UNIVERSITY OF LEEDS

# Speed Limit Adherence and its Effect on Road Safety and Climate Change

## Final Report

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# Glossary

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|---|---|
| Intelligent Speed Adaptation (ISA) | Driver Assistance System that brings speed limit information into the vehicle |
| Advisory ISA | ISA system that informs the driver of the speed limit and warns the driver when the limit is being exceeded |
| Voluntary ISA | ISA system linked to the vehicle drive-train (engine management and perhaps additionally brakes). By default, the system is enabled, but it may be overridden by the driver at will. |
| Mandatory ISA | Like Voluntary ISA, but without the option to override. |
| Dynamic ISA | An ISA system that in addition to knowledge of fixed speed limits, also has the capability to acquire information about limits that can change over time, such as those imposed on motorways in poor weather, or those imposed when congestion builds up on “controlled” motorways. |

# Executive Summary

## Introduction

Intelligent Speed Adaptation (ISA) is the system which uses information and communications technology to provide speed limit information on a vehicle's dashboard. The typical means to do this is with a digital road map of the kind used in satellite navigation systems, but with the important difference that it also contains speed limit data for every road. When the map is combined with current position information from a GPS (Global Positioning System) receiver, then the ISA can display the speed limit and warn the driver if the vehicle is being driven above the speed limit. This is advisory ISA. The same information about speed limit can be linked to the vehicle's engine management system to provide an intervening ISA. This can take two forms: voluntary (overridable) ISA or mandatory (non-overridable) ISA.

The objectives of this study were to:

- To estimate the impact on the number of people killed or injured (both seriously and slightly) in road accidents that would arise through raising the levels of adherence to speed limits through the voluntary introduction of an ISA system;
- To estimate the impact on carbon emissions, other pollutants (including noise) and fuel consumption that would also arise through the voluntary introduction of an ISA system;
- To identify and estimate other benefits and disbenefits, e.g. journey time reliability, that would also arise through the voluntary introduction of an ISA system;
- To perform cost-benefit analyses comparing the cost of introducing and operating an ISA system with the value of accident savings and the value of reductions in carbon emissions, other pollutants and fuel consumption;
- To estimate the critical mass at which benefits increase rapidly as compared to the numbers of vehicles fitted with a system that is in use;
- To advise how a greater take-up and usage of ISA on a voluntary basis can be encouraged; and
- To identify any disbenefits of ISA and to advise how these can be overcome.

Three variants of ISA have been considered:

1. ***Advisory ISA*** which informs the driver of the speed limit and warns the driver when the limit is being exceeded;
2. ***Voluntary (or Overridable) ISA*** in which the information on speed limit is linked to the vehicle's engine management system and perhaps additionally to the braking system — the system comes on with the vehicle ignition, but it may be overridden by the driver at will;
3. ***Mandatory ISA*** which works like Voluntary ISA, but without the option to override.

Each of these has been considered in terms of an overall ISA system capability that covers all fixed speed limits. Dynamic ISA, which provides speed limits that change with current conditions and which can provide additional benefits, has not been covered.

## The predicted impact of ISA on fuel consumption, emissions, noise and network efficiency

Two methodologies have been applied for assessing the effect of ISA on the environment and on network efficiency: (1) using an emission modelling tool on the recorded speed traces from real-world driving with ISA, and (2) simulation modelling of a variety of traffic networks at increasing levels of ISA penetration. It needs to be recognised that, in modelling future emissions, it is not possible to consider fully the impact of future changes in the emissions performance of the vehicle fleet.

The first approach made use of the actual speeds recorded in the extensive real-world trials with cars equipped with voluntary ISA that were conducted in the ISA-UK project. Seventy-nine drivers participated in the trials, and their recorded speeds were used as an input to an emissions modelling procedure that calculated emissions second-by-second. The calculation engine was based on analysis of real-world emissions data for a wide range of vehicles, both petrol and diesel. The procedure took account of the variety of conditions — accelerations, decelerations and periods of cruising. This detail is highly relevant to ISA, because it will tend not only to affect mean speed but also to prevent acceleration above the speed limit. More traditional speed-emissions curves may fail to fully take into account the variety in vehicle forward momentum and thus may be based on cruising speed rather than on more wasteful accelerations and decelerations.

Data from the initial one month of driving with no ISA provided the baseline. Data from the four months of driving with ISA available provided the comparison. Within that ISA period, a further distinction was made. The times when ISA was not overridden in the ISA-active phase were considered to indicate what would happen with a *mandatory* (non-overridable) ISA, even though the ISA system used in the trials had a slightly “soft” control so that it allowed a limited amount of over-speeding. The entirety of driving in the ISA-active phase provided information on the effect of *voluntary* ISA, taking into account different individuals’ propensity to override.

The table below summarises the overall predicted impact of ISA on $CO_2$ per kilometre travelled for a range of speed limits. No change in emissions was found for voluntary ISA, except on 70 mph roads where there was a reduction of 3.4%. The effect of mandatory ISA varied, depending on speed limit. However, on 70 mph roads, there is a more substantial reduction in $CO_2$ emissions of 5.8%. Overall therefore, the change in emissions on non-70 mph speed limit roads is variable and small, but changes predicted on 70 mph speed limit roads are significant.

**Summary results from the detailed $CO_2$ emissions analysis**

| *Speed Limit (mph)* | *Baseline $CO_2$ (Mean g/km)* | *Voluntary ISA $CO_2$ (g/km)* | | *Mandatory ISA $CO_2$ (g/km)* | |
|---|---|---|---|---|---|
| | | *Mean* | *Change* | *Mean* | *Change* |
| 20 | 222.1 | 222.0 | 0.0±0.5% | 222.4 | +0.1±0.6% |
| 30 | 185.1 | 184.3 | −0.4±0.3% | 184.4 | −0.4±0.3% |
| 40 | 164.0 | 162.1 | −1.2±0.1% | 162.1 | −1.2±0.1% |
| 60 | 148.2 | 148.6 | +0.3±0.1% | 148.6 | +0.3± 0.1% |
| 70 | 170.8 | 165.0 | −3.4±0.3 % | 160.9 | −5.8± 0.7% |

The same speed data was also analysed using more traditional speed-emissions curves. Here, for speed limits below 60 mph, small increases of about 2.8% in $CO_2$ were predicted. For 70 mph roads a decrease of 4.2% in $CO_2$ was predicted.

The network simulation used a type of model, called micro-simulation, in which individual driver-vehicle entities are represented. Both light vehicles (passenger cars) and heavy vehicles (trucks) were present in the traffic stream. The following situations were modelled:

- Two types of ISA — voluntary in which driver decision to override depended on the traffic situation and mandatory (no override);
- ISA penetration at 0%, 20%, 40%, 60%, 80% and 100% of vehicles equipped;
- A variety of times of day;
- Four different networks: a rural network in East Yorkshire, two urban networks in Sheffield and a stretch of motorway near Gateshead.

For this work, the more coarse speed-emissions curves were used. It is recognised that these do not model emissions based on instantaneous speed-acceleration information and it is considered likely that the results from the micro-simulation underestimate the potential impacts of ISA. Impacts of ISA on fuel consumption, CO2, other emissions, noise, and journey time variability were calculated. Given the number of networks, penetration levels, time periods, types of ISA and vehicle categories modelled, a considerable number of predictions were produced.

The major results from the micro-simulation modelling are summarised below:

- In the rural network, neither voluntary nor mandatory ISA had a major impact on overall $CO_2$ emissions or fuel consumption at any level of penetration.
- In the two urban networks, increasing ISA penetration had a small detrimental effect on both $CO_2$ emissions and fuel consumption, increasing both by up to 3%. The detrimental effect is stronger at levels of ISA penetration above 20%. This is because, as indicated by the speed-emissions curves, cars tend to operate most efficiently at speeds above 30 mph.

- On the motorway network, increasing ISA penetration has a small, but positive effect on emissions and fuel consumption, reducing both by up to approximately −3%.
- When there was congestion, the impacts of ISA were reduced.
- Regarding other pollutants, no substantial effects were found.
- Regarding noise, the implementation of ISA systems is likely to make a negligible contribution to reducing overall noise levels. Any benefits would not be directly apparent to any human observer.
- Regarding journey time reliability, this was measured in terms of variability in journey times in the modelled networks. Results were generally inconsistent: there were some indications of small improvements in reliability, particularly with mandatory ISA, but these were counterbalanced by contrary results from other networks.

The micro-simulation results do not fully consider the effects of acceleration and deceleration. Both methodologies indicate a positive impact on motorways, while the micro-simulation finding of a negative impact on $CO_2$ in urban driving can be counterbalanced by the real-world data indicating overall no effect when run though a sophisticated calculation engine. Thus for roads with a speed limit lower than 70 mph, a reasonable overall conclusion is that ISA has no effect on emissions. For 70 mph roads, the larger $CO_2$ saving predicted by the sophisticated methodology is considered to be more reliable than the motorway prediction from the micro-simulation. It also has the advantage that it considers driving round the clock as opposed to just for a few hours in the day. Therefore this result from the more sophisticated emissions calculation procedure was applied later in the cost-benefit analysis.

## Critical mass

Another important finding from the micro-simulation was that there was no “critical mass” effect of ISA. Vehicle speeds were analysed to examine whether, at higher levels of penetration, ISA-equipped vehicles would have a knock-on effect on the speed of vehicles following them in the traffic stream. It was broadly concluded that the impact of penetration was linear, so that the effect at 80% is double that at 40% and so on. This has important implications for the subsequent safety prediction, in that it can be concluded that the safety effects of ISA are directly dependent on the number of equipped vehicles on the roads. It was also found that there were inconsistent results from the various networks as regards the effect of ISA on journey time variability.

## The predicted impact of ISA on accidents

The methodology for predicting the impact of ISA on accidents and casualties reduction is based on using observed or modelled changes in speed choice that result from having a vehicle with ISA fitted. The initial assumption is that ISA changes the distribution of speeds for those vehicles equipped with ISA by reducing the propensity to exceed the speed limit. Depending on the type of ISA fitted, the changes in speeds can be greater or smaller. From those observed or calculated changes in speed distribution, it is possible to apply speed-safety relationships that have been derived from real-world data to calculate predicted changes in number of accidents as ISA penetration increases. It is also possible to calculate the impact of ISA on accident severity using a well-established set of relationships. The major source of information on speeds with ISA was once again the UK field trials with 79 drivers. An adjustment factor for the impact of advisory ISA was obtained from the results of the French project, LAVIA, which conducted a similar set of trials using both voluntary and advisory ISA.

Finally, by combining the information on the numbers of accidents that occurred in the period 2002 through 2006 on various types of road with the risk reduction factors based on the speed-accident relationships, the overall potential of the different types of ISA to reduce injury accidents can be calculated. This potential is the proportion of crashes that would be saved, if a given percentage of ISA-capable vehicles were fitted with a particular variant of ISA.

The table below gives the prediction for the proportions of injury accidents on the entire road network that would be saved with increasing penetration of ISA. The voluntary and mandatory variants of ISA are estimated to be considerably more effective than advisory ISA. Effectiveness goes up with penetration level. At 100% penetration, voluntary ISA would reduce the number of injury accidents by 12% and mandatory ISA by 29%.

**Percentage of injury accidents on all roads that would be saved with ISA fitment**

| ***Penetration*** | ***ISA Variant*** | | |
|---|---|---|---|
| | ***Advisory*** | ***Voluntary*** | ***Mandatory*** |
| 20% | 0.5% | 2.4% | 5.8% |
| 40% | 1.1% | 4.8% | 11.6% |
| 60% | 1.6% | 7.2% | 17.3% |
| 80% | 2.2% | 9.6% | 23.1% |
| 100% | 2.7% | 12.0% | 28.9% |

## How many accidents can be saved with the gradual introduction of ISA?

ISA cannot be introduced overnight. Its impact on accidents in the future depends on the number of vehicles fitted with each type of ISA that are on the roads in any given future year. A scenario-based approach was used to develop alternative views of the future. Following the standard procedure for assessing investment in transport, a 60-year period was examined, with ISA deployment beginning in 2010. Two types of scenario were considered:

1. Scenarios in which just a single variant of ISA is implemented — here advisory, voluntary and mandatory ISA were examined separately to indicate how many accidents each would save over the 60-year time period;
2. Mixed scenarios in which more than one variant of ISA is adopted simultaneously.

The first type of scenario is better at indicating the safety potential of different variants of ISA. The baseline number of accidents by future year was calculated using the standard Department for Transport procedure.

The table below depicts the predicted total number of accidents over the period from 2010 to 2070 under the single variant scenarios. The Mandatory scenario saves the greatest number of fatal and serious accidents. Although it this is not considered to be a realistic proposition because it involves only mandatory systems being fitted, it does indicate the potential from this very strong form of ISA. It can also be seen that ISA has a particular impact on serious and fatal crashes.

**Predicted number of accidents for each ISA implementation scenario**

| ***Scenario*** | ***Accident Severity*** | | | ***Total*** |
|---|---|---|---|---|
| | ***Fatal*** | ***Serious*** | ***Slight*** | |
| Baseline (No ISA) | 166,623 | 1,551,485 | 10,721,146 | 12,439,254 |
| Advisory Only | 152,086<br>(9%) | 1,487,283<br>(4%) | 10,498,879<br>(2%) | 12,138,248<br>(2%) |
| Voluntary Only | 125,198<br>(25%) | 1,262,964<br>(19%) | 9,628,839<br>(10%) | 11,017,001<br>(11%) |
| Mandatory Only | 93,494<br>(44%) | 930,436<br>(40%) | 8,036,446<br>(25%) | 9,060,376<br>(27%) |

Note: percentages in brackets indicate reductions against the baseline

The clear finding from the predictions of the safety impact of ISA over time is that ISA can have a large effect on future accident number and particularly on the more severe crashes. Not surprisingly, the impact of ISA is increased by strategies that lead to higher levels of penetration into the vehicle fleet and also by more rapid introduction of intervening ISA in the form of the voluntary system.

## Cost-benefit analysis of ISA

The cost–benefit analysis calculates the monetised social costs and benefits of ISA introduction over the 60-year period from 2010 to 2070. This allows the benefit-to-cost ratio (BCR) to be calculated. The BCR can be seen as indicating whether there is a case for proceeding with ISA implementation on the grounds that the total benefits that accumulate over the period outweigh the costs of investing in ISA.

Once again, the procedures laid out by the Department for Transport have been followed. For ISA, it is necessary to consider not only the safety benefits discussed in the previous chapter but also the benefits in terms of reduced fuel consumption and emissions. It is also of course necessary to estimate the profile of ISA equipment costs over the period and to estimate what additional costs might be incurred by for example, the need to supply digital road maps incorporating speed limits.

The costs of compiling a digital road map incorporating speed limits are comparatively small and the resulting maps would have many other uses. Keeping the information up-to-date would be no more costly than with current manual processes. It is therefore not considered appropriate to ascribe the cost of compiling the initial map to ISA. Broadcasting of updates to the maps, so that the in-vehicle information was up-to-date, would also be quite cheap, and broadcasting services would be used by other traffic management applications, so it is not considered appropriate to ascribe these costs solely to ISA. The major costs of ISA are related to the in-vehicle equipment. The table below shows the prediction of costs over the time period. It is assumed that, as with other electronic equipment, ISA costs will fall substantially over time, but that beyond 2020 costs will not decline further. Retrofitting of ISA is considerably more expensive than fitting as original equipment on new vehicles, because of the required labour.

**Estimated costs for in-vehicle ISA hardware (pounds)**

| | *New vehicle* | | *Retrofit* | |
|---|---|---|---|---|
| | *Advisory* | *Voluntary/ Mandatory* | *Advisory* | *Voluntary/ Mandatory* |
| 2010 | 90 | 200 | 247 | 357 |
| 2015 | 60 | 160 | 233 | 333 |
| 2020 | 60 | 135 | 250 | 325 |
| 2025 | 60 | 135 | 266 | 341 |
| 2030 | 60 | 135 | 282 | 357 |
| 2035 | 60 | 135 | 305 | 380 |
| 2040 | 60 | 135 | 330 | 405 |
| 2045 | 60 | 135 | 354 | 429 |
| 2050 | 60 | 135 | 380 | 455 |
| 2055 | 60 | 135 | 406 | 481 |
| 2060 | 60 | 135 | 433 | 508 |
| 2065 | 60 | 135 | 467 | 542 |
| 2070 | 60 | 135 | 503 | 578 |

The modelled benefits of ISA are:

- The values of fatal, serious and slight accidents as set by the Department for Transport;

- The value of fuel savings as indicated by the emissions analyser used on the ISA-UK field trial data (proportional fuel savings have been considered to be equivalent to $CO_2$ savings);
- The social value of $CO_2$ savings as set by the Department for Transport.

The table below depicts the predicted total quantity of $CO_2$ and fuel saved over the period from 2010 to 2070 under the single-system implementation scenarios.

**Savings in emissions and fuel by ISA implementation scenario**

| *Implementation scenario* | *$CO_2$ (tonnes)* | *Fuel (litres)* |
|---|---|---|
| Advisory ISA only | 0 | 0 |
| Voluntary ISA only | 15,009,557 | 23,470,842,292 |
| Mandatory ISA only | 25,604,538 | 40,038,495,675 |

The calculated social benefits of the accident savings far outweigh the values of fuel or $CO_2$ saved. One method of accident prediction produced smaller overall accident savings, because a greater reduction on baseline (i.e. no ISA) accidents was predicted. Using the resulting more conservative estimates, the overall benefit-to-cost ratios (BCRs) over the whole 60-year period considered are 10.3 for the Mandatory scenario, 5.0 for the Voluntary scenario and 2.4 for the Advisory scenario. The same analysis can be used to indicate the payback period for ISA implementation, i.e. the date by which the benefits have matched the costs (the costs tend to be larger in the earlier years and the benefits to come later when more vehicles have ISA). Both the Voluntary and Mandatory scenarios cover their accumulated costs by 2017. Even the Advisory scenario covers its costs by 2030.

It can be concluded that implementation of ISA is clearly justified from a social cost and benefit perspective. The scenarios involving intervening forms of ISA (Voluntary and Mandatory) outperform the Advisory one. This is not altogether surprising as the benefit side is dominated by the accident savings where voluntary and mandatory ISA are far more effective than advisory ISA.

## Encouraging the adoption of ISA

Whatever the benefits of ISA, they will not be realised without actual adoption and use by members of the public and business fleets. The major aspects of the work to examine attitudes were first a set of focus groups — four with private motorists and one with fleet managers — and second a Stated Preference (SP) survey of drivers. SP is a survey technique used to understand individuals’ preferences and how they use those preferences to make choices. The aim of SP is to explore how individuals respond to a range of hypothetical choices. Respondents are presented with a number of choice sets, or scenarios, and asked to choose one option from each of the choice sets. For this study, separate survey designs were created for three types of vehicle purchaser (identified via an initial screening question):

1. Those who would buy a mandatory ISA system — these drivers received an SP survey where both systems were offered at a cost to the driver (Group 1 with 490 respondents).

2. Those who would buy a voluntary system — here drivers were required to pay for the voluntary system but received incentives to buy a mandatory system (Group 2 with 503 respondents).

3. Those who like neither system — both systems were offered with discounts and incentives to encourage drivers to purchase an ISA vehicle (Group 3 with 466 respondents).

The relative sizes of the three groups are a reflection of differences in initial attitudes among the respondents. They therefore provide an indication of how opinions are split among the population of drivers as a whole.

Factors influencing decision-making that were investigated were purchase price, insurance discount and annual tax discount. Incentives to use voluntary ISA that were studied were a fuel rebate or cash back on a driver's insurance premium for every mile travelled with the system activated. Interviews were conducted with 1487 drivers at their homes (1459 of the interviews were usable for analysis). The interviews were carried out across Great Britain in randomly selected areas and at addresses randomly selected within each area. Only one driver was interviewed per household.

The focus groups with private drivers revealed that many were sceptical or opposed to this type of technology, although there was greater acceptance for its use on urban roads. In spite of this opposition, it was felt that the most effective method to increase the market penetration of ISA would be through enforcement and legislation making fitment compulsory rather than fiscal incentives. When incentives were considered, it was clear that substantial rebates and discounts would be needed to influence purchasing behaviour. The participants favoured transparent and simple incentive schemes designed to address basic costs associated with motoring such as rebates on insurance, road tax and fuel, and showed little enthusiasm for reward schemes such as preferential parking or leisure vouchers.

The focus group with fleet managers indicated a general lack of support for the ISA systems as the managers did not believe that exceeding the speed limit necessarily reduced a driver's safety. They felt that risk was more affected by driving at inappropriate speeds, which ISA may not be able to tackle. The overwhelming message from the group was that the safety benefits associated with ISA were questionable. ISA would only be adopted if it was proven to save costs particularly in the form of a tangible decrease in fuel costs across the fleet. Other potential cost savings included reduction on wear and tear and repairing accidental damage. If such savings could be proven by means of fleet based field trials, there was little doubt that they would adopt this technology.

The survey results revealed that there were considerable variations in sensitivities and preferences in the sample. The main differences were between the three groups already identified prior to the administration of the survey questionnaire. However, even within the groups, there were major variations such that models of choice between the two systems performed much better when sub-classes within the groups were considered. Thus an individual with very negative prior views about the mandatory system was more likely to fall into Group 2 in the initial screening but might actually see his/her preferences change when faced with better than expected characteristics for the system.

