amount of energy released when an impact occurs.

Of the above statements, only number 6 requires qualification. While it is correct that there is always a relationship between speed and road safety, the precise form of that relationship does indeed vary between different traffic environments.

2.1.3.2 The applicability of speed-crash models to ISA

The introduction of ISA is a particular way of affecting speed choice and hence risk. To date ISA has been evaluated in a number of trials across the world but none of these trials, including the UK trials carried out in the current project, have been of sufficient size to provide reliable empirical information on actual crash involvement. Indeed (and not surprisingly given the participant numbers and overall quantity of exposure) most such trials will experience no injury crashes in either the without-ISA or the with-ISA situation. Hence, to arrive at a conclusion about the safety efficacy of ISA, it is necessary to apply models relating speed to crash risk. The observed changes in speed choice (or the estimated changes in speed choice for alternative versions of ISA) can then be used to generate predictions of changes in crash or injury risk both for the ISA fleet, and by extrapolation for the country or population as a whole, assuming a particular level of ISA penetration.

However, not all the models generated from empirical data are equally applicable to the case of the introduction of ISA. It would be preferable, for ISA purposes, to use models derived from before and after observations of how changes in speed choice affect risk. However, many models have been derived from cross-sectional data, i.e. from comparing risk on similar roads with different speed profiles. Such models have an inherent problem when applying them to ISA in that roads with different speed profiles tend to vary in quality and traffic conditions, and this may not be fully accounted for in the model parameters.

Another issue is whether the models cater to changes in the shape of the speed distribution. ISA, and in particular the intervening forms of ISA, will at higher rates of penetration radically alter the shape of the speed distribution by curtailing speeds in excess of the limit. This renders those models that consider only mean speed imperfect on theoretical grounds.

Many interventions affecting the traffic system have an impact on mean speed. Examples might be changes in speed limits, alteration of road layout, warning signs or active roadside feedback to drivers on inappropriate or excess speed. If an intervention is enacted, the consequence of which is a downward shift of the speed distribution (from curve 1 to curve 2 as shown in Figure 8), the expected reduction in crashes may be determined, by applying a model, from the reduction in mean speed. However, should the intervention simply alter the shape of the speed distribution, without an appreciable reduction in the mean (moving from curve 1 to curve 3 in Figure 8, a model based on mean speed alone would not predict any relative reduction in crashes. Such a result lacks face validity as there is clearly a reduction in the number of vehicles travelling at higher speeds and in the potential for conflicts between vehicles.

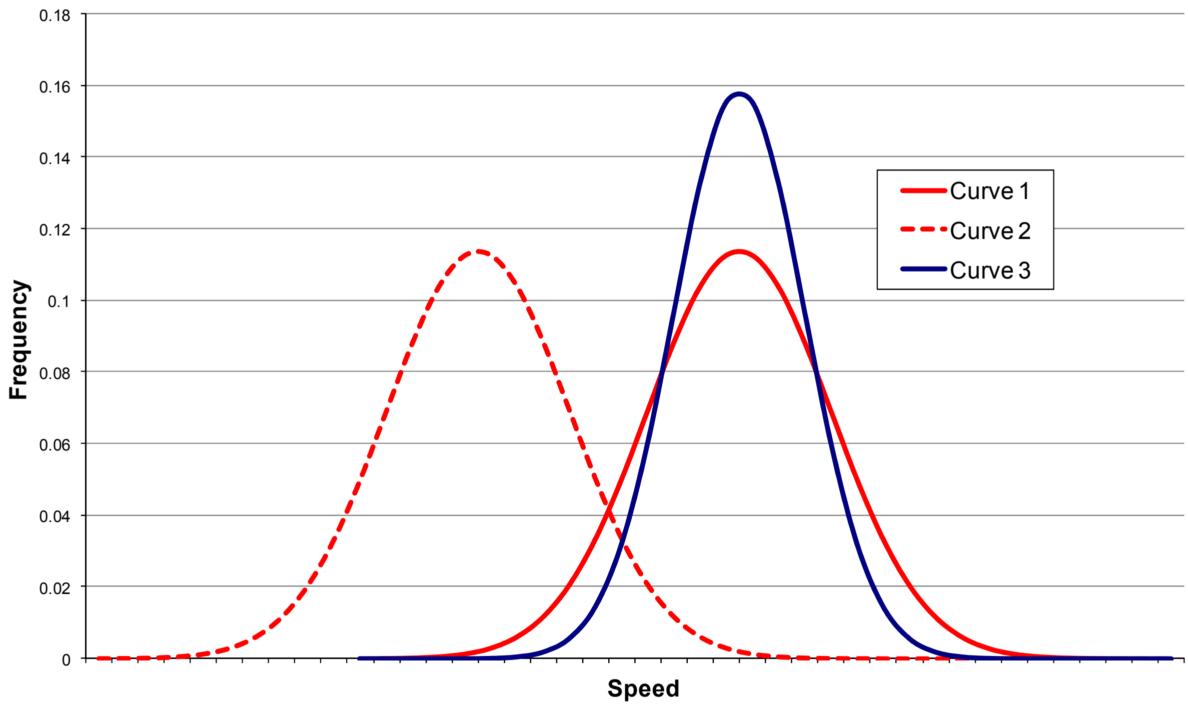


Figure 8: Hypothetical impacts on speed distribution

While this reduction is offset by a similar decrease in the proportion of drivers travelling at very low speeds, the speed-crash relationship is non-linear, and we would expect the reduction in crashes associated with lower top-end speeds to exceed the increase in crashes that results from the rise in bottom-end speeds.

Both voluntary and mandatory ISA specifically target higher speeds and significantly transform the speed distribution, limiting drivers' propensity to travel above the speed limit. This effect was observed in the project trials and can be seen in Figure 2, Figure 4, and Figure 5 as well as in Appendix A. This being the case, we should not expect that models based on mean speed will adequately represent the expected crash reductions of initiatives such as ISA which specifically target those travelling at higher speeds. Analyses based on models that only use mean speed would be expected to underestimate the crash reduction benefits of ISA, and in particular the reduction in higher severity crashes which are typically associated with higher impact speeds.

There is therefore a preference, when selecting models to analyse the safety impacts of ISA to choose those models that are explicitly able to cater to the change in top-end speeds.

Further theoretical problems can arise from the actual parameters used in the models. There are models of risk that use the proportion of speeders in the traffic stream. If that is the only parameter in the model, then with full usage of non-overridable ISA the risk of accident occurrence on a particular category of road would become zero, which is implausible.

In terms of model source, those models based on before and after observations are to be preferred over models derived from cross-sectional data (i.e. from comparing different roads with different speed profiles). The former are much more likely to account for fact that roads with different speed profiles are likely to differ in quality, with better quality roads tending to have faster traffic.

Equally it has been shown that the rate of change of crash risk associated with the impact of changes in speed are not equivalent across roads of different quality. This was demonstrated for example in Taylor et al. (2002), where it was shown that for rural single-carriageway roads, better quality meant not only higher mean speeds and a lower risk for a given mean speed, but also reduced impact on risk of a given change in mean speed (such as an increase of 5 mph). This all indicates the potential problem associated with using models out of the range for which they were calibrated: a model derived from roads with a mean speed of 35 mph may not predict properly when it is applied to a set of roads with a mean speed of 50 mph.

This also implies that general models based on all roads, such as those of Finch et al. (1994), Nilsson (1982) and Elvik et al. (2004), are not as appropriate as models that take into account road category (urban, rural, motorway) and road quality. For example, a model derived for rural single-carriageway roads should preferably not be applied to prediction for rural dual carriageways. Equally, because of extraneous factors such as the level of seatbelt wearing among drivers in different countries, there is a preference for using models derived from data for the country in question.

Based on the above discussion, a number of criteria can be established for evaluating the appropriateness of models found in the literature to the case of ISA. It is preferable for models:

1. To take account of the impact of ISA on the distribution of speed or on speed difference — this is particularly relevant for application to intervening forms of ISA

2. To be specified for the group of roads in question (by road category, speed limit, travel speed, etc.)

3. To be derived from the region or country in question

4. To be based on before and after data

5. To use parameters that are appropriate for ISA so that the models are fit on theoretical grounds

It is also undesirable to use models outside of the range of the observed values from which the models were developed. Thus it is preferable not to apply a model that has been developed for 30 mph roads to the case of 20 mph roads. However, there may be circumstances in which there is little choice but to violate this principle, since a "proper" model for a road category may not be available.

Finally, there are some particular issues stemming from a need to look at the impact of ISA introduction over time. Initially, ISA will only be present in a few vehicles and the safety impact of ISA will be restricted to equipped vehicles. Those ISA-equipped vehicles will have little effect on the speeds of traffic in general. So at low levels of penetration, it is more appropriate to use models that look at the risk for individual vehicles in the traffic stream, in terms of how *difference in speed* (from mean speed or from the speed limit) affects risk. At higher levels of penetration, when ISA vehicles will have an impact on the traffic stream in general, those models that use mean speed may be more appropriate. But of course mixing different models together for an analysis within road category is also not appropriate. So one way or another, some compromises have to made. There is no single best model in the literature that can be applied for the case of ISA. Rather, there is a choice of models with different levels of advantage and disadvantage for safety prediction concerning ISA. The analyst therefore has to select those models with the fewest disadvantages and interpret the results accordingly. It should be recognised that statistical models are a simplified representation of reality and no model is perfect.

2.1.3.3 General models relating speed to crash risk and crash severity

Various formulations have been derived for the relationship between speed and crash risk and/or crash severity. From an overview of the international literature, Finch et al. (1994) concluded that for every 1 mph change in the mean speed of traffic on a road there was a 5% change in the risk of injury accident occurrence. This was a general formula covering all road types.

There is a need to consider the impact of ISA on crash severity as well as on crash involvement. By slowing vehicles, ISA will tend to reduce events that, without ISA, have resulted in fatal crashes into ones that result in serious or slight injuries. Equally, crashes that would without ISA have been serious will tend to become slight, and slight crashes will tend to become damage only crashes or even to be avoided completely. Among the collisions affected by ISA will be those between cars and pedestrians, where the relationship between speed and severity is well known (Ashton and Mackay, 1979; Pasanen and Salmivaara, 1993).

The meta analysis by Elvik et al. (2004) examined both speed and crash severity. The authors propose that the relative reduction in crashes (or casualties) is related to the relative reduction in mean speed, raised to a power, as originally suggested by Nilsson (1982 and 2004) and as supported theoretically by both the laws of physics and human tolerance for injury:

$$\frac{Metric\ After}{Metric\ Before} = \left(\frac{Mean\ Speed\ After}{Mean\ Speed\ Before}\right)^{Power}$$

where the value of the power is specified according to the metric of interest. Table 3 shows the coefficients determined by their analysis.

Table 3: Coefficients of power model (Elvik et al., 2004)

Metric of Interest	Accidents	Road Users
Fatal	3.6	4.5
Serious Injury	2.4	3
Slight Injury	1.2	1.5
All Injury	2	2
Property Damage Only	1	N/A

As discussed in section 2.1.3.2 above, it is not ideal to apply a generic model, derived for all categories, to a particular category of road, particularly when more finely based models are available. As a result, in the analysis reported here, a general model is only used when a more appropriate specific model cannot be found. Such an instance is the case of 70 mph roads and motorways. No appropriate specific study for this category of road has been found, and therefore the results of Elvik et al. (2004) are used.

The work of Nilsson and the meta analysis of Elvik et al. (2004) also demonstrate the differential impact of changes in speed on crashes at different levels of severity: the more severe a crash, the more likely it is that excess speed will have played a role. This needs to be considered in predicting the impact of ISA. It is of course highly significant for a cost-benefit analysis because of the very high values associated with fatal and serious accidents. Therefore, the exponents of Elvik et al. (2004) shown in Table 3 will be applied to translate predictions at the all injury level generated by various models into separate predictions for slight crashes, serious crashes and fatal crashes.

2.1.3.4 Models for urban roads

Taylor and colleagues have developed two speed crash risk models for UK urban roads (Taylor et al., 2000). This urban model, known as the ***U1*** model, uses both mean speed and the coefficient of variation of speed distribution, i.e. standard deviation divided by mean speed, together with a range of road-environment-related explanatory variables. Where the road-environment variables remain unchanged the model simplifies to:

$$\frac{AF_1}{AF_2} = \frac{V_1^{2.252} e^{5.893 Cv_1}}{V_2^{2.252} e^{5.893 Cv_2}}$$

Where

AF = *Accident frequency*

V = *Mean traffic speed*

Cv = *Co-efficient of variation of speed*

:

Since the current study is examining the impact of ISA alone and is therefore assuming that all other factors will indeed stay constant, this reduced version of the U1 model is a candidate for application here. It does consider the impact of a change in speed variance, but it does not cater to the dramatic change in the shape of the speed distribution that it caused by the deployment of Voluntary as shown in Figure 4 and even more so of Mandatory ISA as shown in Figure 5.

The second urban model ***U2*** is based on the proportion of vehicles exceeding the speed limit (P) and excess speed, the difference between the mean speed of speed limit violators and the speed limit:

$$AF = K_{U2}\, P^{0.141}\, e^{0.175Vex}$$

where:

AF	=	accident frequencies
K_{U2}	=	is a site specific constant incorporating road variables
P	=	is the proportion of traffic exceeding the speed limit
V_{ex}	=	mean speed of traffic exceeding the speed limit – speed limit

The ISA system developed for UK ISA trials was imperfect and allowed the user to "over run" the speed limit by a small amount. While this imperfection resulted in a proportion of vehicles exceeding the speed limit even under ISA control, in a more sophisticated ISA system the proportion exceeding the speed limit would be zero and the U2 model would therefore predict no crashes with 100% adoption of a Mandatory ISA.. Nevertheless, it can be used to assess the impact of the Mandatory ISA system used in the field trials, as this system did allow some limited over-speeding.

An alternative approach is to consider the risk associated with drivers' speed choices. Australian researchers have used this approach to investigate the speed choice-crash risk profile for individual drivers on urban 60 km/h speed limit and rural 80 km/h speed limit roads (Kloeden et al., 2001 and 2002; Kloeden and McLean 2001). There has been some criticism of the quadratic form of the models (e.g. in Elvik et al., 2004), on the grounds that this form suggests increased crash risk for those travelling both slower and faster than the mean. The literature review by Aarts and Schagen (2006) points out that, while many older studies show an elevated risk for driving more slowly than the mean, most more recent studies do not. However, the Kloeden models are essentially monotonically increasing over the applicable range (−10 km/h to +30 km/h) and the quadratic is simply the form that best fits the data over this range. The quadratic form is also intuitively sensible, in that very slow moving vehicles in a fast traffic stream may indeed be at excess risk.

The models were initially developed to consider absolute speed choices, but have subsequently been revised to consider the relative risk associated with speed choices above and below the mean or control speed for the road section under consideration. Figure 9 shows the relationship for urban roads.

Figure 9 is clearly dominated by the rapid increase in crash risk for those drivers who chose to travel faster than the mean speed of traffic. This dramatic increase far outweighs the benefits of travelling slower than the mean speed, e.g. travelling 10 km slower than the mean speed would reduce a driver's crash risk by 57%.

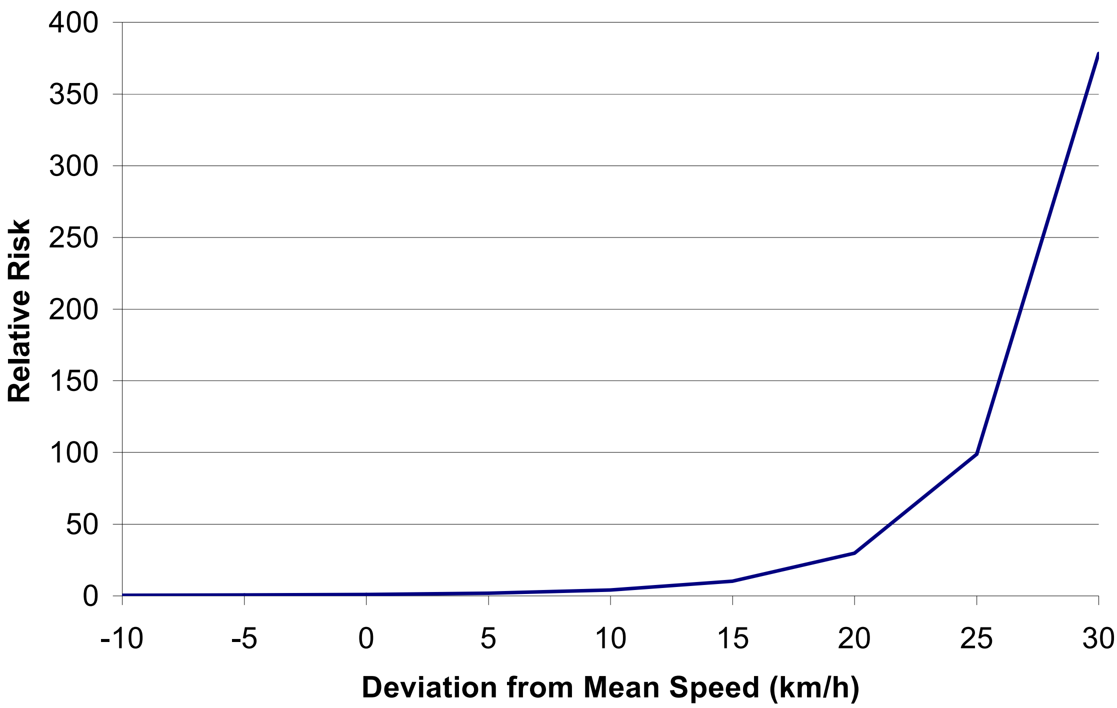


Figure 9: Model of relationship between speed choice and crash risk on urban roads (adapted from Kloeden et al., 2002)

The Kloeden relationships are, however, based on data collected in South Australia and use pre-crash speeds, determined through crash reconstruction. The pre-crash speeds were then compared to the mean speed of free travelling vehicles, those not slowing for junctions etc. Just how applicable these relationships are to the UK situation is unknown. Furthermore the confidence intervals associated with these relationships become very large toward the upper extremes, as shown in Appendix B.

An implicit assumption of the Kloeden models is that it is an individual's speed choice alone which determines crash risk. The researchers themselves acknowledge this issue in the report on the rural road analysis:

> It may be that drivers who choose to travel faster than most other drivers on a specific section of road also exhibit other risk taking behaviour. It may be, therefore, that some of the increase in risk seen in this study is due to this risk taking behaviour and not solely to the higher travelling speed itself. However, the study design largely controlled for one of the other main forms of risk taking, alcohol impaired driving. (Kloeden et al., 2001, page 32)

It should be noted that alcohol was also eliminated as a factor in the Kloeden et al. urban study.

Although correlation does not necessarily equate to causation, there are, as discussed above, a number of physical relationships that support the proposition that a causal relationship exists between speed and crash risk. For example:

- For a given level of deceleration the distance required to stop a vehicle (before collision) is related to the square of the initial speed.
- The cornering forces on a vehicle increase with the square of speed.

- The energy that must be dissipated during a crash, through deformation of vehicles and occupants, increases with the square of speed.

Each suggests that some form of quadratic increase in crash risk as a function of speed is appropriate.

There are some concerns regarding the applicability of the Kloeden relationships to UK roads and about whether they include other risk factors in addition to speed choice. However, they constitute the only recent relationships that take account of speed and crash risk in a manner that will allow the impact of the dramatic changes in speed distribution generated by Mandatory ISA to be considered. As the speed distribution changes with increased penetration of ISA, so will the predicted risk.

The second area of concern relates to the very high levels of risk and the width of the confidence limits (see Appendix B) associated with pre-crash speeds more than 20 km/h greater than the mean speed. Kloeden et al (2002), generated an alternative model based purely on travel speed. Using that model and capping the crash risk above 80 km/h and below 45 km/h, the impacts associated with small amounts of high speed travel are minimised, resulting in a significantly lower, more conservative, predicted crash risk reductions

Figure 10 shows the analysis approach. The top graph in Figure 10 shows the distribution of speeds recorded on roads with a 30 mph speed limit during the ISA field trials. Two speed distributions are shown here: the Baseline data collected during phase 1 of the field trials when subjects drove the test vehicles without ISA operating, and the data collected while subjects had ISA enabled which represent speeds with Mandatory ISA.

The second graph of Figure 10 plots the relative crash risk curve for travel at particular speeds on urban roads as derived from the Kloeden urban model. Combining the speed and risk profiles gives the proportion of journey spent travelling at a particular speed and the relative risk of travelling at that speed, as shown in the lower graph in Figure 10. The areas under the risk profiles in the lower graph represent the expected relative crash risk. The area under the Mandatory ISA curve is 54% of that for the No-ISA curve, i.e. the expected number of crashes with Mandatory ISA will be 54% of the crashes that occur in the absence of ISA.

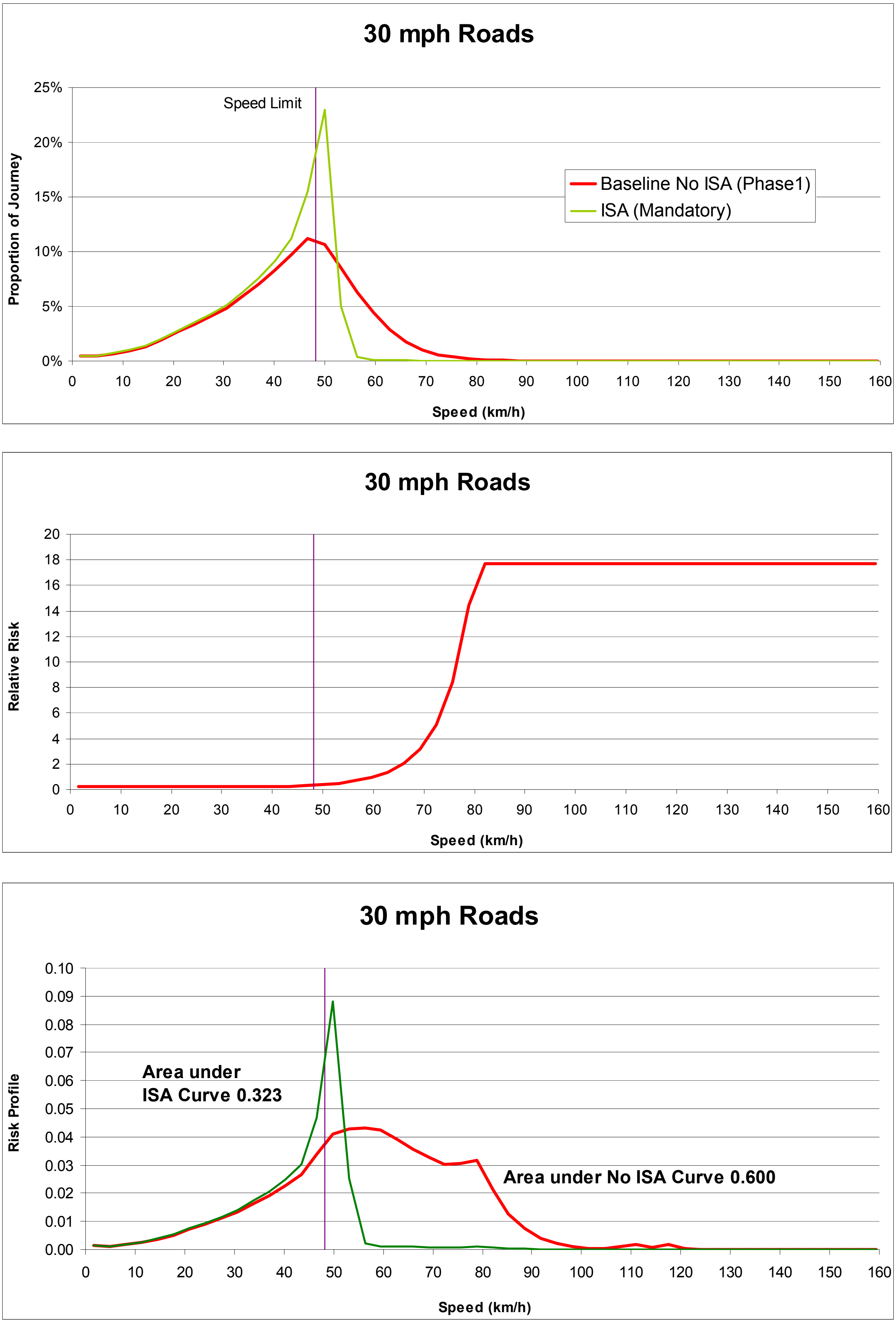


Figure 10: Example of speed profile and risk integration

Although the Kloeden models purport to represent all injury crashes, the crashes included in the studies were in fact those to which an ambulance was called. As a result the crash set is better represented as constituting the killed or seriously injured crash group. To overcome this, the crash reductions predicted by the Kloeden models have been adjusted. The adjustment is based on the power model as follows:

$$C_{allinjury} = X^{b/c}$$

where

$C_{all\ injury}$ = the expected reduction in all injury crashes

X = the crash risk reduction predicted by Kloeden

b = the power relationship for all injury crashes 2.78 (Elvik et al., 2004, Table 14)

c = the power relationship for fatal and serious injury crashes 3.41 (Elvik et al., 2004, Table 14)

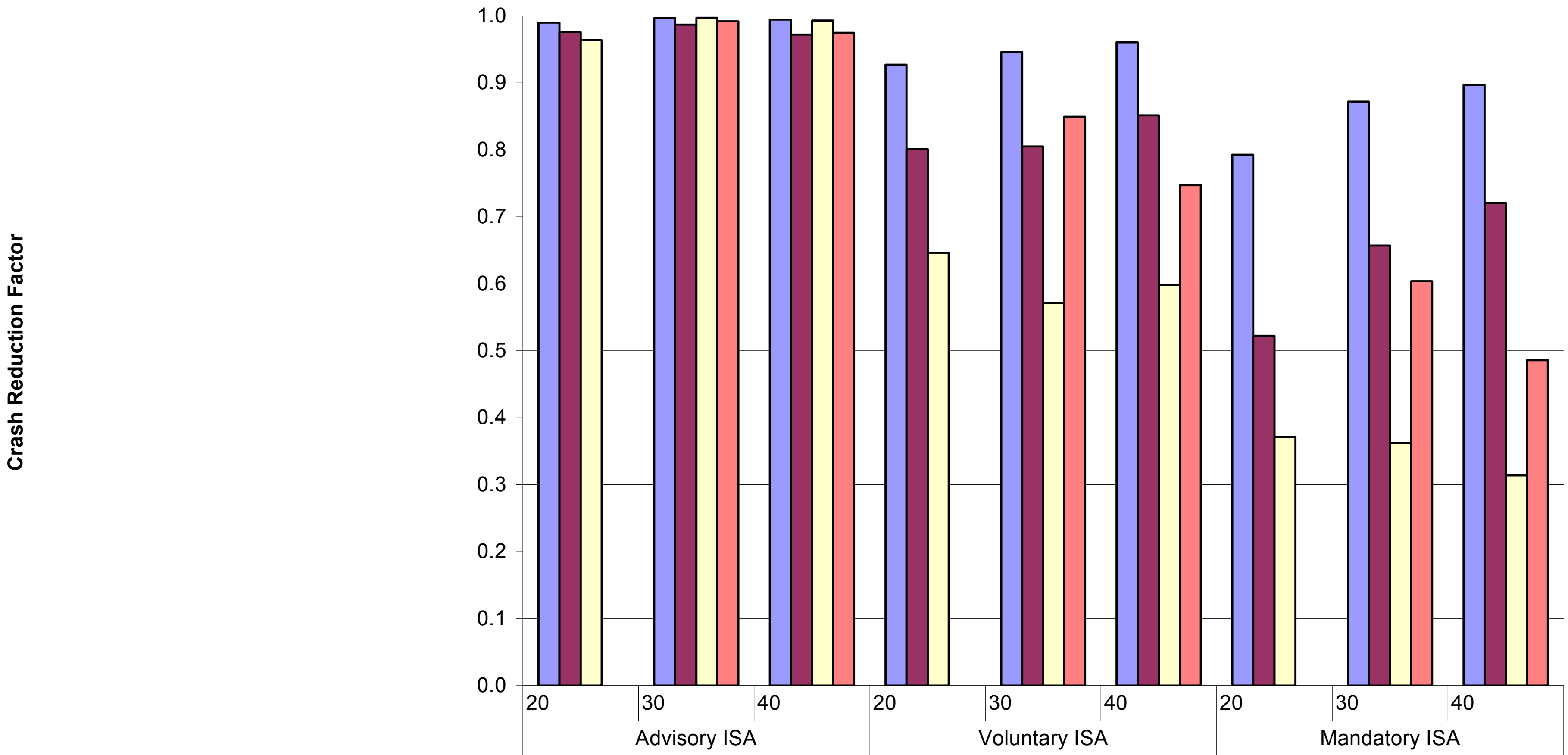
Applying this adjustment to the example of Figure 10 the expected number of injury crashes under 100% penetration of Mandatory ISA will be 60% of that in the absence of ISA. That is the 54% reduction in higher severity crashes (those attended by an ambulance) raised to the power of 0.815 (0.815=2.78/3.41)

Having identified candidate models, the next step is to review the predicted impact on crashes of applying those models to the to the speed data collected during the ISA trials, or in the case of the Advisory ISA, to the synthetic speed profile based on the impacts reported in LAVIA.

The predicted impact of ISA on urban crashes using the various models is shown in Figure 11. The figure shows the predictions of the proportional impact on all injury crashes of each ISA variant by speed limit with 100% penetration of ISA. At lower levels of penetration, these predictions need to be adjusted by the proportion of vehicles fitted with each form of ISA.. Not all models are used in every case. For example, on 20 mph (30 km/h) roads a significant proportion of time is spent travelling at speeds outside the applicable range of Kloeden's urban model. This combined with the fact that Kloeden's data was collected in Australia, leads us to favour the use of the U1 or U2 models for analysing the impact of ISA on 20 mph roads. Even though the speeds on 20 mph roads are outside the range of these models, they are based on data collected in the United Kingdom.

It can be seen from Figure 11 that, for Advisory ISA, the models are in general agreement. Only small reductions in injury crashes, no more than a 4% on urban roads, are predicted for the Advisory ISA.

For the intervening forms of ISA, Voluntary and Mandatory, there is little consensus between the various models, which predict a wide range of crash reductions. Generally the Power Models proposed by Elvik predict the smallest reduction in crashes, presumably because they are not calibrated to urban roads where the rate of change in crash reduction with a decrease in travel speed tends to be quite steep. Furthermore, the predicted reduction increases as the models take increasingly more account of the shape of the top end of the speed distribution. For Voluntary and Mandatory ISA, the U2 model predicts the largest reduction, as both the proportion of speeders becomes quite small and excess speed is substantially reduced. The Kloeden model gives reductions of 40% on 30 mph roads and 51% on 40 mph roads.