Group 1, who preferred the mandatory system, were willing to pay considerably more for a mandatory ISA than for a voluntary one. Group 2 would generally be willing to purchase voluntary ISA for only modest subsidy, provided the cost is not very large. However, within Group 2, who were supposed to prefer the voluntary system, one sub-class actually preferred the mandatory one without a discount even against voluntary ISA with a considerable incentive. This apparent contradictory preference for the mandatory system in one sub-class (given the allocation on the basis of the prior screening) is a reflection of a significant difference between some people's *expectations* of the characteristics of the ISA systems and the levels that were actually used in the survey. The three remaining sub-classes showed a high level of heterogeneity in preferences and sensitivities. One sub-class could not be persuaded to choose mandatory ISA under virtually any realistic subsidy, one sub-class showed relatively even preferences, and a final sub-class would choose either system at equal probability when voluntary ISA costs £600 and mandatory ISA is provided with a payment of £1450 — so that they hugely prefer the voluntary system. Group 3, who nominally like neither system, is also heterogeneous. When they had to choose one version over another, three sub-classes emerged. One would always choose voluntary ISA, one had a strong preference for mandatory ISA (perhaps indicating that if one had to have ISA, one might as well have the stronger form), and one had roughly equal probability of choosing the two variants. In terms of purchase decisions, in 56% of scenarios Group 3 respondents indicated that they would not buy either of the two systems.

The picture is therefore one of some groups with very entrenched positions (both pro and con) who are not really amenable to persuasion by means of incentives. On the other hand, there are other groups who are amenable to subsidy, particularly on purchase price and fuel cost, or who would be willing to purchase an ISA system if the cost were not too high. It is interesting to note that the analysis revealed that, while there are very significant variations in sensitivities and preferences, these cannot easily be linked to socio-demographic attributes of the respondents. Thus it is not necessarily the case that young male respondents have a strong objection to ISA while older respondents with more expensive cars have a more positive attitude.

## Conclusions and recommendations

The study has predicted substantial benefits from the introduction of ISA. These benefits consist principally of the savings in accidents and in particular in more severe accidents. The savings are substantial under all the scenarios examined, and strategies that promote higher penetration of ISA and earlier adoption of intervening forms of ISA lead to greater impact. Thus ISA can be considered as a system with major safety potential.

The environmental benefits of ISA are real but less considerable. They consist in the main of reductions in fuel consumption and in consequent $CO_2$ emissions. The more detailed second-by-second analysis of the speeds recorded in the field trials with ISA is considered more reliable and leads to larger estimates. It also hints that there may be benefits on roads other than 70 mph roads.

The attitudinal work revealed that the public is segmented into three major groups. There are those who are extremely hostile to ISA and who declare that no amount of incentive would sway them to purchase or use ISA. There is a group of non-committed who indicate that they would be persuaded by the right kind of incentives. And there is a group who appreciate the safety potential of ISA and who do not require any incentives to adopt it. Thus there is the potential for incentive to be wasted on those who do not need them, and a danger that, if adopted, there would be a considerable minority of refusers.

Interestingly, there was significant support in the focus groups for the government moving ahead not only with requiring fitment but also in the longer run with requiring usage. The analogy was drawn with the history of seatbelt wearing. Even among the strong opponents of ISA, there were statements that it they were required to use it, they would comply. On the other hand the generally negative views of the fleet managers are somewhat surprising as it might be expected that they would be among the first to see the benefits of ISA, particularly in terms of reducing operating costs. There is a clear need for a campaign directed at this group.

# 1 Introduction

Intelligent Speed Adaptation (ISA) is the system which brings into the vehicle information on the speed limit for the road on which the vehicle is being driven. The technology behind ISA is usually a digital road map of the kind used in satellite navigation systems, but with the important difference that it also contains speed limit data for every road. When the map is combined with current position information from a GPS (Global Positioning System) receiver, then the ISA can display the speed limit and warn the driver if the vehicle is being driven above the speed limit. This is advisory ISA. The same information about speed limit can be linked to the vehicle's engine management system to provide voluntary (overridable) ISA or even mandatory (non-overridable) ISA.

Research on ISA has been going on for over ten years. In the UK, the ISA-UK project which took place with Department for Transport funding between 2001 to 2006 conducted an extensive set of field trials in which 79 drivers used cars that had been fitted with a voluntary ISA system for their routine everyday driving. The previous work has been mainly focused on the safety implications of ISA. The current study is intended to extend that safety focus and assess in addition the environmental implications of ISA deployment.

The objectives of this study were to:

- To estimate the impact on the number of people killed or injured (both seriously and slightly) in road accidents that would arise through raising the levels of adherence to speed limits through the voluntary introduction of an ISA system;
- To estimate the impact on carbon emissions, other pollutants (including noise) and fuel consumption that would also arise through the voluntary introduction of an ISA system;
- To identify and estimate other benefits and disbenefits, e.g. journey time reliability, that would also arise through the voluntary introduction of an ISA system;
- To perform cost-benefit analyses comparing the cost of introducing and operating an ISA system with the value of accident savings and the value of reductions in carbon emissions, other pollutants and fuel consumption;
- To estimate the critical mass at which benefits increase rapidly as compared to the numbers of vehicles fitted with a system that is in use;
- To advise how a greater take-up and usage of ISA on a voluntary basis can be encouraged; and
- To identify any disbenefits of ISA and to advise how these can be overcome.

The study builds on previous work, including the results of the ISA-UK project and in particular data for the field trials. Those field trials provide a rich source of empirical evidence on how drivers behave with a voluntary ISA system. That evidence base has been used in this project as an aid to estimating both the safety and the environmental impacts of

ISA. However, all the analysis carried out in the current project is new. A cost benefit analysis of ISA from a purely safety perspective was carried out in the ISA-UK project. In the current project the analytical approach has been further refined, the accident data used has been updated to more recent years, and environmental aspects considered in addition.

However, the current project has not considered every permutation of ISA. ISA can be made to be “dynamic” so that it considers not only the fixed speed limit for a road but also prevailing time-dependent speed limits. Examples might be temporary 20 mph limits around schools, lower speed limits in fog on motorways and more generally the whole controlled motorway management scheme in which speed limits vary depending on traffic intensity. An ISA with dynamic capability would require some kind of wireless communication from roadside to vehicle. There is considerable potential for dynamic ISA to assist in the safety and environmental management of the road network. But there has been virtually no real-world research into how drivers would behave with such a system, and there is no consensus on how best to incorporate dynamic ISA in traffic management. These factors make it very difficult to model the potential impacts of the dynamic system. Therefore it has not been considered in this project.

The work here examines the direct effects of ISA, especially in terms of improvements in safety resulting from better compliance with speed limits as well as the potential for reduced fuel consumption and reductions in emissions. But there are other benefits, not covered in the project analysis, that ISA can deliver both to particular sections of the driving population and to the community in general:

- Drivers will have a reduced risk of incurring speeding fines and consequent loss of licence, if they comply with an ISA system;
- Those who wish to comply with the speed limit will be helped to do so by having ISA, and indeed may find that the assistance provided by ISA makes driving less stressful;
- Newly qualified and young drivers may benefit from reduced insurance premiums if they use a car fitted with ISA, particularly if they are willing to allow the insurance company to collect data on speed violations (through the Pay As You Drive approach);
- High mileage drivers and fleet operators should particularly benefit from fuel savings afforded by ISA.

In the long run, ISA can provide cheaper alternatives to current safety improvement techniques. For example, 20 mph zones are currently designed to be self-enforcing by means of quite expensive infrastructural changes — humps, chicanes, pinch points, etc. These features in turn cause additional costs in terms of vehicle wear and tear, wasted fuel, emissions and noise. ISA could provide an alternative approach in the form of electronic traffic calming at negligible cost and without the negative side effects of traditional traffic calming.

However, for the individual driver, ISA may also have some less positive impacts. Most significantly, it can increase journey time, both through discouraging or preventing the reduced journey time that is illegally acquired by speeding and by slowing down vehicles such as HGVs that have a lower speed limit than cars and which can act as moving roadblocks in congested networks. But even this effect is likely to be counterbalanced by the journey time savings that ISA can bring through a reduction in the massive congestion that can be caused by traffic accidents. The direct effects of ISA on journey time are assessed below on page 34; the indirect effects are much harder to quantify.

# 2 Choice of Methodologies

Each component of the project has been addressed with the methodology or methodologies considered most appropriate. In some cases more than one approach has been applied in order to evaluate the sensitivity of the results to the approach chosen. The relationship between the various components of the work is shown in Figure 1. External data sources are shown as ovals.

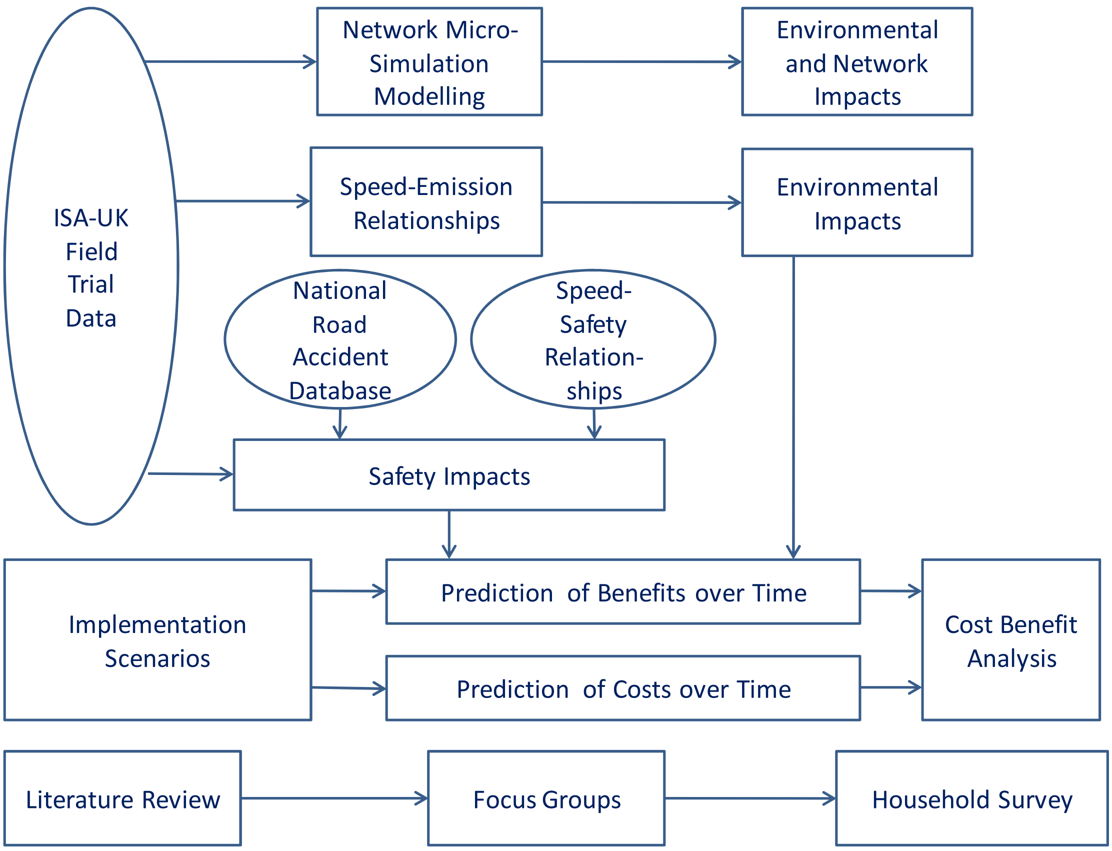



**Figure 1: Links between work components (external data sources are shown as ovals)**

The field trials using a fleet of twenty converted cars conducted in the ISA-UK project (Lai, Chorlton and Carsten, 2007) have provided a major source of empirical data for this work. The objective of the car trials was to investigate how drivers would behave in everyday driving with a car equipped with voluntary ISA. The major focus was on how the ISA system would affect speed choice. A fleet of 20 Skoda Fabia 1.4 Estates was fitted with a voluntary (overridable) ISA system, and these vehicles were used in four successive field trials. The participants in the trials drove a converted car on a daily basis for six months; the first month driving without ISA, the next four months driving with ISA, and the final month driving without ISA once again. The first month of driving served as a baseline for comparison with the ISA activated period, and the final month of driving provided the opportunity to identify any impact of experience with ISA on subsequent driving.

The four trials were:

Trial 1: Leeds area with private motorists
Trial 2: Leeds area with fleet motorists
Trial 3: Leicestershire with private motorists
Trial 4: Leicestershire with fleet motorists

The Leeds trial was in a major urban area, although the speed limit data covered the whole of the Leeds Metropolitan District, which includes some outlying rural areas and villages. The Leicestershire area was mainly rural and small-town. The first trial began early in 2004 and the final trial was completed in the summer of 2006. The total mileage covered by the 79 drivers who completed the trials was 429,487 of which 354,592 miles was on roads with a known speed limit. The mileage covered during the ISA-active phase was 218,790. Speed and position data was collected at 10Hz.

The project task of estimating the effects of ISA on ***fuel consumption and emissions*** has been performed in two ways. The first is by direct use of the recorded speed profiles of the cars used in the extensive field trials of driving with a voluntary ISA that were carried out in the ISA-UK project. These recorded speed profiles were combined with real-life and test-cycle speed-emissions data to produce estimates of fuel consumed and emissions second-by-second. The second approach has been to carry out simulation modelling of a number of networks, looking at how the progressive introduction of ISA affects environmental performance. Those same simulation models have been used to analyse other network effects of ISA, such as noise and reliability.

The task of the ***safety prediction*** has been to estimate the reductions in injury accidents and in casualties at various levels of severity from the adoption of ISA. This has been done by using the changes in the speed choice of drivers that were observed in the four ISA field trials. The baseline (non-ISA) speeds have been compared with the speeds when driving with the voluntary ISA system activated. It should be noted that the drivers were able to override the system at will, but that it defaulted to ISA control being enabled. If the system was overridden, ISA control would resume when vehicle speed returned to below the limit or at the next change in speed limit. The observed changes in speed profiles have then been translated into predicted changes in accident risk using speed-risk models from a considerable body of literature. These models are statistically derived and have been fitted to observed data on speed and crash risk.

One aspect that needs to be considered in making safety predictions about the impact of ISA is whether speed-safety relationships fully capture the changes in safety that result from the introduction of ISA. There might potentially be negative behavioural adaptations, i.e. disbenefits, resulting from the experience of having an ISA. However, there was no confirmation of such changes in the results of the UK trials (Lai, Chorlton and Carsten, 2007):

- There were no changes in the distribution of speeds below the speed limit, when comparing baseline driving to driving with ISA. This indicates that drivers did not surrender their control of the situation to the limiter.

- The drivers indicated that they did not change their choice of headway when driving with ISA.

- Drivers reported that their attention to pedestrians and cyclists and anticipation of conflicts increased when driving with ISA. They disagreed with the proposition that ISA made them less vigilant drivers.

- Detailed assessments of driver performance along a fixed route, which were undertaken at various intervals during the trials using trained observers, found a general improvement with ISA.

Future scenarios for ISA introduction have been developed and these scenarios have been applied to produce estimates of accidents that would be saved with ISA in the future. Those same scenarios have been used in a ***cost-benefit analysis*** of ISA.

Lastly, public ***attitudes*** towards ISA and the susceptibility of members of the public to be encouraged to adopt and use ISA have been investigated through a set of focus groups and a household survey.

# 3 The Predicted Impact of ISA on Fuel Consumption, Emissions, Noise and Network Efficiency

## 3.1 Methodology

### *3.1.1 Introduction*

Fleet trials with new driver assistance systems, such as those conducted in the UK Intelligent Speed Adaptation (ISA-UK) project, do not generally provide direct information on fuel consumption and emissions. Normally, the monitoring equipment needed to record such information second-by-second is not fitted, and the ISA-UK project was no different in this regard.

Still less do they provide information on noise and network efficiency aspects, particularly on how these might be affected at high rates of penetration. Thus it is necessary to use other approaches in order to estimate such effects. For this study, two different overall approaches have been applied:

1. Using the actual speeds recorded in the ISA-UK trials as a basis for calculating emissions. Two analytical methods were applied to these data: (i) using real world emissions data from the Department for Transport, and (ii) using published speed-emissions curves based on test-cycle data.

2. Using network simulation of a variety of networks to estimate how the impacts of ISA vary by type of ISA and by level of ISA penetration into the vehicle fleet.

### *3.1.2 The use of recorded speeds*

The UK trial data provides a very large database of measured vehicle speeds using data from 20 instrumented vehicles driven by 79 drivers. This comprehensive data set provides an opportunity to estimate vehicle emissions of $CO_2$ in a very detailed way by capturing the actual transient nature of real driving conditions. Two approaches have been used for comparison. The first uses a flexible statistical modelling technique known as *Generalized Additive Modelling* (GAM) to develop emissions models at a 1-Hz time resolution. To enable emissions to be calculated at the same time resolution, data from a series of DfT emissions tests have been used to develop the models. These emissions tests provide 1-Hz $CO_2$ emissions for 30 passenger cars tested over a series of "real-world" test cycles. There is a good match therefore between the vehicle activity data, the emissions data and the models subsequently developed. These models are considered to represent the most robust method of estimating emissions changes due to ISA, albeit for a subset of vehicles on the road.

The second approach also uses the ISA trials data but applies a more aggregated approach to calculating emissions by using *speed-emission curves*. These curves have the advantage of simplicity and cover almost all vehicle types and technologies groupings in use. The principal disadvantage of the speed-emission curve approach is that it is not possible for them to take account of actual, specific changes in a vehicle's movement. Because this issue is of prime importance for an intervention such as ISA, this approach is considered to be not as robust as the detailed methods outlined above.

### Recorded speeds combined with DfT emissions testing data

In the ISA trials, speed data was obtained at 10 Hz, and, in addition to speed, the data recording also included time, position, direction of travel, detailed road identification and speed limit (which was known for most roads used). Thus there are “vehicle traces” of speed at a very high level of resolution. The database is very substantial in size, covering 551,181 km of driving with speed limit known. Each driver drove for one initial month without ISA (the baseline), followed by four months with a voluntary ISA activated, and then a final month in which ISA was once again no longer available. For the current study, only the one month of baseline and the four months with ISA available have been used. The initial month provides information on speed traces without ISA. The times when ISA was not overridden in the ISA-active phase are indicative of what would happen with a mandatory (non-overridable) ISA, even though the ISA system used in the trials had a slightly “soft” control so that it allowed a limited amount of over-speeding. The entirety of driving in the ISA-active phase provides information on the effect of voluntary ISA, taking into account different individuals’ propensity to override. The original 10 Hz data were reduced to 1 Hz data in order to make the calculation process tractable. Figure 2 shows a plot of the kind of data produced. The data displayed are for 70 mph roads and the figure shows the comparison of baseline (non-ISA driving) with driving when the ISA system was engaged (not overridden). This latter situation represents driving with a mandatory ISA.

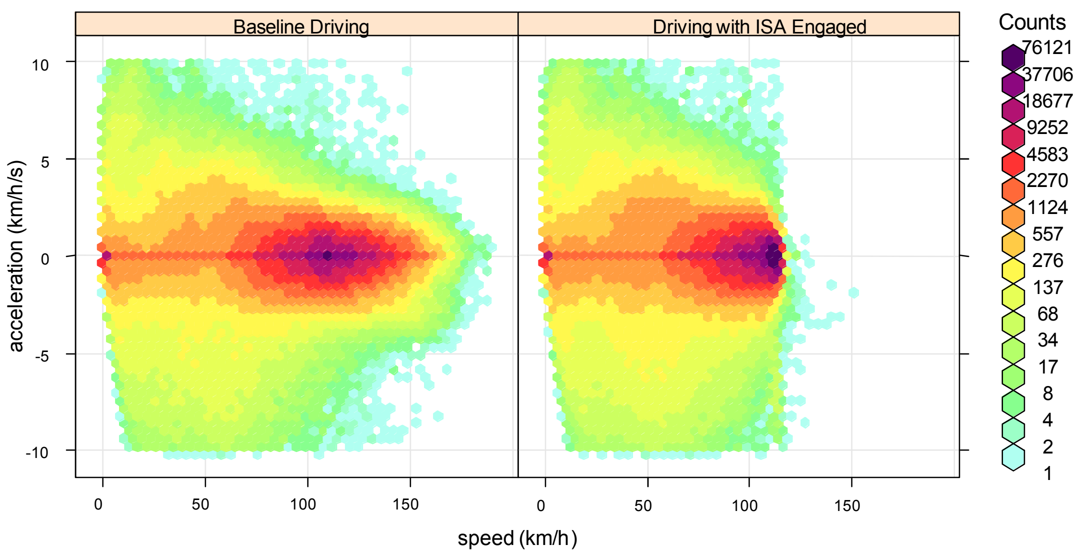



**Figure 2: Frequency of speed and acceleration counts on 70 mph roads**

The 1 Hz speed traces for the 79 drivers could then be used as an input into a calculation engine that would calculate $CO_2$ emissions (approximately equivalent to fuel consumption) second-by-second based on speed and acceleration. The calculation engine was based on analysis of real-world emissions data obtained from DfT. It used emissions testing programmes conducted at the Ricardo and Millbrook test facilities. Emissions data from 30 Euro III and Euro IV petrol and diesel cars were used to develop emissions models. Details of these vehicles are given in Appendix 1. Emissions data were measured over a wide range of "real-world" conditions. These test cycles cover traffic conditions from congested to high-speed motorway driving. One aspect of these (and other) test cycles is that the maximum speed is up to 130 km/h (81 mph) and is somewhat less than actual speeds for many cars using motorways. There is some uncertainty therefore concerning emissions from vehicles at speeds greater than 130 km/h.