	Advisory ISA 20	Advisory ISA 30	Advisory ISA 40	Voluntary ISA 20	Voluntary ISA 30	Voluntary ISA 40	Mandatory ISA 20	Mandatory ISA 30	Mandatory ISA 40
Elvik Power Model	0.990	0.997	0.995	0.927	0.946	0.960	0.793	0.872	0.897
U1 Taylor et al	0.976	0.987	0.972	0.801	0.805	0.852	0.522	0.657	0.721
U2 Taylor et al	0.964	0.997	0.993	0.646	0.571	0.599	0.371	0.362	0.314
Kloeden Fixed Speed Risk (45 km/h to 80 km/h)		0.992	0.975		0.850	0.747		0.604	0.486

Figure 11: Proportional impact of ISA variants on urban crashes by road speed limit (mph)

In order to test the face validity of the predicted Advisory ISA benefits, the results of various models are compared to the expected crash levels from LAVIA and the two PROSPER studies as shown in Figure 12. Here the synthetic estimates of speed reduction generated with the UK trial data are compared with actual reductions observed in the other trials. It should be recognised that such comparisons are confounded by a number of issues. These include the initial levels of speeding and mean speed in each study, the proportional reduction from the baseline condition to the ISA condition, and finally differences between traffic and road conditions in the study area and those prevailing in the UK.

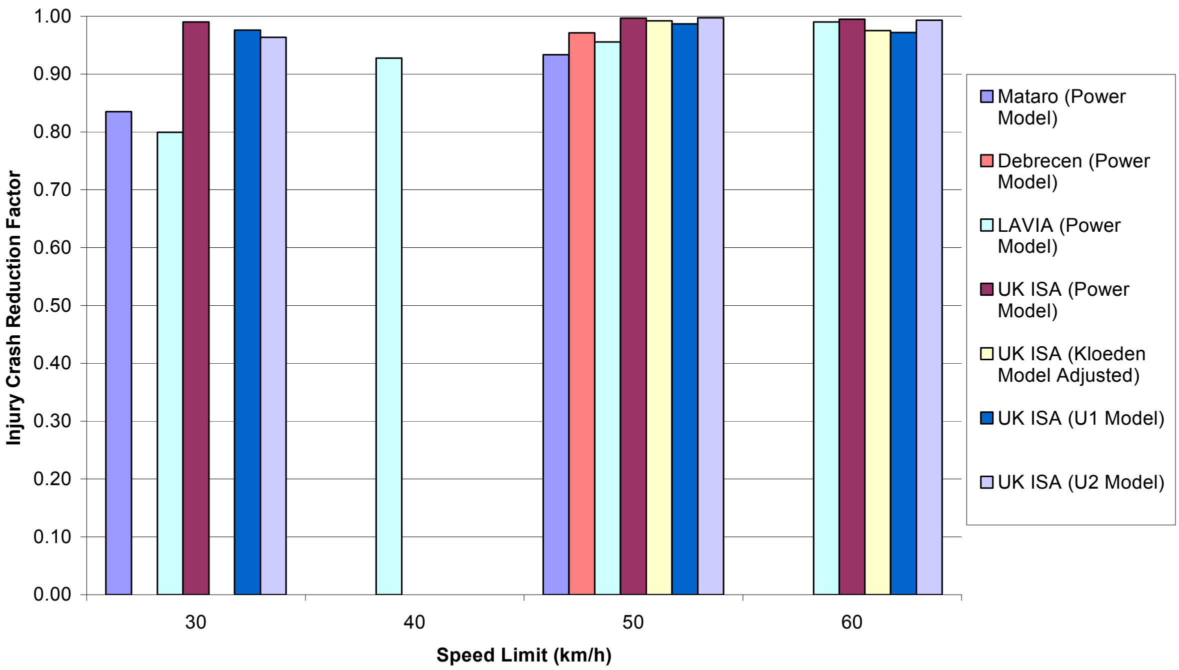


Figure 12: Injury crash reduction factors by speed limit for Advisory ISA in urban speed limits

While the results of the various models and studies are similar for 50 km/h (30 mph) and 60 km/h (40 mph) roads, both LAVIA and PROSPER predict far fewer injury crashes in 30 km/h (20 mph) speed zones than the equivalent UK models based on the ISA field trial data. While the UK ISA trials report 50% more driving in excess of the speed limit in the base case, the relative reduction in the proportion speeding under Voluntary ISA was only 5.4% compared to the 18.2% relative reduction in the proportion speeding achieved in LAVIA. However, only a very small proportion of injury crashes occur in 30 km/h (20 mph) zones in the UK, so even relatively substantial differences in estimated ISA performance in these zones are unlikely to have a major impact on the overall estimate of the benefit stream for ISA.

2.1.3.5 Models for rural and high-speed roads

In the UK, Taylor et al. (2002) have investigated the speed and crash relationship for rural single carriageways, developing a number of models to predict the annual number of crashes on a link, in the form:

$$AF = C_1 \times Q^{b1} \times L^{b2} \times V^{b3} \times G_i$$

where AF = accident frequency (accidents per year on link)
C = constant

Q	=	traffic flow (AADT)
L	=	link length (km)
V	=	speed (mph)
G	=	a group variable/expressions representing road type
bx	=	model coefficients

In a situation where some intervention reduces the speed on the road, but all other characteristics such as flow and road layout remain unchanged, the relative change in crashes will be given by:

$$\frac{Crashes\ After}{Crashes\ Before} = \left(\frac{V_{After}}{V_{Before}}\right)^{b3}$$

The values of the speed power *b3* are 2.666 for crashes involving death or serious injury (KSI), 2.408 for crashes resulting in only slight injuries and 2.479 for all crashes involving injury. Although the crash categories covered by these models differ from those presented by Elvik et al. (2004), the values for all injury crashes and the slight injury crashes are somewhat higher than those proposed by Elvik et al. (2004). Trial applications of the power model suggest that for the higher severity crashes, those involving death or serious injury, there are minimal differences between the crash reductions predicted using the coefficients proposed by Elvik et al. (2004) and those proposed by Taylor et al. (2002). The Taylor models have the advantage that they are specifically for UK two-lane rural roads. However, the coefficients have only been reported for cumulative aggregation of crash severities i.e. fatal and serious injury crashes combined and all injury crashes. Given that there is generally little difference in the reductions predicted obtained using the Taylor et al (2002) coefficients and the reduction predictions obtained using the Elvik et al coefficients; the latter are favoured for use in the subsequent analysis. .

Although Taylor et al. (2002) conclude that the mean speed based power models are more reliable than their earlier EURO models developed under the MASTER project (Baruya, 1998; Baruya et al., 1999; Taylor et al., 2000), these older models have the advantage that they include either the standard deviation of speed or the proportion and mean speed of those exceeding the speed limit and so consider explicitly the variation in speed around the mean.

The final EURO model, for rural single carriageways, is based on that originally developed under MASTER (Baruya, 1998), which included link width, length and traffic flow as well as the number of junctions. The speed related variables in the original model included speed limit, mean speed and the proportion of traffic exceeding the speed limit. Formulated in this way, mean speed acted as a proxy for geometric standard such that lower mean speeds were associated with higher crash rates. While this may apply to a cross-section of roads with varying standards, it is not appropriate for ISA.

Taylor et al. (2000) revised and simplified the model, expressing the relative change in crashes as a function of the change in the proportion of vehicles exceeding the speed limit:

$$\frac{AF_1}{AF_2} = \frac{P_1^{0.1143}}{P_2^{0.1143}}$$

where	AF	=	accident frequency
	P	=	proportion of vehicles exceeding the speed limit

However, this simplified EURO model relies heavily on the relationship between the proportion of speeders and the key assumption that the speed profile of speeders is relatively constant. Also, like the U2 urban model discussed above, the simplified EURO model would predict no crashes if there were no speeders. It therefore appears inappropriate to apply it to Mandatory ISA and questionable for Voluntary ISA.

Kloeden and his colleagues applied the same case-control methodology that they had used on urban roads to rural single carriageway roads in South Australia with speed limits of 80 to 110 km/h (Kloeden et al., 2001; Kloeden and McLean, 2001). Given the range of speed limits, the resulting relationship is presented in terms of deviation from mean speed and risk as shown in Figure 13.

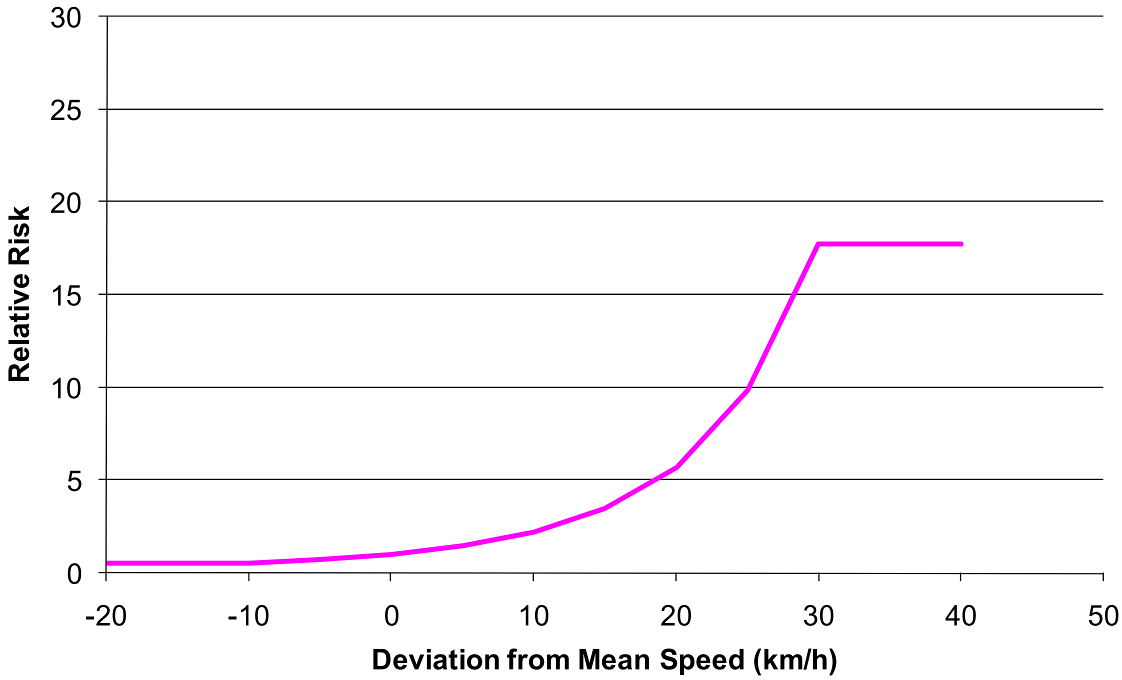


Figure 13: Model of relationship between speed choice and crash risk on rural roads (adapted from Kloeden et al., 2001 and Kloeden and McLean, 2001)

Once again this relationship is not based on UK data and once again it has high confidence intervals at the top end, although nowhere near as high as the top end of the urban models, as shown in Appendix B. However, it does have the advantage of fully considering the impact of intervening ISA on the shape of the speed distribution. The rural model is therefore a candidate for subsequent analysis. As with Kloeden's urban model the risk has been capped, and a severity adjustment has been applied.

However, the model in Figure 13 is derived in terms of the relative risk of travelling faster or slower than the mean traffic speed. In this analysis the mean speed is that of the particular scenario under consideration. Thus the risk profile for the no-ISA scenario is based on the mean speeds in the absence of ISA, while the risk profile for Voluntary ISA is based on the mean speeds recorded using Voluntary ISA.

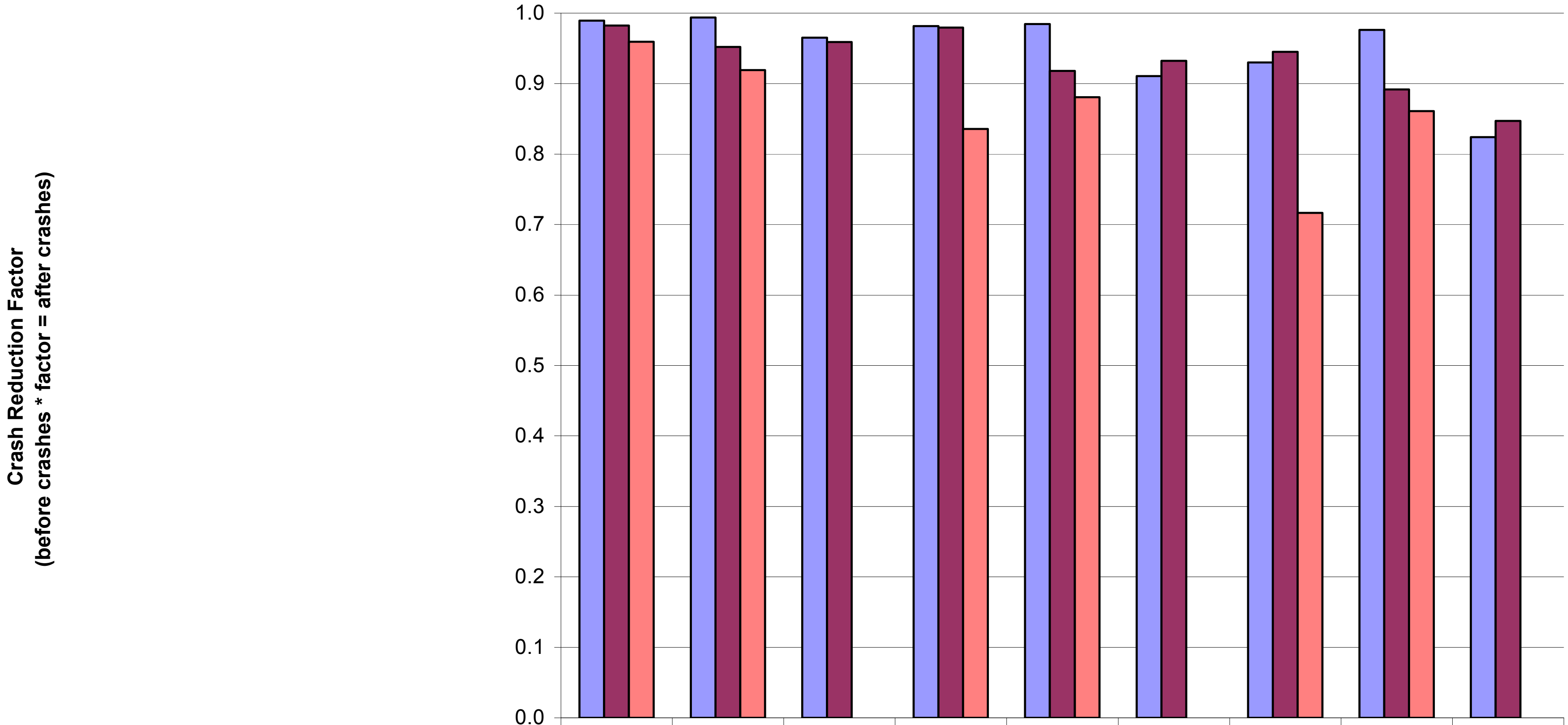
It could be argued that the model should be applied by considering deviations from the mean speed with no ISA, as using the scenario-specific mean speed does not take into account the Newtonian laws of motion and vehicle kinematics i.e. two identical speed distributions would have the same risk profile even if one were distributed around a mean of 70 mph and the other were distributed around a mean of 50 mph. Given the potential difficulty in partitioning the sources of risk, the approach adopted here, namely deviation from the scenario-specific mean, is considered conservative as it produces lower risk reductions than when the deviation from the no-ISA mean speeds is used throughout.

It is interesting to note that Kloeden's rural model predicts that, when travelling 24 km/h over the mean speed, the crash risk is almost nine times higher than when travelling at the mean speed. By comparison a 1967 UK study (Munden, 1967) predicts relative risk increases seven times if it is assumed that the standard deviation of rural free speeds is around 12 km/h. Although it must be stressed that such a comparison is between very different studies, the results would suggest that they are at least of the same order of magnitude.

As mentioned earlier, there is no suitable model that has been developed for 70 mph roads and motorways. As a result, the general model of Elvik et al. (2004) is considered most appropriate for these roads.

Once again, having identified candidate models, the next step is to review the predicted impact on crashes of applying those models to the speed data collected during the ISA trials, or in the case of the Advisory ISA, to the synthetic speed profile based on the impacts reported in LAVIA. The predicted impact of ISA on rural crashes using the various models is shown in Figure 14. The figure shows the predictions of the proportional impact on all injury crashes of each ISA variant by speed limit with 100% penetration of ISA. Again, not all models are used in every case. Thus Kloeden's rural model is specific to two-lane rural roads not motorways or dual carriageways. As for urban roads, it can be seen that the impact of Advisory ISA is relatively small with no model predicting a larger reduction than 8%.

It is important to note that, while the Kloeden model predicts the highest level of crash reduction, the results with this model are generally similar to, although always greater than, the crash reductions predicted using the EURO model for 60 mph roads. Overall the reduction factors tend to be smaller than those for urban roads. However, the greatest number of fatal crashes occur on 60 mph roads, and 60 mph roads have the second to highest number of serious injury and slight injury crashes, second to 30 mph roads (see Appendix C), so that the impact of ISA on rural roads will not be negligible.



	Advisory ISA			Voluntary ISA			Mandatory ISA		
	50	60	70	50	60	70	50	60	70
Elvik Power Model	0.989	0.994	0.965	0.982	0.985	0.911	0.930	0.976	0.824
EURO Taylor et al	0.982	0.952	0.959	0.980	0.918	0.932	0.945	0.892	0.847
Kloeden Deviation from Mean Speed of Scenario	0.959	0.919		0.836	0.881		0.717	0.861	

Figure 14: Proportional impact of ISA variants on rural crashes by road speed limit (mph)

Again a comparison has been made between the impacts of Advisory ISA predicted using the synthetic data from the UK ISA trials and those made with actual data from LAVIA and PROSPER. The results are shown in Figure 15. The LAVIA data, when used in the EURO model, predicts significantly higher injury crash reductions than either the PROSPER Mataro study data (using the Power Model) or the UK ISA trials, under any of the models applied. However, the crash reduction predictions for the LAVIA Advisory system are greater than those predicted for both the Voluntary and Mandatory ISA systems, which suggests that they are far too large. Otherwise there is general similarity among the predictions.

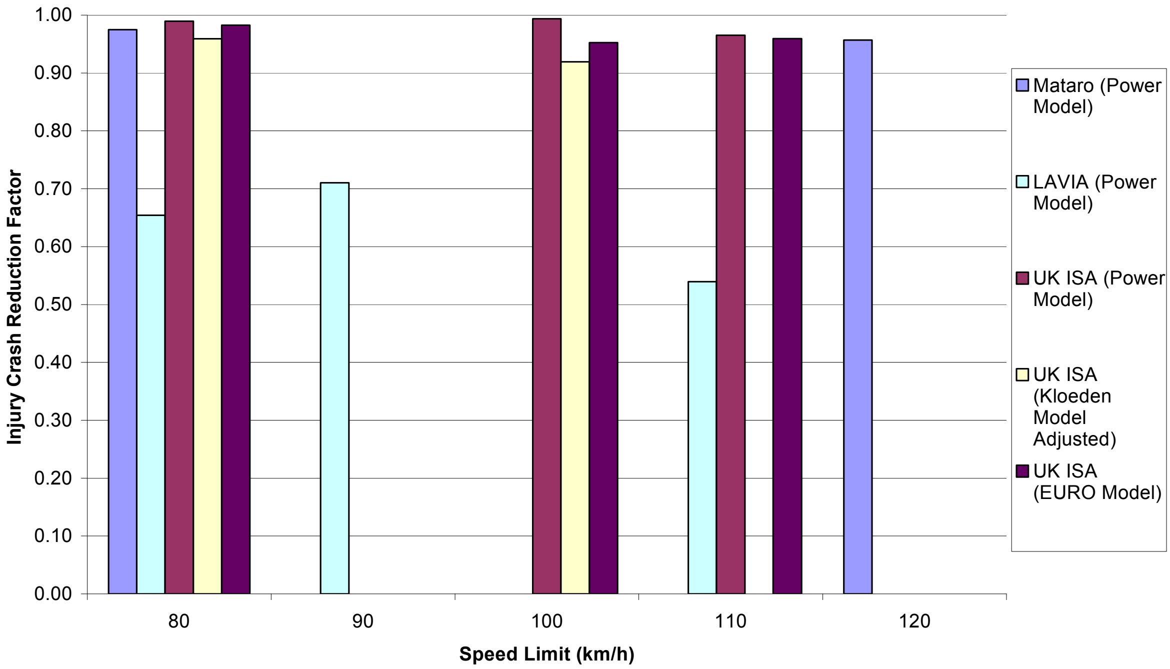


Figure 15: Injury crash reduction factors by speed limit for Advisory ISA in rural speed limits

2.1.4 Selection of models for translating speed changes into changes in crash risk

The impact of a range of ISA variants on the speed profiles of drivers has been assessed in section 2.1 and a range of speed-crash relationships have been applied to these speed profiles in section 2.1.3. This process has generated a number of crash reduction predictions. The predicted crash reductions span a wide range, depending primarily on the speed-crash model. Those models that take specific account of changes in the shape of the upper end of the speed distribution generally predict greater crash reductions for all forms of ISA. Crash reduction factors include the potential for a reduction in severity, so that injury crashes which are reportable to the police become damage-only and therefore not reportable. There are also models that consider the relationship between speed and crash severity and which can therefore be used to assess the potential of ISA to make crashes less severe and thus to affect the severity scale of injury crashes. However, the question is which of these models should be used in the subsequent analysis.

The models considered can be grouped according to their type and pedigree. In terms of type, the Power Model of Elvik et al., and the EURO model of Taylor et al. do not specifically take into account changes in the upper end of the speed distribution, and their implicit assumption that the shape of the speed distribution will remain constant will certainly be violated by some ISA variants. The U1 model takes some account of the shape of the distribution by including the coefficient of variation (std. deviation/mean). However, in the absence of an intervention such as ISA, speed distributions have some general symmetry and the dramatic changes to the speed distribution that occur under Mandatory and sometimes Voluntary ISA are expected to be outside the range observed in the data used to create these models. It is therefore likely that the standard deviation for ISA scenarios will be overly affected by speeds below the mean. Only the U2 and the Kloeden models take specific account of the impact of ISA in targeting those travelling at higher speeds, and these are therefore the models of first choice. The U2 model has the advantage that it has been developed in the UK using local data. However, the U2 model would predict zero crashes if a perfect Mandatory ISA system, one that allows no over-speeding, were implemented. On the other hand, the Kloeden models use data collected in South Australia and implicitly assume that an individual's relative crash risk is a function of that individual's speed choice alone.

The preferred analysis scenario involves using the U2 model for the analysis of an Advisory system where under ISA the shape of the speed distribution for those drivers exceeding the speed limit will be similar, although smaller in variance, to that observed in the absence of ISA. Under Voluntary ISA, the distribution of speeds, is similar to that resulting from Mandatory ISA. The resulting truncation of the speed distributions (see Appendix A) suggests that the Kloeden Model is most appropriate since it is best able to handle this change in the shape of the speed distribution. The Kloeden urban model is used in its raw form for the 30 and 40 mph roads. Thus, even for 30 mph roads, risk is computed as predicted by the curve which is shown in Appendix B. As a result the crash risk at say 35 mph will only be slightly higher than at 30 mph, with both speeds being below the speed limit of 37.3 mph (60 km/h) that was in force on the roads studied by Kloeden and colleagues. To take account of the large confidence intervals at the extremes of the Kloeden curve, the impact of changes speed was capped at 45 km/h at the lower end and 80 km/h at the top end.

The Kloeden model is not valid for 20 mph speed zones. Here the U2 model is applied, accepting that the ISA system used in the UK trials does allow some over-speeding. This assumption is considered acceptable as only a relatively small proportion of crashes occur in 20 mph zones (see Appendix D).

For rural speed limits, the Kloeden model is favoured, as this model takes greater account of the impact of ISA on the higher end of the speed distribution. The model is applied by using the new (with-ISA) mean speed as the basis for calculation. Risk is then calculated based on the deviation of speed from this new mean. However the Elvik power model is applied to 70 mph dual carriageway roads and motorways as both the Kloeden adjusted model and the Euro power model were constructed for single carriageways. This resulting combination of crash reduction models is termed *the Base Combination of crash reduction models*, and the resulting crash reduction factors for each speed limit are given in Table 4 for 100% ISA penetration.

It is recognised that using a combination of different models for different road types is likely to result in different errors applying to different situations. However, the alternative — applying the same model throughout — is considered less desirable, given the dramatic changes in speed distribution generated by Voluntary and Mandatory ISA, and the inability of some models to take adequate account of the impact of ISA on higher speed vehicles. This Base Combination uses models that are reasonably fit for purpose, without using too large a variety of models.

Table 4: Crash reduction factors by speed limit and crash severity for the Base Combination of crash reduction models

Speed Limit	Source Model for All Injury Crashes	Crash Reduction Factors (*x*)[1] for All Reported Injury Crashes		
		Advisory ISA	Voluntary ISA	Mandatory ISA
20 mph	U2	0.964	0.646	0.371
30 mph	U2 for Adv, Kloeden for Vol and Mandatory	0.997	0.850	0.604
40 mph	U2 for Adv, Kloeden for Vol and Mandatory	0.993	0.747	0.486
50 mph	Kloeden Adjusted	0.959	0.836	0.717
60 mph	Kloeden Adjusted	0.919	0.881	0.861
70 mph	Elvik Power	0.965	0.911	0.824

[1] *Note crashes with ISA =* x *crashes without ISA, assuming 100% ISA penetration in the fleet*

While the Base Combination of crash reduction models predicts that Mandatory ISA will deliver very large benefits on 20 mph roads, the impact of any over prediction is minimal as 20 mph roads account for a very small number of crashes and thus the impact of this large factor will be minimal.

It can be argued that, for urban roads, the U2 model should be used in preference to the Kloeden model, since it is derived from UK data. For Voluntary ISA, it also reflects drivers' choice to exceed the speed limit or not. Therefore an analysis applying the U2 model to these roads has been carried out. This is the Second Combination of models and the crash reduction factors for it are shown in Table 5. It can be seen that the application of the U2 model to Voluntary and Mandatory ISA on 30 and 40 mph roads gives substantially greater impacts than the application of the raw Kloeden model.

Table 5: Crash reduction factors by speed limit and crash severity for the Second Combination of crash reduction models

Speed Limit	Source Model for All Injury Crashes	Crash Reduction Factors (*x*) for All Reported Injury Crashes		
		Advisory ISA	Voluntary ISA	Mandatory ISA
20 mph	U2	0.964	0.646	0.371
30 mph	U2	0.997	0.571	0.362
40 mph	U2	0.993	0.599	0.314
50 mph	Kloeden Adjusted	0.959	0.836	0.717
60 mph	Kloeden Adjusted	0.919	0.881	0.861
70 mph	Elvik Power	0.965	0.911	0.824

The final combination sees the U1 model applied for all types of ISA on urban roads. Taylor's EURO model is applied for Advisory and Voluntary ISA on 50 mph and 60 mph roads. This Third Combination, shown in Table 6, tends to give somewhat smaller reductions on both urban and rural roads than combination 2.

Table 6: Crash reduction factors by speed limit and crash severity for the Third Combination of crash reduction models

Speed Limit	Source Model for All Injury Crashes	Crash Reduction Factors (*x*) for All Reported Injury Crashes		
		Advisory ISA	Voluntary ISA	Mandatory ISA
20 mph	U1	0.976	0.801	0.522
30 mph	U1	0.987	0.805	0.657
40 mph	U1	0.972	0.852	0.721
50 mph	EURO for Adv and Vol, Kloeden Adjusted for Mandatory	0.982	0.980	0.717
60 mph	EURO for Adv and Vol, Kloeden Adjusted for Mandatory	0.952	0.918	0.861
70 mph	Elvik Power	0.965	0.911	0.824

It can be argued that the information on contributory factors coded by police officers who attend the scene of an accident can serve as a validity check on the crash reduction factors suggested by Table 4, Table 5 and Table 6. The accident reduction factors for Mandatory ISA equate to a prediction of how many accidents would be eliminated if there were no driving in excess of the speed limit. Thus the Base Combination of crash reduction models predicts that, with the elimination of excess speed, there would be a saving of 40% of accidents on 30 mph roads, 51% of accidents on 40 mph roads and 18% of accidents on 70 mph roads.

These reduction factors can be compared with the 2006 data on contributory factors reported in Road Casualties Great Britain (Department for Transport, 2007a). Contributory factors information is provided for 92% of fatal accidents in 2006, 89% of serious accidents and 75% of slights. “Exceeding speed limit” was coded for 14% of the fatal accidents included in the coverage of the contributory factors data, 7% of the serious accidents and 4% of the slights, making 5% overall.

These numbers are clearly much smaller than the crash reduction factors identified in the tables above. It is interesting to note that for motorways, “exceeding speed limit” does not even appear in the top ten factors, indicating that it was coded for fewer than 8% of the accidents covered. One major explanation for the discrepancy between the contributory factors data and the model predictions is that the police officers coding contributory factors need evidence of the infraction or error. Where such evidence is missing, for example when a driver does not admit to speeding prior to an accident or where there are no skid marks allowing an assessment of pre-crash speed to be estimated, the factor may not be coded. The numbers in the contributory factors data can be compared with the data collected from the roadside on the free-flow speed of traffic (Department for Transport, 2007b). According to those data, 53% of cars were travelling at speeds in excess of 70 mph on motorways in 2006. The comparable number for dual carriageways with a 70 mph speed limit was 45%. The rate of speeding by drivers of light goods vehicles was similar. Thus the contributory factors numbers for excess speed look remarkably low, almost certainly lower than the rate of exposure as measured by the roadside data, even allowing for the fact that much motorway driving is in congested conditions. The contributory factors appear to significantly underestimate the occurrence of excess speed.

2.2 Future crashes

The benefits of ISA are the expected reduction in future injury crashes. These benefits depend not only on how effective the various forms of ISA are in reducing crashes, but also on the expected number of crashes in future years in the absence of ISA. This section looks at the crashes that have occurred over the five years 2000 to 2004 inclusive, to identify those that could be reduced by ISA and the roads on which they occurred. The method by which the baseline level of crashes in futures years is modelled is then described.

2.2.1 Involvement of ISA capable vehicles in crashes

It has been assumed here that, as a safety measure, ISA can only affect crash risk when a potential crash involves one or more vehicles that are capable of being fitted with ISA. This is a conservative assumption that does not take into account the potential of ISA-equipped vehicles to slow down those vehicles following them in the traffic stream. As regards vehicles capable of ISA fitment, it has been assumed that pedal cycles, motorcycles[1] and a few other minor vehicle types are not ISA capable. An analysis of the "vehicles" involved in reported crashes each year of the five-year period 2000 to 2004 inclusive is shown in Table 7 according to the STATS20 vehicle classifications and whether or not the vehicle is likely to be capable of having ISA fitted. Approximately 87% of vehicles involved in injury crashes would be capable of having ISA fitted.

Looking at the vehicle composition of injury crashes, three groups of vehicles can be considered: (1) non-ISA capable vehicles, (2) passenger cars and light vehicles, and (3) heavy goods vehicles and coaches. Although ISA may be fitted to the latter group (heavy goods vehicles and coaches), these are considered separately as they are currently fitted with fixed speed governors and their speeds on 70 mph roads are unlikely to be dramatically affected by ISA.

The type of vehicles involved in each reported injury crash, occurring over the five years 2000 to 2004 inclusive, have been investigated and the crashes allocated to one of three groups, those involving:

- Only non-ISA capable vehicles (HGVs and coaches are considered to be non-ISA capable on 70 mph roads)
- Some ISA capable vehicles and some non-ISA capable vehicles, and
- Only ISA capable vehicles.

[1] While an ISA-equipped motorcycle has been demonstrated in this project, it has not been trialled on public roads. Thus it is not possible to estimate the impact of ISA equipment on motorcycle speed profiles. Nor are there any empirically derived models available regarding the relationship between speed and crash risk for motorcycles. Of course where a motorcycle is in collision with an ISA capable vehicle such as a car and that other vehicle's speed affects the crash risk, then the modelling carried out here will consider the crash.

Table 7: "Vehicle" involvement in reported injury crashes (source STATS19 2000 to 2004 inclusive)

ISA	Vehicle	2000	2001	2002	2003	2004
	Pedal cycle	4.9%	4.6%	4.3%	4.5%	4.5%
	Moped	1.0%	1.2%	1.3%	1.3%	1.4%
	Motor cycle ≤125cc	1.8%	1.9%	1.9%	2.0%	2.0%
	Motor cycle >125 cc	4.0%	4.0%	4.0%	4.2%	3.7%
No	Agricultural vehicles (inc diggers etc)	0.2%	0.2%	0.2%	0.2%	0.2%
	Tram	0.0%	0.0%	0.0%	0.0%	0.0%
	Ridden horse	0.0%	0.0%	0.0%	0.0%	0.0%
	Other non-motor vehicle	0.1%	0.1%	0.1%	0.0%	0.1%
	Other motor vehicle	0.8%	0.6%	0.8%	0.6%	1.0%
	Taxi	1.1%	1.1%	1.0%	1.0%	1.0%
	Car	75.3%	75.3%	75.8%	75.2%	75.5%
	Goods vehicle 3.5 t or less	4.1%	4.4%	4.3%	4.5%	4.1%
Yes	Minibus (8-16 passenger seats)	0.3%	0.3%	0.3%	0.3%	0.3%
	Goods vehicle >3.5 but <7.5t	0.8%	0.7%	0.6%	0.6%	0.6%
	Good vehicle 7.5t and over	2.8%	2.8%	2.7%	2.8%	2.7%
	Bus or coach 17 or more seats	2.7%	2.7%	2.6%	2.8%	2.8%

Table 8: Structure of injury crashes by ISA vehicle capability, severity and speed limit based on STATS19 data 2000 to 2004 inclusive

Type	Involvement of ISA Capable Vehicles	Speed Limit of Roads on which Crashes Occurred						
		20	30	40	50	60	70	All
Fatal	No ISA capable vehicles	2	471	121	29	503	211	1337
	Some ISA capable vehicles	3	926	278	126	1377	170	2880
	All ISA capable vehicles	14	3756	984	411	4617	1630	11412
	Total crashes	19	5153	1383	566	6497	2011	15629
	All ISA capable	74%	73%	71%	73%	71%	81%	73%
	At least some ISA capable	89%	91%	91%	95%	92%	90%	91%
Serious	No ISA capable vehicles	46	6146	889	253	4231	994	12559
	Some ISA capable vehicles	92	23003	3315	749	7750	1169	36078
	All ISA capable vehicles	278	56485	8140	2332	26103	8267	101605
	Total crashes	416	85634	12344	3334	38084	10430	150242
	All ISA capable	67%	66%	66%	70%	69%	79%	68%
	At least some ISA capable	89%	93%	93%	92%	89%	90%	92%
Slight	No ISA capable vehicles	136	20287	2036	528	5550	1619	30156
	Some ISA capable vehicles	527	131366	12684	2386	16364	3562	166889
	All ISA capable vehicles	2132	465445	64207	17039	129045	64955	742823
	Total crashes	2795	617098	78927	19953	150959	70136	939868
	All ISA capable	76%	75%	81%	85%	85%	93%	79%
	At least some ISA capable	95%	97%	97%	97%	96%	98%	97%
All	No ISA capable vehicles	184	26904	3046	810	10284	2824	44052
	Some ISA capable vehicles	622	155295	16277	3261	25491	4901	205847
	All ISA capable vehicles	2424	525686	73331	19782	159765	74852	855840
	Total crashes	3230	707885	92654	23853	195540	82577	1105739
	All ISA capable	75%	74%	79%	83%	82%	91%	77%
	At least some ISA capable	94%	96%	97%	97%	95%	97%	96%

2.2.2 Future crashes involving ISA capable Vehicles

The number of reported injury crashes from 2004, in which at least one ISA capable was involved, form the basis of the future crash predictions. These predictions aim to identify the set of crashes that could be eliminated or reduced in severity by ISA. The predictions are based on the premise that crashes are rare multi-factor events and that a reduction in the risk of one or more links in the chain of events will reduce the risk of a crash occurring. This assumption may be a little conservative when applied to multi-vehicle crashes when all vehicles are operating with ISA.

The crashes have been categorised on the basis of the speed limit of the road which the crash occurred, the type of road, and severity. The total number of crashes that involve ISA capable vehicles, has then been determined for each future year, taking into account:

- the expected growth in the volume of travel from the National Road Traffic Forecasts Table 3 (DETR, 1997)[2], as shown in Figure 16; and
- the expected reductions in injury crash rates for different road types provided in Table 4/1 of the COBA Manual (DfT, 2004b) which apply through to 2030 (see Figure 17).

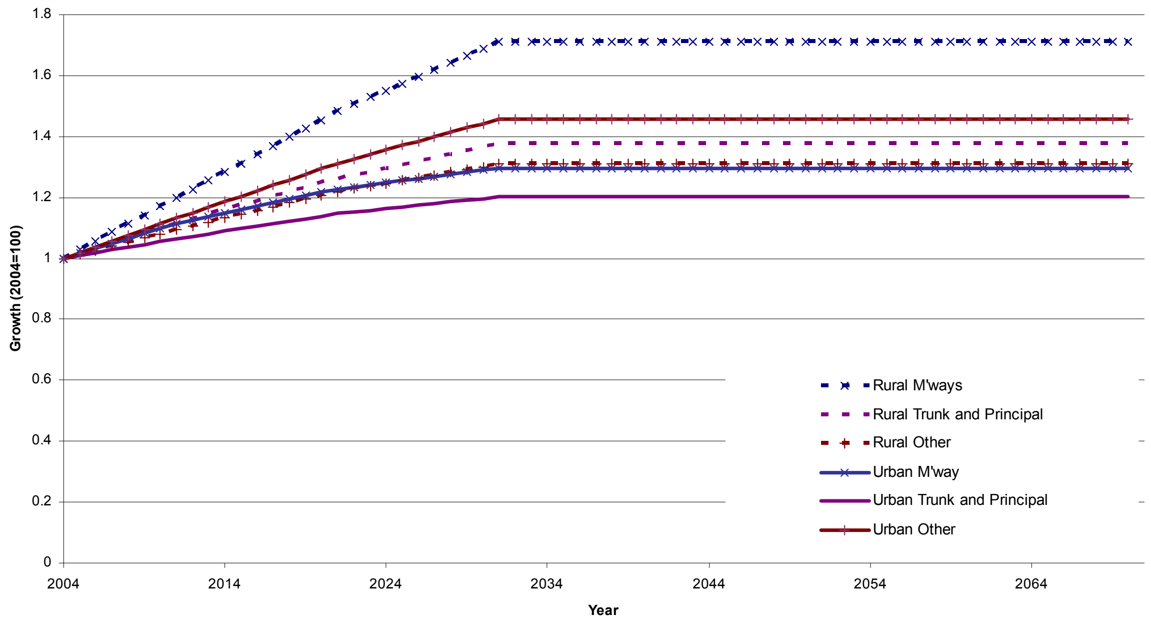


Figure 16: Expected proportionate increase in travel on various road types (adapted from National Road Traffic Forecasts, DETR, 1997, Table 3)

[2] Arguably, the National Road Traffic Forecasts have been superseded by the National Transport Mode (NTM). However, aggregated data from NTM was not available when this work was carried out. A check carried out subsequently shows that the maximum difference of NTM estimates from those of NRTF is less than 5%.

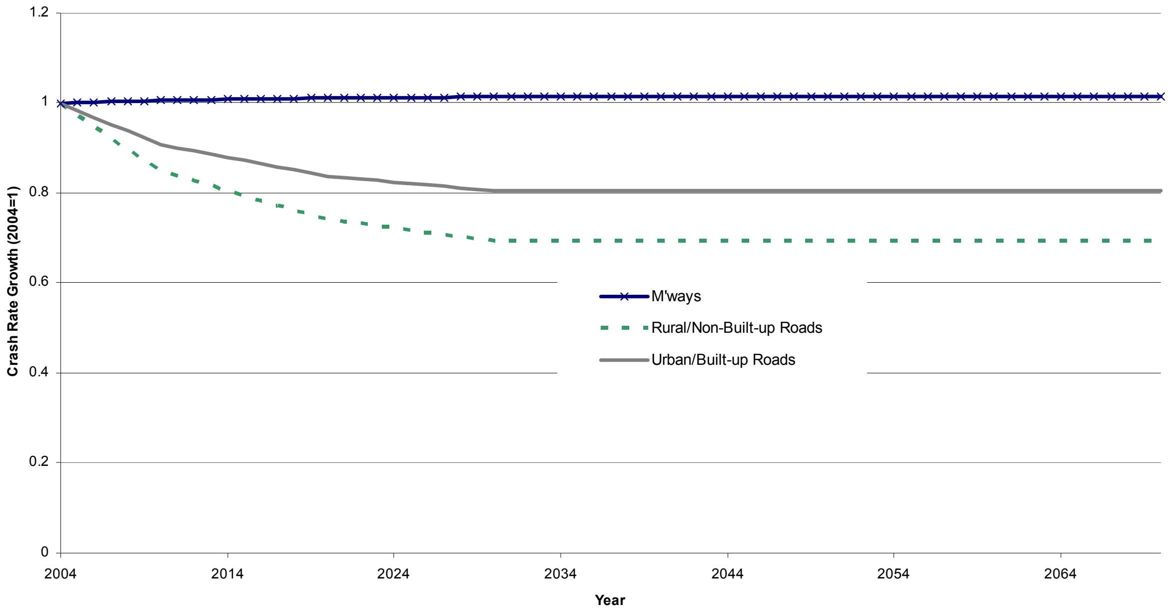


Figure 17: Crash rate change adapted from COBA Table 4/1 (DfT, 2004b)

The COBA projections, for traffic growth stop at 2031, and assume zero growth beyond that date, and are consistent with the National Road Traffic Forecasts (see Design Manual for Roads and Bridges volume 13 section 1 part 4) . That assumption has been maintained here. However, the COBA projections for traffic and crash rates have been adapted to a 2004 base. It should be noted that the flatlining of the projection after 2031 does not work in favour of ISA.

It is important to note that the National Road Traffic Forecasts define urban roads as those passing through continuous built development, irrespective of speed limit. However, a similar classification is not available for all the crash data in the years used for this analysis, nor is it available for the differential impacts of ISA. It has therefore been necessary to assume that the terms urban and built-up are interchangeable and apply to roads with speed limits of less than or equal to 40 mph. Similarly the terms rural and non-built-up are interchangeable and apply to roads with speed limits of greater than 40 mph as opposed to those where the speed limit is less than or equal to 40 mph.

3. COSTS

The costs associated with nationwide implementation of ISA can be divided into two main groups. First are the infrastructure costs, those public costs that might be expected to be borne by central or regional government, and which are associated with:

- creating the digital map databases, that form the basis of ISA,
- keeping these maps current, and
- dissemination of the base maps and subsequent updates.

The second set of costs are those associated with the in-vehicle functionality of ISA and which represent an additional feature of the vehicle that would be included in the vehicle purchase price. Unlike the database costs, which are to all intents and purposes fixed, the in-vehicle costs will vary depending on the degree of functionality and the ISA scenario.

3.1 Infrastructure costs

3.1.1 Creation of database

The last decade has seen significant advancements in digital mapping and the advent of detailed and readily available navigation systems. However, the base digital maps are proprietary products of the various developers, be they private companies such as Navteq or government agencies such as the Ordnance Survey in the UK.

There are a number of mapping and map standardisation initiatives currently being progressed. The EuroRoadS project is intended to provide a pan-European specification for digital road maps which includes speed limits (Svard, 2005), while within the PReVENT Integrated Project the three-year MAPS&ADAS subproject is developing, testing and validating appropriate methods in gathering, certifying and maintaining ADAS attributes to enable the provision of maps to support ADAS systems.

Given the range of transport-related and in particular safety-related digital mapping initiatives currently underway in the UK and Europe, it is considered unlikely that ISA alone would bear the cost of such developments. Outside of national or pan-European ownership, the most plausible scenario for the purposes of this study is one in which map developers cover their costs through charges for dissemination and updating. Such a scenario underpins the SpeedAlert initiative and is assumed to apply under the Market Driven implementation scenario for Advisory ISA, and to a lesser extent for Voluntary ISA.

It is therefore likely that the cost associated with accessing the base maps will be covered by a range of other initiatives. We have however sought to estimate the cost of adding speed limit data to an already available map.

Our experience in this project and recent experience in Greater London suggests that in dense urban networks speed limit data can be added to digital maps at a rate of 20 km per person hour and that the rate is far higher for trunk roads and motorways. Given that there are 387,647 km of road in Great Britain, a third of which could be considered dense urban, we estimate that around 13,000 person hours (10 person-years) would be required to construct a speed limit map database from scratch.

3.1.2 Updating the speed limit database

In order to ensure that the speed limit information provided to the vehicles is current, there need to be in place processes for logging, and updating speed limit changes. While such procedures are essential to ISA, they are considered a normal requirement of day-to-day highway management. Admittedly, the current manual procedures would have to be replaced with new electronic procedures (so that, for example, a Speed Limit Order would become an electronic instrument). However, there is no reason to suppose that this new set of procedures would be any more costly to operate than the current manual procedures. Indeed they would probably result in efficiency gains. Therefore the costs associated with creating a streamlined electronically based speed limit management system should not be assigned to ISA as they represent improved efficiencies within government. Equally there would very likely be savings in speed enforcement and subsequent prosecution as a result of ISA deployment.

However, the additional costs associated with disseminating the speed limit changes to the vehicles equipped with ISA would be a direct cost. Earlier studies generally envisaged that such distribution would be by CD-ROM. But more recently, attention has focussed on the use of the internet combined with high-speed data broadcasting systems. Recent Danish ISA trials have used GPRS (2.5G mobile phone technology) as a means of supplying the speed limit data to the ISA vehicle (Jamson et al., 2005), while the Transport Protocol Experts Group (TPEG) formed by the European Broadcasting Union (EBU), has been developing digital audio broadcasting (DAB) as a means of transmitting traffic information. The DAB-TPEG initiatives are expected to provide the high quality, high reliability data to support a wide range of intelligent transportation systems (Livock and Gardiner, 2005).

Given the potential to share digital map construction and dissemination costs across a number of future applications and the expectation that the cost savings associated with current speed limit enforcement (including legal system costs) will greatly outweigh the digital map costs, these elements are considered cost-neutral for the purposes of this study.

3.2 In-vehicle costs

The costs associated with the in-vehicle equipment required to provide the ISA functionality are relatively modest on a per unit basis. However, when these costs are applied to an average of 3.2 million vehicles that will require fitment each year[3], this equipment becomes the major cost component in the economic evaluation. The cost of in-vehicle equipment depends on the ISA functionality; whether the equipment is fitted as new or retro fitted; the current level of vehicle technology and the potential for sharing equipment installed in vehicles for other purposes; and the economies of scale that result from mass production.

3.2.1 Speed limit knowledge

Irrespective of the ISA functionality, each vehicle must have the ability to "position" itself on a digital speed limit database or map. In order to do so the vehicle must be fitted with a means of receiving and holding the database map and the means of identifying where it, the vehicle, is on that map. At the crudest level this functionality may be provided through a PDA with an integrated GPS. Low-end navigations systems are currently available for as little as £100, but given the extra memory and functionality required for ISA a base (2010) cost of £150 is thought

[3] It should be noted that, for intervening forms of ISA, such fitment will mainly be as original equipment.

reasonable. As demand for these increases and the cost of production reduces, the costs of these units is expected to reduce to £100 by 2020.

While such units would be most suitable for Advisory ISA, the greater positional accuracy required for Voluntary or Mandatory ISA probably requires a combination of GPS and dead-reckoning. This is expected to increase the costs of this component of ISA to £200 in 2010 dropping to £150 by 2020 and £100 by 2030.

However, such functionality is included in the majority of navigation systems fitted as original equipment to current vehicles, and is expected to be fully extended through the vehicle market. Intervening (Voluntary) ISA systems may be linked to such systems for a relatively small marginal cost, around £100. By 2010 the stocks of new vehicles fitted with such systems, should be sufficient to allow Voluntary ISA to be deployed under the Market Driven Scenario. Table 9 gives a set of component costs for in-vehicle ISA equipment, based on the current cost of Personal Navigation Devices (PNDs) and on discussion with automotive experts. Only minimal cost reduction over time is assumed, so that these cost estimates are likely to be conservative.

Table 9: Costs of In-vehicle Speed Limit Equipment 2006£s

Fitment	ISA Category	2010	2020	2030 onwards
New	Advisory	150	100	100
	Voluntary/Mandatory	200	150	100
Retrofit	Advisory	200	150	150
	Voluntary/Mandatory	250	200	150

3.2.2 Vehicle speed management

The second component of in-vehicle cost relates to what the various ISA systems do with the speed limit information provided. These costs depend on the ISA functionality, and the type and specification of the vehicle to which ISA is being fitted.

If the ISA system is Advisory a simple HMI interface that displays the speed limit of the road on which the vehicle is travelling is all that is required. The cost of this unit is expected to be £20 if fitted from new and £50 if the unit is to be retro-fitted. However, Voluntary or Mandatory ISA requires an active speed management component. This includes speed detection, and two phases of active speed control; the first phase being throttle control, the second being low-level vehicle braking to prevent inadvertent vehicle acceleration on downhill gradients. Such braking is already provided in Adaptive Cruise Control.

The current speed of the vehicle is determined by interrogating the ABS and or traction control sensors. It is assumed that these features will be fitted as standard to the majority of the fleet by 2010, and this functionality is assumed to be provided “free of charge” to all vehicles. This leaves only the costs associated with the two levels of active speed control

With increasing proportions of the new vehicle fleet having electronic throttle control and electronic engine management, the costs of throttle control will decrease markedly. However, we do not expect the costs associated with braking to reduce so markedly. When considering the braking requirements for heavy vehicles it must be recognised that there is a very wide range of requirements, and the expected costs in Table 10 are only an average; some installations will be considerably more while others will be similar to the light vehicle fleet. These heavy vehicles make up only a small proportion of the fleet and subsequent experimentation found that doubling the cost estimates for braking technology reduced the final benefit cost ratio for the Market Driven Scenario by less than 0.2.

Our assumptions regarding the costs of the various components are outlined in Table 10.

Table 10: Expected costs of speed control equipment 2006£s

Vehicles	Fitment	ISA Category		2010	2020	2030 onwards
Light	New	Advisory	HMI	20	10	10
		Voluntary/Mandatory	Throttle	100	50	50
			Braking	400	300	300
	Retrofit	Advisory	HMI	50	40	40
		Voluntary/Mandatory	Throttle	200	150	150
			Braking	500	400	400
Heavy	New	Advisory	HMI	20	10	10
		Voluntary/Mandatory	Throttle	200	150	150
			Braking	700	500	500
	Retrofit	Advisory	HMI	50	40	40
		Voluntary/Mandatory	Throttle	300	250	250
			Braking	1500	1000	1000

Combining the two cost components (Table 9 and Table 10), the expected costs of in-vehicle equipment for each ISA variant is shown in Table 11.

Table 11: Total expected cost of in-vehicle equipment (2006£)

Vehicles	Fitment	ISA Category	2010	2020	2030 onwards
Light Vehicles	New	Advisory	220	110	110
		Voluntary/Mandatory	820	560	560
	Retrofit	Advisory	350	240	240
		Voluntary/Mandatory	1150	890	790
Heavy Vehicles	New	Advisory	220	110	110
		Voluntary/Mandatory	1220	860	860
	Retrofit	Advisory	350	240	240
		Voluntary/Mandatory	2250	1590	1490

4. ISA PENETRATION

4.1 Fleet prediction

The implementation costs and crash reduction benefits of ISA are related to the number of vehicles fitted with ISA each year and the proportion of ISA capable vehicles within the fleet, respectively. The number of new vehicles joining the fleet each year is the difference between the predicted fleet size and the current fleet minus scrappage that occurs.

Two vehicle fleets are considered in the analysis, reflecting the differences in fleet age profiles and the differences in implementation scenarios:

- The light vehicle fleet which includes passenger cars, taxis and light goods vehicles, and
- The heavy vehicle fleet which includes heavy goods vehicles, buses and coaches.

The expected size of the light vehicle fleet in any year up to 2031 is based on applying the fleet growth factors from the National Road Traffic Forecasts (DETR, 1996), to the 2005 fleet of cars[4], taxis and light goods vehicles, of which cars have comprised 90% over the last 10 years (DfT, 2006b; Tables 1 and 3).

Although there has been a relatively steady increase in the volume of travel undertaken by buses, coaches and heavy goods vehicles, the size of the fleet undertaking this travel has fluctuated dramatically over time, as a result of changes in economic climate and various alterations in the licensing categories. To overcome these issues, the future size of the heavy vehicle fleet is based on the fleet model developed by Dutton and Page (in press). However, this model has been adjusted, i.e. increased by approximately 10%, to better fit the historic data. This is a conservative assumption as it will increase the expected implementation cost of ISA, but not the expected benefits. The final model is shown in Figure 18, together with the historic data.

The scrappage rates for vehicles, have been derived from the vehicle licensing data for 2005 (DfT, 2006b; Table 7) and are based on the proportion of first-licensed vehicles remaining in the fleet by age, as shown in Figure 19.

[4] The National Road Traffic Forecasts of "car" ownership, are based on the Census definition of a "car" which includes all cars and vans available to the household for private use (DETR,1998).

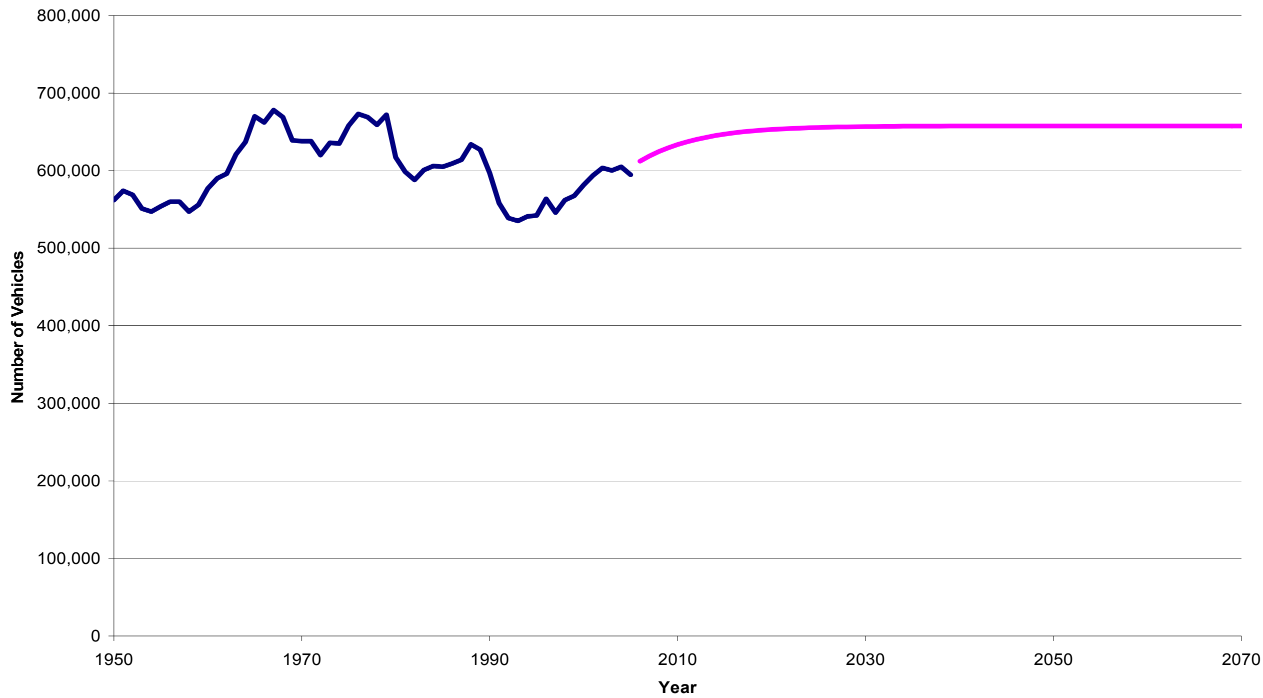


Figure 18: Numbers of heavy goods vehicles, buses and coaches (adapted from DfT, 2006b)

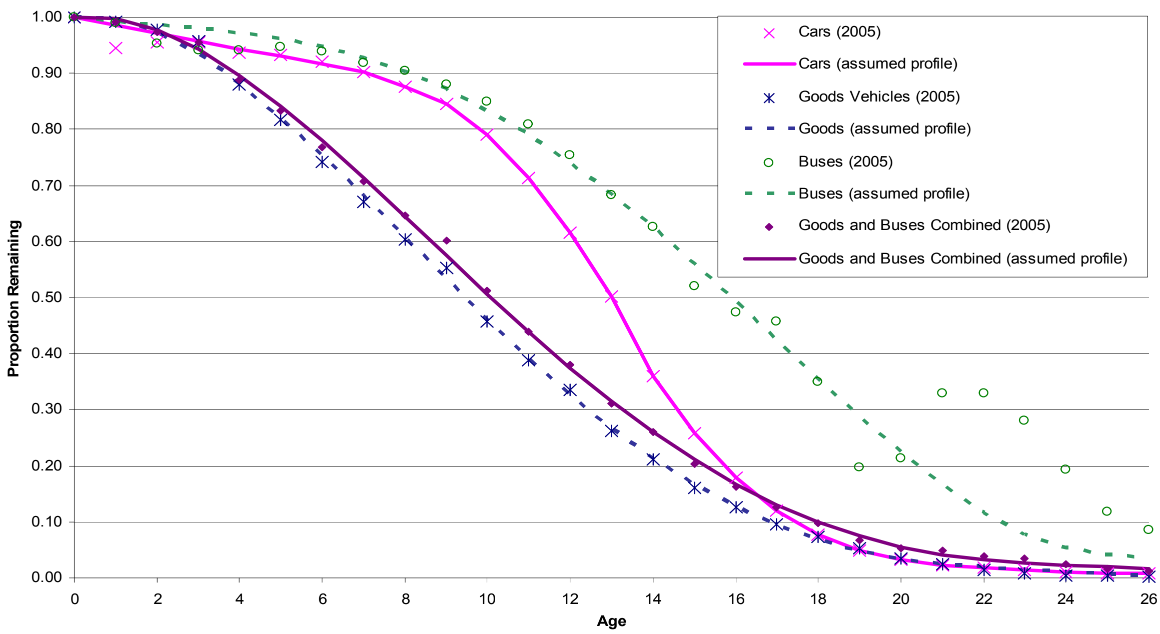


Figure 19: Proportion of vehicles remaining in fleet by age (adapted from DfT, 2006b)

4.2 ISA implementation

The major influences on the impact of ISA are the type of ISA that is fitted and the rate of fitment. In the EVSC project (Carsten and Tate, 1997 and 2000), various futures were envisaged in which only one form of ISA was adopted. It was also envisaged that take-up would be as rapid as physically possible. Neither of these assumptions is realistic: it is almost certain that a variety of ISA systems will appear on the market, and the rate of adoption will depend on such matters as incentives and legal requirements. Therefore, the work here examines two alternative scenarios of the future for ISA. It should be stressed that these scenarios are exemplars — they are possible futures, but there are many other possible futures. The scenario-based approach is now commonly used in predicting the impacts of Advanced Driver Assistance Systems such as ISA (Mehta et al., 2006).

Previous research (Carsten et al., 2006) investigated the timelines for the future technologies necessary to enact ISA, and identified two implementation scenarios, that are considered most viable. The scenarios cover the rate of ISA roll-out and the mix of ISA systems that are fitted. They are termed:

- *The Market Driven Scenario*
- *The Authority Driven Scenario*

The first assumes slower adoption and early take-up dominated by advisory forms of ISA in response to market demand. The second assumes faster adoption and earlier take-up of voluntary (intervening) forms of ISA. Details of the implementation scenarios are outlined below, along with two variations to the Authority Driven Scenario, which would see the use of Mandatory ISA enacted earlier.

4.2.1 Market driven scenario

It is assumed that the Market Driven Scenario is driven by voluntary take-up of ISA, as demand for intelligent transport systems (ITS) increases. This will include demand for satellite navigation systems which in the near future will also provide on-board speed limit information as a standard feature. The digital map database with accurate speed limit information required to implement ISA variants based on fixed speed limits is predicted to be available in 2010.

The Market Driven scenario is assumed to start in 2010, when it is expected that 50% of new passenger cars and 100% of heavy vehicles would be fitted with Advisory ISA. It is worth noting that under the Market Driven Scenario, ISA fitment to newly registered vehicles only would see ISA in some form (advisory or voluntary) saturate the heavy vehicle and light vehicle fleets, in approximately 25 years and 35 years, respectively. While there may be some initial resistance to ISA from some quarters, research indicates that those who have actually used ISA, view the system positively. It is therefore realistic to expect that some retrospective fitment of ISA to older vehicles would be undertaken, particularly for the fleet vehicles that make up a significant proportion of the car taxi and light vehicle fleet, and such retrofitting has been assumed here.

The scenario also assumes that, in 2010, five percent of the existing passenger cars will also be retrofitted with Advisory ISA as a result of the system being available through standard navigation systems. It is further assumed that this figure will rise to 100% by 2020. For the heavy vehicle fleet, it is assumed that retro fitting of both Advisory and Voluntary ISA will increase in similar proportions so that by 2020 half of the existing heavy vehicle fleet will have been retrofitted with Advisory ISA and the other half will have been retrofitted with Voluntary ISA. This assumption is based on discussion with fleet owners and operators which indicate a substantial appetite for ISA support.

Given the predicted safety benefits of ISA, it is less likely that ISA vehicles will be involved in crashes and therefore less likely to be written off and removed from the fleet. It may therefore be possible to assume lower scrappage rates for ISA capable vehicles. This would result in more rapid ISA penetration. However, owners who do not favour ISA may be inclined to delay replacing non-ISA vehicles when the only alternative is an ISA fitted vehicle, suggesting a lower scrappage for non-ISA vehicles. Balancing these conflicting views, the above profiles assume scrappage rates are similar for both ISA and non-ISA vehicles, and that retro-fitment of ISA is equally likely over the entire fleet age profile. The projection for the fitment of ISA to the light vehicle fleet (cars, taxis and light goods vehicles) under the Market Driven scenario is shown in Figure 20. Under this projection, retro-fitting of ISA will see the entire fleet fitted with some ISA capability by 2020.