The data from the DfT testing programmes were modelled with the Generalized Additive Models (GAMs) which are able to handle non-linear relationships between variables as well as interactions between variables (the situation where variables can have joint effects that are not just additive). This technique has many advantages over the more traditional fuel consumption and emissions modelling approach in which simple speed-emissions curves are applied.

For example, a mean speed of 30 km/h from emissions tests would include a certain amount of accelerations, decelerations and periods of cruising. However, under actual driving conditions a mean speed of 30 km/h can be arrived at in many ways. For the application to ISA, these issues are very important because of the specific effects that speed limiting may have on a vehicle's behaviour, including preventing most acceleration above the current speed limit. The models were also constructed so as to take account of time lags, i.e. of the fact that speed and emissions at one time point are influenced by previous time points. There is not an exact correspondence in time between a vehicle's movement and the tailpipe emission. These time lags are vehicle and operation specific. The models aim to take account of these effects by finding the optimum time lag that produces the best model, and this is done on an individual vehicle basis.

An example of the smooth relationship between vehicle speed, acceleration and $CO_2$ is shown in Figure 3. The plot shows that as either the speed or acceleration increase in magnitude, then so does the emission of $CO_2$. It should be noted, however, that the final models also account for time lag effects, which are not shown here.

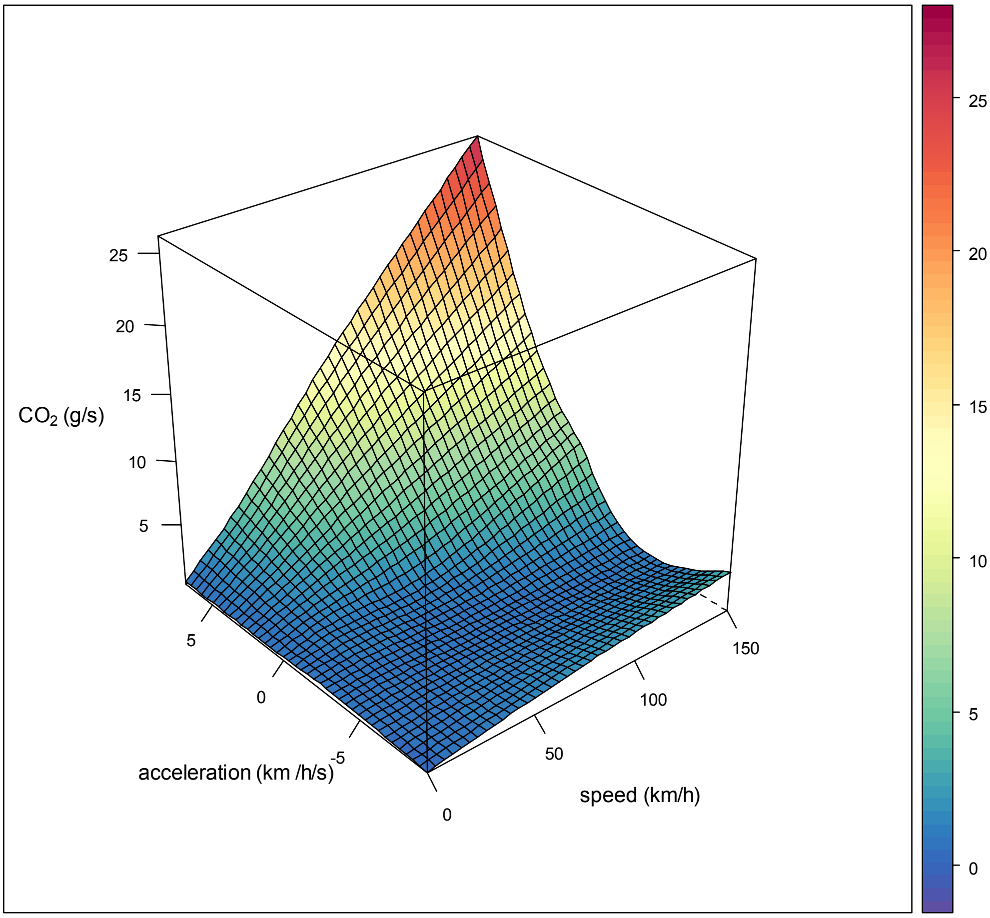



**Figure 3: Relationship between speed, acceleration (km/h/s) and emission of $CO_2$ (gram/s) for one of the 30 cars as predicted by the GAM emissions modelling**

The models produced were assessed using independent data and showed that good predictions could be made of $CO_2$ emissions on a 1-Hz basis. This was achieved by omitting a randomly selected fraction of the data (20% of it) from the model building. The models were then tested on that 20% of withheld data to ensure the model assessment was conducted using data not used in the initial model development. On average, the explained variance ($R^2$) value was 0.95 for petrol and diesel vehicles and there was no obvious bias in the results. The models were shown to capture the full range of speed and acceleration behaviour experienced in real driving conditions. It is considered, therefore, that the models are able to produce reliable estimates of $CO_2$ over a wide range of conditions, from vehicle idling to speeds of 130 km/ h (81 mph).

One limitation of the test cycle data is the maximum speed of 130 km/h. On motorways vehicles do exceed this speed. In the UK, about 19% of passenger cars and 17% of LGVs exceed 80 mph (Vehicle Speeds in Great Britain, 2005). There is therefore greater uncertainty in the emissions estimates for very high speeds. On the other hand, at high speeds changes in vehicle acceleration tend to be small. Considering Figure 3 at zero acceleration shows the gradient of the surface at high speeds is not great and that predictions beyond 80 mph are likely to be reasonable.

Models were produced for each of the 30 vehicles tested for emissions on behalf of DfT. The resulting models were then applied to the ISA field trial speed data (baseline, voluntary and mandatory ISA). The models provide 1-Hz predictions of $CO_2$ emissions for each car in the ISA trials over all driving conditions. In order to make the comparison between the different road types more clear, the data were processed to provide a mean emission rate in g/km across all 30 vehicles tested for emissions.

### Recorded speeds combined with speed-emission curves

A more traditional and less fine-grained approach to emissions modelling is to use speed-emissions curves. Such curves are the primary means of calculating road vehicle emissions in the UK, and they are used in the compilation of the National Atmospheric Emissions Inventory (NAEI). While the data and to some extent the methods have changed over the years, the approach has remained more or less the same. A sample of vehicles is tested over different drive-cycles that aim to replicate actual, typical drive patterns for in-use vehicles. Typically, average speed is plotted against average emission and a curve fitted to provide a polynomial expression, which can then be used to calculate emissions by vehicle type. These relationships are shown in Figure 4 for different types of car (fuel, engine size and Euro class). In general, there is a “U”-shape relationship, with notably higher emissions at low speeds. Indeed higher emissions at low speeds are expected when plotting the data in this way as the emissions will tend towards infinity as the speed approaches zero. This approach is useful for many applications because vehicle speed is a readily available variable. The disadvantage of this approach is that for any speed, there is an implicit assumption about the dynamics of the vehicle (e.g. duration and magnitude of accelerations), i.e. that the dynamics essentially match those in the emissions test cycles. While on average these relationships may provide good estimates of emissions, under the specific changes brought about by an intervention such as ISA, this may not be the case.

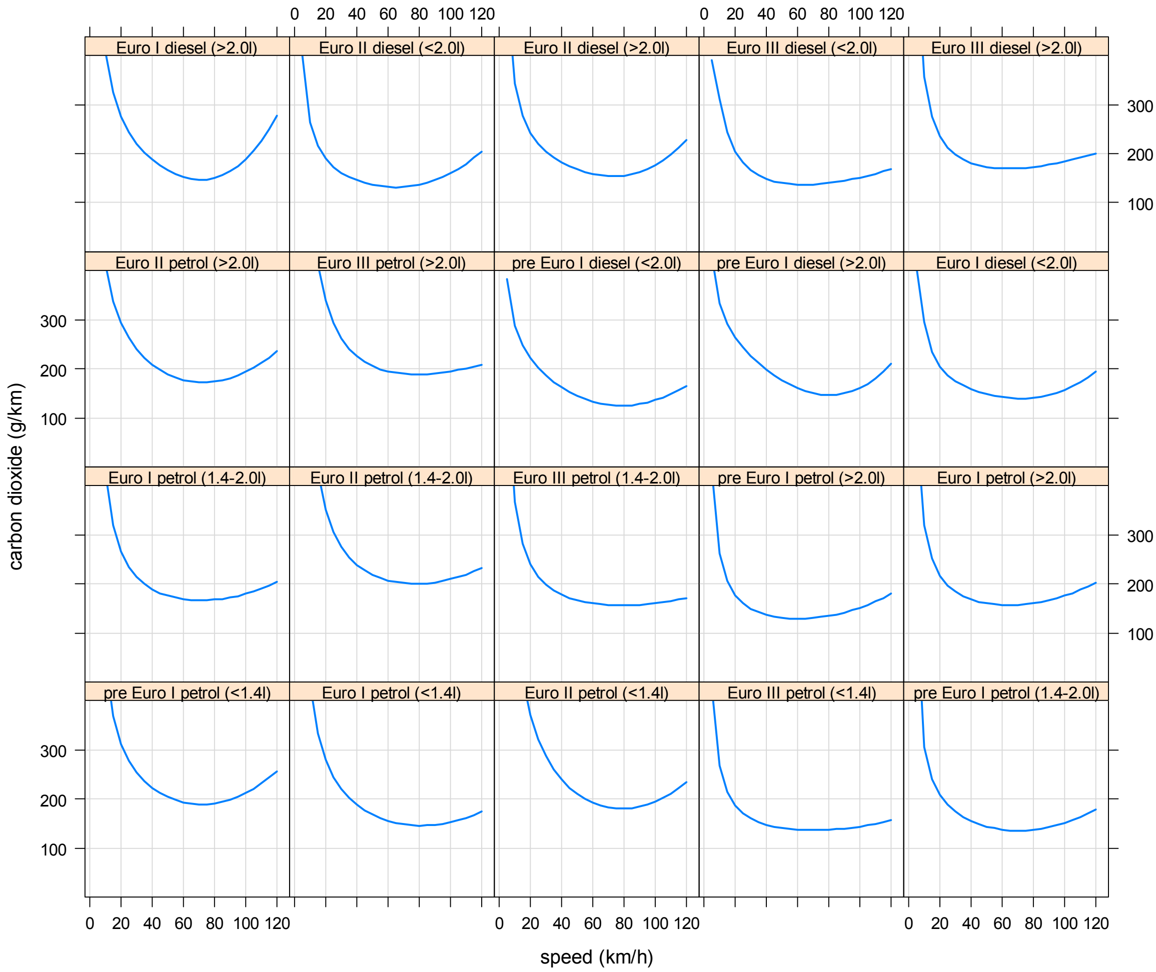



**Figure 4: Speed-emission curves for $CO_2$ of the type used by the NAEI but including more recent data from Collier et al. (2005)**

### *3.1.3 Network simulation*

Looking at the impact of ISA on $CO_2$ and other emissions using the speeds recorded in the field trials is a useful method for looking at the environmental implications of ISA when a few cars are equipped under current traffic conditions. But this approach does not provide a very good handle on scaling up the effects of ISA if it is widely deployed. Here questions to be examined are what might be the network-wide effects of ISA at higher levels of penetration, or whether as penetration of ISA increases there is a knock-on effect of ISA-equipped vehicles on other vehicles. It is also important to examine the effects of equipping other vehicles than passenger cars, such as large trucks, with ISA.

To study such effects under a variety of traffic conditions, traffic micro-simulation has been used. Traffic micro-simulation studies the actions of individual vehicles as they travel through road networks. Micro-simulation operates by updating vehicle positions on a time-slice basis (usually 1-Hz or greater) in accordance with rules governing such behaviour as: following leading vehicles, accepting gaps at conflict points, changing lanes and responding to traffic signals. Each vehicle is defined by a number of kinematic and behavioural parameters including, for example, length, maximum acceleration or deceleration, driver willingness to obey the speed limit, reaction time etc.

There has been extensive prior use of micro-simulation models to assess the effects of ISA (e.g. Liu, Tate and Boddy, 1999 or Liu and Tate, 2004), given their ability to effectively replicate on-street speed and acceleration behaviour. The traffic micro-simulation toolkit chosen for modelling in this instance was AIMSUN NG 5.1.10 by Transport Simulation Systems (TSS) of Barcelona, Spain (TSS, 2006). AIMSUN has previously been used in hypothetical assessments of the effects of ISA on noise levels for Swedish roads within the EU project QCITY. AIMSUN was used because it has the capability of replacing its internal models of driver behaviour and response with new special-purpose ones. This feature was particularly attractive, because it permitted the representation of a voluntary ISA that might be overridden depending on situation and driver propensity to override.

For this project, the baseline AIMSUN model has been extended to:

- interface with NAEI speed-emissions curves (as described in the previous section) to provide emissions estimates for all pollutants in the NAEI database (Carbon Monoxide, Carbon Dioxide, Oxides of Nitrogen, Total Hydrocarbons, Benzene, 1,3-Butadiene and Particulate Matter) as well as estimate consumption of fuel;

- interface with the HARMONOISE/IMAGINE emissions curves for noise (Peeters and van Blokland, 2007);

- use a bespoke car-following model which allows the modelling of both *voluntary/advisory* ISA systems, as well as *mandatory* ISA systems within the same overall framework. Initial validation of this model has been achieved through the use of calibration data from the ISA-UK field trials.

As noted previously, the use of speed-emissions curves is not ideal, given that the aggregation of data used in their generation fails to reflect emissions based on instantaneous speed-acceleration information, which is readily available from micro-simulation. Hence it may be expected that the results from the micro-simulation underestimate the potential impacts of ISA.

Four real-world locations have been studied, which represent three distinct driving scenarios, on *rural*, *urban* and *motorway* road networks. Temporally, data from at least the AM- and PM- peak periods have been analysed, with some data available for inter-peak periods. Obviously, the presence of congestion in the peak periods is a potential limiting factor to the effectiveness of ISA systems.

The **rural network** represents an 11 km stretch of the A614 in the East Riding of Yorkshire, between the towns of Howden and Holme-on-Spalding-Moor, as shown in Figure 5. The road between the towns is a typical single-carriageway road, subject to the National Speed Limit (60 mph or 96.5 km/h for cars, 40 mph or 64.4 km/h for HGVs) along the majority of its length, though with some sections restricted to 30 or 40 mph (48 or 64 km/h). This road was chosen because it has both straights (where overtaking is allowed) and sharp curves. It also, like many other rural arterials, has a mix of truck, commuting and leisure traffic. The network was created in AIMSUN specifically for this study, and calibrated and validated, using data collected on-site in October-November 2007. AM (08:00 – 09:00), PM (17:00 – 18:00) and Inter-peak (10:00 – 11:00) periods have been analysed, though there was little variation in between the three periods. The effects of ISA on this section of road have previously been studied by Liu, Tate and Boddy (1999).

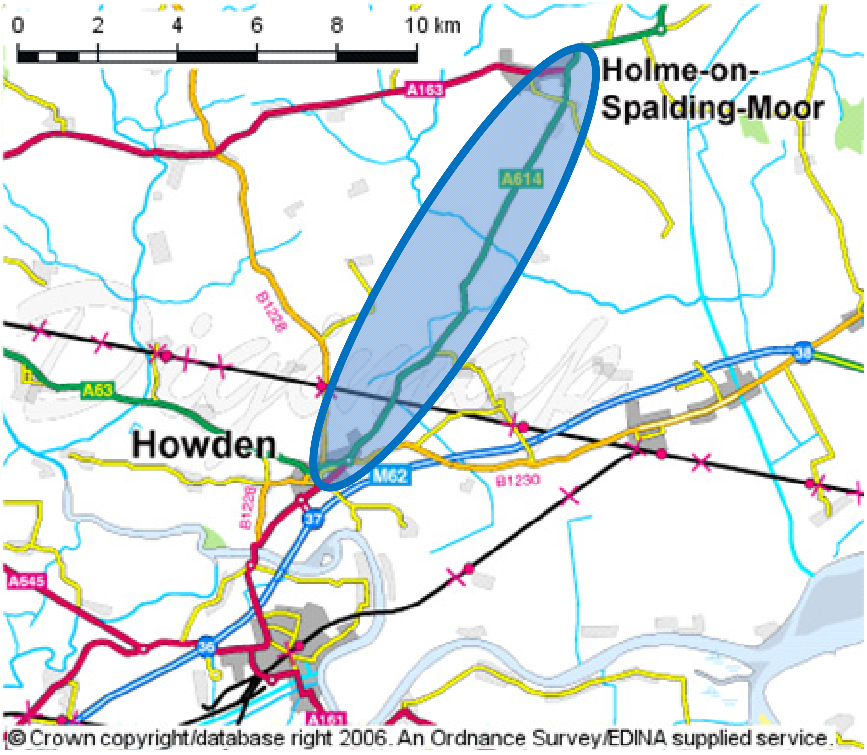



**Figure 5: The A614 rural network**

The rural network has a typical total traffic flow of approximately 900 vehicles per hour, with approximately 12% of those vehicles being HGVs. The mean modelled network speed is approximately 44 mph (70 km/h). Direct observation of speed at two locations subject to the National Speed Limit revealed some vehicles travelling at far higher speeds (up to 74 mph/119 km/h). Approximately 8% of passenger cars and 79% of HGVs were observed exceeding the 60 mph and 40 mph limits respectively — these figures are consistent with those reported in *'Vehicle Speeds in Great Britain: 2005'* (Department for Transport, 2006), and are duplicated by the base case model. All junctions within the network are considered as priority (give-way) intersections

During all periods traffic may be considered as freely flowing, though some platooning and aggressive overtaking behaviour was observed. This latter behaviour cannot be successfully duplicated in the current AIMSUN simulation, which lacks an opposed overtaking model. Hence it would be expected that the implementation of ISA on the network would be somewhat over-modelled, especially when the effects of a mandatory 40 mph limit on HGVs is imposed. Therefore a modified version of the AM network was also tested, with two short

(<400m) sections of dual-carriageway added to allow some overtaking at points on the network.

Two **urban networks** have been studied, one representing roads within the Sheffield S10 postcode area to the west of Sheffield City Centre, the other representing roads along the Sheaf Valley to the South of the City Centre, as shown in Figure 6. Both networks are based on pre-existing data provided by Halcrow Consultants Ltd and Sheffield City Council. Both feature a mix of junctions of various types, i.e. signalised, priority and roundabout. The networks also possess public transport features: i.e. timetabled routes and stops for buses and trams (S10 network only). Data for both networks cover the AM peak period from 06:30 to 08:30 and the PM peak period for 16:30 to 18:30. Additional inter-peak data was available for the S10 network. Both networks feature roads mainly subject to urban, 30 mph speed limits.

The baseline modelled S10 network has a typical total flow per period of approximately 22,000 vehicles in the AM peak (07:30–09:30), approximately 19,000 in the PM peak (16:30–18:30) and approximately 24,000 in the inter-peak period (10:00–14:00). The percentage of large vehicles is around 3% in both peaks, and around 7% in the inter-peak, with the majority of such vehicles being buses. The mean network modelled speeds for both peak periods are low, at around 12-16 mph (20-26 km/h), with congestion observed at a number of points in the network, often involving several junctions. Overall mean speeds in the inter-peak period are somewhat higher, but still limited by the number of junctions in the network to typically below 32 km/h.

The baseline Sheaf Valley network has a typical flow of approximately 40,000 vehicles in the AM peak and approximately 35,000 vehicles in the PM peak with roughly 2% being HGVs. As with the S10 network, mean modelled speeds are less than 16 mph (26 km/h) for a sizable proportion of both peak periods.

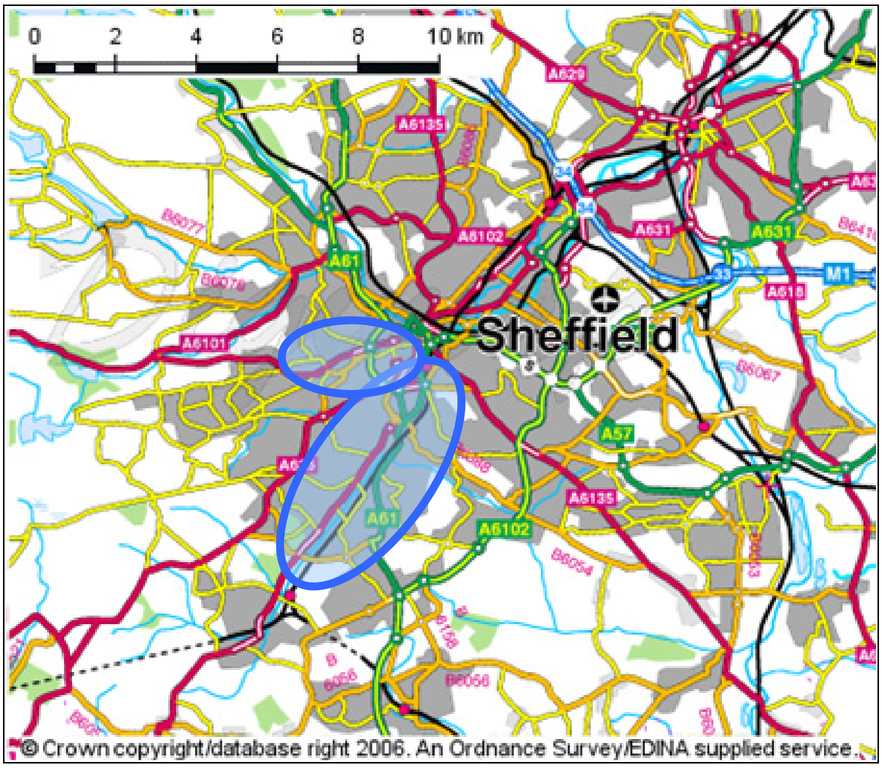



**Figure 6: The Sheffield S10 and Sheaf Valley urban networks**

The **motorway network** represents a 15 km section of the A1M to the south and west of Gateshead (see Figure 7). As with the urban network, base case data were provided by Halcrow Consultants Ltd. (Fox, 2007). The network includes sections of 2, 3 and 4 lane motorway, subject to the 70 mph limit, as well as slip roads subject to a 40 mph limit. Data for the network covered the weekday AM period (06:30–10:30) and the weekday PM period (16:30–19:30). All junctions are merging sections between slip-roads and the main carriageway.