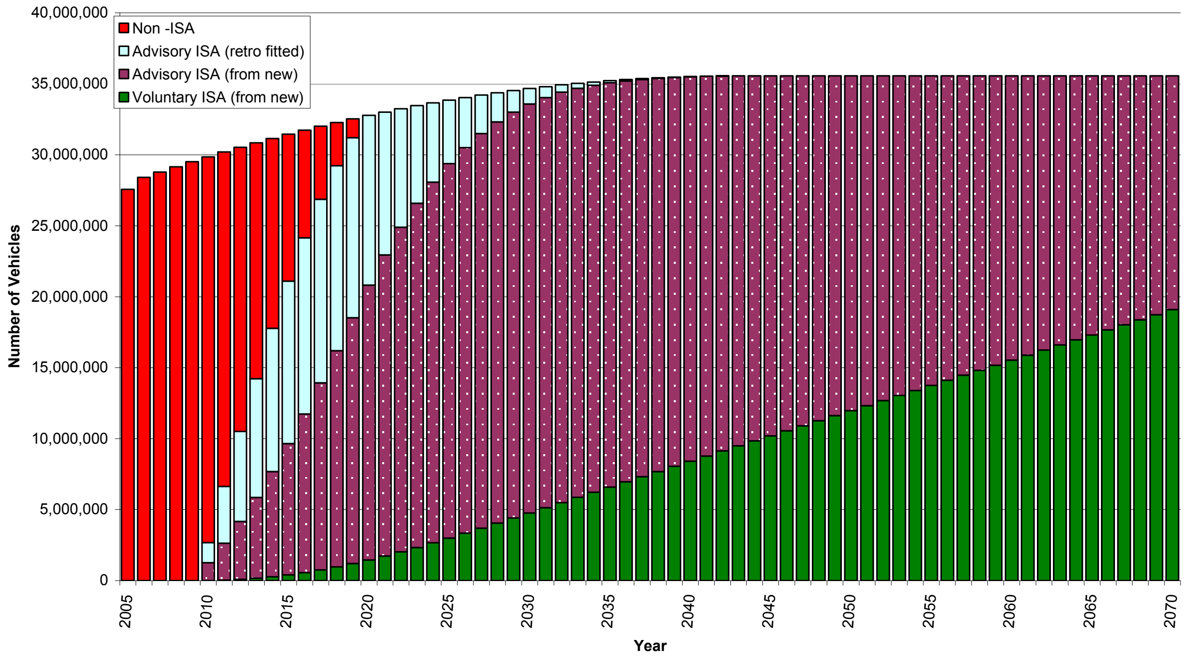


Figure 20: Implementation of ISA in passenger cars and light goods vehicles under the market driven scenario

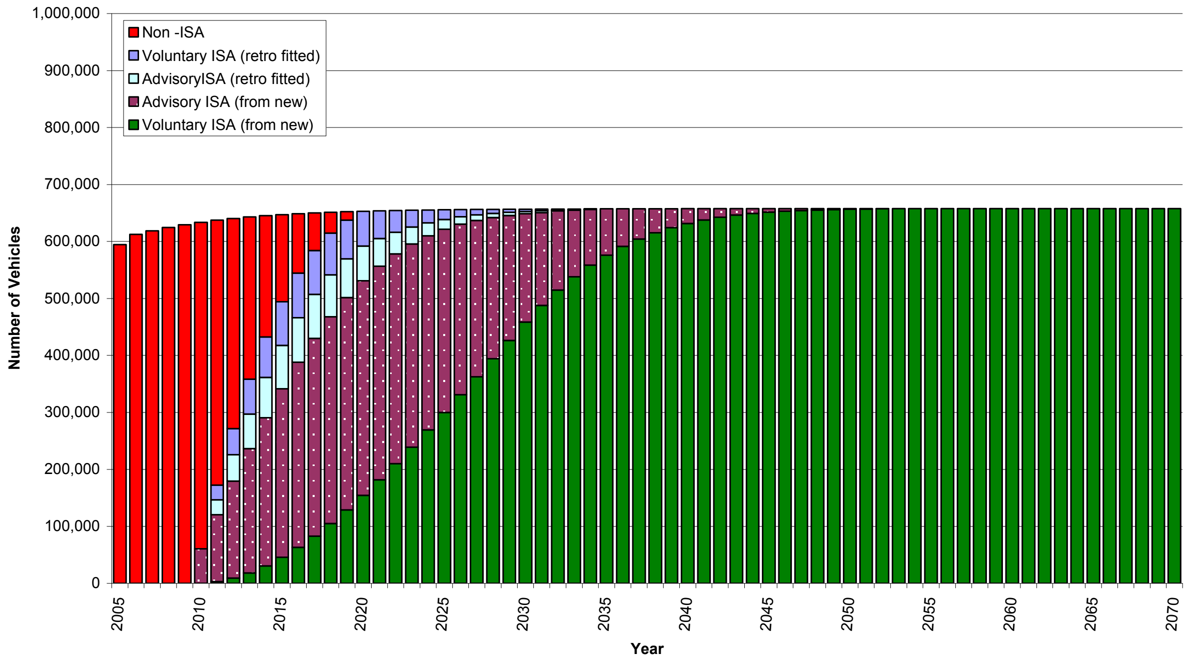


Figure 21: Implementation of ISA in buses, coaches and heavy goods vehicles under the market driven scenario

4.2.2 Authority driven scenario

It is assumed that the Authority Driven Scenario is centred round the use of legislation to drive the obligatory fitment of ISA to new vehicles. It is recognised that regulation of vehicle construction standards is governed by the EC Whole Vehicle Type Approval process. Unless manufacturers begin to fit equipment voluntarily, a widespread rollout of an authority-led approach would require European decision-making or regulation rather than just a UK government decision.

The Authority Driven Scenario is assumed to commence in 2017, which gives sufficient lead-in time for decision-making and implementation. Before 2017, the situation under this scenario is the same as under the Market Driven Scenario. The Authority Driven Scenario emphasises deployment of Voluntary ISA over Advisory ISA so that by 2025 at least 70% of all new light vehicles entering the fleet would be fitted with Voluntary ISA and the remaining 30% would be fitted with Advisory ISA. For the heavy vehicle fleet, the proportions would be 75% and 25% respectively.

While the Authority Driven Scenario sees an increased rate of Voluntary ISA for new light vehicles, the proportion of older vehicles retro-fitted with Advisory ISA simply follows the trend of the Market Driven Scenario which would see all older vehicles retro-fitted with Advisory ISA by 2020 (see Figure 22). No retro-fitment of Voluntary ISA is assumed to occur.

For the heavy vehicle fleet, following the Market Driven Scenario until 2017 results in approximately 35% of the existing fleet being retrofitted with Advisory ISA and 35% of the existing fleet being retro-fitted with Voluntary ISA in 2017. While the retro-fitment of Voluntary would continue, increasing by 5% per year, retro-fitting of Advisory ISA would cease, and those that remain would form a decreasing proportion reaching 25% by 2025.

However, it is not until 2045 that 99% of the total fleet is Voluntary ISA capable. At this time all remaining vehicles are retro-fitted with Voluntary ISA, and a Mandatory System could be "switched" on. This is approximately 10 years later than previously predicted by Carsten et al. (2006) when studying pan-European implementation of ISA. In the absence of a complete set of vehicle fleet age profiles, Carsten et al. (2006) assumed that vehicle scrappage was based on a first on first off basis. That is, each year's new registrations would increase the fleet size in accordance with the fleet size prediction model and would replace the oldest vehicles in the fleet. As a consequence, no vehicles that were fitted from new with ISA would be scrapped, until the older non-ISA vehicles had been scrapped from the fleet.

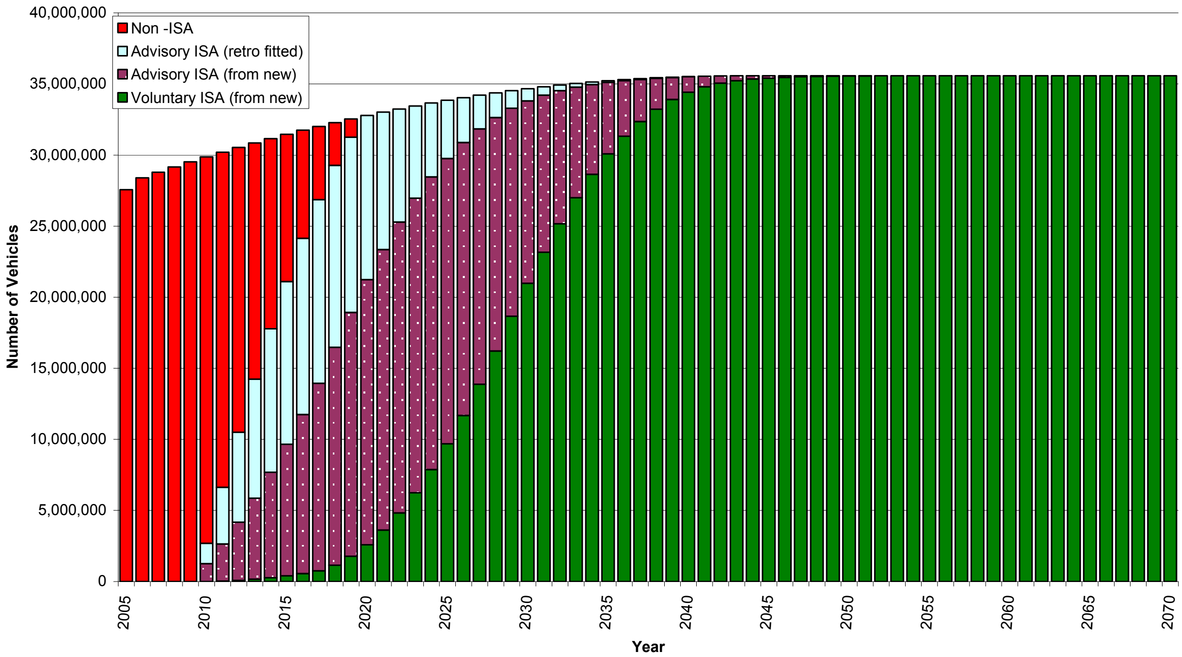


Figure 22: Implementation of ISA in the light vehicle fleet under the authority driven scenario

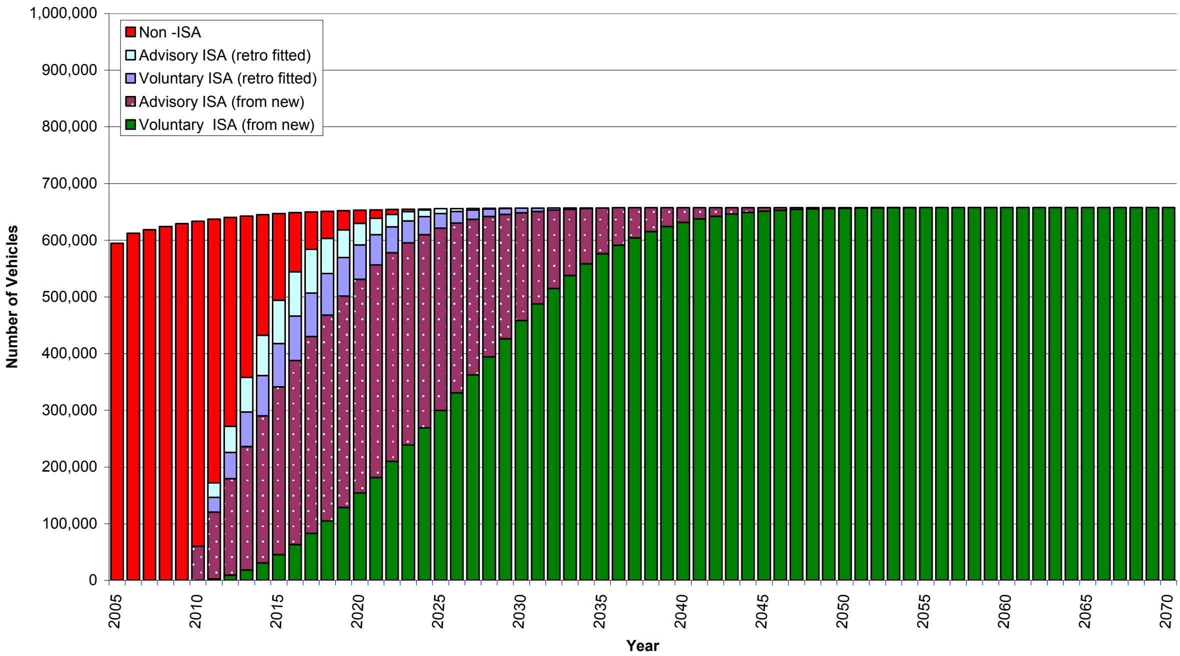


Figure 23: Implementation of ISA in the heavy vehicle fleet under the authority driven scenario

4.2.3 Early Implementation of Mandatory ISA

As discussed above, under the Authority Driven implementation scenario, it has been assumed that in 2045, when 99% of the vehicle fleet has been fitted with a Voluntary ISA capability, Mandatory ISA will be implemented. At this time the remaining non-ISA vehicles would be retrofitted with ISA and the Mandatory system would be "switched on".

Given that Mandatory ISA would provide significantly greater road safety benefits, compared to Voluntary ISA, it could be expected that earlier implementation of Mandatory ISA may be worthwhile. To test this proposition the impact of setting an earlier date for the enactment of Mandatory ISA has been investigated, considering the adoption of Mandatory ISA in 2040 and 2035, five and ten years earlier than in the basic Authority Driven implementation scenario.

Under the Authority Driven Scenario, all ISA-capable vehicles would be fitted with some form of ISA by the year 2022. However, it is not until 2028 that there will be more Voluntary ISA vehicles than Advisory. By 2035 approximately 85% of the vehicle fleet would have Voluntary ISA and slightly more than 5 million (5.233 million) Advisory ISA vehicles (about 15% of the fleet) would require upgrading to Voluntary ISA in order to implement Mandatory ISA ten years early.

In 2040, 3.2% of the vehicle fleet (1.1 million vehicles) would require an upgrade from Advisory ISA to Voluntary ISA, in order to "switch on" mandatory ISA five years earlier.

While moving to Mandatory ISA within the year 2035 would require more than 20,000 vehicles to be converted each working day, a more practicable implementation strategy could in the event be developed. The principal aim of carrying out the economic analysis for the early implementation of Mandatory ISA is to gain a better understanding of the possible merits of such a proposal and whether further investigation is warranted.

5. ECONOMIC ANALYSIS

5.1 Scenarios considered

This section provides details of the economic analysis of ISA based on the four implementation scenarios outlined in section 4.2 and the three combinations of crash prediction models outlined in section 2.1.4. and Appendix D.

Although numerous other scenarios can be contrived and combined to generate an almost limitless number of other possible combinations, the 12 combinations of implementation and crash prediction scenarios presented here are considered sufficient to indicate the implications of applying alternative models and scenarios for the purposes of economic analysis.

Initial investigations revealed that the order in which the crash reduction factors are applied impacts on the outcome. Initially separate crash reduction factors were derived, for each severity class and road speed limit. To do this, the all injury crash reduction predictions from the various crash reduction models were adjusted using the Elvik power models to generate separate factors for fatal serious and slight for each speed limit. This approach generated results that appear somewhat counter-intuitive: nationwide, the reductions in serious crashes were very close to, and in some cases exceeded, the percentage reduction in fatal crashes.

This issue arises because the number and proportion of fatal, serious and slight crashes varies by speed limit, as does the effectiveness of ISA. For example Mandatory ISA has a dramatic impact on the speed distribution for 30 mph roads, where there are over 16 times more serious crashes than fatal crashes, but only a moderate impact on the speed distribution for 60 mph roads on which the number of serious crashes is only 5 times more than the number of fatal crashes. For this and similar reasons, when the individual crash reduction factors were applied to the fatal, serious and slight crashes that occurred on the individual speed limits, the total crash reduction did not equal the number of crashes predicted when the all injury crash reduction factors were applied to the total number of injury crashes.

The alternative approach is to assess the impacts of ISA in terms of all injury crashes nationwide, and produce estimates of the differential impacts the system will have on the crash severity levels (fatal, serious and slight), by applying the Elvik Power model coefficients (Table 3) to the all injury crash reductions nationwide, to generate nationwide reductions for fatal, serious and slight crashes. Once again, the sum of the resulting estimates of the nationwide fatal, serious and slight crash reductions was less than the resulting estimate of the nationwide reduction in all injury crashes. Rather than attempting to factor up the various components to equal the expected reduction in injury crashes, we have continued the analysis based on the component totals which are less than the overall expected reductions.

Thus for each of the twelve scenario combinations, there are two alternative methods for calculating the expected reductions in crashes at the various levels of severity:

Method A: Separate reduction factors are calculated for the fatal, serious and slight crashes that occur in each speed limit (note the components are not scaled up to make the sum equal to the estimated all injury crash reduction).

Method B: All injury crash reductions factors are developed for each speed limit, the all injury crash reduction is calculated nationwide and the nationwide estimates for the reduction in fatal, serious, and slight crashes are obtained and used in the economic analysis (again the components are not scaled up to equal the all injury crash reduction).

5.2 Costs and benefits

In total some 24 separate analyses have been undertaken. A summary of the costs, benefits and overall economic performance is presented here, followed by a detailed discussion of the crash reduction performance of the key scenarios.

The cost and benefit streams of the analysis have been projected through until 2070, which is 60 years after the suggested first implementation of ISA in the year 2010. The net present value of both costs and benefit has been discounted back to a base year of 2006, using an annual discounting factor of 3.5% through until 2040 and an annual factor of 3% beyond that date.

The cost implications of ISA are relatively straightforward and the resulting net present values of costs for the four implementation scenarios are given in Table 12.

Table 12: Net present value of costs (expressed in 2006£s)

Implementation Scenario	Net Present Value of Costs 2006£million
Market Driven	£16,903
Authority Drive (mandatory ISA at 2045)	£26,629
Authority Drive (mandatory ISA at 2040)	£26,860
Authority Drive (mandatory ISA at 2035)	£28,044

The economic benefit of the crash reductions expected to be achieved through ISA has been based on the most recent Highways Economics Note 1 (DfT, 2006c). HEN1 provides information on the average monetary valuation of prevention of crashes by severity (Table 4a) in pounds for a base year of 2005 (Table 13). The values depend in part on the number of injured persons involved in an accident at each level of severity and the injury severities for those involved persons. The values have been updated in accordance with HEN1 to provide a base cost for 2006 and increased each year by the expected increase in Gross Domestic Product (GDP), in line with COBA Volume 13 Table 3/4 (DfT, 2004b).

Table 13: The economic valuation of prevention of crashes (Highways Economic Note 1, Appendix 1)

Year	Fatal	Serious	Slight
2005	£1,644,790	£188,920	£19,250
2006	£1,715,023	£196,987	£20,072

The net present value of crash reduction benefits for each of the four crash reduction modelling scenarios and the two analysis methods discussed above are given in Table 14.

Table 14: Net Present value of crash reduction benefits of ISA (£m)

Implementation Scenario	Crash Reduction Model Combination	Analysis method	
		A	B
Market Driven	Base Combination	£31,316	£27,308
	Second Combination	£50,409	£51,734
	Third Combination	£30,676	£30,877
Authority Driven (2045)	Base Combination	£84,155	£89,824
	Second Combination	£127,547	£146,150
	Third Combination	£75,740	£83,338
Authority Driven (2040)	Base Combination	£90,734	£97,772,
	Second Combination	£133,120	£152,684
	Third Combination	£80,682	£88,733
Authority Driven (2035)	Base Combination	£98,058	£106,597
	Second Combination	£139,719	£160,464
	Third Combination	£86,251	£94,849

Looking at Table 14, it is immediately obvious that the analysis method used to apply the various crash models has an impact on the benefit streams predicted. Analysis Method B predicts higher benefits than Method A in which separate crash reductions are calculated for the fatal, serious and slight crashes in each speed limit. However, the variations are relatively small when compared to the variations that result from:

- the different implementation scenarios, and
- the different crash reduction model combinations.

The Market Driven scenario produces between 30% and 40% of the expected benefits of the various Authority Driven scenarios. A comparison of the impacts of early adoption of Mandatory ISA suggests that the key driver is the higher penetration rates associated with the Authority Driven Scenario rather than the switch to Mandatory ISA.

Adopting Mandatory ISA five years earlier than the 2045 date assumed in the Authority Driven Scenario, increases the benefits between 4% and 9% depending on the crash reduction model combination and the analysis method.

As expected the Third Combination of crash reduction models provides the lowest levels of benefits across all analyses. This is because the U1 model which is used to assess the impact of all ISA variants on urban speed limit crashes, does not take full account of the impact that ISA will have on the top end of the speed distribution.

At the other end of the spectrum, the Second Combination of crash reduction models predicts the highest level of crash reduction benefits. This is in the main due to the use of the U2 model to assess the crash reduction benefits of all ISA variants in urban speed limits. As noted earlier, the U2 model is expected to over-predict the crash reduction benefits of Mandatory ISA in particular, as the model form is based around the proportion of speeders in the traffic stream.

The Base Combination of crash reduction models relies heavily on the use of Kloeden's Australian based models to assess the crash risk reduction benefits associated with the dramatic changes to the speed distributions that occur under Voluntary and Mandatory ISA. Given the lack of a directly applicable model set, this combination of models is judged by the authors to be the most appropriate of those investigated, and provides crash reduction benefits that are slightly below the middle of the range of the other two combinations for the Authority Driven scenarios, and very similar results to the Third Combination for the Market Driven Scenario.

Combining the costs of Table 12 with the benefits of Table 14 yields the social benefit to cost ratios for the various analyses, which are reported in Table 15.

Table 15: Resulting benefit to cost ratios for ISA

Implementation Scenario	Crash Reduction Model Combination	Analysis method	
		A	B
Market Driven	Base Combination	1.9	1.6
	Second Combination	3.0	3.1
	Third Combination	1.8	1.8
Authority Driven (2045)	Base Combination	3.2	3.4
	Second Combination	4.8	5.5
	Third Combination	2.8	3.1
Authority Driven (2040)	Base Combination	3.4	3.6
	Second Combination	5.0	5.7
	Third Combination	3.0	3.3
Authority Driven (2035)	Base Combination	3.5	3.8
	Second Combination	5.0	5.7
	Third Combination	3.1	3.4

Table 15 clearly shows that all forms of Authority Driven ISA result in safety benefits with an economic value more than 2.8 times greater than the economic costs of implementation, irrespective of the crash prediction estimates and the analysis method. In all but one case, that based on the Third Combination of crash reduction models using Analysis Method A, the economic value of safety benefits are more than three times greater than the costs of implementation; at the top end the estimates indicate that the benefits could outweigh the costs by as much as five times. Early implementation of Mandatory ISA increases the minimum return on investment only marginally. Overall, it is clear that the benefit to cost ratio improves with increasing fleet penetration and with earlier adoption of Voluntary ISA.

6. CRASH REDUCTION BENEFITS

Chapter 5 reports the economic assessment of ISA, based on four implementation scenarios, three alternative combinations of crash reduction prediction models and two alternative methods of applying these crash reduction estimates. In total 24 separate analyses were undertaken.

This chapter examines in detail the crash reduction implications associated with the four implementation scenarios, using each of the three crash reduction modelling combinations:

1. The Base Combination, the favoured combination of models
2. The Second Combination, which typically generates greater crash reduction benefits than the Base Combination, and
3. The Third Combination, which typically produces lower crash reduction benefits.

In each case the model combinations are applied using Analysis Method A (see page 49), which allows reporting of the impact of ISA in terms of expected crash reductions by year and severity, and by speed limit and severity.

The expected number of fatal, serious injury and slight injury crashes predicted by the various combinations of crash prediction models, are given in Appendix E, for each road speed limit.

6.1 Base Combination of crash reduction models

Recapping the discussion of Section 2.1.4 and Table 4, the Base Combination of crash reduction models uses:

- the UK derived U2 models to establish the benefits of Advisory ISA, and the Kloeden (adjusted) models to derive the impacts of Voluntary and Mandatory ISA on all urban speed limit roads (except 20 mph roads where the U2 model is used)
- the Kloeden adjusted model to assess the impact of all ISA variants on 50 mph and 60 mph roads, and
- the Elvik Power Models for all ISA variants on 70 mph roads.

This is the favoured combination of the available crash reduction models, as it takes the best account of the impact that ISA has on the speed distribution.

6.1.1 Crash reduction profile over time

Figure 24 shows the predicted reduction in crashes over time under the Market Driven scenario, calculated using the Base Combination of crash reduction models. The safety impacts rise gradually in line with penetration of ISA. By 2070 the Market Driven scenario is achieving a 16% reduction in fatal crashes, a 10% reduction in serious injury crashes and almost a 5% reduction in slight injury crashes, when compared to the no-ISA baseline for the same year.

In contrast the Authority Driven scenario, shown in Figure 25, delivers a 42% reduction in fatal crashes from 2045. In that year, the retro-fitting of older vehicles and eliminating the override of ISA produces a step change in speed compliance, so that all vehicles fully comply with the posted limits. The corresponding reduction in serious and slight injury crashes is 38% and 23% respectively. Beyond that year there is no further increase in the effectiveness of ISA — hence the flatlining of the reductions after 2045.

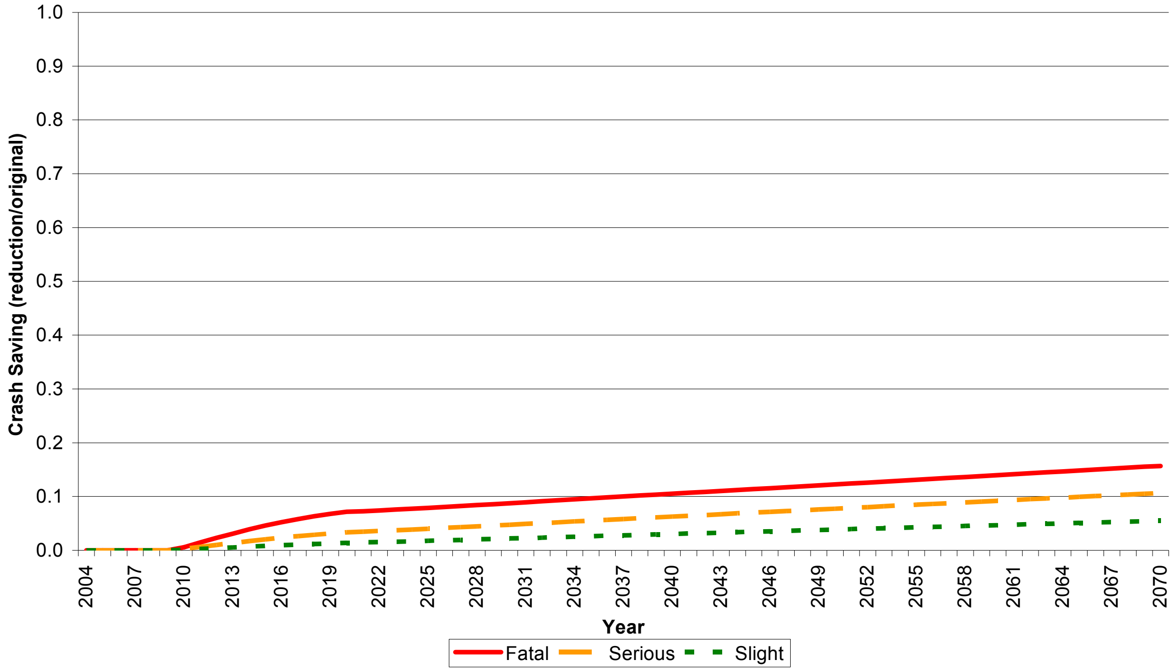


Figure 24: Crash reduction over time for Market Driven ISA using the Base Combination of crash reduction prediction models

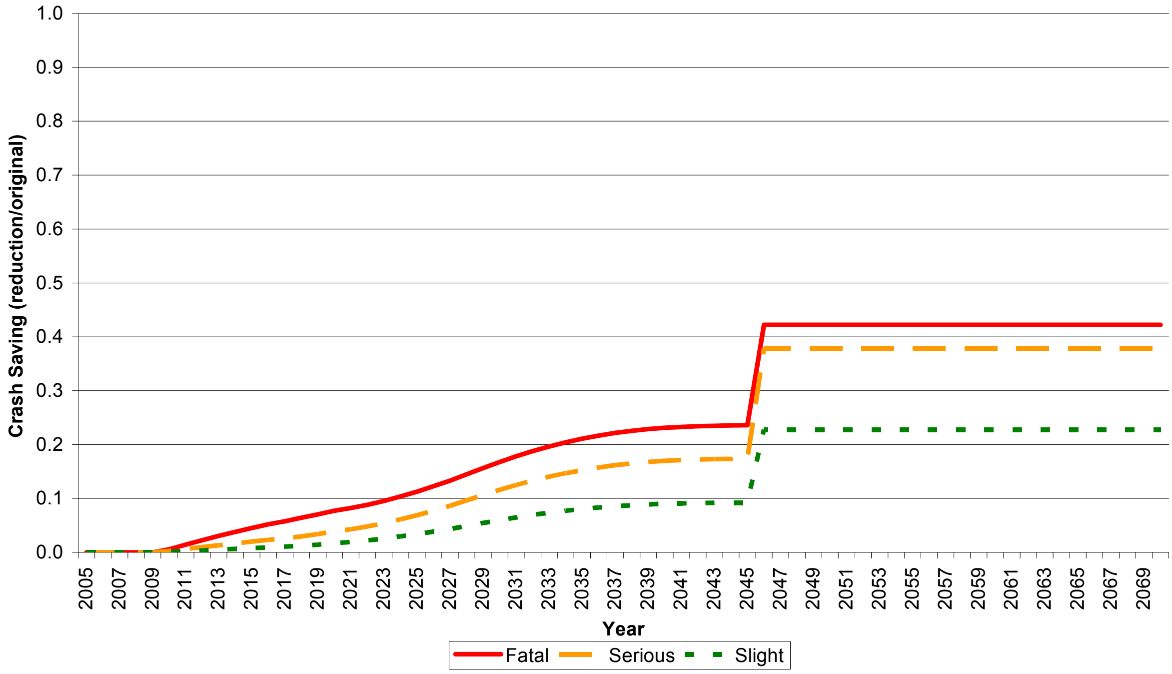


Figure 25: Crash reduction over time for Authority Driven ISA using the Base Combination of crash reduction prediction models

6.1.2 Crash reduction by road type

The full details of the expected number of crashes by severity and speed limit are tabulated in Appendix E. However, in this section we consider the high severity (fatal and serious injury crashes) and slight injury crashes separately for clarity.

Figure 26 shows the overall predicted number of fatal and serious crashes over the period from 2010 to 2070 in the baseline (no ISA situation) and under the Market Driven and Authority scenarios. The numbers are broken down by speed limit, and it is assumed that all speed limits remain constant, i.e. the same as at present. Also shown are the impacts of mandating ISA usage earlier than 2045, i.e. in 2040 or 2035.

Under the Market Driven scenario, ISA saves 10% of fatal accidents and 6% of serious injury accidents over the period, as compared to respective savings of 26% and 23% under the Authority Driven scenario with mandatory usage in 2045. Bringing mandatory usage forward to 2035 increases the total reduction over the period to 29% of fatal accidents and 25% of serious injury crashes. It can be noted that this is not a very large additional increase.

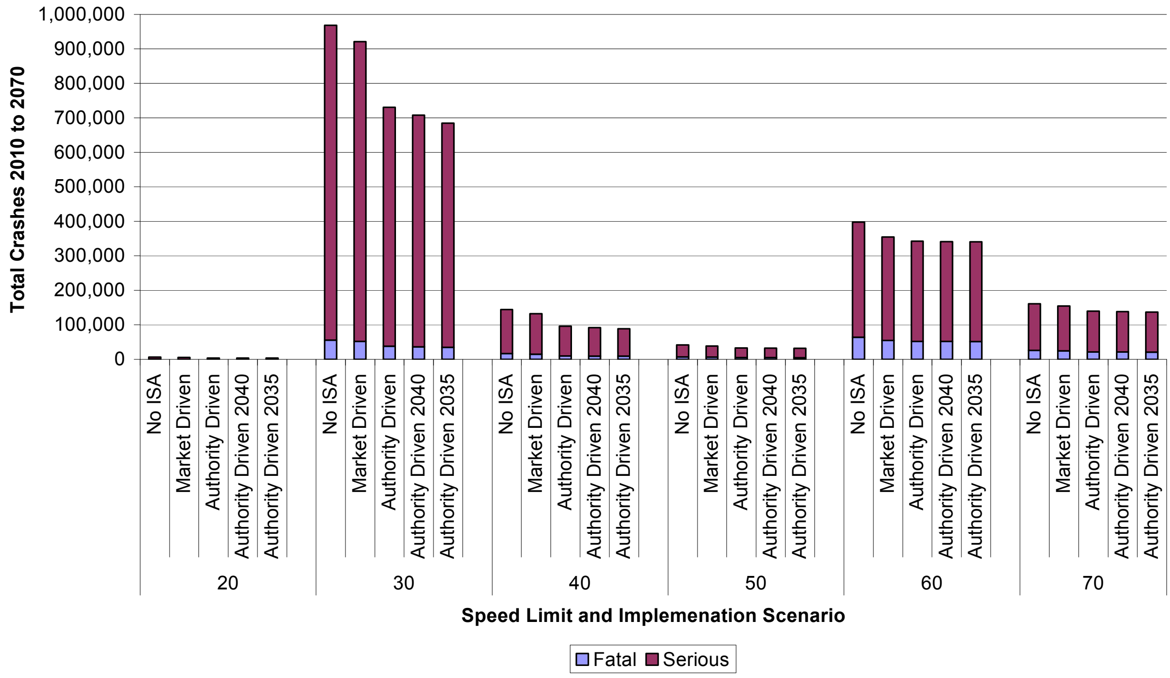


Figure 26: Predicted number of fatal and serious crashes for the period 2010 to 2070 under the Base Combination of crash reduction prediction models for each ISA implementation scenario disaggregated by speed limit

It is clear from Figure 26 that ISA has the greatest benefits on 30 mph roads. On such roads, the Market Driven scenario predicts a 5% reduction in high severity accidents, those resulting in death or serious injury. This figure rises to 32% under the Authority Driven 2045 scenario and to 38% under the Authority Driven 2035 scenario.

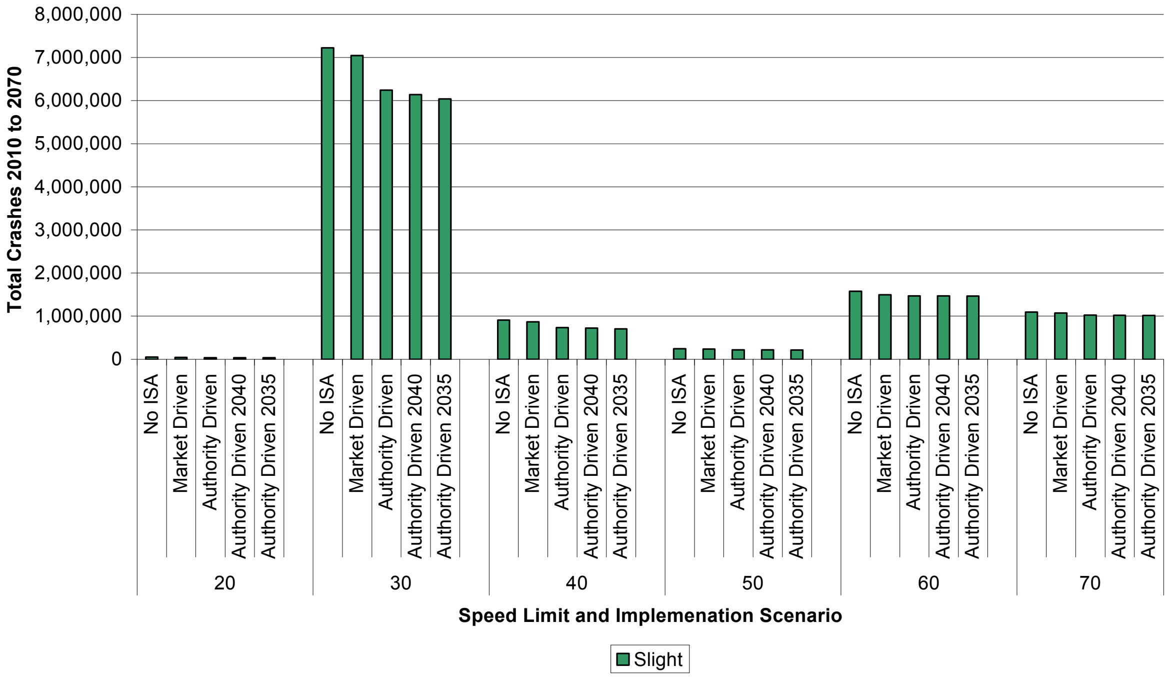


Figure 27: Predicted number of slight crashes for the period 2010 to 2070 under the Base Combination of crash reduction prediction models for each ISA implementation scenario disaggregated by speed limit

Figure 27 makes the same comparison for slight crashes. Again the most significant impact is predicted for 30 mph roads, with crash reductions of 2%, 14% and 16% being forecast for the Market Driven, Authority Driven 2045, and Authority Driven 2035 scenarios, respectively. Overall, the Market Driven scenario delivers a saving of 3% of slight crashes, while the Authority Driven scenario with usage mandated in 2045 delivers a 12% saving. Initiating mandatory usage in 2035 is predicted to result in a 15% reduction in slight injury crashes.

6.2 Second Combination of crash reduction models

Recapping the discussion of Section 2.1.4 and Table 4; the Second Combination of crash reduction models uses:

- the UK derived U2 models to establish the benefits of all ISA variants on all urban speed limit roads,
- the Kloeden adjusted model to assess the impact of all ISA variants on 50 mph and 60 mph roads, and
- the Elvik Power Models for all ISA variants on 70 mph roads.

The use of the U2 model for all ISA variants on urban roads gives higher crash reduction benefits as the proportion of vehicles exceeding the speed limit reduces.

6.2.1 Crash reduction profile over time

Figure 28 shows the predicted reduction in crashes over time under the Market Driven scenario, calculated using the Second Combination of crash reduction models. The safety impacts rise gradually in line with penetration of ISA, as is the case with each Market Driven implementation scenario. However, by 2070 the Second Combination of crash reduction models predicts that the

Market Driven implementation scenario achieves a 24% reduction in fatal crashes. This is 8% more than predicted using the Base Combination of crash prediction models. The predicted 2070 reduction for serious injury crashes is 21%, compared to 10% for the Base Combination, and 13% compared to the almost 5% reduction in slight injury crashes.

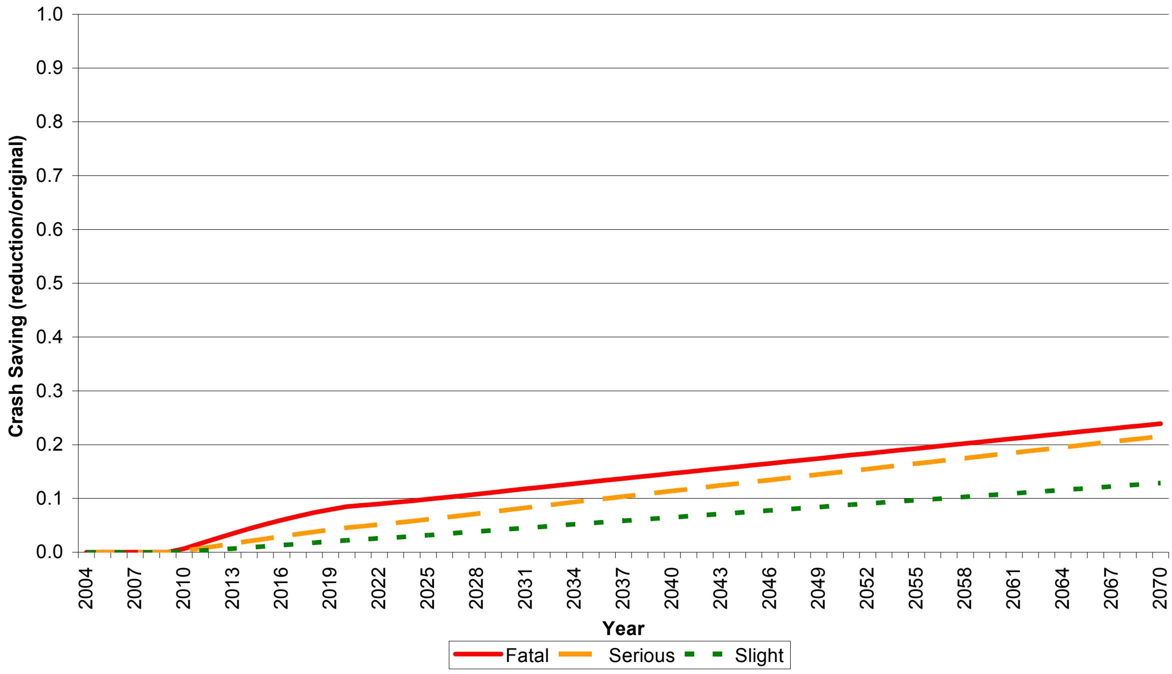


Figure 28: Crash reduction over time for Market Driven ISA using the Second Combination of crash reduction prediction models

Under the Authority Driven scenario, shown in Figure 29, the Second Combination of crash reduction models predicts a 52% reduction in fatal crashes, a 54% reduction in serious injury crashes, and a 37% reduction in slight injury crashes as compared to the baseline from 2045. Once again, the step change at 2045 relates to the retro-fitting of older vehicles and the disabling of the override of ISA so that all vehicles fully comply with the posted limits.

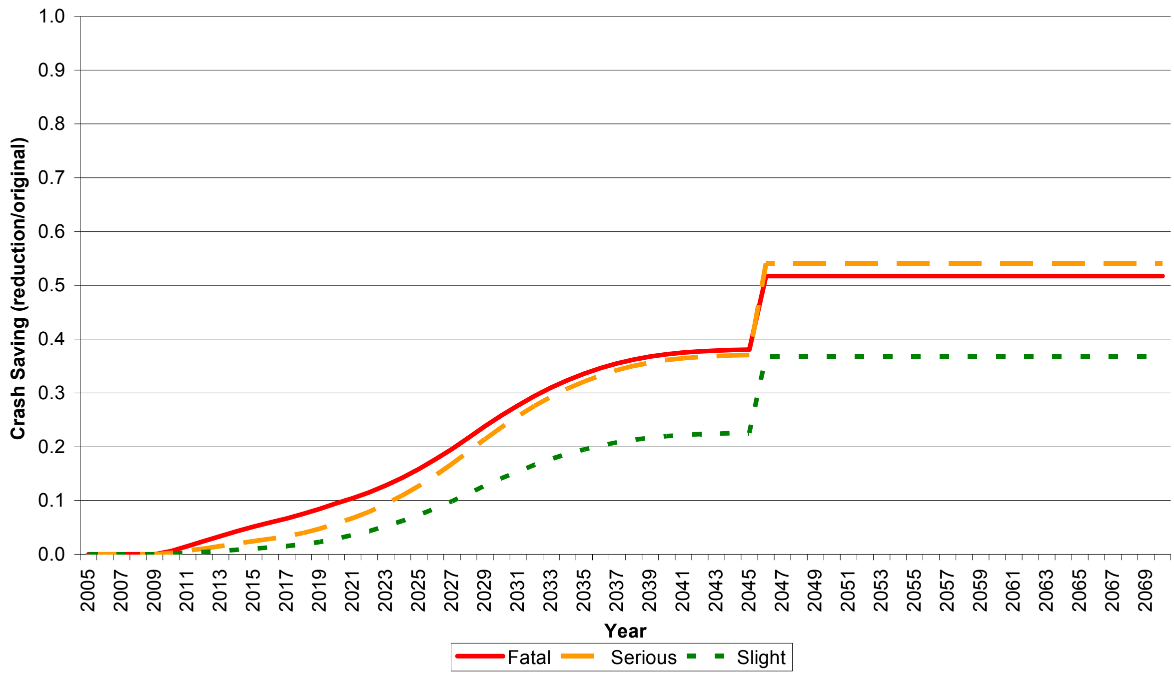


Figure 29: Crash reduction over time for Authority Driven ISA using the Second Combination of crash reduction prediction models

It is notable that the Second Combination of crash reduction models predicts a higher reduction in serious crashes than in fatal crashes. While this may appear counter-intuitive, it is a function of the relative proportions of fatal and serious injury crashes and the effectiveness of ISA on roads with different speed limits. When compared to the Base Combination of crash reduction models, the predictions of the Second Combination provides 2070 crash reductions that are 10% higher for fatal crashes and 14% higher for both serious crashes and slight injury crashes.

6.2.2 Crash reduction by road type

Figure 30 shows the overall predicted number of fatal and serious crashes over the period from 2010 to 2070 in the baseline (no ISA situation) and under the Market Driven and Authority scenarios. The numbers are broken down by speed limit, and it is assumed that all speed limits remain constant, i.e. the same as at present. Also shown are the impacts of mandating ISA usage earlier than 2045, i.e. in 2040 or 2035.

Under the Market Driven scenario, the Second Combination of crash reduction models predicts that ISA saves 14% of fatal and 11% of serious injury accidents over the period, as compared with a saving of 34% for fatal and 34% for serious injury accidents under the Authority Driven scenario with mandatory usage in 2045.

The respective predictions for the Base Combination were 10% and 6% for fatal and serious injury accidents respectively under the Market Driven implementation scenario. For the Authority Driven 2045 implementation scenario the Base Combination predicted fatal and serious accident reductions of 27% and 26% respectively.

Bringing mandatory usage forward to 2035 increases the total reduction in fatal accidents to 36% while serious accidents will reduce by 37%. These predicted savings are 7% (fatal accidents) and

12% (serious injury accidents) higher than those predicted by the Base Combination of crash reductions and serious injury crashes.

Again the major contribution is the reduction in fatal and serious injury accidents on 30 mph roads. The Second Combination of crash reduction models predicts that on 30 mph roads high severity accidents, those resulting in death or serious injury will reduce by 5% under the Market Driven implementation scenario, 25% under the Authority Driven implementation scenario with mandatory usage of ISA from 2045, and 29% with mandatory usage of ISA from 2035.

Figure 31 makes the same comparison for slight crashes and shows the Market Driven scenario delivering a saving of 7% of slight crashes overall while the Authority Driven scenario with usage mandated in 2045 delivers a 22% saving. Initiating mandatory usage in 2035 is predicted to result in a 24% reduction in slight injury crashes.

Again the most significant impact is on 30 mph roads, where slight accidents are predicted to fall by 7%, 22% and 24% for the Market Driven, Authority Driven 2045, and Authority Driven 2035 scenarios respectively.

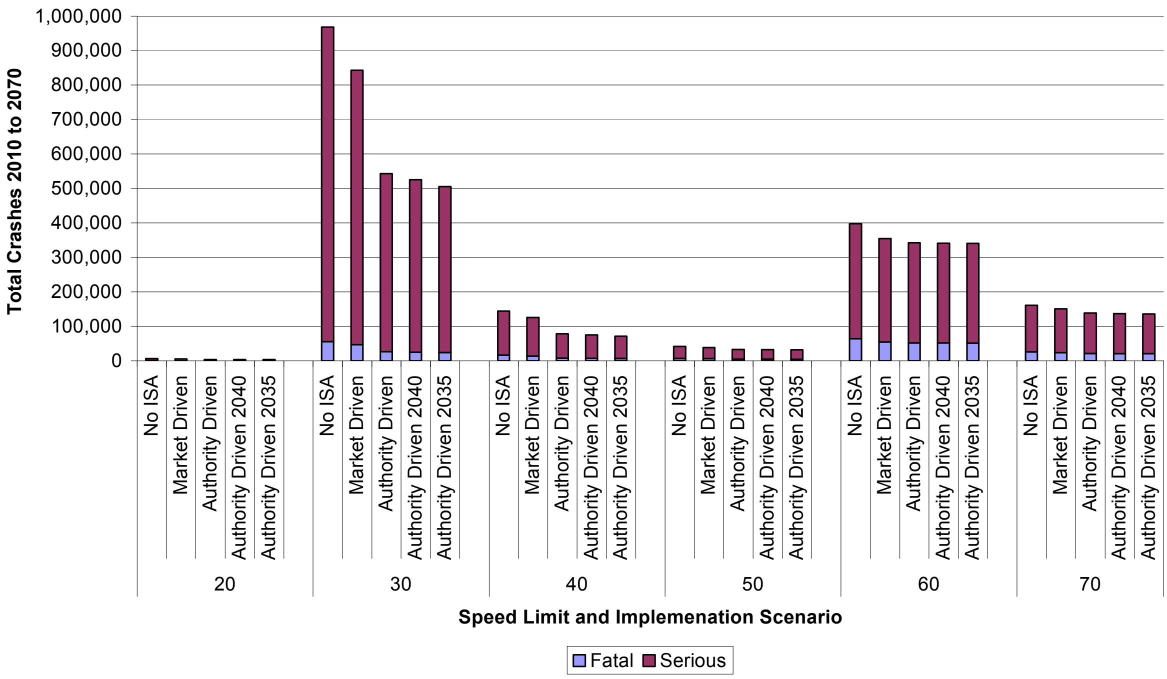


Figure 30: Predicted number of fatal and serious crashes for the period 2010 to 2070 under the Second Combination of crash reduction prediction models for each ISA implementation scenario disaggregated by speed limit

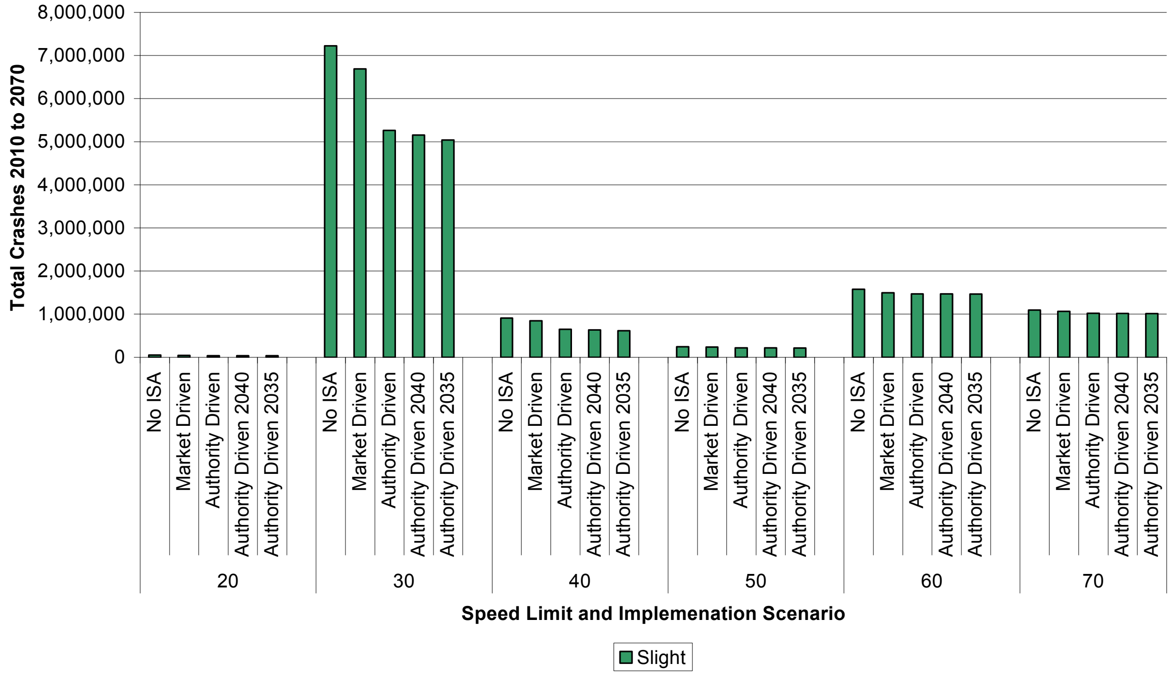


Figure 31: Predicted number of slight crashes for the period 2010 to 2070 under the Second Combination of crash reduction prediction models for each ISA implementation scenario disaggregated by speed limit

6.3 Third Combination of crash reduction models

As outlined in Section 2.1.4 and Table 6, the Third Combination of crash reduction models uses:

- the UK derived U1 models to establish the benefits of all ISA variants on all urban speed limit roads,
- the Kloeden adjusted model to assess the impact of all ISA variants on 50 mph and 60 mph roads, and
- the Elvik Power Models for all ISA variants on 70 mph roads.

Although the U1 model uses both the mean speed and speed variance as predictors of injury crashes on urban roads, the dramatic changes in speed distribution that result from some ISA variants are expected to violate the implicit assumptions of the model, which will have been constructed using observed data that is more symmetrical about the mean than is the case with Voluntary and Mandatory ISA. This Third Combination typically results in smaller crash reduction predictions than the other two combinations, principally due to the inability of this model to take adequate account of the impact that ISA has on top end speeds.

6.3.1 Crash reduction profile over time

Figure 32 shows the predicted reduction in crashes over time under the Market Driven scenario, calculated using the Third Combination of crash reduction models. Once again the safety impacts rise gradually in line with penetration of ISA. However, by 2070 the Third Combination of crash reduction models predicts that the Market Driven implementation scenario achieves a 14% reduction in fatal crashes. This is 2% less than the 16% reduction predicted using the Base Combination of crash reduction models. The predicted 2070 reduction for serious injury crashes is 11%, compared to 10% for the Base Combination, and 6% compared to the almost 5% predicted by the Base Combination for slight injury crashes.

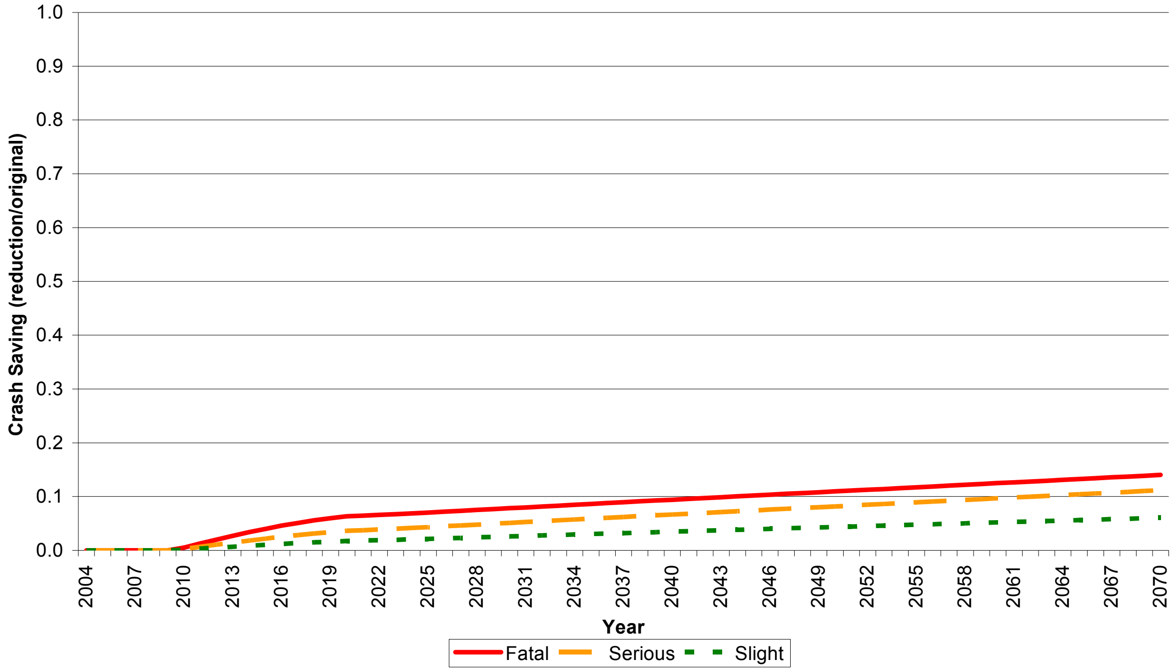


Figure 32: Crash reduction over time for Market Driven ISA using the Third Combination of crash reduction prediction models

Under the Authority Driven scenario, shown in Figure 33, the Third Combination of crash reduction models predicts a 37% reduction in fatal crashes, a 32% reduction in serious injury crashes, and a 19% reduction in slight injury crashes from 2045. The respective values for the Authority Driven implementation scenario using the Base Combination are a 42% reduction in fatal accidents, a 38% reduction in serious injury accidents and a 23% reduction in slight injury accidents. The differences in the 2045 to 2070 predicted performance under this Third Combination of crash reduction models is typically only 3% to 5% less than that predicted by the Base Combination of crash reduction models.

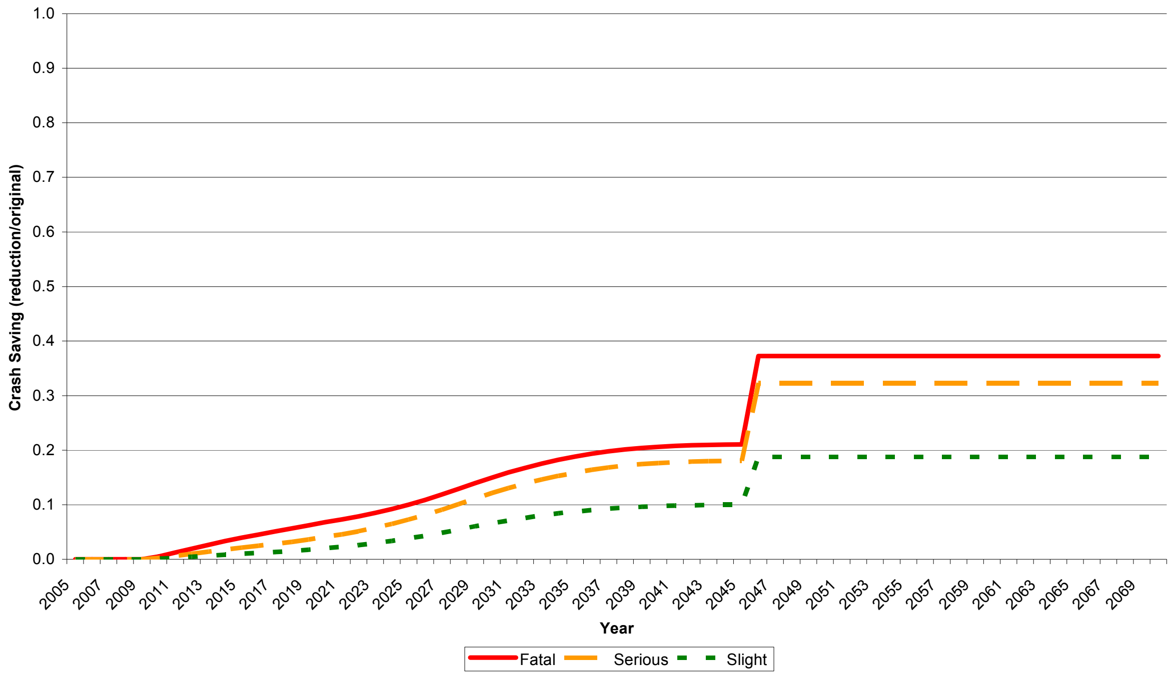


Figure 33: Crash reduction over time for Authority Driven ISA using the Third Combination of crash reduction prediction models

6.3.2 Crash reduction by road type

Figure 34 shows the overall predicted number of fatal and serious crashes over the period from 2010 to 2070 in the baseline (no ISA situation) and under the Market Driven and Authority scenarios. The numbers are broken down by speed limit, and it is assumed that all speed limits remain constant, i.e. the same as at present. Also shown are the impacts of mandating ISA usage earlier than 2045, i.e. in 2040 or 2035.

Under the Market Driven scenario, the Third Combination of crash reduction models predicts that ISA saves 9% of fatal and 7% of serious injury accidents over the period, as compared with a saving of 23% for fatal and 19% for serious injury accidents under the Authority Driven scenario with mandatory usage in 2045.

The comparable predictions for the Base Combination were 10% and 6% for fatal and serious injury accidents respectively under the Market Driven implementation scenario. For the Authority Driven 2045 implementation scenario the Base Combination predicted fatal and serious accident reductions of 26% and 21% respectively.

Bringing mandatory usage forward to 2035 increases the total reduction in fatal accidents predicted by the Third Combination of crash reduction models to 26% while serious accidents will reduce by 23%. These predicted savings are in each case 3% less than those predicted by the Base Combination of crash reductions.

Again the major contribution is the reduction in fatal and serious injury accidents on 30 mph roads. The Third Combination of crash reduction models predicts that on 30 mph roads high severity accidents, those resulting in death or serious injury, will reduce by 10% under the Market Driven implementation scenario. This increase of 3% over the Base Combination may appear counter-intuitive but the U1 model that is used to model the performance of ISA predicts a greater reduction in injury crashes than both the U2 or Kloeden models.

Under the Authority Driven implementation scenario with mandatory usage of ISA from 2045, the expected reduction in high severity accidents on 30 mph roads is 24%. This rises to 27% with mandatory usage of ISA from 2035.

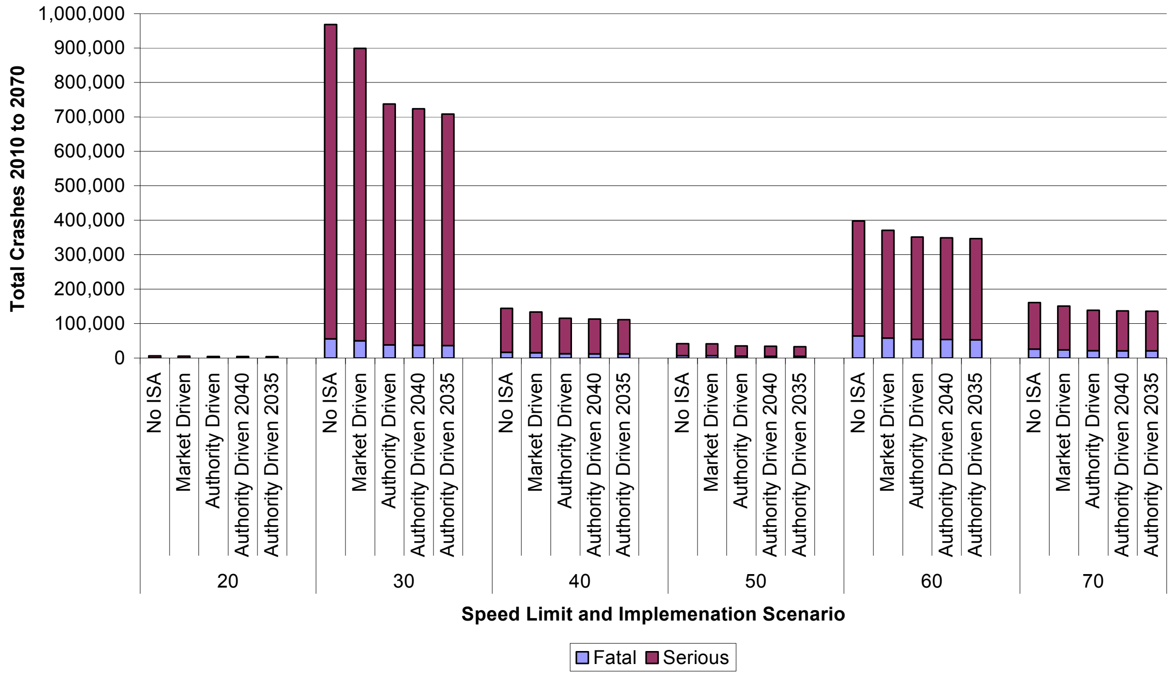


Figure 34: Predicted number of fatal and serious crashes for the period 2010 to 2070 under the Third Combination of crash reduction prediction models for each ISA implementation scenario disaggregated by speed limit

Figure 35 shows the overall reduction for slight injury accidents by implementation scenario. Under the Market Driven scenario slight injury accidents are predicted to reduce by 3% while the Authority Driven scenario with usage mandated in 2045 is predicted to deliver an 11% reduction. If mandatory usage is initiated in 2035, a 13% reduction in slight injury crashes is predicted using the Third Combination of crash reduction models.