The baseline motorway network has a total flow per period of approximately 56,000 vehicles in the AM peak and 53,000 in the PM peak with some 15-20% HGVs in the AM peak and 7-10% HGVs in the PM peak. Modelled network speeds are variable. During the AM peak the mean speed falls from over 60mph (96 km/h) in the 06:00–07:00 period, to just above 40 mph (64 km/h) before rising again as congestion clears in the final hour from 09:00–10:00. This is primarily due to the large increase in flow during the peak, from 6000 veh/h at 06:00, to 18000 veh/h at 08:00, In the PM peak modelled mean speeds remain above 50 mph (80 km/h) at all times.

One of the fundamental parameters of the AIMSUN micro-simulation model is the Speed Acceptance Factor (SAF) selected for a vehicle from a suitable input distribution as the vehicle is modelled entering a network. Generally, If the generated SAF is ≤ 1.0 then the vehicle will obey the speed limit, whilst if it is > 1.0 then the vehicle will tend to speed, if given the opportunity (i.e. is unconstrained by other vehicles). SAF distributions for base case networks have been derived for each class of road (20, 30, 40, 50, 60 dual and single carriageway, 70 mph), disaggregated by vehicle type using the data in *Vehicle Speeds in Great Britain: 2005* (Department for Transport, 2006). Data available on mean speed of vehicles in free flow traffic conditions, the percentage of vehicles exceeding the limit and, where appropriate, the percentage 5 mph or 10 mph above the limit, were used to fit normal distributions, with appropriate mean and variance to reproduce observed behaviour, via an iterative procedure.

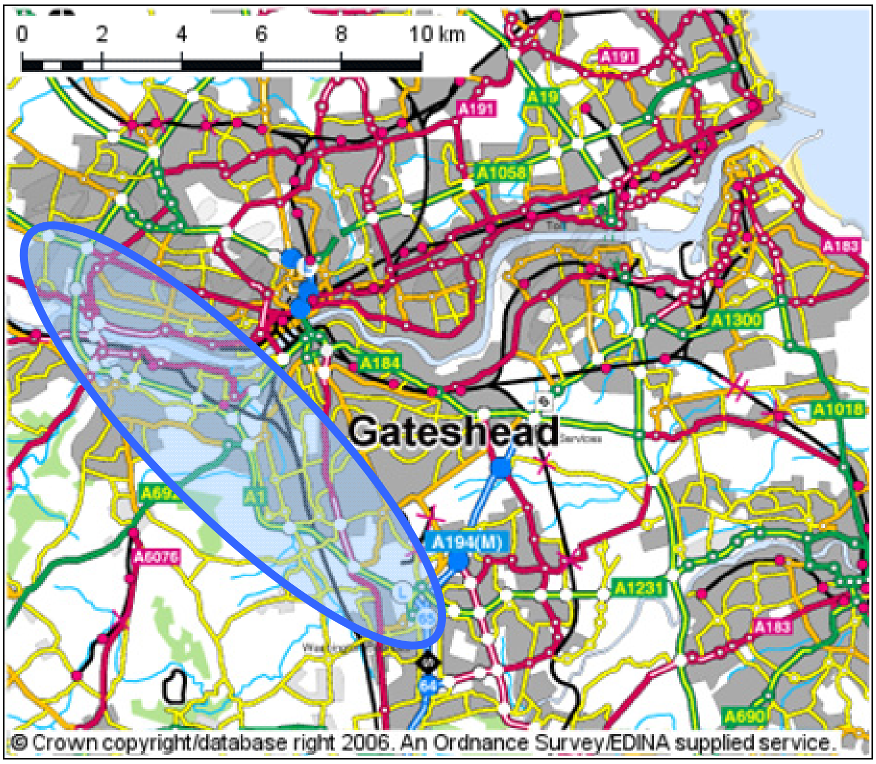



**Figure 7: The Gateshead A1M motorway network**

The methodology for modelling ISA using AIMSUN in this project was developed using the AIMSUN SDK (Software Development Kit) (Casas and Garcia, 2006). By using the SDK, the AIMSUN model has been extended to allow different distributions of SAFs for different classes of vehicle on roads subject to different speed limits, rather than applying a single distribution for a network as a whole. For vehicles equipped with mandatory ISA systems, the SAF distribution is simply curtailed to the limit value (usually 1.0, but may be different for some combinations of vehicle types and roads – e.g. HGVs on rural single carriageway roads). For vehicles equipped with voluntary ISA systems, the applied ISA model was somewhat more involved.

Essentially the voluntary ISA model works as follows. During each micro-simulation simulation update the local traffic conditions around a vehicle equipped with a voluntary ISA system are assessed. If those local conditions potentially allow the vehicle to speed (e.g. because the vehicle is a platoon leader, or is following a speeding vehicle, or the vehicle wishes to overtake a slow moving leader and adjacent lanes are clear) then a test is made to see if the vehicle will override the ISA system. This test is based on the difference between the driver's desired SAF, and the speed limit threshold SAF: the greater the difference, the greater probability that overriding will occur. If the test is passed, then the vehicle will override the ISA system until such time the vehicle's speed falls below the current speed limit. If the test is failed the vehicle remains compliant with the system. The model updates the SAFs applied to a vehicle based on AIMSUN's assigned speed limit for the current road section and the vehicle type – though other possibilities, such as dynamically changing factors due to calculated traffic conditions or assumed weather are feasible. The model also allows for different penetration ISA rates in *fleet-owned* vehicles, as opposed to *privately-owned* vehicles, as well as different behavioural parameters with vehicle ownership and type. Initial calibration of the model was based on analysis of data from the ISA-UK field trials.

Micro-simulation models are stochastic (variable) in nature and therefore require a number of simulation runs to be performed so that robust statistical analysis may be performed on output data. All subsequent analyses in this section are based on at least 10 runs of the model (motorway and urban networks) or 25 runs (rural network), for each time period, for each scenario. More runs were undertaken for the rural network, given the high relative variability found in analysis of initial results. This variability was due to relatively large effects arising from the presence of heavy vehicles in the network.

Scenarios represented either the base case (do-nothing) or the introduction of either voluntary or mandatory ISA at a certain penetration rate. Modelled penetration rates were 20%, 40%, 60%, 80% and 100% penetration. Hence results for a given set of scenarios, for a particular network and time period represent analysis of either 110 (motorway and urban networks) or 275 (rural network) individual simulations.

Emissions calculations were based on analysis at the individual vehicle and road section level. As each vehicle was generated by the micro-simulation model it was assigned a detailed type including information on engine size and technology, where appropriate (e.g. EURO-IV Petrol Car with engine <1.4L). This assignment was based on the fleet composition data within the NAEI. In all scenarios NAEI fleet composition and emissions rates for the year 2010 have been used. The assumption of a base year of 2010 has an impact on any subsequent cost-benefit analysis as the effect of subsequent standards and legislation need to be accounted for over an expanded time horizon. However, given the progression of engine technologies, it would be expected that future EURO standards will make less of an impact on $CO_2$ emissions and fuel consumption than the introduction of current, earlier standards.

As the vehicle travelled through the network, its time of entry and exit on individual road sections were recorded. This information was then combined with knowledge of section lengths to produce the average speed for that vehicle over a particular section. The distance travelled and average speed of the vehicle were then used to calculate its contribution to overall emissions within a defined time period. For air-pollutants, emissions for all vehicles were simply summed arithmetically and then normalised by total distance travelled to give an emissions rate in g/km. For noise, average emissions were calculated using the logarithmic sum of contributions to produce a sound power level rate in A-weighted decibels per metre (dBA/m).

## 3.2 Results

### *3.2.1 Using the recorded speeds with the GAMs models*

Table 1 summarises the mean change in $CO_2$ for a range of road speed limits. The results provide an indication of the effect of speed on emissions for the average fitted vehicle. It can be seen that, in the baseline situation, the highest emissions are for 20 mph roads (mean emission of 222 g/km) and the lowest emissions for 60 mph roads (148 g/km). Emissions increase again for 70 mph speed limit roads (171 g/km). These results help to highlight the typical levels of emissions on different road types.

**Table 1: Summary results from the detailed $CO_2$ emissions analysis using DfT data**

| *Speed Limit (mph)* | *Baseline $CO_2$ (Mean g/km)* | *Voluntary ISA $CO_2$ (g/km)* | | *Mandatory ISA $CO_2$ (g/km)* | |
|---|---|---|---|---|---|
| | | *Mean* | *Change* | *Mean* | *Change* |
| 20 | 222.1 | 222.0 | 0.0±0.5% | 222.4 | +0.1±0.6% |
| 30 | 185.1 | 184.3 | −0.4±0.3% | 184.4 | −0.4±0.3% |
| 40 | 164.0 | 162.1 | −1.2±0.1% | 162.1 | −1.2±0.1% |
| 60 | 148.2 | 148.6 | +0.3±0.1% | 148.6 | +0.3± 0.1% |
| 70 | 170.8 | 165.0 | −3.4±0.3 % | 160.9 | −5.8± 0.7% |

The effect of mandatory ISA is mixed across the different road types. At speed limits of 60 mph or lower, there are some increases and some decreases, but the changes are not very large in size. On 70 mph roads, there is a more substantial reduction in $CO_2$ emissions of 5.8± 0.7%[1]. Overall therefore, the change in emissions on non-70 mph speed limit roads is variable and small, but changes predicted on 70 mph speed limit roads are significant.

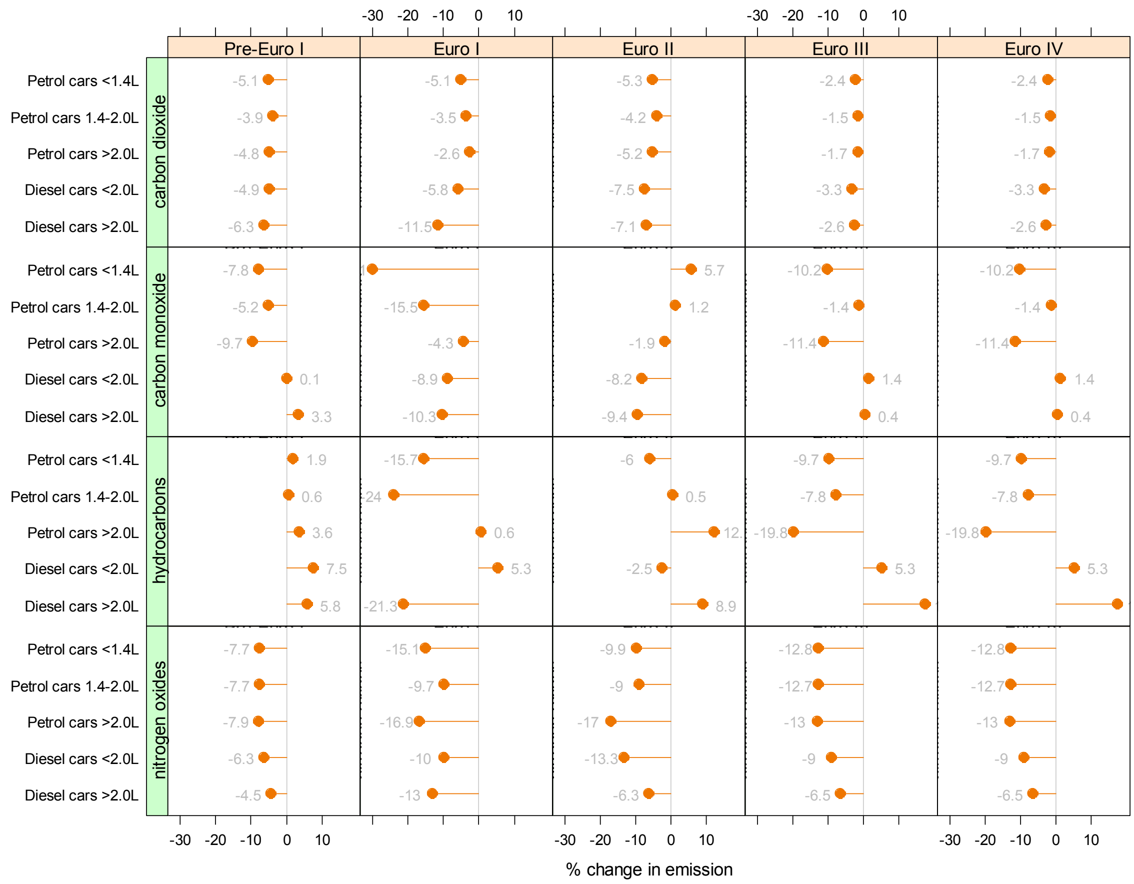
The changes due to voluntary ISA are also mixed. It is only for the 70 mph speed limit roads that a significant difference is observed, i.e. a reduction of 3.4 ± 0.3%. For 60 mph, roads, no change in emissions is predicted. For speeds less than 60 mph, voluntary ISA and mandatory ISA show similar behaviour with respect to their $CO_2$ emissions.

There are several limitations and uncertainties related to these detailed calculations. The effect of vehicle speeds has already been mentioned. In addition, these results relate only to Euro III/IV cars and not the full range of vehicles using the road. It should also be noted that the speed database (although very large) relates to observations for one type of vehicle, i.e. the Skoda Fabia 1.4 Estates used in the trials. However, there is no reason to believe that the results are biased in one way or another.

[1] The uncertainty relates to the 95% confidence interval in the mean for the 30 vehicles.

### *3.2.2 Using the recorded speeds with speed-emissions curves*

The detailed speed information from the ISA trials can also be applied to the speed-emission curve method of calculating emissions in order to show the impacts for each fitted vehicle. For these calculations, it is necessary to derive mean speed estimates because the speed-emission curves cannot be used to calculate emissions when vehicles are stationary. The speed data were therefore partitioned into blocks of 1000 seconds i.e. a similar time scale to that used in the derivation of speed-emission curves. Emissions were then calculated separately for each block of time and averaged. It was not possible to include 20 mph zones in this calculation, because of the generally short duration of travel in such zones. Example estimates are provided for a subset of the full conditions, as shown in Table 2.




*Note: The numbers show the individual percentage changes in emissions by pollutant and vehicle class*

**Figure 8: Percentage changes in emissions of different pollutants for motorways (baseline vs. Mandatory) ISA calculated from the speed-emission curves**

Figure 8 shows the calculated percentage change in emissions of $CO_2$ for motorways i.e. the reduction in emissions from the base case to mandatory ISA. These results highlight several features. First, there is a clear effect due to the Euro class of the vehicle: older vehicles tend to show a much greater reduction in $CO_2$ compared with newer models. The effect of Euro class is also large. For example, pre-Euro I petrol vehicles show a mean reduction of 5.7% $CO_2$ compared with only 2.1% for Euro III petrol vehicles. For diesel vehicles, the effects are more pronounced, e.g. 11.5% for Euro I vehicles compared to 2.6% for Euro III/IV vehicles. Modern vehicles therefore tend to show much less dependence on vehicle speeds (at least at motorway speeds) compared with older generation vehicles. This is a potentially important effect to take account of when considering the impacts that ISA has on emissions. The reason for these differences due to technology is unclear, i.e. it is not known whether it is due to actual technology effects or differences in how the speed-emission curves were fitted to the test data in the first instance.

Considering the changes across all the vehicle types shown in Figure 8, Table 2 summarises the mean change in emission of $CO_2$ for the different speed limits. Note that these results are not directly comparable with the detailed modelling because they also include pre-Euro III vehicles. Thus the results in Table 2 are for a wider range of vehicles. These results indicate very little change for 60 mph speed limit roads, similar to the detailed modelling. They also show that, for speed limits below 60 mph, small increases of about 2.8% in $CO_2$ are predicted. This contrasts with the detailed modelling which either indicated small decreases or very little change. Again, the most significant decrease is predicted for 70 mph roads. These differences will relate primarily to the differences in methodology, where it is considered the detailed calculations are more reliable.

**Table 2: Average emissions of $CO_2$ across all vehicle classes for cars using speed-emission curve data for a subset of conditions**

| *Speed limit (mph)* | *Baseline (g/km)* | *Mandatory ISA (g/km)* | *% change* |
|---|---|---|---|
| 30 | 216.0 | 222.0 | +2.8 |
| 40 | 185.0 | 190.1 | +2.8 |
| 60 | 160.6 | 161.2 | +0.4 |
| 70 | 174.5 | 167.1 | −4.2 |

For other pollutants, the changes in emissions predicted are mixed. For CO and hydrocarbons, both increases and decreases in emissions are predicted depending on the vehicle type considered. For $NO_X$ however, there is a consistent decrease in emissions across all vehicle types and technology classes.

There are also important differences compared with the detailed emissions modelling. On average, the detailed modelling calculated a 5.8% (for Euro III and Euro IV vehicles) reduction in emissions for Mandatory ISA compared with non-ISA emissions on roads with a 70 mph speed limit (see Table 1). This compares with reductions from the speed-emission curves of 2.3% for Euro III/IV vehicles. These results suggest that the application of speed-emission curves may underestimate the benefits of ISA.

### 3.2.3 Network simulation

#### Speeds

Changes to the speeds in the modelled networks through the introduction of ISA are summarised below.

***Rural network***

- Given the similarity of traffic patterns in all modelled periods it is unsurprising that similar reductions in mean network speeds are seen. Increasing the penetration rate of mandatory ISA from 0% to 100% resulted in an almost linear decrease in mean network speed by up to 3.7 km/h. Increasing voluntary ISA penetration had a lesser effect, with reductions of up to 1.7 km/h.

- In the modified network which allowed overtaking broadly similar reductions in speeds were observed with increasing ISA penetration, though initial mean speeds in the base case were some 2.5 km/h higher. This suggests that in the unmodified network some vehicles were being trapped by slow-moving lead vehicles.

***Urban networks***

- In the peak periods, increasing voluntary ISA penetration decreased mean network speeds by up to 0.9 km/h. The introduction of mandatory ISA decreased mean network speed by up to 2.2 km/h with increasing penetration.

- Whilst the overall distance travelled by vehicles within the whole of a simulation period did not appreciably change with increasing levels of ISA penetration, there was some trend towards an earlier onset of peak congestion conditions, and spreading of the peak conditions at high levels of penetration. This in turn had knock-on effects in the calculation of total emissions and emission rates in given hours.

***Motorway network***

- In prior to, or post- peak periods the introduction of mandatory ISA decreased mean network speed by up to 6.8 km/h as penetration was increased. For voluntary ISA the decrease was less noticeable, achieving a maximum reduction of only 5.4 km/h.

- During peak periods no real pattern of mean speed decreases emerged, with almost all modelled speeds, for either voluntary ISA or mandatory ISA being within ±1.5 km/h of the base case.

Figure 9 shows a sample set of results from the Motorway network for the period 06:00 – 07:00. The graph shows the effect of ISA on both the mean network speed and on the maximum speed achieved by any individual vehicle in the network. Clearly visible are the general downward trends of speed with increasing penetration, the lesser effect of voluntary ISA and a sharp decline in maximum speeds between 80% and 100% mandatory penetration as all vehicles become constrained to obey the speed limit. Apart from this effect on maximum speed, the impact of increasing penetration is generally linear.

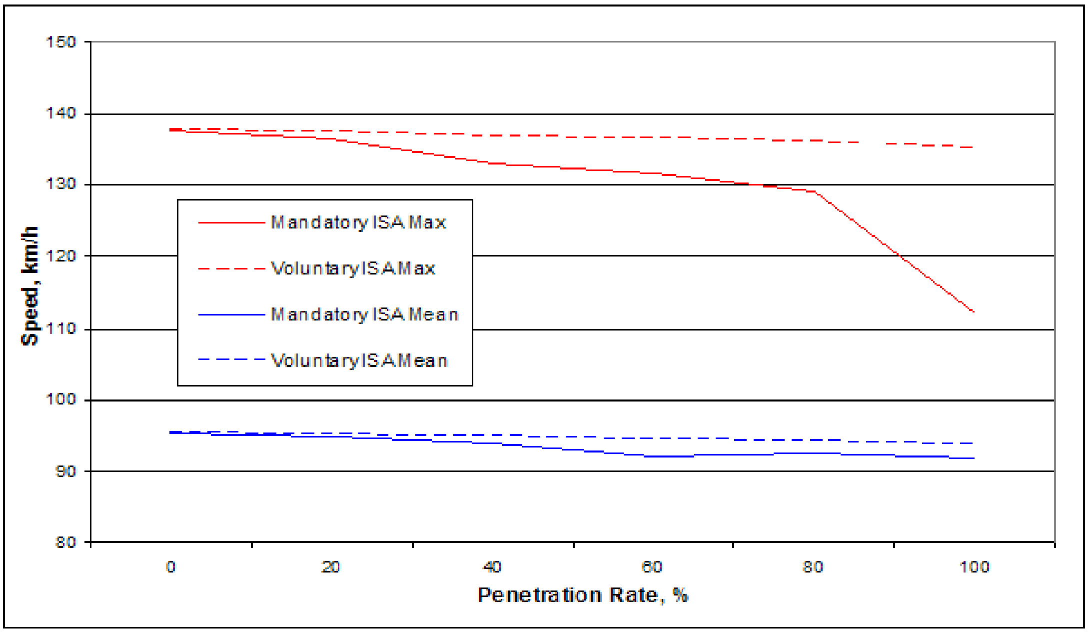



**Figure 9: Effect of ISA type and penetration on mean and maximum speeds on motorway network in the pre- AM Peak (06:00–07:00) period**

### Journey times

The Influence of ISA on journey times and journey time variability was also investigated. For the *rural network*, modelled mean journey times increased in linear fashion with increasing ISA penetration, with maximum increases in journey times of +2.6% and +6.0% apparent with 100% penetration of voluntary and mandatory ISA respectively, in any period. These increases are almost entirely due to the increasing effect of ISA-limited heavy vehicles impeding the progress of lighter traffic.

If network variability is expressed in terms of the Coefficient of Variation (CoV = ratio of standard deviation to the mean) then there is some slight evidence to suggest that low levels of ISA penetration (20%–60%) increase instability in the network, but higher levels of penetration produce results that are comparable to the base case. When considering CoVs it is also interesting to note that mandatory ISA produces a more consistent pattern in variability than voluntary ISA.

For the *urban network*, a general trend for increases in mean journey time was found for increasing penetration. These increases averaged at +2.9% and +6.5% for voluntary and mandatory ISA at 100% penetration across all time periods, and for both networks.

For the AM and inter-peak periods CoVs remain fairly stable and comparable to the base case conditions. However for the PM peak period, in the S10 network, at 100% penetration of mandatory ISA the CoV was approximately half of the base case (i.e. 9.0% as compared with 4.5%), suggesting that ISA had some benefit to reliability for that combination of network and period. As with the rural network the mandatory ISA results produced more consistent network behaviour in terms of journey times than the equivalent voluntary results.

For the *motorway network*, changes in journey time were not as apparent as those for the rural and urban networks. Prior to the onset of the AM peak (06:00-07:00) a slight linear trend for increases in journey times was observed, with maximum increases of +2.1% and +3.7% apparent at 100% voluntary and mandatory ISA penetration respectively. In the late PM and post-PM peak, mean journey times with any level of ISA penetration were −0.5% to −3.1% below the base case. For all other periods both increases and decreases in mean journey time, in the range (−1.3% to +4.7%) were apparent, suggesting that the results were affected more by variability due to network congestion.

In the 06:00-07:00 period CoVs at all penetration levels were comparable to the base case. For other periods, CoVs are mixed, with approximately half of the results showing increases in variation in journey times with increases in penetration, whilst the others follow a similar pattern to rural results — with the 100% penetration cases having comparable variability to the base case, but those at lower penetration levels showing higher variability. Unlike the rural and urban cases, it was not possible to distinguish differences between variability associated with the two ISA types.

One possible explanation for the increased variability at mid-penetration levels in both the motorway and rural scenarios is the action of heavy vehicles in blocking lighter ones affecting the pattern of flow and speed of light vehicles.

Thus, the rural and urban networks showed a general trend of linear increases in journey time with increased ISA penetration. Increases associated with voluntary ISA were found to be approximately 45% of those for the equivalent mandatory ISA penetration. For the motorway network results were highly variable, with both increases and decreases in journey time apparent, and little to distinguish voluntary ISA from mandatory ISA.

However increases have not been found to be consistently linked to any excessively detrimental effects on network reliability (as examined through the coefficients of variation for each network), though a pattern does emerge of mid-levels of ISA penetration being slightly more variable than the base and 100% penetration cases for the rural and urban networks. On average, voluntary ISA also produced slightly, but not significantly, more variability than mandatory ISA. One of the urban networks tested also showed improvements to network reliability in the PM-peak congested period with mandatory ISA.

### Emissions, fuel consumption and noise

#### *Rural network – $CO_2$ emissions and fuel consumption*

Table 3 shows comparative emissions rates for $CO_2$ expressed in terms of g/km with differing ISA types and penetration rates. Table 4 presents the same data for fuel consumption. The percentage change in emission rate from the baseline is shown in brackets. In these and subsequent tables, the highlighted results are statistically significant at the 5% significance level. Significant reductions have been highlighted in green, whilst significant increases have been highlighted in red. It should be noted that in Table 3 only one scenario (Mandatory ISA at 80% penetration during the AM peak) was found to produce a significant reduction in $CO_2$ emissions. From Table 4 no scenarios were found to produce statistically significant differences in fuel consumption.

Figure 10 and Figure 11 present both sets of results in graphical format. Note that the higher base emissions in the inter-peak period may be attributed both to the higher average speed of vehicles and to the larger relative contribution from HGVs within this period.

**Table 3: $CO_2$ emissions rates (g/km) per vehicle for the rural network**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Base** | **20%** | **40%** | **60%** | **80%** | **100%** |
| 08:00 – 09:00 | Voluntary | **236.3** | 235.9 (-0.2) | 234.9 (-0.6) | 232.3 (-1.7) | 235.1 (-0.5) | 235.3 (-0.4) |
| | Mandatory | **236.3** | 236.0 (-0.1) | 235.5 (-0.3) | 232.6 (-1.6) | 230.8 (-2.3) | 235.5 (-0.3) |
| 10:00 – 11:00 | Voluntary | **267.6** | 267.5 (-0.0) | 268.6 (+0.4) | 265.0 (-1.0) | 268.5 (+0.3) | 265.8 (-0.7) |
| | Mandatory | **267.6** | 267.0 (-0.2) | 265.6 (-0.8) | 265.9 (-0.6) | 265.2 (-0.9) | 267.9 (+0.1) |
| 17:00 – 18:00 | Voluntary | **221.7** | 224.2 (+1.1) | 222.7 (+0.5) | 222.8 (+0.5) | 223.6 (+0.9) | 222.6 (+0.4) |
| | Mandatory | **221.7** | 222.5 (+0.4) | 224.7 (+1.4) | 221.8 (+0.1) | 220.2 (-0.7) | 222.0 (+0.1) |
| Modified Network | Voluntary | **237.3** | 233.8 (-1.5) | 234.4 (-1.2) | 232.7 (-2.0) | 232.3 (-2.1) | 238.9 (+0.6) |
| 08:00 – 09:00 | Mandatory | **237.3** | 233.7 (-1.5) | 234.5 (-1.2) | 231.7 (-2.4) | 233.5 (-1.6) | 232.8 (-1.9) |


**Figure 10: $CO_2$ emissions rates (g/km) per vehicle for all scenarios and time periods on the rural network (error bars show 95% confidence intervals for the mean)**

**Table 4: Fuel consumption rates (g /km) per vehicle for the rural network**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Base** | **20%** | **40%** | **60%** | **80%** | **100%** |
| 08:00 – 09:00 | Voluntary | **89.0** | 88.9 (-0.2) | 88.6 (-0.5) | 87.8 (-1.4) | 88.8 (-0.3) | 88.3 (-0.9) |
| | Mandatory | **89.0** | 88.9 (-0.2) | 88.2 (-1.0) | 87.3 (-1.9) | 86.3 (-3.0) | 88.4 (-0.8) |
| 10:00 – 11:00 | Voluntary | **103.0** | 103.9 (-0.9) | 104.4 (+1.3) | 102.9 (-0.1) | 103.7 (+0.7) | 103.5 (+0.5) |
| | Mandatory | **103.0** | 103.6 (-0.6) | 102.5 (-0.5) | 102.5 (-0.6) | 102.5 (-0.5) | 103.0 (+0.0) |
| 17:00 – 18:00 | Voluntary | **80.0** | 80.4 (+0.5) | 79.8 (-0.2) | 79.9 (+0.1) | 80.4 (+0.6) | 79.7 (-0.3) |
| | Mandatory | **80.0** | 80.0 (+0.0) | 80.7 (+0.9) | 79.1 (-0.6) | 79.1 (-1.1) | 79.2 (-0.9) |
| Modified Network | Voluntary | **89.1** | 87.7 (-1.5) | 88.7 (-0.4) | 87.7 (-1.6) | 87.6 (-1.6) | 89.9 (+0.9) |
| 08:00 – 09:00 | Mandatory | **89.1** | 87.8 (-1.4) | 88.0 (-1.2) | 87.6 (-1.7) | 87.7 (-1.3) | 87.7 (-1.5) |

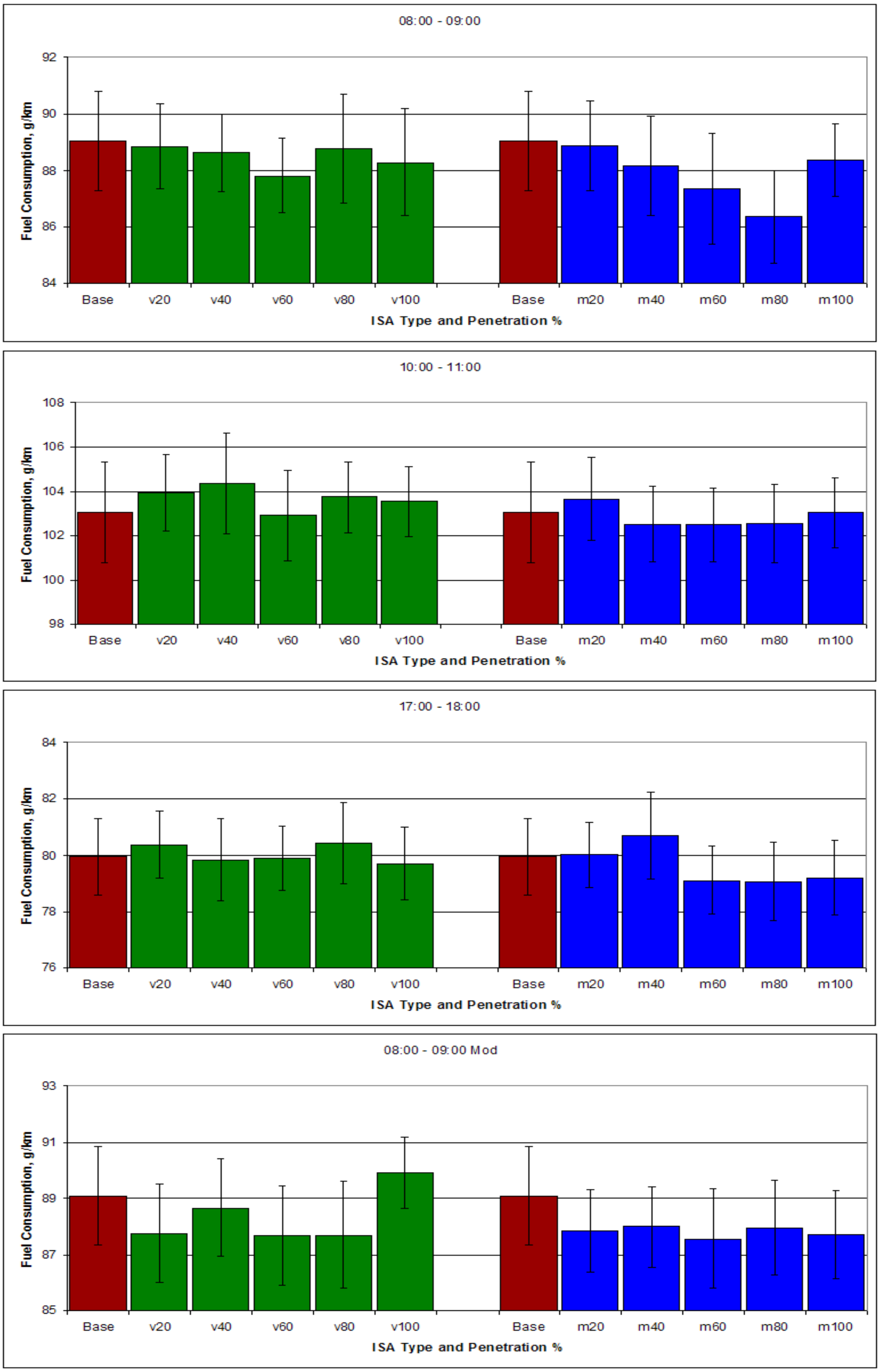



**Figure 11: Fuel consumption rates (g/km) per vehicle for all scenarios and time periods on the rural network (error bars show 95% confidence interval for the mean)**

From Table 3 and Table 4, and Figure 10 and Figure 11, it may be seen that all changes in emissions rates are small at any penetration level, with only one set of runs (mandatory ISA at 80% penetration) produced a statistically significant change in mean $CO_2$ emission level. Any variation in results could readily be due to variations in vehicle type selection, or non-ISA related behaviour.

In the modified network, with the exception of a slight increase in emissions and fuel consumption recorded in the voluntary 100% scenario, all results show some apparent benefit through the implementation of ISA, although no outcomes achieved statistical significance. The modified network allows overtaking, so that cars are not blocked by HGVs. Thus ISA may have some benefit in the rural network. However, any effects are small and not statistically significant.

The earlier study by Liu, Tate and Boddy (1995) on the effects of mandatory ISA reported a statistically significant decrease in total fuel consumption for this network of approximately 3% at 60% mandatory ISA penetration and beyond. The work used the DRACULA micro-simulation model and QUARTET (1992) emissions factors. The current work finds that changes in total fuel consumption beyond 60% mandatory ISA penetration are not statistically significant, and lie in the range of +0.6% to −2.2%. These lesser decreases may be consistent with the reduced impact of ISA on emissions of the newer vehicle fleet described previously.

***Rural network – other pollutants***

For other pollutants no clear picture emerged from the modelling. There is a large amount of variation in the emissions rates for Carbon Monoxide (CO), Total Hydrocarbons (THC), Oxides of Nitrogen (NOx) and Particulate Matter (PM), with changes ranging from −3.7% to +4.4%. There is no clear trend as penetration increases of either type of ISA.

***Rural network – noise***

The analysis of noise levels is based on examination of two "typical" link sections selected from the middle of the network, both subject to the national speed limit. For the rural network base case, the results suggest that the predominant sources of noise are road/tyre noise and powertrain noise from heavy goods vehicles. These sources are approximately 5 dBA louder than noise emissions from the powertrain of cars. For both voluntary ISA and mandatory ISA, an increasing reduction in the noise generated by all sources is predicted as ISA penetration level increases. However, whilst some of the modelled reductions are statistically significant at the 5% significance level, the magnitude of reductions lie in the range of 0.05–0.3 dBA. To put these values in perspective, a reduction of 1–3 dBA would be required to be barely perceptible to humans.

***Urban networks – $CO_2$ emissions and fuel consumption***

Table 5 and Table 6 show the comparative emissions rates for $CO_2$ and fuel consumption expressed in terms of g/km with differing ISA types and penetration rates for the Sheffield S10 network, whilst Table 7 and Table 8 present the same for the Sheaf Valley network. As with the previous tables, results that are statistically significant at the 5% level are highlighted. Figure 12 and Figure 13 present the Sheaf Valley scenarios graphically.

In broad terms, as modelled, increasing levels of ISA penetration result in increases both $CO_2$ emissions and fuel consumption. The Sheaf Valley network shows statistically significant changes at lower levels of ISA penetration than the S10 network. This may be due to the comparative higher density of junctions and shorter link lengths in the S10 network limiting ISA effects.

For mandatory ISA, increasing penetration causes a fairly linear increase in both $CO_2$ emission and fuel consumption rates. At 100% mandatory ISA penetration, the increases in the peak periods range from +2.3% to +3.5%. The increases are also found to be statistically significant at the 5% significance level at penetration levels of approximately 40% and beyond. Outside the peak period the changes associated with mandatory ISA are more variable, with increases ranging from +0.1% to +1.9%. Changes generally only achieve statistical significance beyond 60% penetration.

**Table 5: $CO_2$ emissions rates (g/km) per vehicle for the Sheffield S10 urban network**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | Base | 20% | 40% | 60% | 80% | 100% |
| AM Peak 06:30 – 07:30 | Voluntary | **234.0** | 235.7 (+0.8) | 236.5 (+1.1) | 236.3 (+1.0) | 237.0 (+1.3) | 238.9 (+2.1) |
| | Mandatory | **234.0** | 236.1 (+0.9) | 237.2 (+1.4) | 238.7 (+2.0) | 237.8 (+1.7) | 239.6 (+2.4) |
| AM Peak 07:30 – 08:30 | Voluntary | **257.6** | 256.8 (-0.3) | 258.6 (+0.4) | 259.9 (+0.9) | 258.9 (+0.5) | 260.6 (+1.1) |
| | Mandatory | **257.6** | 260.7 (+1.2) | 260.1 (+1.0) | 261.6 (+1.6) | 261.3 (+1.4) | 262.4 (+1.9) |
| Inter Peak 10:00 – 11:00 | Voluntary | **248.5** | 248.3 (-0.1) | 246.9 (-0.6) | 247.8 (-0.3) | 249.1 (+0.2) | 250.5 (+0.8) |
| | Mandatory | **248.5** | 250.3 (+0.8) | 249.6 (+0.4) | 249.8 (+0.5) | 250.6 (+0.8) | 250.2 (+0.7) |
| Inter-Peak 11:00 – 12:00 | Voluntary | **253.8** | 256.3 (+1.0) | 255.5 (+0.7) | 254.9 (+0.4) | 257.6 (+1.5) | 257.5 (+1.4) |
| | Mandatory | **253.8** | 255.4 (+0.6) | 256.4 (+1.0) | 260.2 (+2.5) | 258.7 (+1.9) | 257.2 (+1.3) |
| Inter-Peak 12:00 – 13:00 | Voluntary | **250.6** | 250.0 (-0.2) | 252.7 (+0.8) | 252.5 (+0.8) | 252.1 (+0.6) | 250.7 (+0.0) |
| | Mandatory | **250.6** | 250.1 (-0.2) | 252.7 (+0.8) | 254.7 (+1.6) | 254.4 (+1.5) | 255.4 (+1.9) |
| Inter-Peak 13:00 – 14:00 | Voluntary | **253.8** | 253.3 (-0.2) | 254.9 (+0.4) | 252.3 (-0.6) | 252.5 (-0.5) | 253.9 (+0.1) |
| | Mandatory | **253.8** | 250.7 (-1.2) | 254.2 (+0.2) | 255.0 (+0.4) | 254.3 (+0.2) | 255.4 (+0.7) |
| PM Peak 16:30 – 17:30 | Voluntary | **231.9** | 234.6 (+1.1) | 233.3 (+0.6) | 234.1 (+0.9) | 234.3 (+1.0) | 234.4 (+1.0) |
| | Mandatory | **231.9** | 230.9 (-0.5) | 235.9 (+1.7) | 236.8 (+2.1) | 235.9 (+1.7) | 237.4 (+2.3) |
| PM Peak 17:30 – 18:30 | Voluntary | **230.2** | 231.9 (+0.7) | 232.4 (+1.0) | 232.9 (+1.2) | 231.5 (+0.6) | 233.1 (+1.2) |
| | Mandatory | **230.2** | 230.6 (+0.2) | 233.0 (+1.2) | 233.4 (+1.4) | 233.7 (+1.5) | 233.2 (+1.3) |

**Table 6: Fuel consumption rates (g/km) per vehicle for the Sheffield S10 urban network**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | Base | 20% | 40% | 60% | 80% | 100% |
| AM Peak 06:30 – 07:30 | Voluntary | **82.4** | 82.7 (+0.4) | 83.0 (+0.7) | 82.7 (+0.4) | 83.0 (+0.7) | 83.5 (+1.3) |
| | Mandatory | **82.4** | 83.1 (+0.9) | 83.4 (+1.2) | 83.7 (+1.5) | 83.0 (+0.7) | 84.3 (+2.3) |
| AM Peak 07:30 – 08:30 | Voluntary | **92.0** | 91.3 (-0.0) | 92.0 (+0.4) | 92.3 (-1.0) | 91.6 (+0.3) | 92.8 (-0.7) |
| | Mandatory | **92.0** | 93.0 (-0.2) | 92.4 (-0.8) | 92.8 (-0.6) | 93.1 (-0.9) | 93.4 (+0.1) |
| Inter Peak 10:00 – 11:00 | Voluntary | **94.0** | 93.4 (-0.7) | 93.2 (-0.8) | 93.5 (-0.5) | 94.0 (+0.0) | 94.4 (+0.5) |
| | Mandatory | **94.0** | 94.2 (+0.2) | 94.1 (+0.1) | 94.1 (+0.1) | 94.4 (+0.5) | 94.1 (+0.1) |
| Inter Peak 11:00 – 12:00 | Voluntary | **96.5** | 96.8 (+0.3) | 97.1 (+0.7) | 96.8 (+0.2) | 97.9 (+1.5) | 98.2 (+1.8) |
| | Mandatory | **96.5** | 97.2 (+0.7) | 97.5 (+1.0) | 99.4 (+3.0) | 97.8 (+1.4) | 97.2 (+0.6) |
| Inter-Peak 12:00 – 13:00 | Voluntary | **94.7** | 94.6 (-0.1) | 95.0 (+0.3) | 95.9 (+1.3) | 95.0 (+0.3) | 94.1 (-0.6) |
| | Mandatory | **94.7** | 94.2 (-0.5) | 95.0 (+0.3) | 96.3 (+1.7) | 95.9 (+1.3) | 95.9 (+1.3) |
| Inter-Peak 13:00 – 14:00 | Voluntary | **95.7** | 95.5 (-0.3) | 96.0 (+0.2) | 95.2 (-0.6) | 94.8 (-1.0) | 96.3 (+0.6) |
| | Mandatory | **95.7** | 94.4 (-1.4) | 96.1 (+0.3) | 95.8 (+0.1) | 95.3 (-0.4) | 96.4 (+0.7) |
| PM Peak 16:30 – 17:30 | Voluntary | **79.1** | 80.3 (+1.6) | 79.8 (+1.0) | 79..8 (+0.9) | 80.1 (+1.3) | 80.0 (+1.1) |
| | Mandatory | **79.1** | 78.7 (-0.4) | 80.7 (+2.0) | 81.1 (+2.5) | 80.5 (+1.8) | 80.9 (+2.2) |
| PM Peak 17:30 – 18:30 | Voluntary | **77.6** | 78.1 (+0.7) | 78.4 (+1.0) | 78.2 (+0.8) | 78.0 (+0.5) | 78.4 (+1.1) |
| | Mandatory | **77.6** | 77.6 (-0.0) | 78.3 (+0.9) | 78.3 (+0.9) | 78.5 (+1.1) | 78.5 (+1.1) |