Again the most significant impact is on 30 mph roads, where slight accidents are predicted to fall by 4%, 13% and 15% for the Market Driven, Authority Driven 2045, and Authority Driven 2035 scenarios respectively.

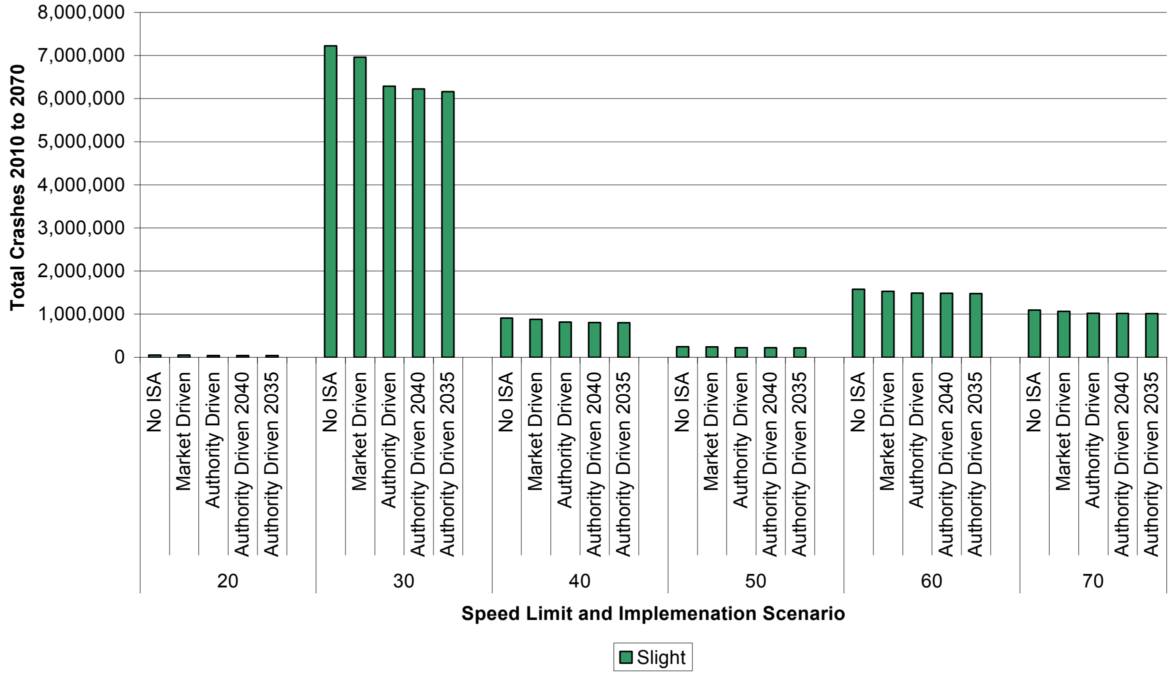


Figure 35: Predicted number of slight crashes for the period 2010 to 2070 under the Third Combination of crash reduction prediction models for each ISA implementation scenario disaggregated by speed limit

6.4 Summary

The overall predicted reductions in crashes for the two main scenarios are shown in Table 16 and Table 17. Not surprisingly, the impacts under the Authority Driven scenario are substantially greater than those under the Market driven Scenario. The range of reduction for fatal crashes is 9–14% for the former and 23–34% for the latter. In terms of road category, by far the greatest impact of ISA under both scenarios is on 30 mph roads. The preferred (Base) combination of models delivers estimates that are between those of the other combinations.

Table 16: Predicted reductions in crashes for the period 2010 to 2070 under the Market Driven scenario by combination of models

	Predicted Reductions		
	Slight crashes	Serious crashes	Fatal crashes
Base Combination of models	3%	6%	10%
Second Combination of models	7%	11%	14%
Third Combination of models	3%	7%	9%

Table 17: Predicted reductions in crashes for the period 2010 to 2070 under the Authority Driven scenario with Mandatory ISA in 2045 by combination of models

	Predicted Reductions		
	Slight crashes	**Serious crashes**	**Fatal crashes**
Base Combination of models	12%	23%	26%
Second Combination of models	22%	34%	34%
Third Combination of models	11%	19%	23%

7. SUMMARY AND CONCLUSIONS

This report has investigated the safety impacts and the socio-economic benefits and costs of implementing Intelligent Speed Adaptation. Other impacts of ISA, such as those on fuel consumption and emissions, have not been considered here. The modelling has been based on three ISA system variants and two implementation scenarios.

The ISA system variants are:

> **Advisory ISA** that provides an auditory signal is given when speed limit is exceeded, or a new speed limit is encountered.
>
> **Voluntary ISA** in which the vehicle's top speed is by default limited to the speed limit of the road being travelled, but the driver can choose to disengage the system during the course of their journey, and
>
> **Mandatory ISA**, which is similar to the Voluntary ISA but without the option to disengage the system.

The fitment, use and subsequent accident reduction benefits of these three ISA variants has been investigated in the context of two hypothetical implementation scenarios:

> A **Market Driven** implementation scenario under which vehicle owners (and operators) may choose to purchase and fit a commercially available ISA variant, and an
>
> An **Authority Driven** implication scenario which begins with voluntary fitment of ISA (as in the Market Driven scenario above) but which assumes that the Government or the EU at some point mandates the fitment of ISA on new vehicles and the retro-refitting of existing fleets to accelerate take-up. This implementation strategy seeks to ensure high levels of penetration of Voluntary ISA by 2045, at which time the obligation to use ISA in the form of Mandatory functionality would be enacted.

The road accident reduction benefits expected from ISA have been estimated through consideration of the impact that ISA has on travel speeds and in particular on the proportion of travel undertaken at higher speeds. This has been done through the application of available speed crash relationships derived from empirical observations.

The major source of information on speed compliance without and with ISA was the set of field trials conducted by this project. These trials involved some 12,119 person days of driving over which the participants travelled 570,661 km. Although there is considerable literature on the impact of speed on accident risk, there are no UK based models that are directly applicable to ISA. It is therefore crucial to conduct sensitivity tests to evaluate the effect of using different models. Three combinations of the available models have been used, in the analysis: the favoured Base Combination, the more optimistic Second Combination and the more conservative Third Combination.

The analysis using the favoured Base Combination of crash reduction models indicates that, over a 60-year period from 2010 to 2070, the Market Driven implementation scenario is expected to reduce fatal accidents by 10% (approximately 15,400 fatal accidents), serious injury accidents by 6% (96,000 accidents), and slight injury accidents by 3% (336,000 accidents).

The same combination of crash reduction models predicts that, over the 60-year period, the Authority Driven implementation scenario is expected to reduce fatal accidents by 26% (approximately 43,300 fatal accidents); serious injury accidents by 21% (330,000 accidents), and slight injury accidents by 12% (1.3 million accidents). Overall, ISA has a considerably greater impact on more severe crashes.

Two variations on the Authority Driven implementation scenario were also tested. These variations would see mandatory fitment and usage of ISA brought forward to either 2040 or 2035. The early mandating of ISA increased the predicted accident reductions for each severity class by around 1% to 2% for 2040, and 3% to 4% for 2035.

The greatest source of accident reduction benefits occurs on 30 mph roads where the Market Driven implementation scenario is expected to reduce high-severity (fatal and serious injury) accidents by 5% (range 5% to 13%). The Authority Driven scenario is expected to reduce fatal and serious injury accidents by 25% (range 24% to 44%) over the 60-year analysis period. The fact that the major savings are on 30 mph roads, closely followed by 40 mph roads, also indicates the potential of ISA to improve the safety of pedestrians and cyclists.

The economic benefit associated with the predicted crash reductions is substantial. Under both the implementation scenarios, the benefits considerably outweigh the costs. The Market Driven implementation scenario is expected to result in benefits 1.9 times greater than the cost of introduction under the Base Combination of accident prediction models (range 1.8 to 3.0 under the other combinations). The Authority Driven implementation of ISA is expected to produce economic benefits 3.2 times greater than the investment costs under the Base Combination of accident prediction models (range 2.8 to 4.8 under the other combinations).

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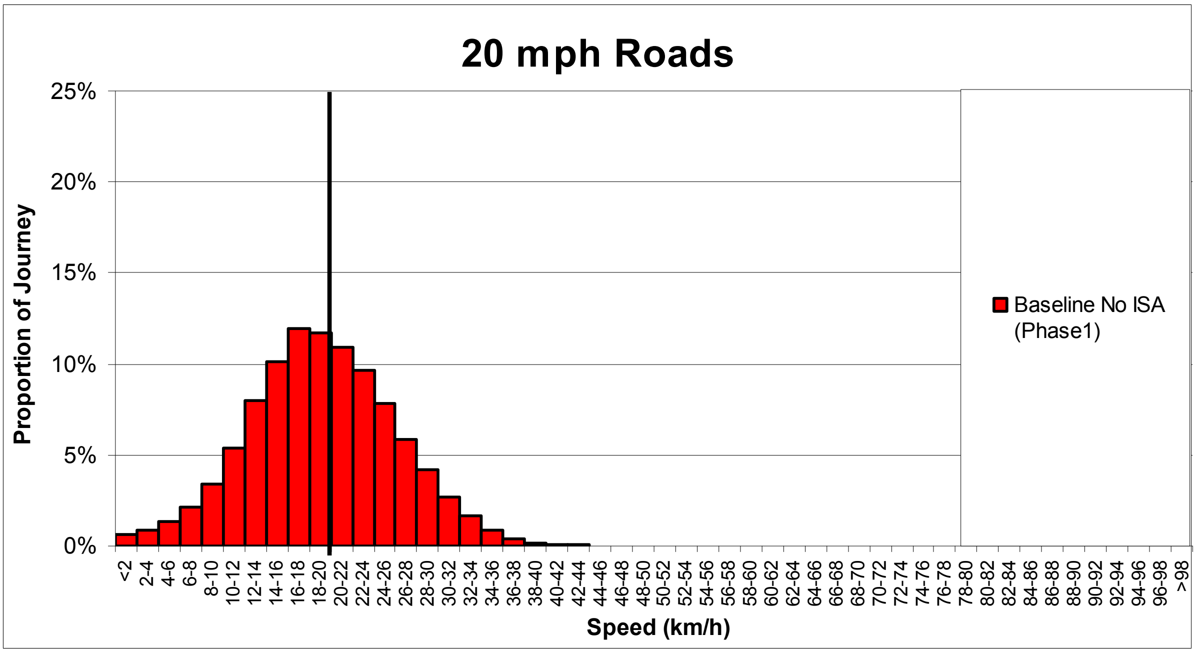
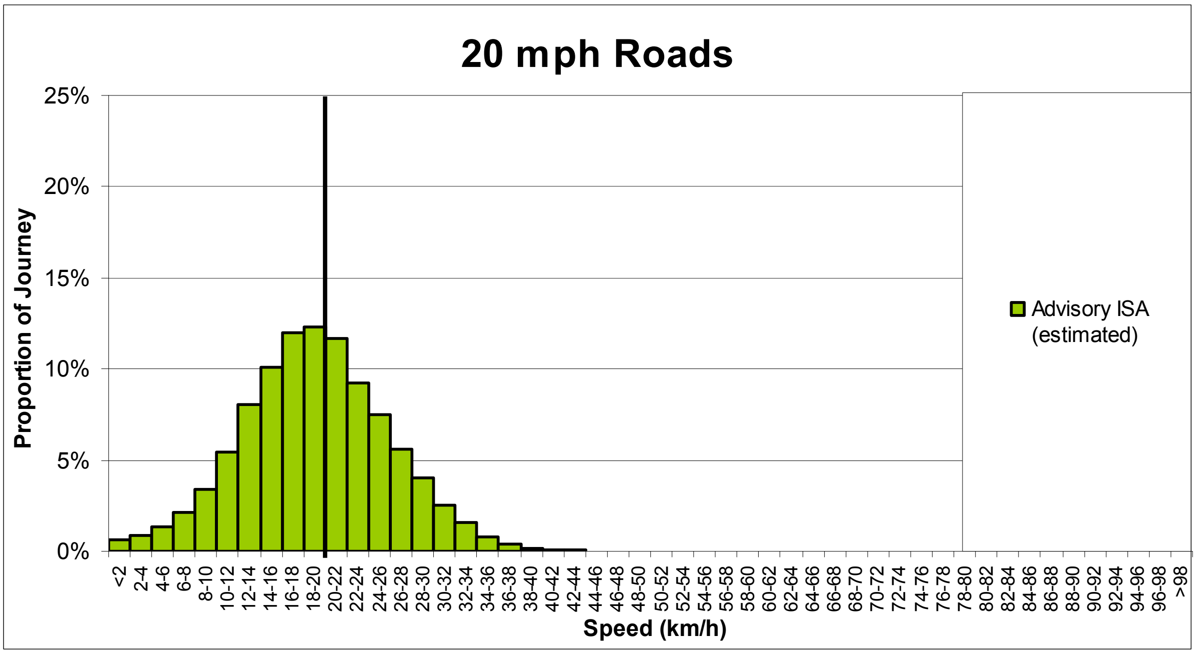
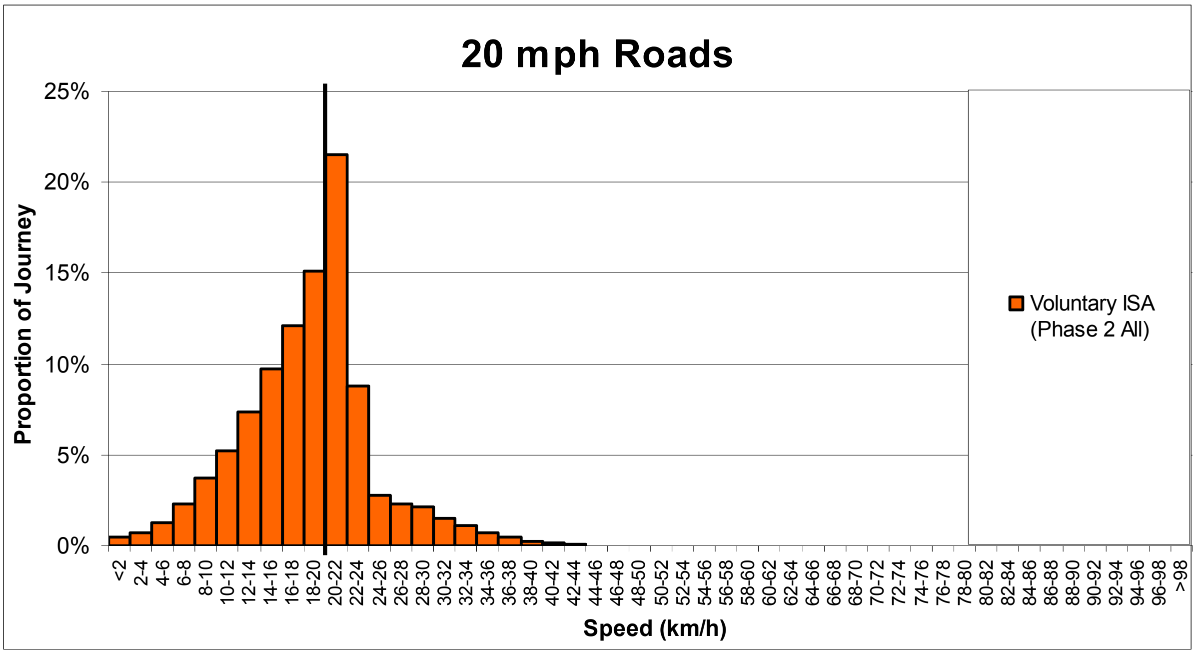
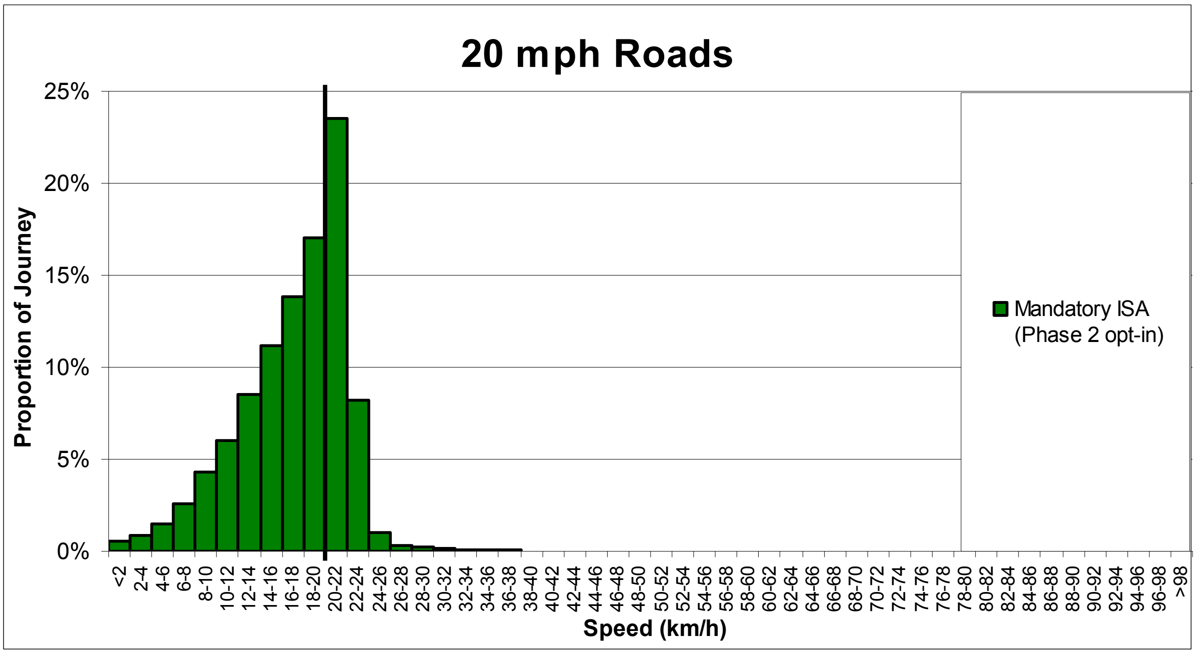
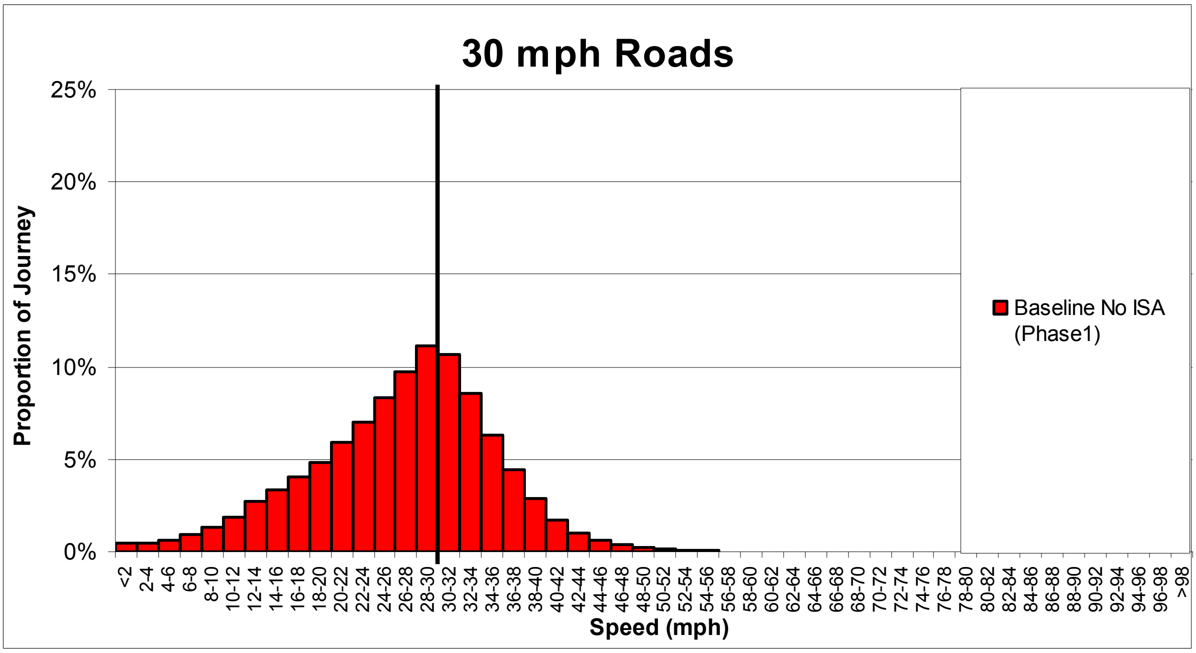
APPENDIX A: SPEED DISTRIBUTIONS BY ROAD SPEED LIMIT

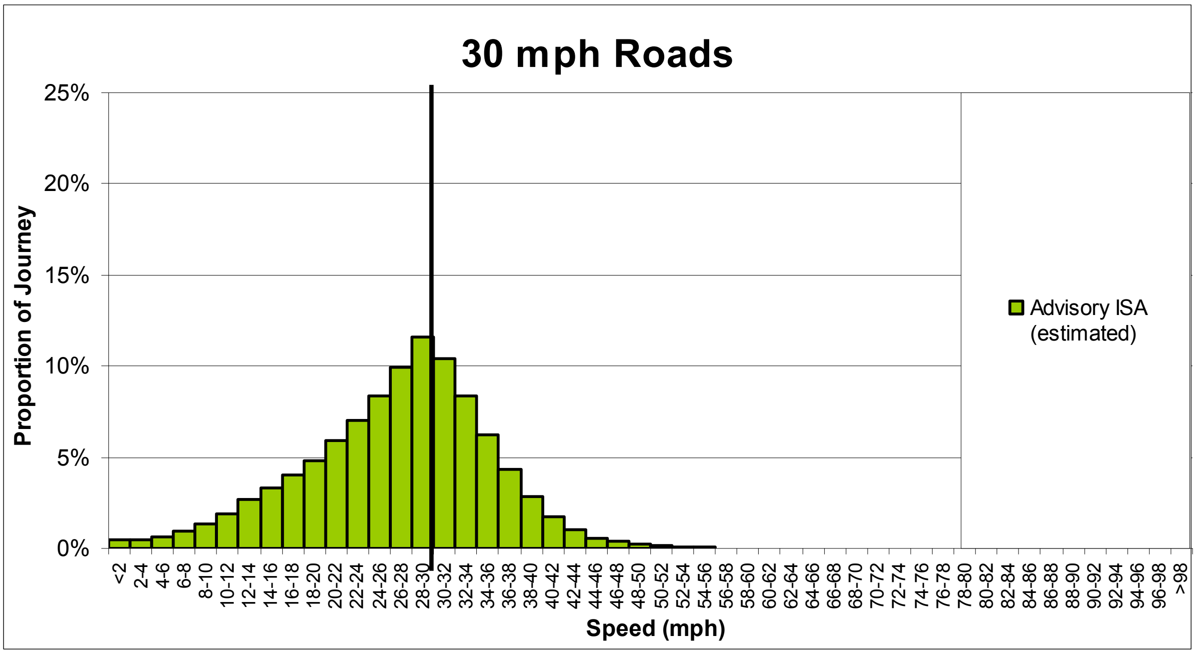

20 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (km/h)
Baseline No ISA (Phase1)

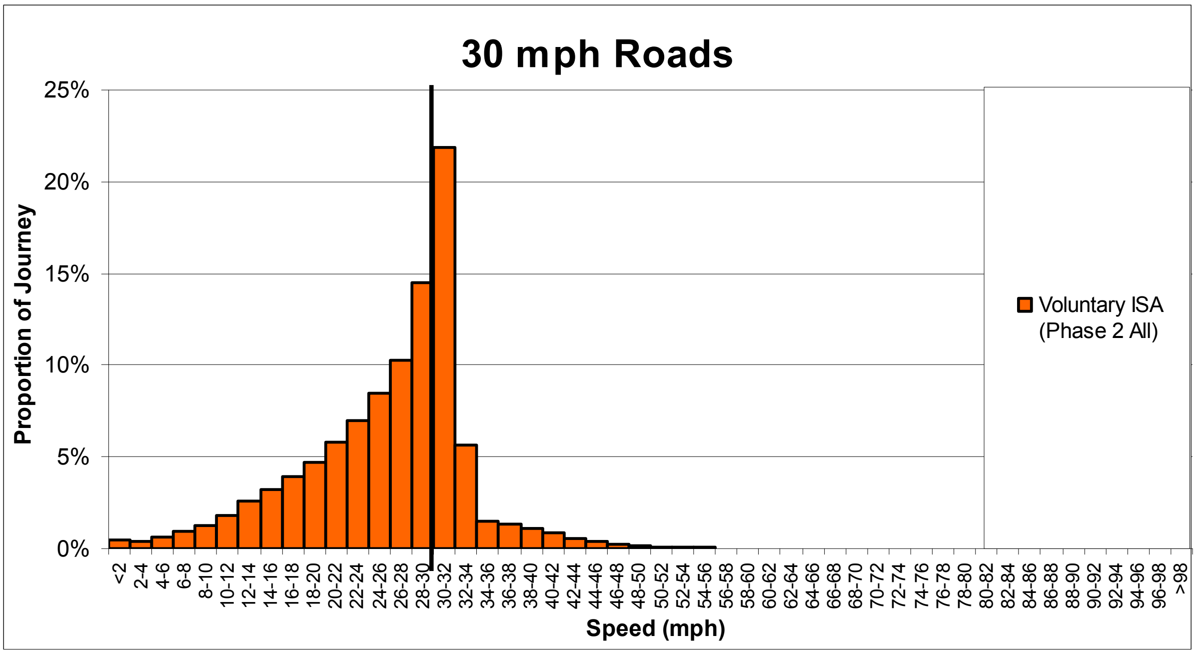

20 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (km/h)
Advisory ISA (estimated)

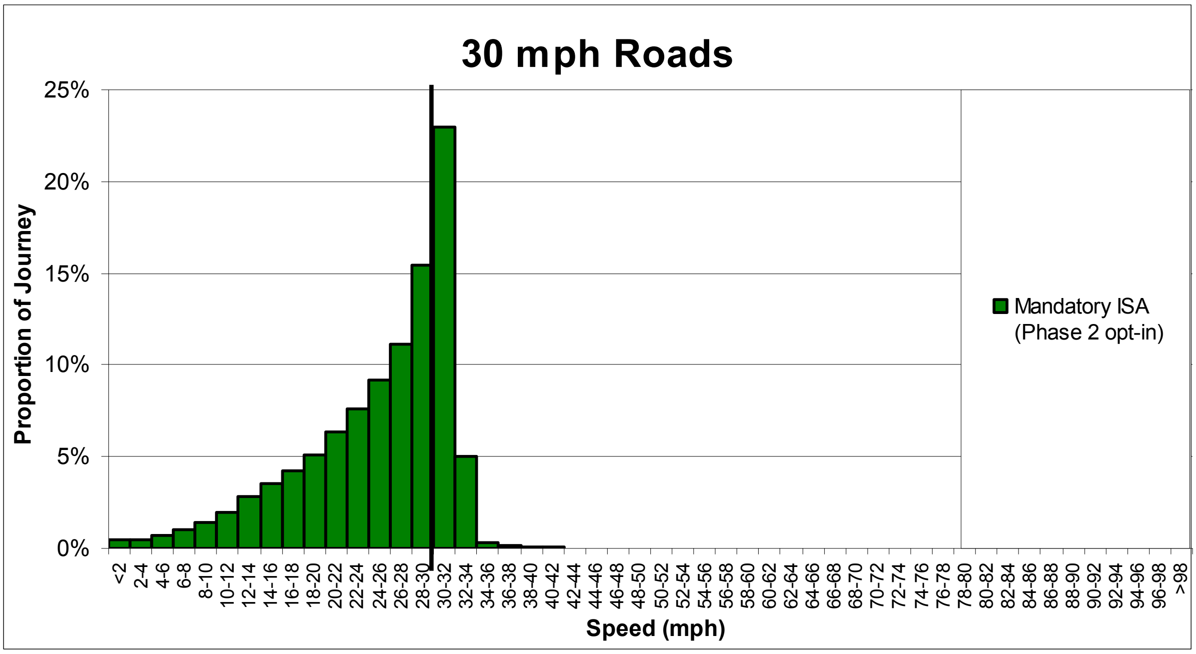

20 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Voluntary ISA (Phase 2 All)
Speed (km/h)

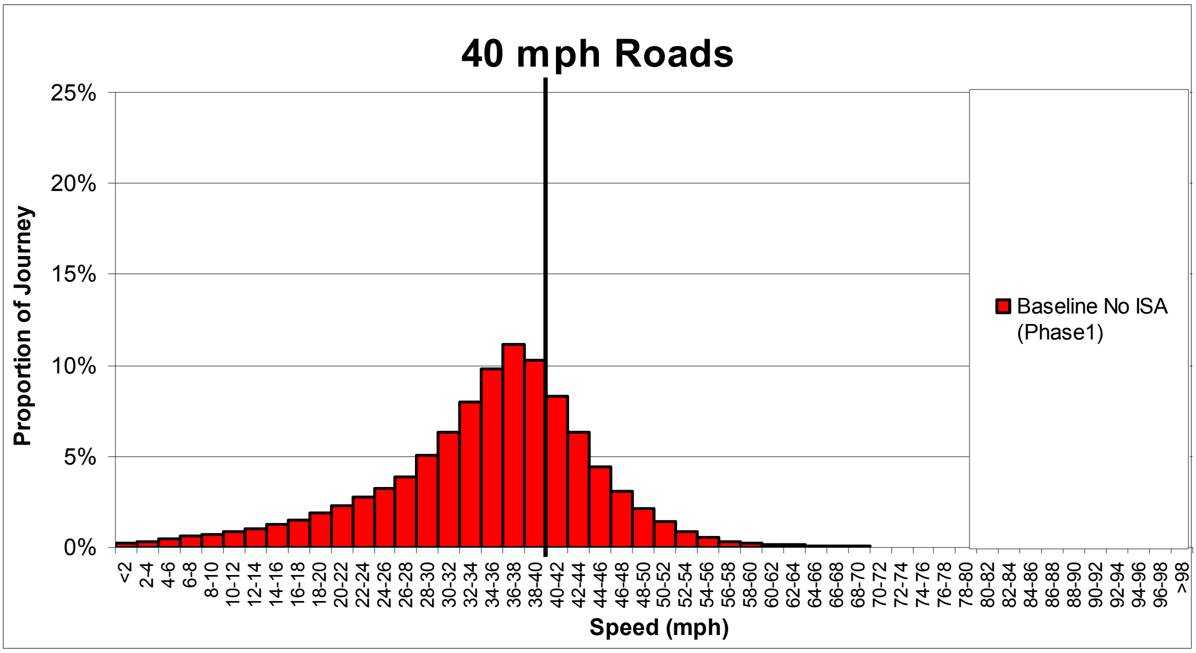

20 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Mandatory ISA (Phase 2 opt-in)
Speed (km/h)