**Table 7: $CO_2$ emissions rates (g/km) per vehicle for the Sheffield Sheaf Valley urban network**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | Base | 20% | 40% | 60% | 80% | 100% |
| AM Peak 06:30 – 07:30 | Voluntary | **225.9** | 225.6 (-0.1) | 227.9 (+0.9) | 226.6 (+0.3) | 227.9 (+0.9) | 228.4 (+1.1) |
| | Mandatory | **225.9** | 226.9 (+0.5) | 229.5 (+1.6) | 228.8 (+1.3) | 230.9 (+2.2) | 232.1 (+2.8) |
| AM Peak 07:30 – 08:30 | Voluntary | **245.7** | 247.2 (+0.6) | 249.7 (+1.6) | 245.3 (-0.2) | 248.3 (+1.1) | 249.8 (+1.7) |
| | Mandatory | **245.7** | 248.5 (+1.1) | 250.5 (+1.9) | 249.3 (+1.4) | 250.9 (+2.1) | 252.8 (+2.9) |
| PM Peak 16:30 – 17:30 | Voluntary | **203.6** | 203.2 (-0.2) | 203.8 (+0.1) | 204.3 (+0.3) | 205.4 (+0.9) | 204.6 (+0.4) |
| | Mandatory | **203.6** | 204.4 (+0.4) | 205.7 (+1.0) | 205.4 (+0.9) | 205.3 (+0.8) | 206.6 (+1.5) |
| PM Peak 17:30 – 18:30 | Voluntary | **215.2** | 214.7 (-0.3) | 217.1 (+0.8) | 216.6 (+0.6) | 216.8 (+0.7) | 216.0 (+0.4) |
| | Mandatory | **215.2** | 215.7 (+0.2) | 217.7 (+1.2) | 219.3 (+1.8) | 219.6 (+2.1) | 222.7 (+3.5) |

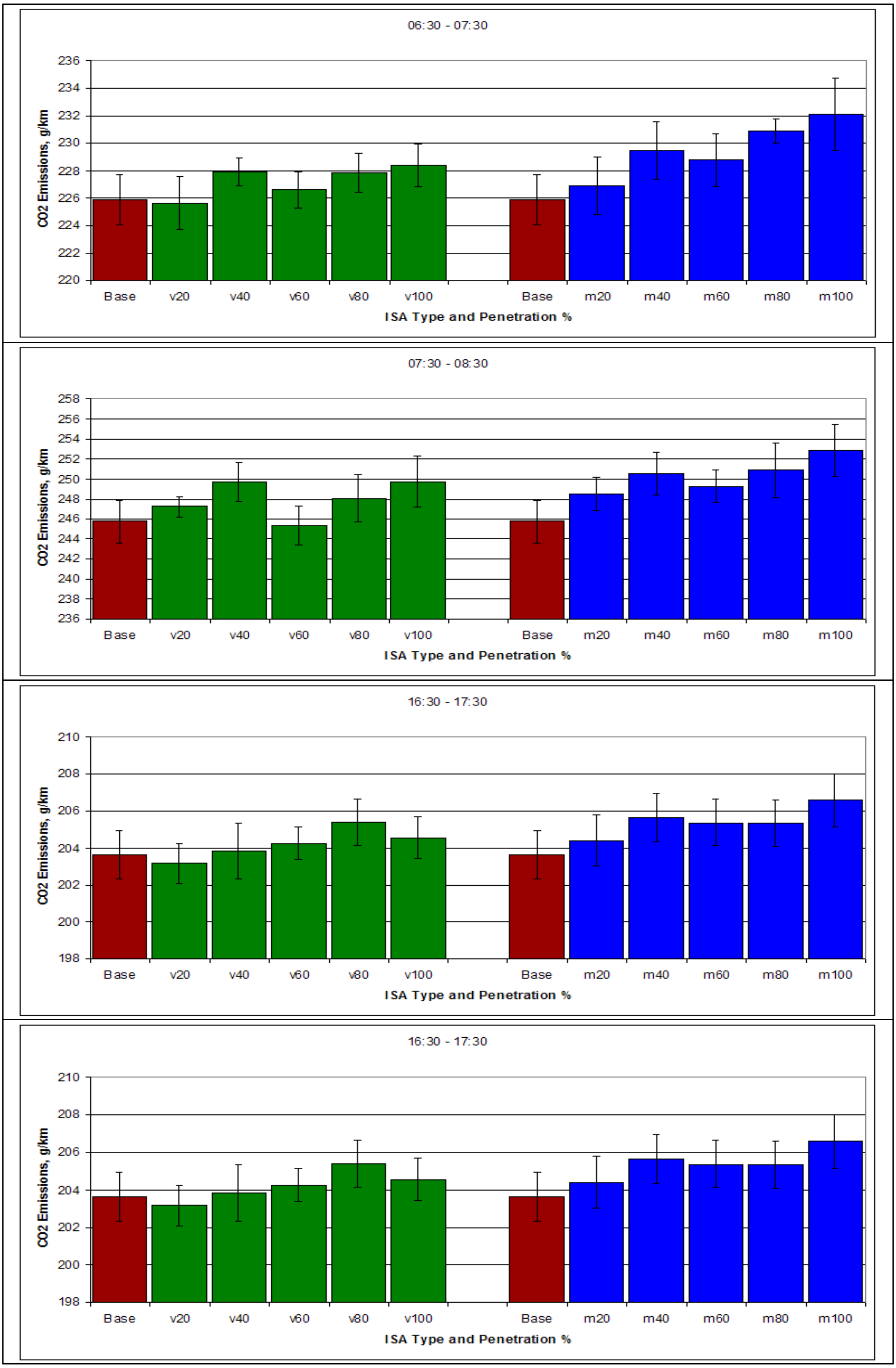



**Figure 12: $CO_2$ emissions rates (g/km) per vehicle for all scenarios and time periods for the Sheffield Sheaf Valley network (error bars show 95% confidence interval for the mean)**

**Table 8: Fuel consumption rates (g /km) per vehicle for the Sheffield Sheaf Valley urban network**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Base** | **20%** | **40%** | **60%** | **80%** | **100%** |
| AM Peak 06:30 – 07:30 | Voluntary | **79.3** | 79.5 (+0.3) | 80.6 (+1.6) | 79.7 (+0.5) | 80.3 (+1.3) | 80.5 (+1.5) |
| | Mandatory | **79.3** | 79.6 (+0.3) | 80.7 (+1.7) | 80.8 (+1.9) | 81.2 (+2.4) | 81.4 (+2.7) |
| AM Peak 07:30 – 08:30 | Voluntary | **88.4** | 89.1 (+0.7) | 90.0 (+1.8) | 88.6 (+0.2) | 90.0 (+1.5) | 90.1 (+1.9) |
| | Mandatory | **88.4** | 89.8 (+1.5) | 90.2 (+2.0) | 89.9 (+1.6) | 90.1 (+1.9) | 90.6 (+2.4) |
| PM Peak 16:30 – 17:30 | Voluntary | **69.3** | 69.0 (-0.4) | 69.3 (+0.1) | 69.5 (+0.4) | 69.9 (+0.9) | 69.6 (+0.5) |
| | Mandatory | **69.3** | 69.6 (+0.5) | 70.1 (+1.3) | 69.9 (+1.0) | 69.7 (+0.5) | 70.3 (+1.5) |
| PM Peak 17:30 – 18:30 | Voluntary | **73.7** | 73.6 (-0.1) | 74.5 (+1.0) | 74.2 (+0.6) | 74.4 (+0.8) | 74.0 (+0.4) |
| | Mandatory | **73.7** | 73.8 (+0.1) | 74.6 (+1.2) | 75.1 (+1.8) | 75.2 (+2.1) | 76.2 (+3.3) |

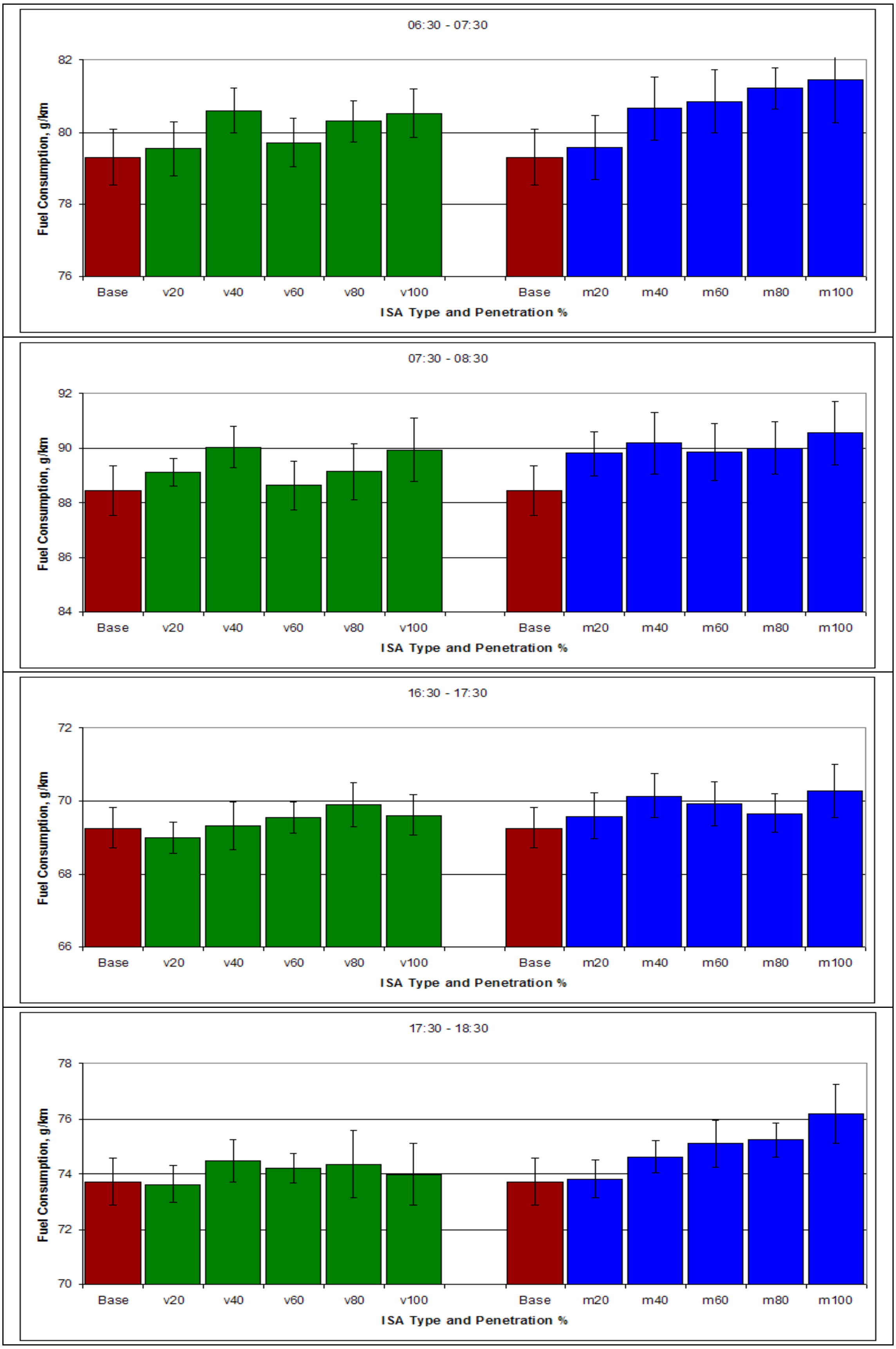



**Figure 13: Fuel consumption rates (g/km) per vehicle for all scenarios and time periods from the Sheffield Sheaf Valley urban network (error bars show 95% confidence limits for the mean)**

Even more variable behaviour is observed in the voluntary ISA scenarios, with final changes in $CO_2$ emission and fuel consumption rates at 100% voluntary ISA penetration ranging from −0.7% to +1.8%. However fewer results are found to be statistically significant, and these are generally limited to penetration levels of 80% and above for the S10 network or 40% and above for the Sheaf Valley network.

It is therefore concluded that, as modelled, mandatory ISA may have a slightly detrimental effect on $CO_2$ emissions and fuel consumption rates within the urban context. The results obtained from the micro-simulation modelling are consistent with the previous results obtained using the NAEI emissions curves and the recorded speeds from the ISA-UK field trials, as presented in section 3.2.2. As with that methodology, it must be kept in mind that the use of speed-emission curves does not accurately reflect transient emissions associated with acceleration events which ISA systems may help to limit. This could potentially mitigate some of the detrimental effects found.

***Urban networks – other pollutants***

As with the rural network there is much variation in the emission rates of other pollutants. Changes in rates lie in a range from −2.3% to +5.7% with no clear pattern emerging with increasing penetration of ISA. An average increase in the emissions rate for CO, THC and PM of +1.0%, and +0.7% for NOx was found across all penetration levels for the S10 network. For the Sheaf Valley network no change was detected in CO and THC emission rates, with a slight increase (+0.5%) in NOx and PM rates. Increases associated with the peak periods are higher than those associated with the inter-peak periods. No testing for statistical significance has been performed.

***Urban networks – noise***

No attempt has been made to quantify changes in noise emissions for any of the urban networks. Below speeds of 50 km/h, traffic noise levels are increasingly dominated by engine noise, which is less sensitive to road speed than tyre noise. Hence, changes in mean noise emission levels through the introduction of ISA would be expected not to be significant — certainly in the sub-decibel range. The exceptions to this could possibly be beneficial changes to low-gear acceleration noise in localised areas around junctions or signals if ISA reduced harsh acceleration events, and reductions in peak noise events during evening and night periods through the limitation of occurrences of speeding.

***Motorway network – $CO_2$ emissions and fuel consumption***

Table 9 through Table 12 present the results for the motorway scenarios. Figure 14 and Figure 15 show the results from the AM periods (06:00 – 10:00) graphically.

**Table 9: $CO_2$ emissions rates (g/km) per vehicle for the motorway network during the AM peak**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Base** | **20%** | **40%** | **60%** | **80%** | **100%** |
| 06:00 – 07:00 | Voluntary | **423.8** | 417.7 (-1.4) | 421.6 (-0.5) | 418.8 (-1.2) | 417.4 (-1.5) | 419.0 (-1.2) |
| | Mandatory | **423.8** | 418.9 (-1.2) | 417.8 (-1.4) | 417.7 (-1.4) | 414.3 (-2.2) | 415.3 (-2.0) |
| 07:00 – 08:00 | Voluntary | **345.0** | 343.9 (-0.3) | 343.9 (-0.3) | 341.0 (-1.1) | 342.0 (-0.9) | 343.6 (-0.4) |
| | Mandatory | **345.0** | 342.9 (-0.6) | 341.8 (-0.9) | 340.3 (-1.4) | 340.7 (-1.2) | 340.0 (-1.4) |
| 08:00 – 09:00 | Voluntary | **353.7** | 354.8 (-0.3) | 353.2 (-0.1) | 352.8 (-0.3) | 351.1 (-0.9) | 351.0 (-0.8) |
| | Mandatory | **353.7** | 353.4 (-0.1) | 354.7 (+0.3) | 351.1 (-0.7) | 349.8 (-1.1) | 352.4 (-0.4) |
| 09:00 – 10:00 | Voluntary | **384.3** | 386.5 (+0.5) | 379.5 (-1.2) | 384.1 (-0.1) | 383.8 (-0.1) | 382.2 (-0.9) |
| | Mandatory | **384.3** | 381.8 (-0.6) | 382.5 (-0.5) | 381.1 (-0.8) | 380.1 (-1.1) | 379.4 (-1.3) |

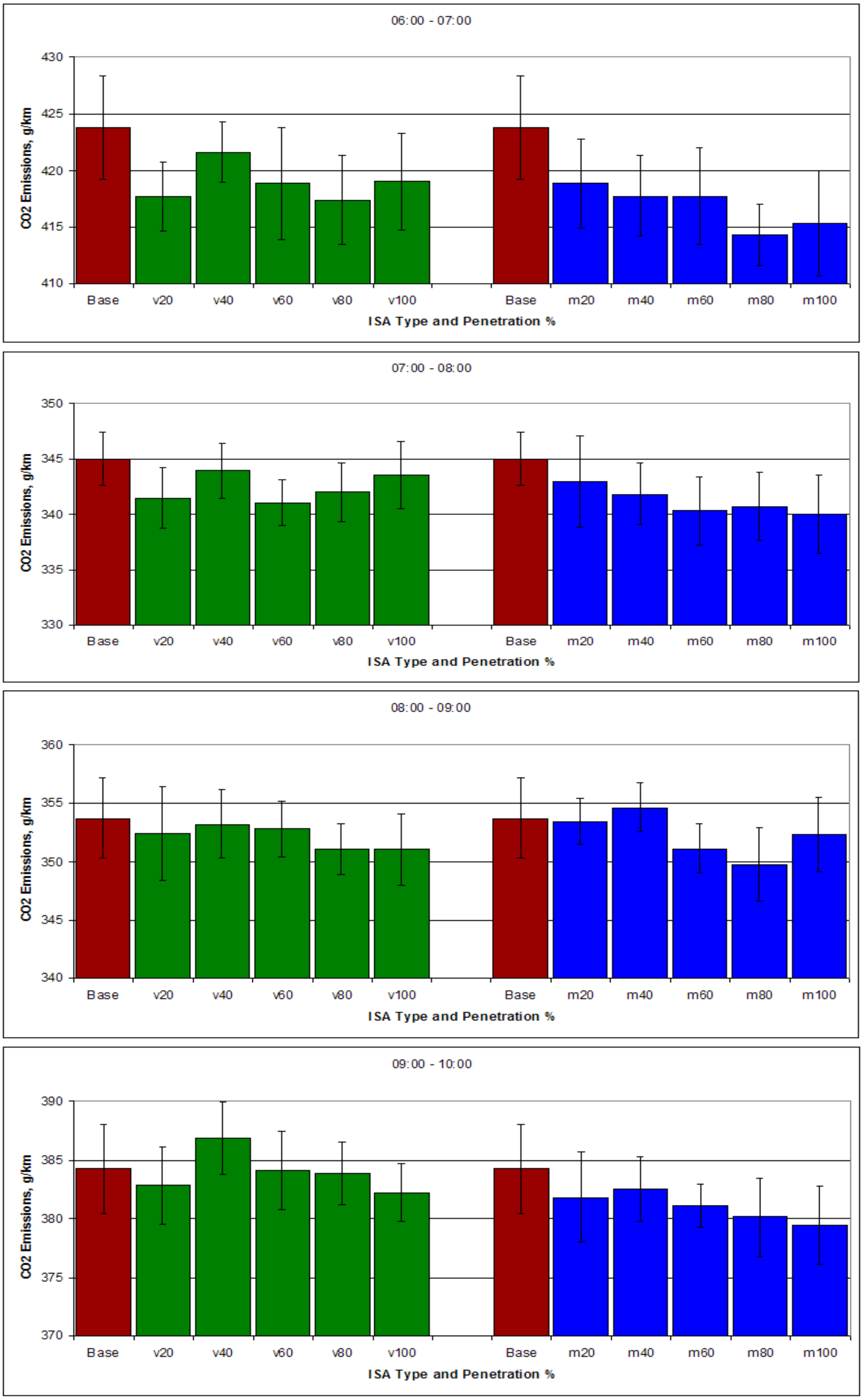



**Figure 14: $CO_2$ emissions rates (g/km) per vehicle for all scenarios and time periods from the motorway network (error bars show 95% confidence interval for the mean)**