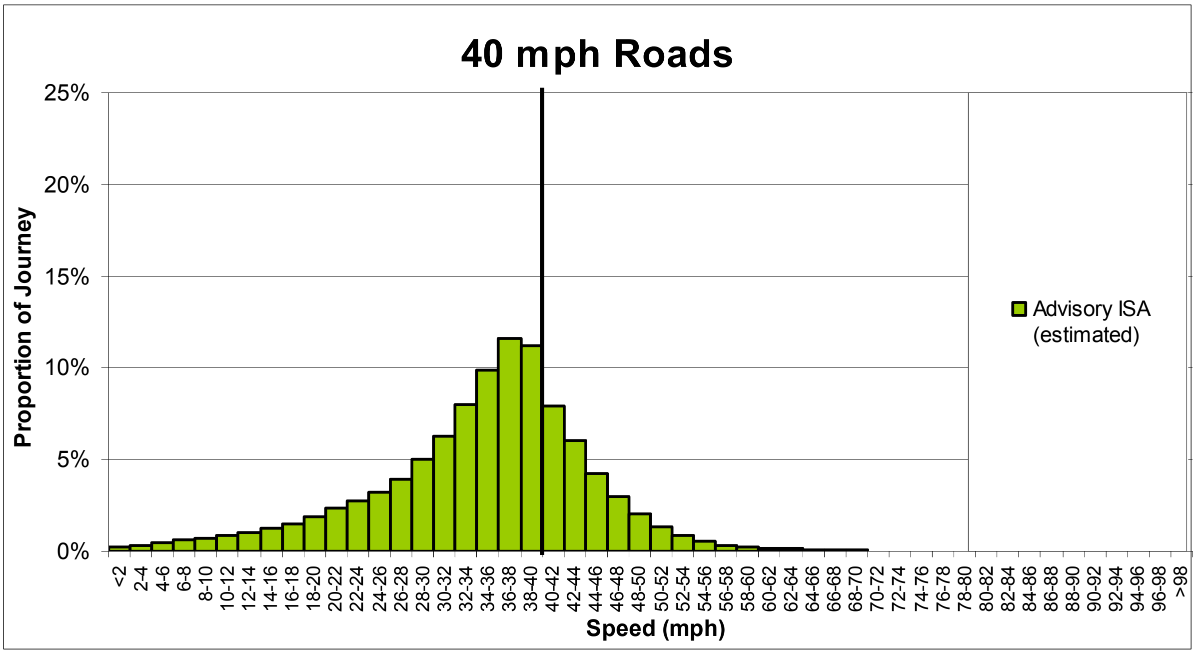

30 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Baseline No ISA (Phase1)

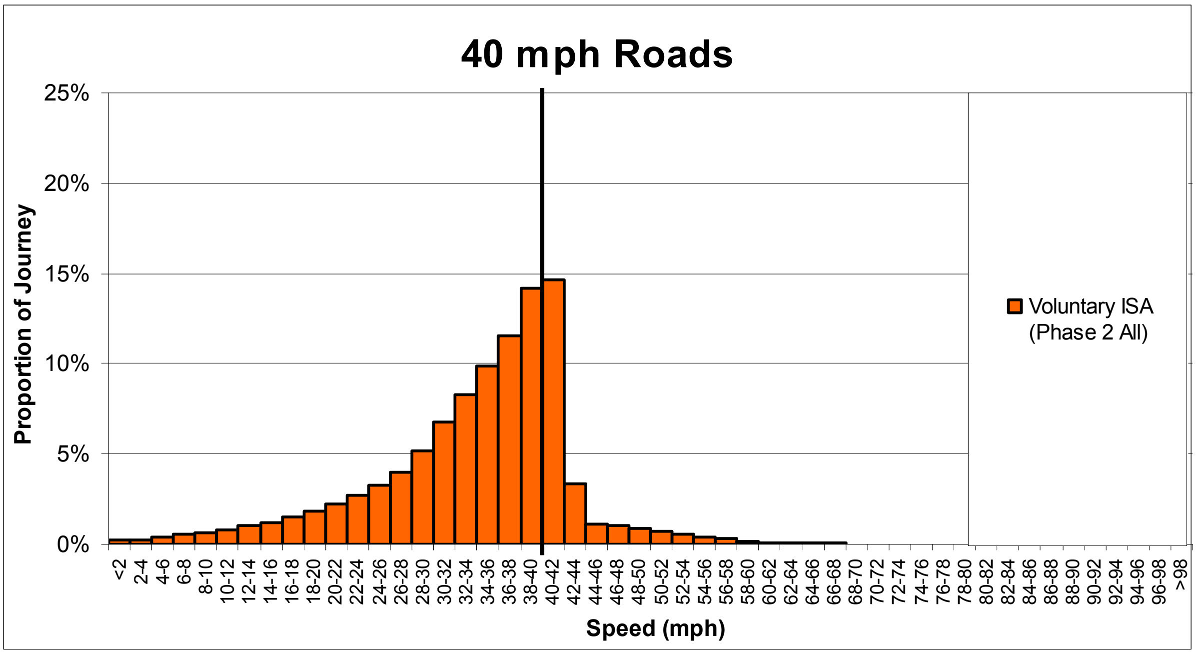

30 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Advisory ISA (estimated)

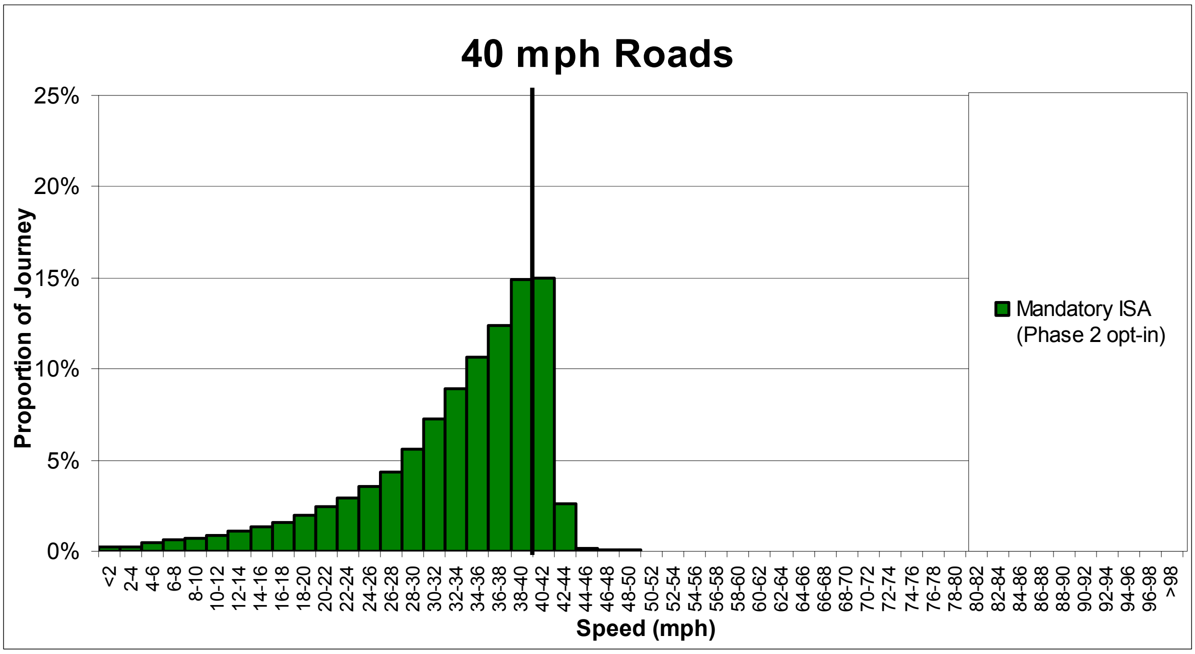

30 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Voluntary ISA (Phase 2 All)
Speed (mph)

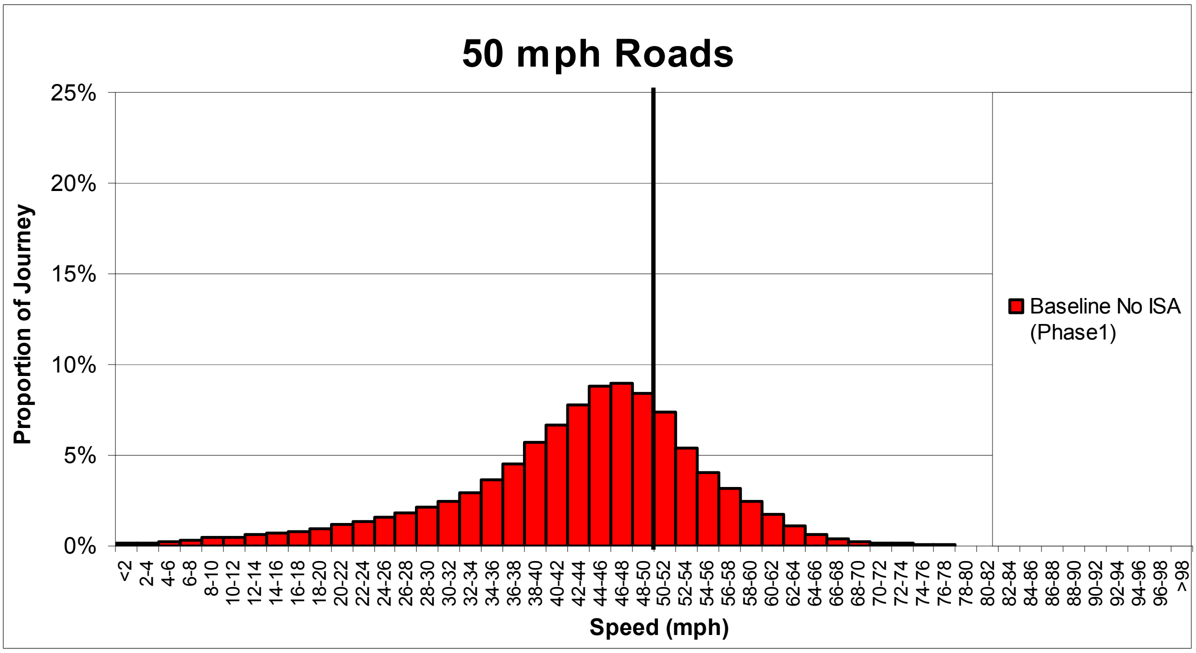

30 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Mandatory ISA (Phase 2 opt-in)
Speed (mph)

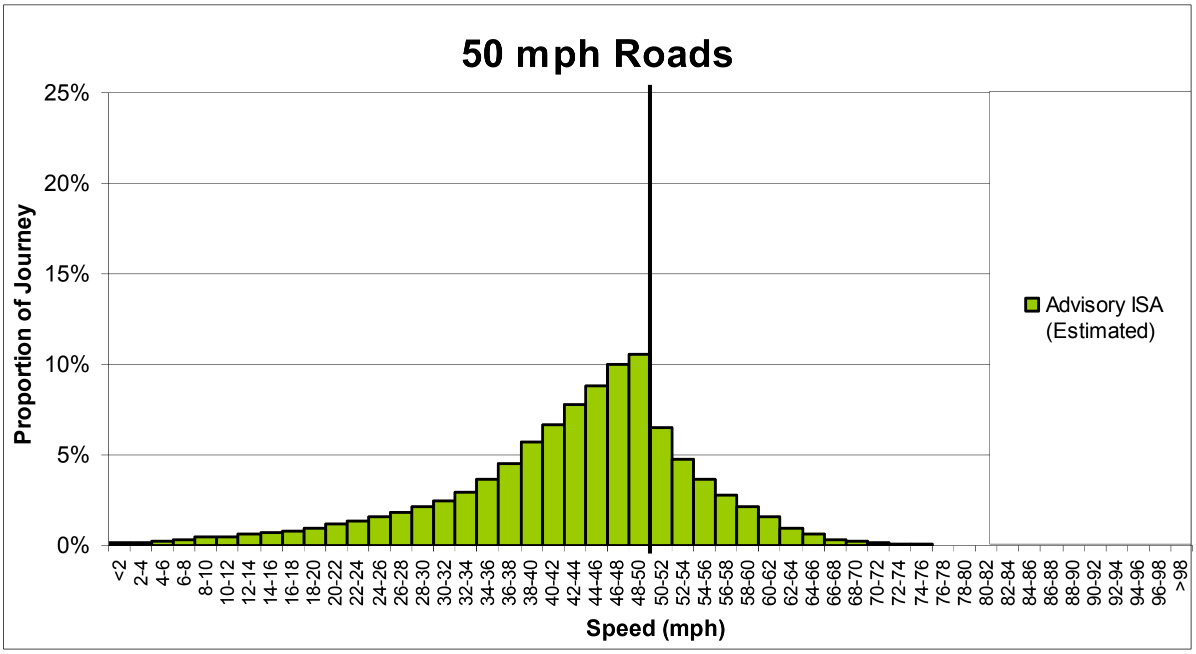

40 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Baseline No ISA (Phase1)

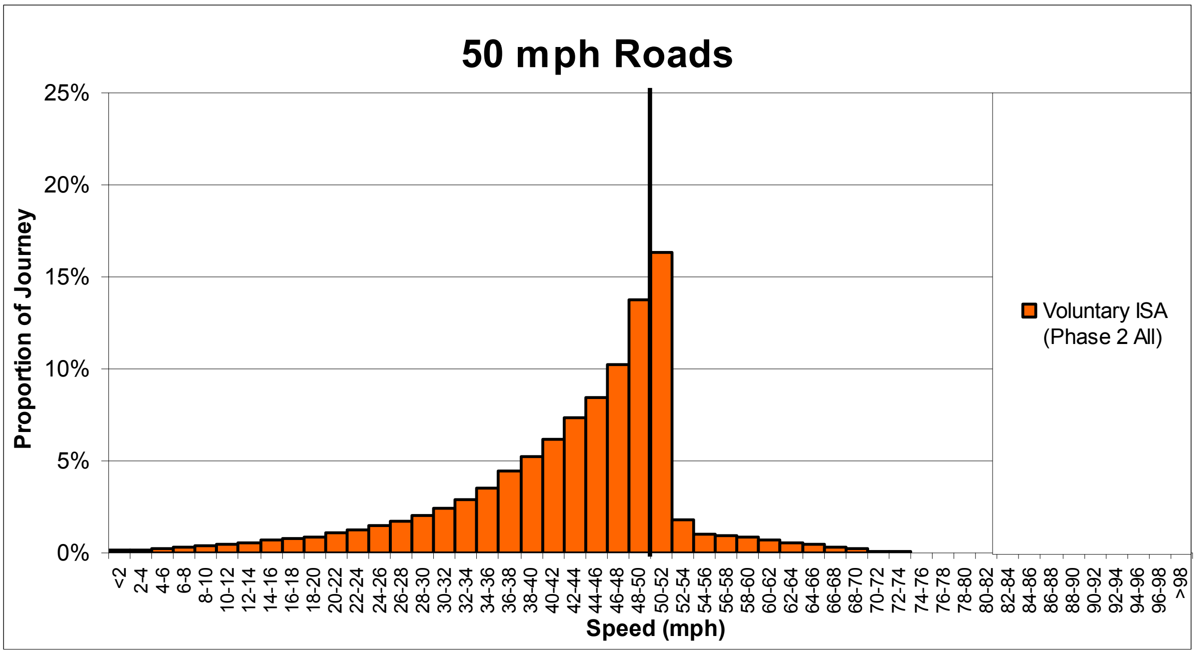

40 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Advisory ISA (estimated)

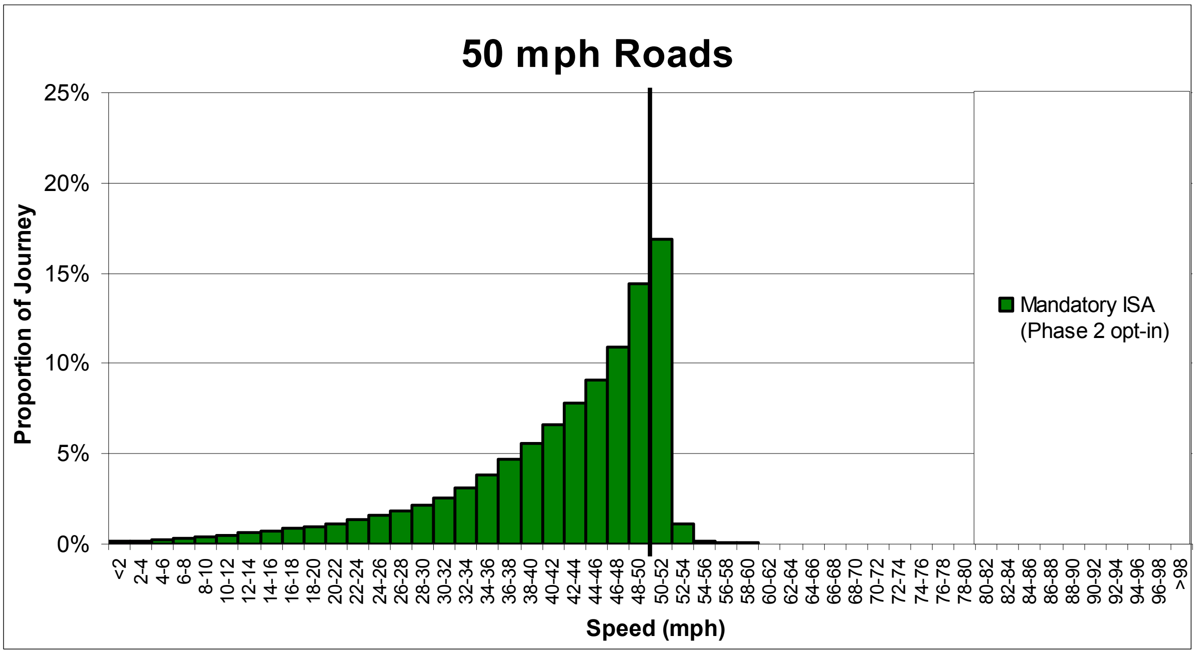

40 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Voluntary ISA (Phase 2 All)

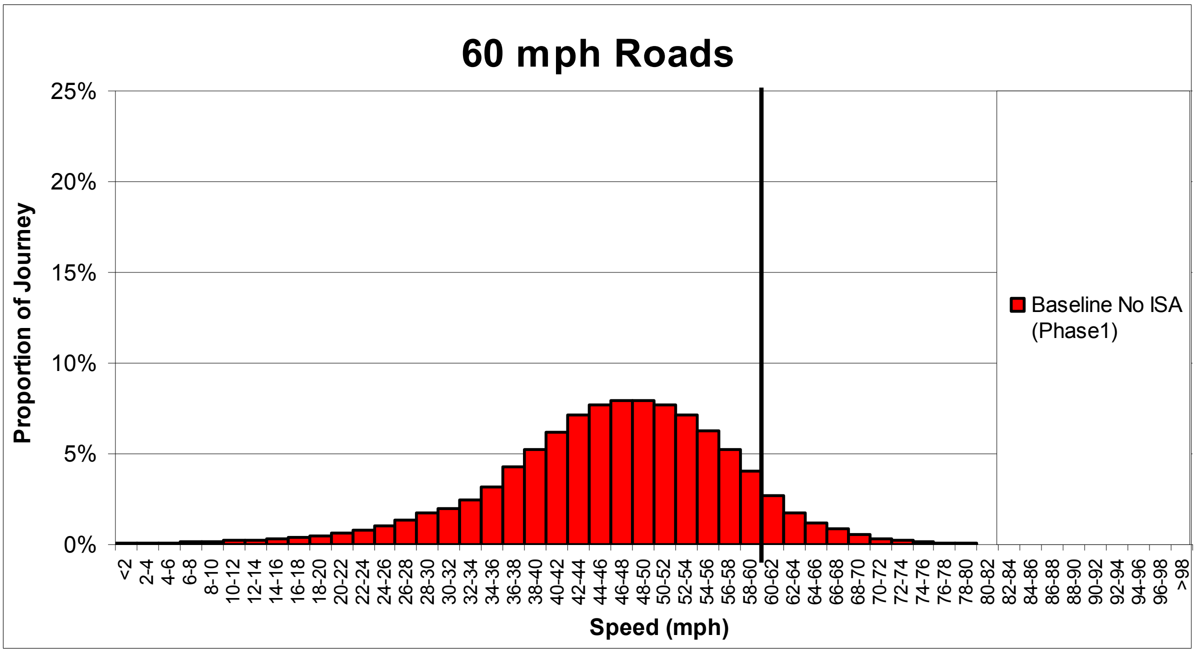

40 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Mandatory ISA (Phase 2 opt-in)

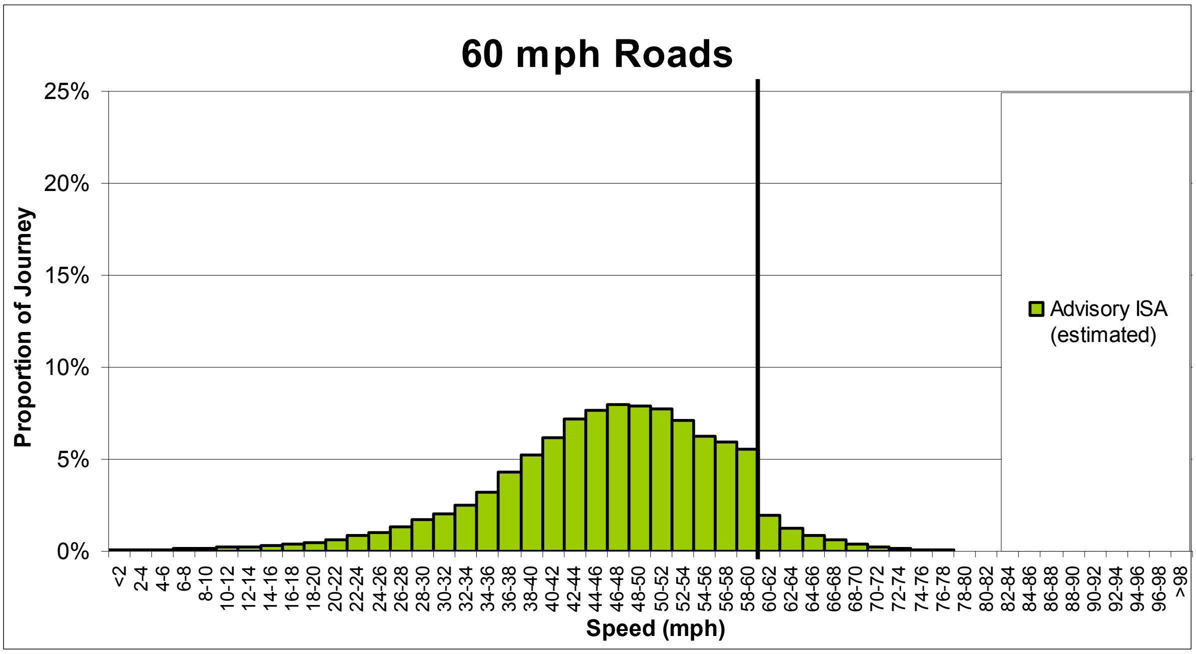

50 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Baseline No ISA (Phase1)

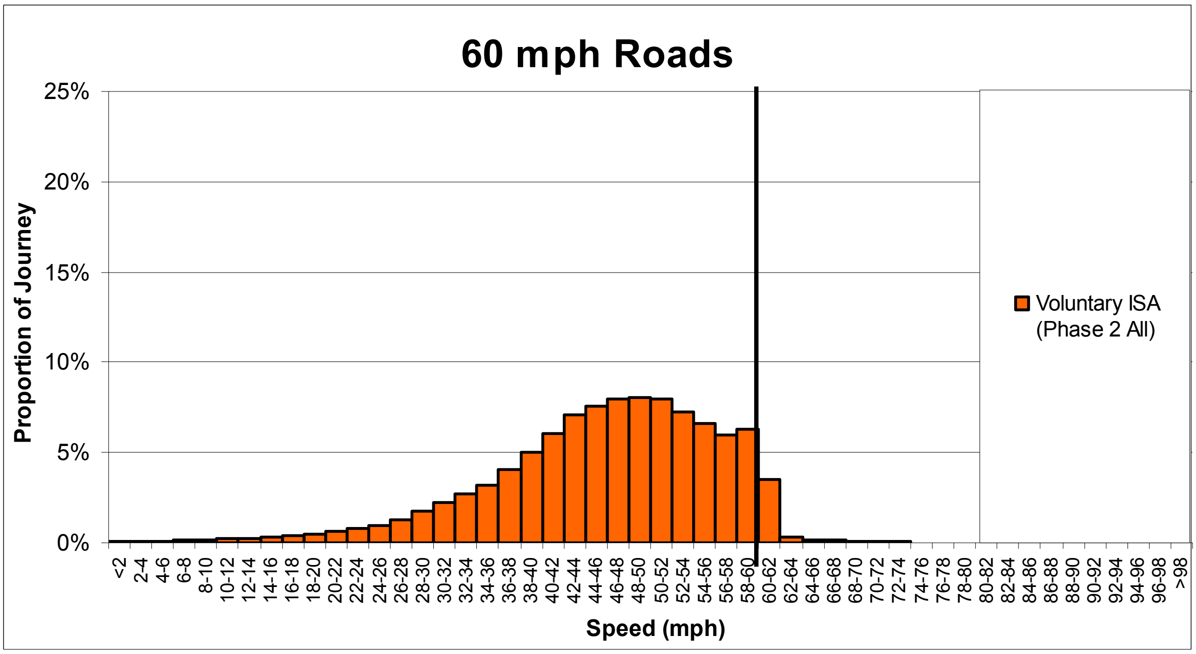

50 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Advisory ISA (Estimated)

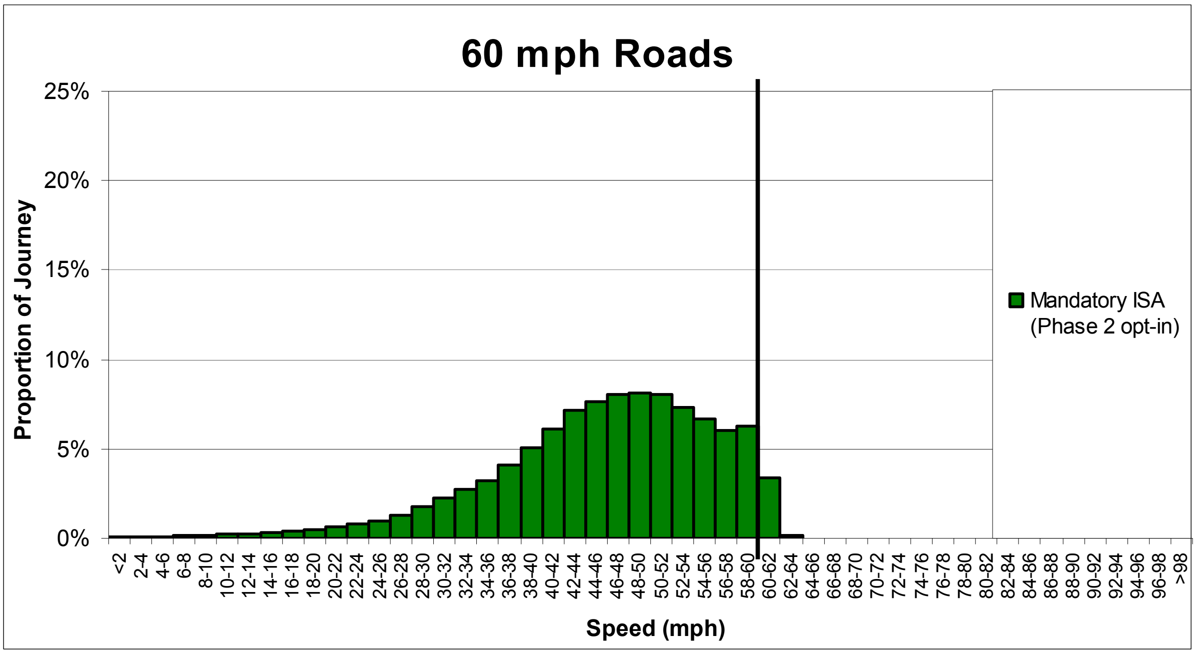

50 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Voluntary ISA (Phase 2 All)

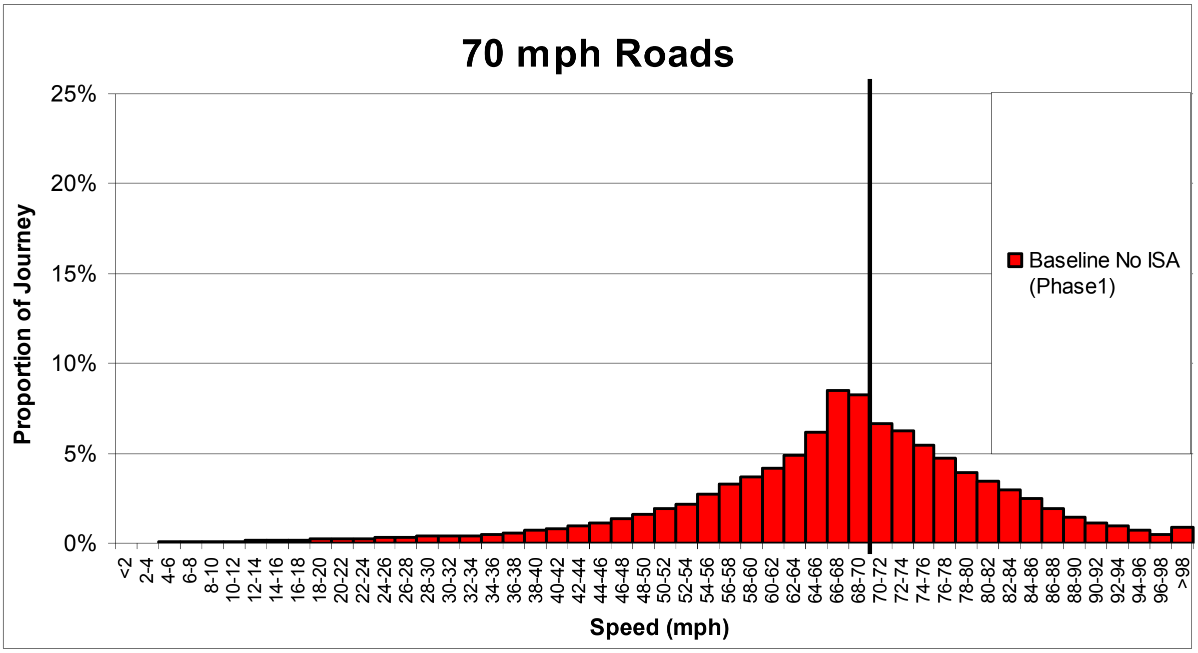

50 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Mandatory ISA (Phase 2 opt-in)