**Table 10: Fuel consumption rates (g/km) per vehicle for the motorway network during the AM peak**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | Base | 20% | 40% | 60% | 80% | 100% |
| 06:00 – 07:00 | Voluntary | **150.1** | 147.7 (-1.6) | 148.9 (-0.8) | 148.3 (-1.2) | 147.4 (-1.8) | 148.2 (-1.3) |
| | Mandatory | **150.1** | 148.3 (-1.2) | 147.8 (-1.5) | 147.8 (-1.5) | 146.4 (-2.5) | 146.6 (-2.3) |
| 07:00 – 08:00 | Voluntary | **120.4** | 120.0 (-0.3) | 119.8 (-0.4) | 118.8 (-1.3) | 119.3 (-0.9) | 119.7 (-0.5) |
| | Mandatory | **120.4** | 119.4 (-0.7) | 118.9 (-1.2) | 118.4 (-1.6) | 118.6 (-1.5) | 118.3 (-1.7) |
| 08:00 – 09:00 | Voluntary | **123.3** | 123.9 (+0.5) | 123.2 (-0.0) | 123.2 (-0.0) | 122.3 (-0.8) | 122.2 (-0.8) |
| | Mandatory | **123.3** | 123.2 (-0.0) | 123.4 (+0.2) | 122.5 (-0.6) | 121.6 (-1.3) | 122.9 (-0.4) |
| 09:00 – 10:00 | Voluntary | **135.1** | 135.4 (+0.3) | 133.1 (-1.5) | 134.5 (-0.4) | 134.2 (-0.6) | 134.0 (-0.8) |
| | Mandatory | **135.1** | 134.0 (-0.8) | 134.0 (-0.8) | 133.7 (-1.0) | 133.0 (-1.6) | 133.0 (-1.6) |

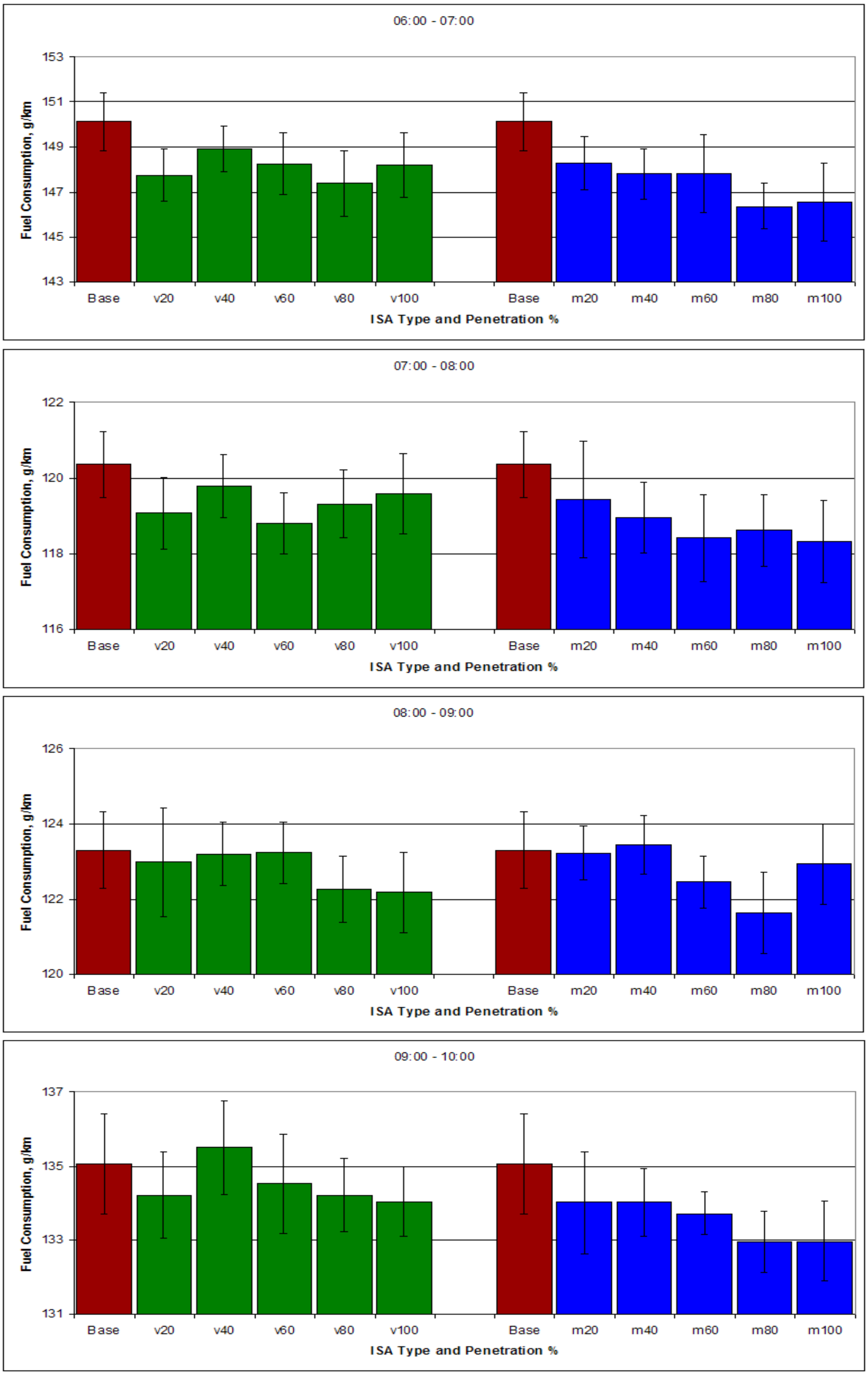



**Figure 15: Fuel consumption rates (g/km) per vehicle for all scenarios and time periods from the motorway network (error bars show 95% confidence interval for the mean)**

**Table 11: $CO_2$ emissions rates (g/km) per vehicle for the motorway network during the PM peak**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Base** | **20%** | **40%** | **60%** | **80%** | **100%** |
| 16:00 – 17:00 | Voluntary | **298.2** | 299.4 (+0.4) | 298.1 (-0.0) | 297.2 (-0.3) | 298.4 (+0.1) | 298.5 (+0.1) |
| | Mandatory | **298.2** | 298.5 (+0.1) | 299.3 (+0.4) | 295.8 (-0.8) | 296.9 (-0.5) | 297.7 (-0.1) |
| 17:00 – 18:00 | Voluntary | **266.9** | 268.7 (+0.7) | 263.3 (-1.4) | 268.0 (+0.3) | 268.1 (+0.5) | 266.3 (-0.2) |
| | Mandatory | **266.9** | 267.9 (+0.4) | 265.9 (-0.4) | 267.4 (+0.2) | 264.0 (-1.1) | 265.3 (+0.6) |
| 18:00 – 19:00 | Voluntary | **256.9** | 253.9 (-1.1) | 252.8 (-1.5) | 251.2 (-2.1) | 251.4 (-2.0) | 249.3 (-2.8) |
| | Mandatory | **256.9** | 254.7 (-0.7) | 250.1 (-2.5) | 253.3 (-1.3) | 251.1 (-2.2) | 249.4 (-2.8) |

**Table 12: Fuel consumption rates (g/km) per vehicle for the motorway network during the PM peak**

| Time period | ISA Type | Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Base** | **20%** | **40%** | **60%** | **80%** | **100%** |
| 16:00 – 17:00 | Voluntary | **103.9** | 103.9 (+0.0) | 103.5 (-0.4) | 103.1 (-0.7) | 103.7 (-0.2) | 103.6 (-0.3) |
| | Mandatory | **103.9** | 103.7 (-0.2) | 103.8 (-0.1) | 102.9 (-0.9) | 102.8 (-1.0) | 103.2 (-0.7) |
| 17:00 – 18:00 | Voluntary | **92.3** | 92.8 (+0.7) | 90.9 (-1.3) | 92.7 (+0.4) | 92.6 (+0.5) | 92.0 (-0.2) |
| | Mandatory | **92.3** | 92.5 (+0.4) | 91.7 (-0.4) | 92.4 (+0.2) | 91.1 (-1.1) | 91.5 (-0.6) |
| 18:00 – 19:00 | Voluntary | **88.6** | 87.7 (-1.1) | 87.3 (-1.5) | 86.7 (-2.2) | 86.7 (-2.1) | 86.2 (-2.7) |
| | Mandatory | **88.6** | 88.0 (-0.6) | 86.5 (-2.4) | 87.2 (-1.5) | 86.4 (-2.5) | 85.8 (-3.1) |

Generally, increasing ISA penetration has been modelled as having a beneficial effect, with reductions apparent in both $CO_2$ emissions and fuel consumption. In the AM period, before the onset of the peak, mandatory ISA produced statistically significant reductions, at the 5% significance level, in $CO_2$ emissions, for the 80% and 100% penetration levels. The maximum reduction $CO_2$ emission rate is approximately −2%. For fuel consumption, statistically significant reductions appear at all levels of mandatory penetration prior to the onset of congestion, with a maximum reduction at 100% penetration of −2.3%. With the onset of congestion, the beneficial effects of ISA are diminished, with few significant changes apparent.

The voluntary ISA results for the 06:00-07:00 period are somewhat anomalous, with the 20% penetration scenario resulting in $CO_2$ and fuel consumption benefits that are greater than those at the 40%, 60% and 100% penetration rates. Examination of underlying data suggested that the contribution to emissions from articulated HGVs were significantly less than for the other penetration levels, but no indication was found as to why that was the case. The benefits of voluntary ISA at other penetration levels are modelled as being less than the corresponding mandatory ISA results at the same penetration. For fuel consumption, all voluntary ISA results prior to the onset of the AM peak, and except at the 40% penetration level, are statistically significant, with changes similar in magnitude to their mandatory counterparts.

For the PM scenarios, a similar picture emerges. In the busiest period between 16:00 and 18:00, neither voluntary ISA nor mandatory ISA, have a great impact on $CO_2$ emissions or fuel consumption. In the slightly quieter period from 18:00 to 19:00, both voluntary ISA and mandatory ISA generally produce statistically significant reductions beyond 40% penetration. Again, as modelled, the benefits achieved through voluntary ISA appear comparable to those achieved through mandatory ISA, with maximum reductions of −2.8% for both ISA types at 100% penetration for $CO_2$ emissions, and −2.7% versus −3.1% respectively for fuel consumption.

Equally the results from the motorway micro-simulation runs are comparable with the results in sections 3.2.1 and 3.2.2 for passenger cars on motorways, tempered somewhat by the presence of a large percentage of heavy vehicles in the network whose speeds are not unduly altered by either ISA type. Given that the motorway scenarios only cover the peak periods (though they do include approximately 30 minutes of build-up and easing of congestion at the beginning and end of the peak periods respectively), it may be suggested that the modelled benefits of ISA are somewhat conservative, and that greater percentage reductions would be achieved in the inter-peak hours. Also it must be noted that as speed-emission curves were limited to a maximum of 130 km/h, the potential benefits of ISA are further underestimated. For example in the base case scenario, during the 06:00-07:00 time period, approximately 3.4% of distance travelled was at speeds above 130 km/h.

Therefore, it is concluded that, as modelled, both voluntary ISA and mandatory ISA have a small, but positive, effect in reducing $CO_2$ emissions and fuel consumption rates, by approximately 3%. This benefit is, however, eroded by the presence of congestion in the road network.

***Motorway network – other pollutants***

With the exception of THC, emission rates of all other pollutants (CO, NOx and PM) examined show a downward trend with increasing levels of ISA penetration. In the pre- and post-peak periods (06:00–07:00 and 18:00–19:00) modelled changes exceed −4% for CO and PM and −0.9% for NOx for 100% mandatory ISA Penetration, with voluntary ISA generally less effective. In the peak periods relative changes are around −1.0% for CO, PM and no change for NOx.

For THC emission rate, results are more variable. In the modelled AM period, decreases occur both in, and out, of the peak period, though these are small and generally under −1.0%. For the PM period, increases are modelled in the congested portion peak of up to +3.0%, with decreases of up to −1.0% present in the post-peak period.

As with the rural and urban scenarios, results for these pollutants have not been checked for statistical significance.

***Motorway network – noise***

As with the rural network, reductions in noise levels on selected links at the centre of the network have been studied. Again, whilst some reductions at higher penetrations of ISA are statistically significant, the magnitude of reductions (0.05–0.4 dBA) makes them imperceptible and negligible in practical terms.

Unlike the *rural* network, the noise in the *motorway* network is dominated by road/tyre noise. Thus is approximately 4 dBA above noise from HGV powertrains, and almost 8 dBA above that from car powertrains.

## 3.3 Conclusions

The results of the micro-simulation work suggest that, as modelled:

- In the context of the A614 rural network, neither voluntary nor mandatory ISA make a major impact on overall $CO_2$ emissions or fuel consumption rates at any level of penetration.

- In the context of the two urban Sheffield networks, increasing ISA penetration may prove slightly detrimental to both $CO_2$ emission and fuel consumption rates, increasing both by up to approximately +3%. The detrimental effect becomes increasingly apparent at levels of ISA penetration beyond 20%. This is because, as indicated by the speed-emissions curves, cars tend to operate most efficiently at speeds above 30 mph.

- In the context of the Gateshead A1M motorway network, increasing ISA penetration has a small, but positive effect on emissions and fuel consumption, reducing both by up to approximately −3%. Benefits may be apparent event at low levels of ISA penetration.

- All benefits or disbenefits are reduced by the presence of congestion, where the effect of ISA systems becomes less apparent.

- Regarding other pollutants, no substantial effects have been found.

- Regarding noise, the implementation of ISA systems is likely to make a negligible (up to 0.4 dBA) contribution to reducing overall broadband noise levels. As modelled, any benefits would not be directly apparent to any human observer.

All results must be viewed in the context of the use of speed-emissions curves, which do not allow for the accounting of transient emissions associated with acceleration events. A mean speed of travel that is above 30 mph on urban roads is in reality likely to involve considerable acceleration and deceleration, which is wasteful of fuel. Other studies using micro-simulation have demonstrated that results are highly dependent on specific conditions in a given network (Int Panis, Broekx and Liu, 2005). Therefore caution must be exercised in extrapolating results from specific networks to the general case.

The other analysis was carried on the speed profiles recorded in the ISA field trials and using the more complex emissions calculation engine that took into account second-by-second speed and acceleration. This analysis found no negative impact of ISA on $CO_2$ on urban (30 and 40 mph) roads. Indeed there was a small positive effect for mandatory ISA. On rural 60 mph roads there was no impact of voluntary ISA, but a small increase with mandatory ISA. On 70 mph roads, however, there was a substantial reduction of 3.4% with voluntary ISA and 5.8% with mandatory ISA. Thus both methodologies indicate a positive impact on motorways, while the micro-simulation finding of a negative impact on $CO_2$ in urban driving can be counterbalanced by the real-world data indicating overall no effect when run though a sophisticated calculation engine. Thus for roads with a speed limit lower than 70 mph, a reasonable overall conclusion is that ISA has no effect on emissions. For 70 mph roads, the larger $CO_2$ saving of 3.4% (voluntary) and 5.8% (mandatory) predicted by the sophisticated methodology is considered to be more reliable than the motorway prediction from the micro-simulation. It also has the advantage that it considers driving round the clock as opposed to just for a few hours in the day. Therefore this result from the more sophisticated emissions calculation procedure is applied later in the cost-benefit analysis.

# 4 The Predicted Impact of ISA on Accidents

## 4.1 Methodology

The methodology for predicting the impact of ISA on accidents and casualties reduction is based on using observed or modelled changes in speed choice that result from having a vehicle with ISA fitted. The initial assumption is that ISA changes the distribution of speeds for those vehicles equipped with ISA by reducing the propensity to exceed the speed limit. Depending on the type of ISA fitted, the changes in speeds can be greater or smaller. From those observed or calculated changes in speed distribution, resulting changes in the propensity of ISA-equipped vehicles to be involved in crashes can be calculated using empirically derived models of the speed-safety relationship from a large body of literature on the subject.

By combining the speed profiles from the ISA trials with the speed-safety relationships, predictions of overall crash savings can be generated. There are also well-established relationships between speed and crash *severity* in the form of the “Power Model” (see Elvik et al., 2004). This allows the impact of ISA on crashes at various severities to be predicted.

## 4.2 Cars

There have been a considerable number of studies looking at the relationship between the speed choice of car drivers and crash risk. From the observed speeds and accident data acquired in these studies, a variety of statistical relationships or models relating speeds to crash risk have been calculated. The ISA-UK project reviewed these models and identified those that were best suited to being applied to predicting the impact of ISA on crash risk (Tate and Carsten, 2008). Preferred models were identified for each speed limit. Criteria for model selection included that they should be appropriate theoretically for a system such as voluntary or mandatory ISA which tends to curtail high speeds and that they should be based on data that covered the relevant speed limit.

The preferred or “base combination” of models selected for the ISA-UK analysis is shown in Table 13. Two other combinations of models were also tested: one that produced substantially higher overall predicted impacts and one that produced slightly lower impacts. Given these findings, the base combination has been applied in the current study. Table 14 shows how the models have been applied across road category for the current analysis, which uses more road categories than the analysis reported in Tate and Carsten (2008). Further details on the models are supplied in Appendix 2. In general, Table 14 follows Table 13. The major exceptions are the unclassified rural roads with speed limits of 50 mph and 60 mph. Here the Elvik power model has been applied because of the approximately normal distribution of the speeds both in the baseline case and with all variants of ISA. This makes the Kloeden rural model less appropriate.

**Table 13: The base combination of speed-accident models from ISA-UK**

| *ISA Variant* | *Speed Limit* | | | | | |
|---|---|---|---|---|---|---|
| | ***20 mph*** | ***30 mph*** | ***40 mph*** | ***50 mph*** | ***60 mph*** | ***70 mph*** |
| Advisory | U2 | U2 | U2 | Kloeden Rural | Kloeden Rural | Elvik Power |
| Voluntary | U2 | Kloeden Urban | Kloeden Urban | Kloeden Rural | Kloeden Rural | Elvik Power |
| Mandatory | U2 | Kloeden Urban | Kloeden Urban | Kloeden Rural | Kloeden Rural | Elvik Power |

Note: U2 model (Taylor et al, 2000)
Kloeden rural model (Kloeden et al., 2001)
Kloeden urban model (Kloeden et al., 2002)
Elvik power model (Elvik et al., 2004)

**Table 14: The models applied for the accident reduction analysis**

| *Road Type* | *ISA Variant* | *Speed Limit* | | | | | |
|---|---|---|---|---|---|---|---|
| | | ***20 mph*** | ***30 mph*** | ***40 mph*** | ***50 mph*** | ***60 mph*** | ***70 mph*** |
| Unclassified roads | Advisory | U2 | U2 | U2 | P | P | |
| | Voluntary | U2 | KU | KU | P | P | |
| | Mandatory | U2 | KU | KU | P | P | |
| B roads | Advisory | U2 | U2 | U2 | KR | KR | |
| | Voluntary | U2 | KU | KU | KR | KR | |
| | Mandatory | U2 | KU | KU | KR | KR | |
| A roads | Advisory | | U2 | U2 | KR | KR | P |
| | Voluntary | | KU | KU | KR | KR | P |
| | Mandatory | | KU | KU | KR | KR | P |
| Motorways | Advisory | | | U2 | KR | | P |
| | Voluntary | | | KU | KR | | P |
| | Mandatory | | | KU | KR | | P |

Note: KR: Kloeden rural model
KU: Kloeden urban model
P: Elvik power model

The next step was to apply the models to the data on the speed of vehicles with ISA. The main source of information on car speeds was the trials conducted in the ISA-UK project. These data were used as follows:

- Speeds without ISA — this was provided by the data on driving in the first month (baseline period);

- Speeds with voluntary ISA — this was provided by the overall data on driving during the four months with voluntary ISA available;
- Speeds with mandatory ISA — this was provided by the data on driving during the four months with voluntary ISA when drivers had the ISA engaged (i.e. had not overridden the system).
- Speeds with advisory ISA — this was calculated based on recorded speeds with voluntary ISA adjusted by the relative impact on speed choice of an advisory ISA as compared to a voluntary ISA obtained from the results of the French project LAVIA (Ehrlich et al., 2006).

The ISA-UK database had information on a total of 79 drivers. The data on the initial month of driving without ISA and the four months of driving with ISA had a total of 292,000 accumulated miles on roads with a known speed limit. The data were analysed to provide the relative frequency of travel in 2 km/h "bins" (0.01–2.00 km/h, 2.01–4.00 km/h, etc.).

The analysis was carried out by road type, including speed limits (ranging from 20 mph to 70 mph) and road categories (Motorways, A roads, B roads, and unclassified roads). Data from some road types did not warrant their inclusion in the analysis due to insufficient information. These road types are highlighted in yellow in Table 15. The missing cells are ones where there are only a handful of accidents on British roads.

**Table 15: Overview of data quality**

| | ***20 mph*** | ***30 mph*** | ***40 mph*** | ***50 mph*** | ***60 mph*** | ***70 mph*** |
|---|---|---|---|---|---|---|
| Unclassified roads | ✓ | ✓ | ✓ | ✓ | ✓ | |
| B roads | ✓ | ✓ | ✓ | ✓ | ✓ | |
| A roads | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Motorways | No data | | ✓ | ✓ | | ✓ |

The results of the accident reduction analysis are reported in Table 16. The numbers represent a ratio of the accident risk between an ISA variant and the baseline (i.e. no ISA). For example, a ratio of 0.8 indicates that the ISA system reduces the likelihood of accident occurrence for an equipped vehicle by 20%. Some of the effects appear somewhat large, particularly those for mandatory ISA on 20 mph roads. This is largely due to the impact of ISA when engaged of curtailing speeding between such features as humps. However, this will have little impact on the overall effect of ISA on crashes, given the small number of accidents on 20 mph roads.