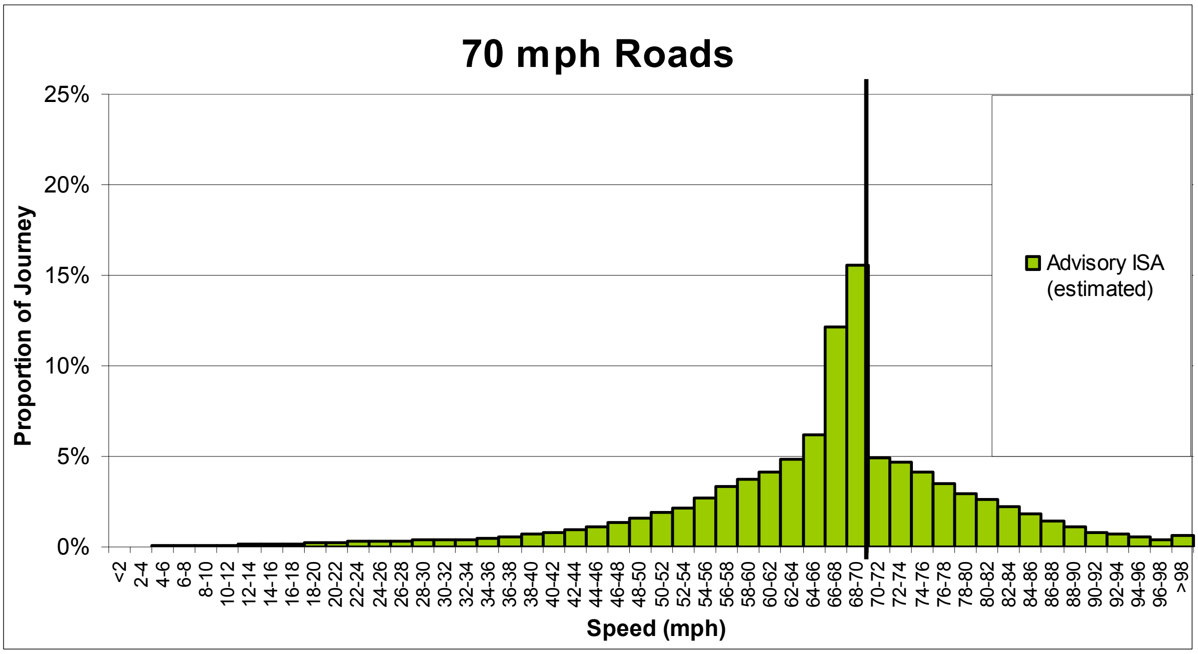

60 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Baseline No ISA (Phase1)

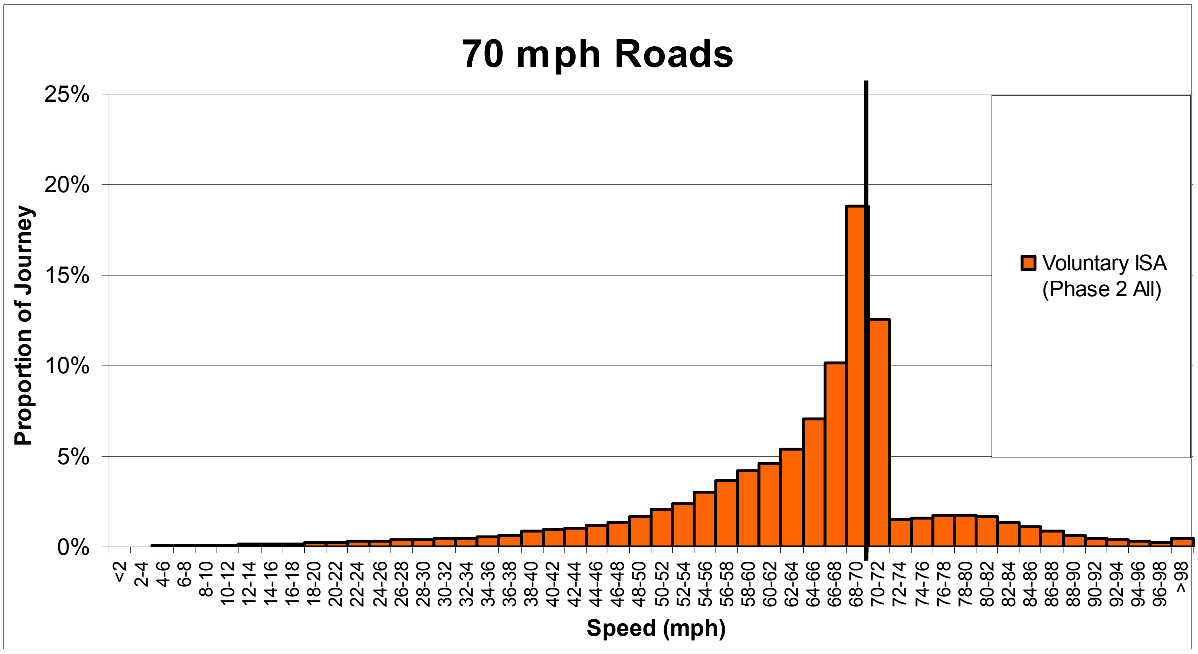

60 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Advisory ISA (estimated)

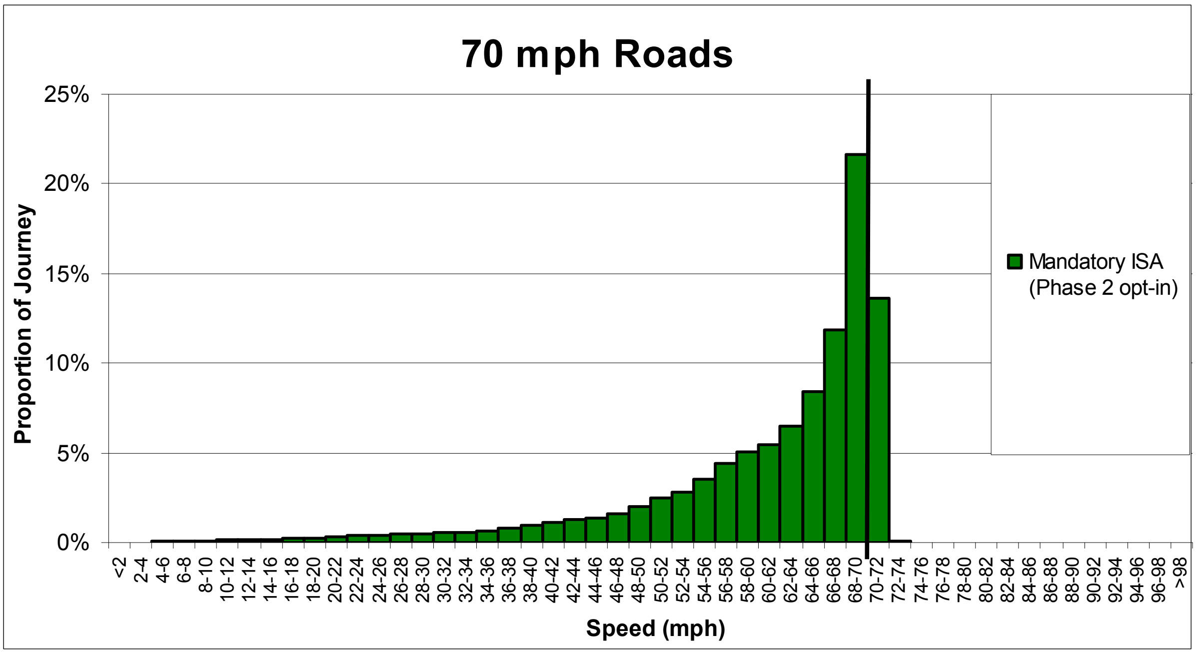

60 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Voluntary ISA (Phase 2 All)
<2 2-4 4-6 6-8 8-10 10-12 12-14 14-16 16-18 18-20 20-22 22-24 24-26 26-28 28-30 30-32 32-34 34-36 36-38 38-40 40-42 42-44 44-46 46-48 48-50 50-52 52-54 54-56 56-58 58-60 60-62 62-64 64-66 66-68 68-70 70-72 72-74 74-76 76-78 78-80 80-82 82-84 84-86 86-88 88-90 90-92 92-94 94-96 96-98 >98


60 mph Roads
Proportion of Journey
25%
20%
15%
10%
5%
0%
Speed (mph)
Mandatory ISA (Phase 2 opt-in)
<2 2-4 4-6 6-8 8-10 10-12 12-14 14-16 16-18 18-20 20-22 22-24 24-26 26-28 28-30 30-32 32-34 34-36 36-38 38-40 40-42 42-44 44-46 46-48 48-50 50-52 52-54 54-56 56-58 58-60 60-62 62-64 64-66 66-68 68-70 70-72 72-74 74-76 76-78 78-80 80-82 82-84 84-86 86-88 88-90 90-92 92-94 94-96 96-98 >98


70 mph Roads
25%
20%
15%
10%
5%
0%
Proportion of Journey
Baseline No ISA (Phase1)
<2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
26-28
28-30
30-32
32-34
34-36
36-38
38-40
40-42
42-44
44-46
46-48
48-50
50-52
52-54
54-56
56-58
58-60
60-62
62-64
64-66
66-68
68-70
70-72
72-74
74-76
76-78
78-80
80-82
82-84
84-86
86-88
88-90
90-92
92-94
94-96
96-98
>98
Speed (mph)


70 mph Roads
25%
20%
15%
10%
5%
0%
Proportion of Journey
Advisory ISA (estimated)
<2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
26-28
28-30
30-32
32-34
34-36
36-38
38-40
40-42
42-44
44-46
46-48
48-50
50-52
52-54
54-56
56-58
58-60
60-62
62-64
64-66
66-68
68-70
70-72
72-74
74-76
76-78
78-80
80-82
82-84
84-86
86-88
88-90
90-92
92-94
94-96
96-98
>98
Speed (mph)


70 mph Roads
25%
20%
15%
10%
5%
0%
Proportion of Journey
Voluntary ISA (Phase 2 All)
<2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
26-28
28-30
30-32
32-34
34-36
36-38
38-40
40-42
42-44
44-46
46-48
48-50
50-52
52-54
54-56
56-58
58-60
60-62
62-64
64-66
66-68
68-70
70-72
72-74
74-76
76-78
78-80
80-82
82-84
84-86
86-88
88-90
90-92
92-94
94-96
96-98
>98
Speed (mph)


70 mph Roads
25%
20%
15%
10%
5%
0%
Proportion of Journey
Mandatory ISA (Phase 2 opt-in)
<2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
26-28
28-30
30-32
32-34
34-36
36-38
38-40
40-42
42-44
44-46
46-48
48-50
50-52
52-54
54-56
56-58
58-60
60-62
62-64
64-66
66-68
68-70
70-72
72-74
74-76
76-78
78-80
80-82
82-84
84-86
86-88
88-90
90-92
92-94
94-96
96-98
>98
Speed (mph)

APPENDIX B: SPEED CRASH RISK MODELS PROPOSED BY KLOEDEN INCLUDING CONFIDENCE INTERVALS

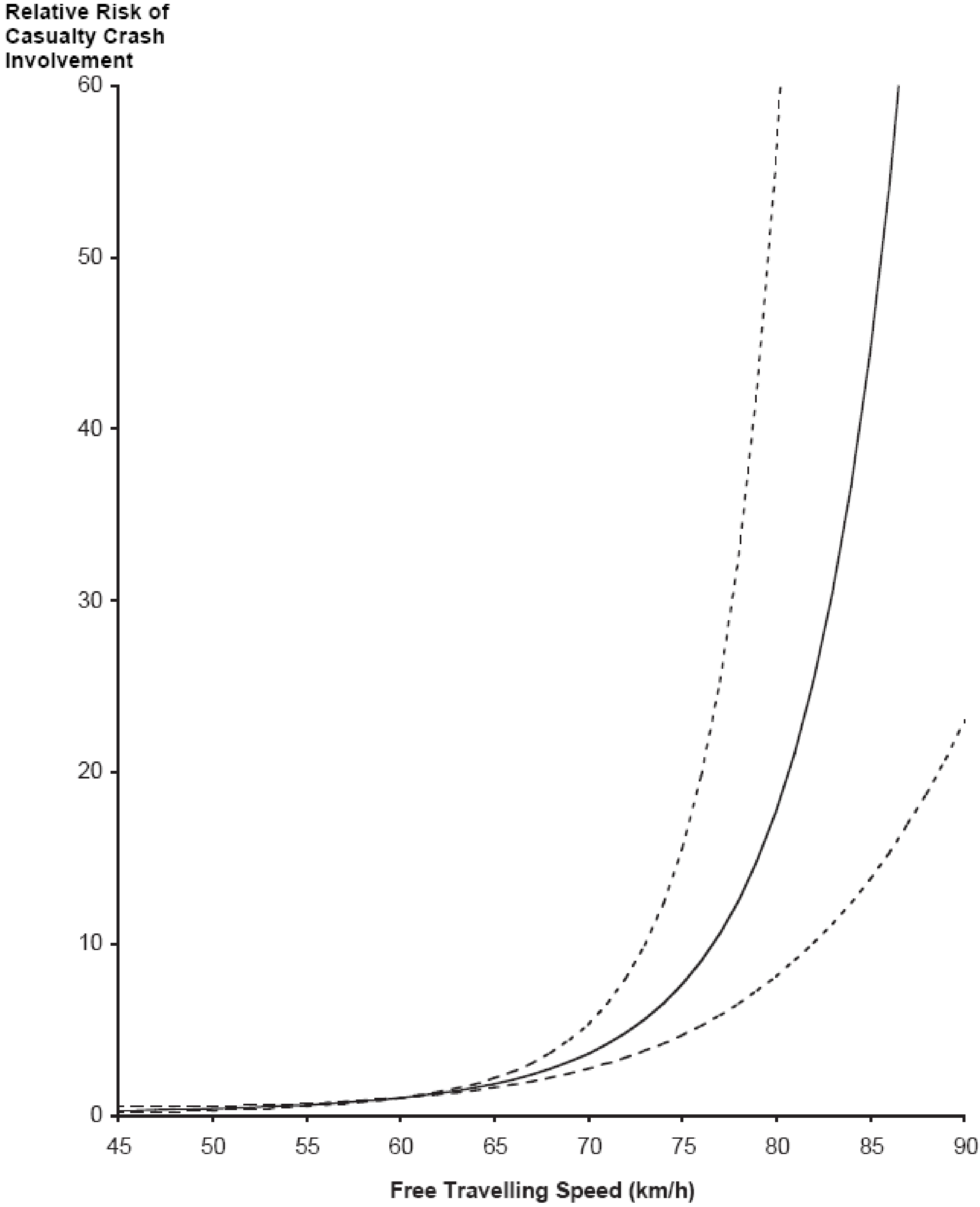
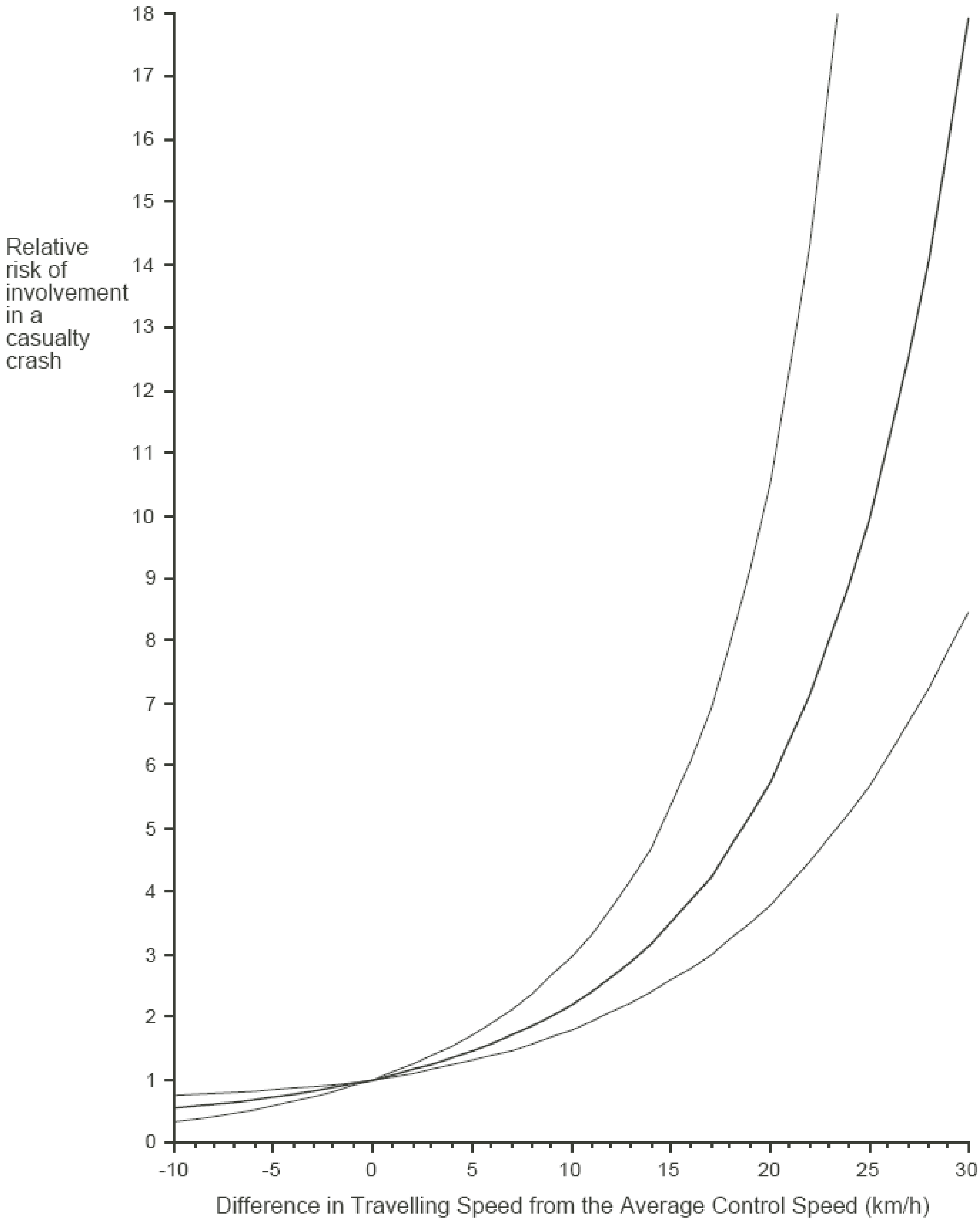


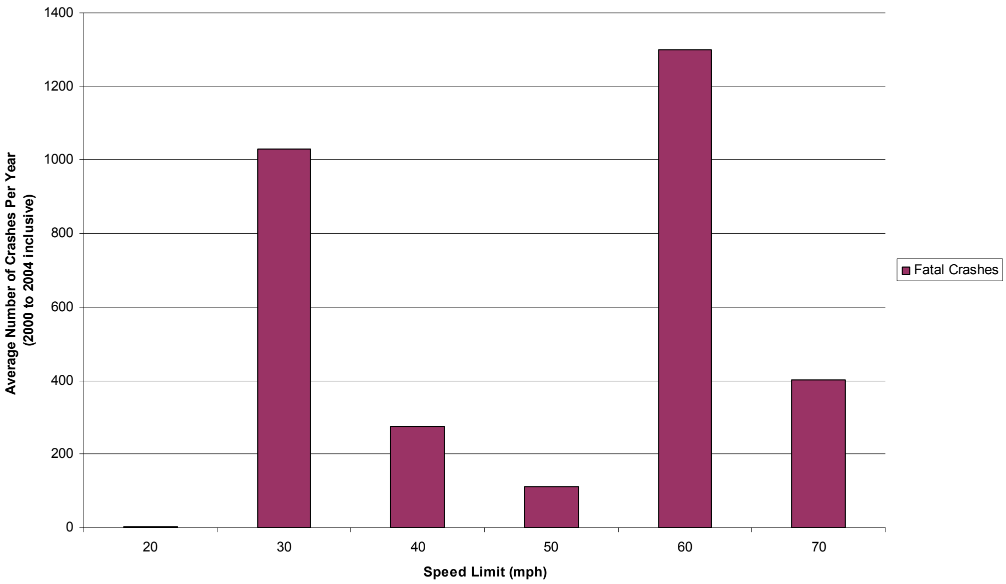
Figure 36: Modelled relationship between free travelling speed on 60 km/h roads and the risk of involvement in a serious crash showing 95% confidence interval (source: Kloeden et al., 2002)

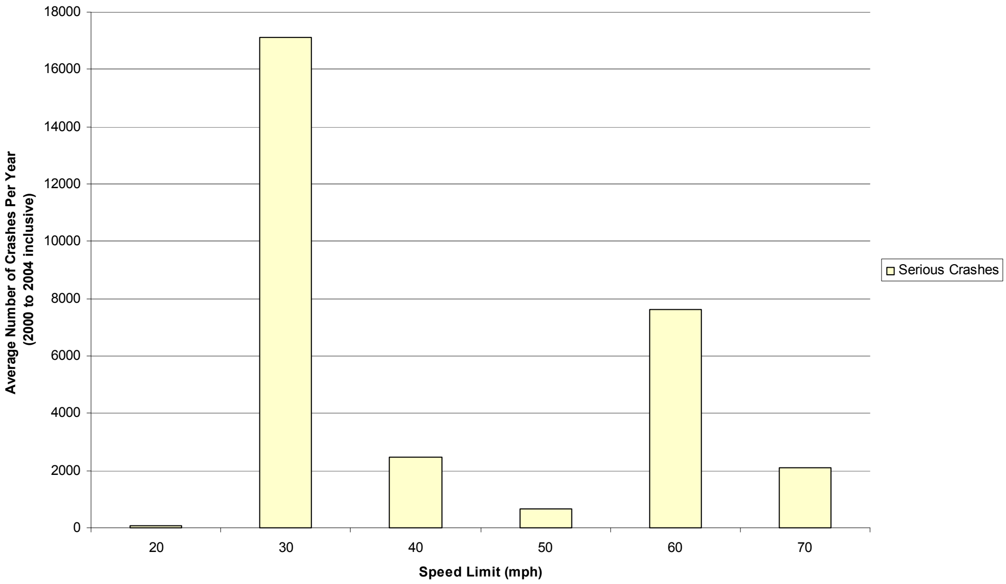


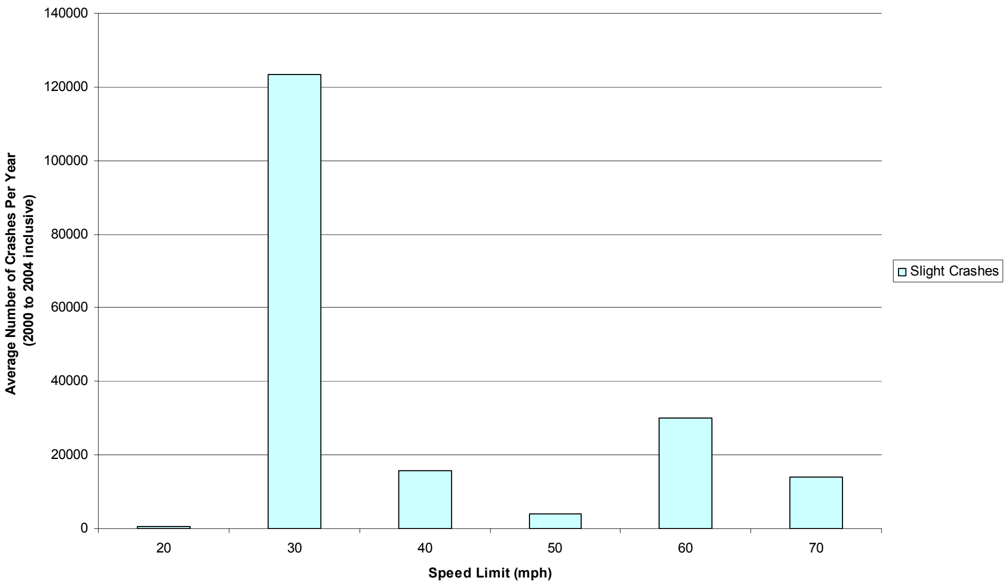
Note: 95 per cent confidence intervals are shown by the thin lines

Figure 37: Modelled relationship between deviation from mean speed on rural roads (speed limit 80 km/h to 110 km/h) and the risk of involvement in a serious crash showing 95% confidence interval (source: Kloeden et al., 2001)

APPENDIX C: DISTRIBUTION OF CRASH SEVERITY BY SPEED LIMIT FOR GREAT BRITAIN


1400
1200
1000
800
600
400
200
0
Average Number of Crashes Per Year (2000 to 2004 inclusive)
20
30
40
50
60
70
Speed Limit (mph)
Fatal Crashes


18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Average Number of Crashes Per Year (2000 to 2004 inclusive)
20
30
40
50
60
70
Speed Limit (mph)
Serious Crashes


140000
120000
100000
80000
60000
40000
20000
0
Average Number of Crashes Per Year (2000 to 2004 inclusive)
20
30
40
50
60
70
Speed Limit (mph)
Slight Crashes

APPENDIX D: CRASH REDUCTION FACTORS USED IN ANALYSIS

		Speed Limit (mph)					
Base Combination		20	30	40	50	60	70
Advisory	All Injury	0.9637	0.9973	0.9932	0.9593	0.9190	0.9893
	Fatal	0.9356	0.9952	0.9878	0.9279	0.8590	0.9808
	Serious	0.9566	0.9968	0.9918	0.9513	0.9036	0.9872
	Slight	0.9780	0.9984	0.9959	0.9754	0.9506	0.9936
Voluntary	All Injury	0.6465	0.8495	0.7470	0.8358	0.8809	0.9106
	Fatal	0.4560	0.7456	0.5915	0.7241	0.7959	0.8449
	Serious	0.5925	0.8223	0.7047	0.8064	0.8588	0.8937
	Slight	0.7697	0.9068	0.8394	0.8980	0.9267	0.9454
Mandatory	All Injury	0.3711	0.6040	0.4858	0.7167	0.8610	0.8241
	Fatal	0.1679	0.4035	0.2727	0.5490	0.7638	0.7059
	Serious	0.3044	0.5460	0.4205	0.6705	0.8356	0.7928
	Slight	0.5517	0.7390	0.6485	0.8188	0.9141	0.8904
Second Combination							
Advisory	All Injury	0.9637	0.9973	0.9932	0.9593	0.9190	0.9652
	Fatal	0.9356	0.9952	0.9878	0.9279	0.8590	0.9382
	Serious	0.9566	0.9968	0.9918	0.9513	0.9036	0.9583
	Slight	0.9780	0.9984	0.9959	0.9754	0.9506	0.9790
Voluntary	All Injury	0.6465	0.5712	0.5985	0.8358	0.8809	0.9106
	Fatal	0.4560	0.3649	0.3970	0.7241	0.7959	0.8449
	Serious	0.5925	0.5107	0.5401	0.8064	0.8588	0.8937
	Slight	0.7697	0.7146	0.7349	0.8980	0.9267	0.9454
Mandatory	All Injury	0.3711	0.3621	0.3137	0.7167	0.8610	0.8241
	Fatal	0.1679	0.1607	0.1241	0.5490	0.7638	0.7059
	Serious	0.3044	0.2956	0.2488	0.6705	0.8356	0.7928
	Slight	0.5517	0.5436	0.4988	0.8188	0.9141	0.8904
Third Combination							
Advisory	All Injury	0.9759	0.9869	0.9719	0.9825	0.9521	0.9652
	Fatal	0.9570	0.9766	0.9499	0.9687	0.9155	0.9382
	Serious	0.9711	0.9843	0.9663	0.9790	0.9428	0.9583
	Slight	0.9855	0.9921	0.9830	0.9895	0.9710	0.9790
Voluntary	All Injury	0.8012	0.8049	0.8515	0.9795	0.9181	0.9106
	Fatal	0.6711	0.6767	0.7488	0.9634	0.8575	0.8449
	Serious	0.7665	0.7708	0.8246	0.9755	0.9026	0.8937
	Slight	0.8755	0.8779	0.9081	0.9877	0.9500	0.9454
Mandatory	All Injury	0.5221	0.6571	0.7206	0.7167	0.8610	0.8241
	Fatal	0.3104	0.4696	0.5544	0.5490	0.7638	0.7059
	Serious	0.4584	0.6042	0.6748	0.6705	0.8356	0.7928
	Slight	0.6771	0.7773	0.8215	0.8188	0.9141	0.8904

APPENDIX E: PREDICTED CRASHES 2010 TO 2070

Base Combination of Crash Reduction Prediction Models

		Speed Limit 20	30	40	50	60	70	Total
No ISA	Fatal	279	55688	16570	6745	63767	25704	168753
	Serious	5964	912530	127294	35133	333871	134851	1549644
	Slight	49428	7221101	907927	244349	1577065	1094271	11094141
Market Driven	Fatal	228	51886	14711	5945	54380	24335	151484
	Serious	5164	869067	117028	32249	300142	129948	1453597
	Slight	45767	7041138	868355	233925	1495013	1073888	10758086
Authority Driven	Fatal	134	37768	9618	4855	51784	21246	125406
	Serious	3475	693083	85884	28043	290423	118470	1219379
	Slight	36656	6241480	733802	217584	1470388	1024321	9724231
Authority Driven 2040	Fatal	127	36166	9174	4757	51612	20940	122775
	Serious	3329	671890	82850	27644	289771	117302	1192787
	Slight	35743	6139703	719300	215966	1468714	1019139	9598563
Authority Driven 2035	Fatal	120	34498	8699	4652	51421	20617	120007
	Serious	3173	649949	79646	27222	289050	116073	1165112
	Slight	34781	6034817	704135	214259	1466866	1013704	9468560

Second Combination of Crash Reduction Prediction Models

		Speed Limit 20	30	40	50	60	70	Total
No ISA	Fatal	279	55688	16570	6745	63767	25704	168753
	Serious	5964	912530	127294	35133	333871	134851	1549644
	Slight	49428	7221101	907927	244349	1577065	1094271	11094141
Market Driven	Fatal	228	46467	13891	5945	54380	23588	144498
	Serious	5164	796341	111702	32249	300142	127298	1372895
	Slight	45767	6686268	844242	233925	1495013	1062978	10368193
Authority Driven	Fatal	134	26134	7689	4855	51784	20994	111591
	Serious	3475	517236	70926	28043	290423	117579	1027683
	Slight	36656	5260472	650800	217584	1470388	1020674	8656574
Authority Driven 2040	Fatal	127	25152	7305	4757	51612	20689	109642
	Serious	3329	500425	67796	27644	289771	116414	1005379
	Slight	35743	5155481	632808	215966	1468714	1015508	8524219
Authority Driven 2035	Fatal	120	24005	6875	4652	51421	20372	107445
	Serious	3173	481528	64398	27222	289050	115208	980578
	Slight	34781	5040862	613711	214259	1466866	1010166	8380643

Third Combination of Crash Reduction Prediction Models

		Speed Limit						Total
		20	30	40	50	60	70	
No ISA	Fatal	279	55688	16570	6745	63767	25704	168753
	Serious	5964	912530	127294	35133	333871	134851	1549644
	Slight	49428	7221101	907927	244349	1577065	1094271	11094141
Market Driven	Fatal	247	50198	14947	6540	57816	23588	153336
	Serious	5489	849288	118700	34415	312711	127298	1447901
	Slight	47359	6957009	876228	241832	1526131	1062978	10711538
Authority Driven	Fatal	169	37973	12139	5373	53747	20994	130395
	Serious	4175	699236	102830	29941	297652	117579	1251413
	Slight	40823	6287349	813624	224565	1488393	1020674	9875428
Authority Driven 2040	Fatal	161	36995	11868	5143	53253	20689	128109
	Serious	4020	686359	101232	29057	295802	116414	1232885
	Slight	39996	6225907	807046	221149	1483705	1015508	9793312
Authority Driven 2035	Fatal	152	35939	11582	4913	52742	20372	125700
	Serious	3859	672567	99550	28173	293890	115208	1213247
	Slight	39143	6160592	800150	217731	1478864	1010166	9706646