Mandatory ISA achieves the greatest potential of accident reduction across all combinations of road types. The differences between mandatory ISA and the other two variants of ISA are most prominent on urban roads, where a large proportion of accidents occur. Voluntary ISA is generally most effective in urban environments. The effect of voluntary ISA obviously is subject to the amount of overriding. The ISA-UK results indicate ISA was most often overridden on urban A-roads and motorways, thus reducing the additional impact of a voluntary ISA over an advisory ISA as shown in Table 16. The effect of Advisory ISA is generally minimal.

Overall it can be seen that the impact of advisory ISA is quite small. But the impact of intervening forms of ISA — voluntary and mandatory — is predicted to be quite large, particularly on urban (30 and 40 mph) roads. This means that ISA has a large potential to save accidents involving vulnerable road users.

**Table 16: Predicted accident reduction factors for cars by ISA variant and road type**

| *Road Type* | *ISA Variant* | *Speed Limit* | | | | | |
|---|---|---|---|---|---|---|---|
| | | *20 mph* | *30 mph* | *40 mph* | *50 mph* | *60 mph* | *70 mph* |
| Unclassified roads | Advisory | 0.95 | 0.98 | 0.97 | 0.98 | 1.00 | – |
| | Voluntary | 0.99 | 0.80 | 0.53 | 0.91 | 0.96 | – |
| | Mandatory | 0.38 | 0.59 | 0.39 | 0.91 | 0.96 | – |
| B roads | Advisory | 0.88 | 0.98 | 0.96 | 0.88 | 0.93 | – |
| | Voluntary | 0.70 | 0.76 | 0.69 | 0.85 | 0.88 | – |
| | Mandatory | 0.57 | 0.59 | 0.52 | 0.82 | 0.87 | – |
| A roads | Advisory | – | 0.98 | 0.98 | 0.87 | 0.89 | 0.97 |
| | Voluntary | – | 0.90 | 0.73 | 0.84 | 0.81 | 0.96 |
| | Mandatory | – | 0.46 | 0.42 | 0.73 | 0.77 | 0.87 |
| Motorways | Advisory | – | – | 0.98 | 0.84 | – | 0.92 |
| | Voluntary | – | – | 0.74 | 0.95 | – | 0.86 |
| | Mandatory | – | – | 0.32 | 0.66 | – | 0.75 |

Outputs from the various micro-simulation networks discussed in Chapter 3 have been examined to ascertain whether the modelling indicates that there is a “critical mass” effect of either voluntary or mandatory ISA on traffic speed. The hypothesis here is that, at higher levels of penetration, ISA-equipped vehicles would have a knock-on effect on the speed of vehicles following them in the traffic stream. Such effects were observed in some networks, particularly the motorway network where trucks limited to 60 mph tended to act as moving obstacles. But overall, there was no substantial confirmation of anything apart from a linear increase in ISA impact with increasing penetration. This can be seen from Figure 16 which shows the predicted percentage of vehicles exceeding the speed limit as ISA penetration increases on the various networks (all the modelled time periods have been summed). It can broadly be concluded that the impact of penetration is linear, so that the effect at 80% is double that at 40% and so on. Therefore the linear assumption has been adopted for the safety prediction.

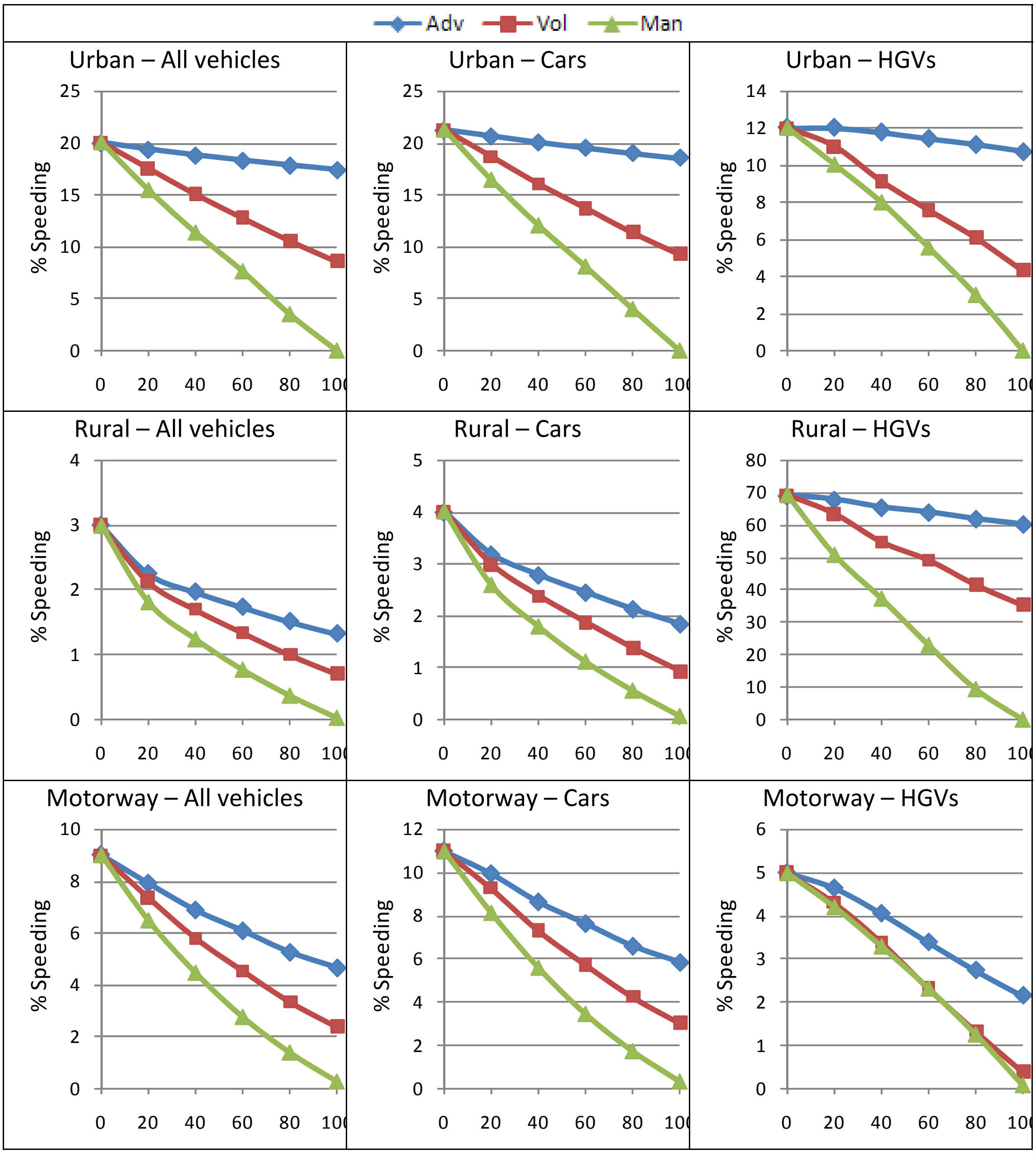



**Figure 16: Percentage of distance travelled over speed limit at by ISA penetration**

## 4.3 Other vehicles

### *4.3.1 Introduction*

ISA can be fitted to other vehicles besides passenger cars. In the ISA-UK project both a truck and a motorcycle were fitted. The truck was used in an on-road trial and the motorcycle was used for a set of rides on a test track. For the purposes of this study, however, two-wheeled motor vehicles, such as motorcycles, mopeds and motor scooters, are considered not capable of being fitted with ISA. This is mainly because it is not possible to predict the safety effect of ISA on such vehicles. Similarly, pedal cycles, agricultural vehicles, trams and what are termed "other motor vehicles" and "other non-motor vehicles" in the national accident database are considered non-ISA-capable. The following vehicle types, in addition to cars, are considered to be capable of fitment:

1. Taxis and private hire cars
2. Minibuses
3. Buses and coaches
4. Goods vehicles up to 3.5 tonnes maximum gross weight
5. Goods vehicles over 3.5 tonnes and less than 7.5 tonnes
6. Goods vehicles over 7.5 tonnes

Altogether, at least one ISA-capable vehicle was involved in 87% of injury accidents in Great in 2002 through 2006, while 13% of accidents had no ISA-capable vehicle involved.

Of the vehicle categories listed above, (1) and (2) have been treated as cars. Goods vehicles up to 3.5 tonnes are discussed under “Light Goods Vehicles” below. Goods vehicles over 3.5 tonnes have been grouped with buses and coaches and are discussed under “Heavy Goods Vehicles” below.

### *4.3.2 Light Goods Vehicles*

Unlike cars, LGVs were not tested in the ISA-UK trials, so that there was no real-world information on how ISA might change their speeds. The micro-simulation models did not treat them as a separate group. As an alternative, a comparison was made between the speed patterns of cars and LGVs as indicated by the annual publication Vehicle Speeds in Great Britain for the years 2002 through 2006. Mean speed, speed variance and proportion of vehicles speeding were examined. The comparison indicated that, for motorways, rural single-carriageway roads and built-up (urban) roads, the speed patterns of cars and LGVs were remarkably similar. As a result, it has been considered appropriate to apply the same safety models to LGVs as to cars. This assumption can be considered to be conservative, since LGVs tend to be heavier than cars and therefore tend to cause more damage in a crash.

### *4.3.3 Heavy Goods Vehicles*

As for LGVs, an observed speed distribution for HGVs without and with ISA was not available — the data from the single HGV driven by one driver in the ISA-UK project was not considered to be sufficient. However, HGV speeds were modelled in the micro-simulation networks, and the results used for safety prediction. Newer HGVs are fitted with speed limiters that restrict their maximum speed to 56 mph (90 km/h). Therefore HGVs’ speeds on motorways, where a 60 mph legal limit applies to them, are much less likely to be affected by ISA (although there is a small amount of actual speeding, including on downhill stretches). Therefore, it was presumed that ISA would have no safety benefit for HGVs on motorways and rural dual carriageways with the national speed limit.

From the rural and urban simulation models, speed distributions were developed for HGVs with voluntary and mandatory ISA as compared with the baseline situation of no ISA. Speed compliance with advisory ISA was calculated using the same procedure as applied for cars, namely applying the relative impact of an advisory ISA as opposed to a voluntary ISA from the LAVIA project.

The resulting speed distributions for HGVs on urban roads with a 30 mph speed limit are shown in Figure 17. The distributions for HGVs on rural single carriageways with a 40 mph speed limit are shown in Figure 18.

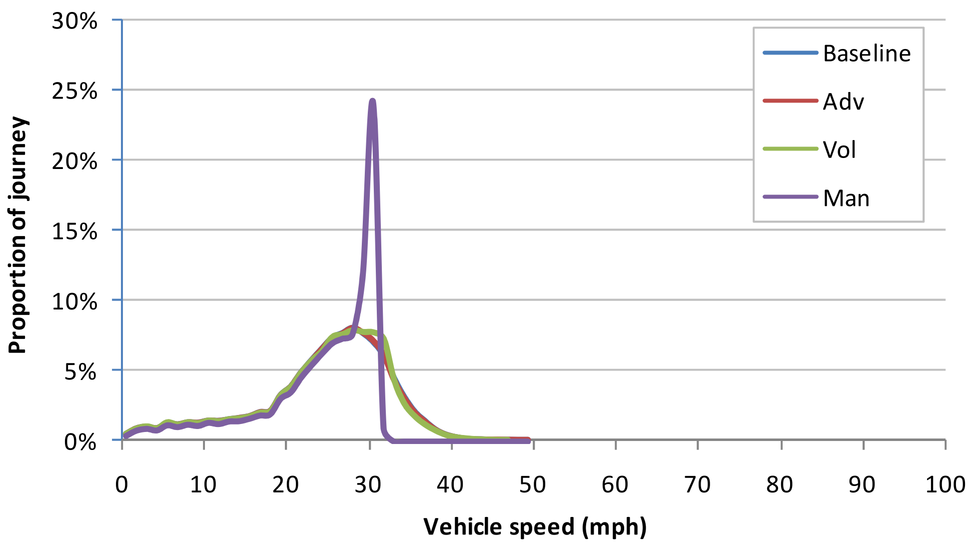



**Figure 17: Speed distributions for HGVs on 30 mph roads**

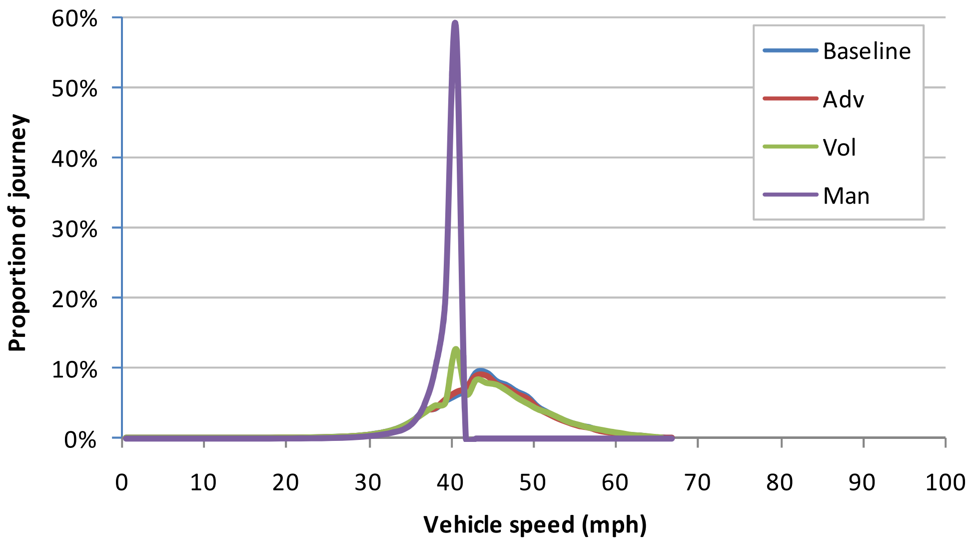



**Figure 18: Speed distributions for HGVs on rural single carriageways**

Speed-accident relationships for HGVs are not available in the literature. All of the existing speed-accident relationships were developed based on car accident data. Given the dramatic change in HGV speed distribution with ISA, (apart from advisory ISA), the Kloeden models were considered to be the best candidate speed-accident relationship for this analysis, as these account for changes in risk at the high end of the speed distribution better than other models. The predicted accident reduction factors for each equipped HGV by ISA variant and road type are shown in Table 17. It should be noted that the benefit of ISA on HGVs is likely to be even greater than predicted due to the weight of these vehicles.

**Table 17: Predicted accident reduction ratios for HGVs by ISA variant**

| *ISA Variant* | *Urban (30 mph)* | *Rural single carriageway (40 mph)* |
|---|---|---|
| Advisory | 0.991 | 0.981 |
| Voluntary | 0.951 | 0.955 |
| Mandatory | 0.483 | 0.216 |

However, there was some concern about using estimates of the speed changes for HGVs obtained only from micro-simulation modelling. There was also concern about not having any speed-accident relationships for HGVs. As a consequence, it was decided to apply the car relationships to accidents involving HGVs just as those relationships were also applied to accidents involving light goods vehicles.

## 4.4 Handling the safety impact of ISA at the accident level

The fact that that a vehicle is equipped with ISA will not necessarily affect its risk at the accident level. For example, the ISA-equipped vehicle might be the vehicle setting off from the minor road in a two-vehicle crash at an intersection. For single-vehicle accidents, the issue is relatively straightforward: risk will be affected by the proportion of ISA-equipped vehicles on the road. For two-vehicle crashes, it can be assumed that the proportion of crashes affected by ISA will be equal to the proportion of ISA in the "at fault" vehicles. This again will at least be equal to the proportion of ISA vehicles overall. It is actually a conservative assumption, since in head-on collisions, for example, both participants could be affected by ISA, and even rear-end collisions at high speeds could be affected by both vehicles having ISA. For multiple-vehicle crashes, it is again assumed that risk will be affected by at least one vehicle having ISA, and once again this assumption is somewhat conservative.

## 4.5 Overall safety impact of ISA

By combining the information on the numbers of accidents that occurred in the period 2002 through 2006 on various types of road with the risk reduction factors based on the speed-accident relationships, the overall potential of the different types of ISA to reduce injury accidents can be calculated. This potential is the proportion of crashes that would be saved, if a given percentage of ISA-capable vehicles were fitted with a particular variant of ISA.

Table 18 gives the prediction for the proportions of injury accidents on the entire road network that would be saved with increasing penetration of ISA. The voluntary and mandatory variants of ISA are estimated to be considerably more effective than advisory ISA. Effectiveness goes up with penetration level. At 100% penetration, voluntary ISA would reduce the number of injury accidents by 12% and mandatory ISA by 29%.

**Table 18: Percentage of injury accidents on all roads that would be saved with ISA fitment**

| ***Penetration*** | | ***ISA Variant*** | |
|---|---|---|---|
| | ***Advisory*** | ***Voluntary*** | ***Mandatory*** |
| 20% | 0.5% | 2.4% | 5.8% |
| 40% | 1.1% | 4.8% | 11.6% |
| 60% | 1.6% | 7.2% | 17.3% |
| 80% | 2.2% | 9.6% | 23.1% |
| 100% | 2.7% | 12.0% | 28.9% |

Table 19 shows an equivalent set of predictions for motorways belonging to the trunk (i.e. national) road network. On motorways, as compared to all roads, ISA is predicted to have a smaller but still considerable safety impact.

**Table 19: Percentage of injury accidents on trunk motorways that would be saved with ISA fitment**

| ***Penetration*** | | ***ISA Variant*** | |
|---|---|---|---|
| | ***Advisory*** | ***Voluntary*** | ***Mandatory*** |
| 20% | 0.9% | 1.8% | 3.6% |
| 40% | 1.8% | 3.6% | 7.3% |
| 60% | 2.8% | 5.4% | 10.9% |
| 80% | 3.7% | 7.2% | 14.5% |
| 100% | 4.6% | 9.0% | 18.1% |

Table 20 gives the estimates for trunk A roads, both single and dual carriageway. Here ISA is predicted to have a slightly greater impact than on motorways. Finally, Table 21 gives the prediction for 30 mph roads. Here the impact of ISA is greatest, because many of these crashes involve a collision with a pedestrian where vehicle speed strongly affects the risk of severe injury or fatality. On such road, ISA has the potential to save up to one-third of injury accidents.

**Table 20: Percentage of injury accidents on trunk A-roads that would be saved with ISA fitment**

| *Penetration* | *ISA Variant* | | |
|---|---|---|---|
| | ***Advisory*** | ***Voluntary*** | ***Mandatory*** |
| 20% | 1.7% | 2.4% | 4.2% |
| 40% | 3.3% | 4.8% | 8.3% |
| 60% | 5.0% | 7.2% | 12.5% |
| 80% | 6.6% | 9.6% | 16.7% |
| 100% | 8.3% | 12.0% | 20.8% |

**Table 21: Percentage of injury accidents on 30 mph roads that would be saved with ISA fitment**

| *Penetration* | *ISA Variant* | | |
|---|---|---|---|
| | ***Advisory*** | ***Voluntary*** | ***Mandatory*** |
| 20% | 0.3% | 2.3% | 6.7% |
| 40% | 0.5% | 4.7% | 13.4% |
| 60% | 0.8% | 7.0% | 20.1% |
| 80% | 1.0% | 9.3% | 26.8% |
| 100% | 1.3% | 11.7% | 33.6% |

## 4.6 Conclusions

It can be concluded that ISA is a system with the potential to save a very considerable proportion of accidents. That potential is largest on 30 mph roads, where there is considerable speeding and a large proportion of crashes involve collisions with pedestrians. However, on other types of road such as trunk motorways and A-roads, ISA also has considerable potential as a safety measure. Overall, advisory ISA is predicted to be substantially less effective than the intervening (voluntary and mandatory) forms of ISA.

# 5 How Many Accidents Can be Saved with the Gradual Introduction of ISA?

## 5.1 Introduction

The previous chapter ended with predictions of the proportion of accidents that could be saved at various levels of ISA penetration. However, this does not tell us how many accidents would be saved in the future. ISA cannot be introduced overnight, and a considerable time might elapse before ISA reached 100% penetration. In that time traffic levels would almost certainly grow, but safety would generally improve because of measures other than ISA. Such factors need to be considered in making predictions of how many accidents ISA could save in the future.

## 5.2 Methodology

There is a well-established methodology, set out by the Department for Transport, on how to make predictions of future safety on the road network. The procedures are laid out in the Department for Transport manual for cost-benefit analysis (Department for Transport, 2004). The following need to be considered (for each there are standard predictions):

1. How many vehicles of various types there are in the country

2. The average annual travel for each type of vehicle

3. The risk of accident involvement per kilometre travelled

Combining these three factors give a prediction of the number crashes in future years. The procedure has been adopted here for the period 2010 through 2070. It is assumed that 2010 is the first year of ISA implementation. It is also assumed that ISA is a system that will continue to deliver benefits over a long period. Therefore the advice from DfT to evaluate ISA over a 60-year appraisal period from initial adoption has been followed.

Analysis of the distribution of Injury accidents in the years 2002 through 2006 by road type, severity level and whether an ISA-capable vehicle was involved provides the initial basis for the prediction of future accidents. A baseline number of accidents in all years from 2010 to 2070 is calculated. Because DfT does not provide guidance on how to calculate the severity level of future accidents it is assumed that fatal accidents, serious accidents and slight accidents will all decline at the same rate.

The next step is to consider the impact of ISA. In any given future year, ISA will alter the predicted baseline number of accidents by an amount that depends on the number of vehicles with advisory, voluntary or mandatory ISA that are predicted to be driving on British roads. For each of those variants of ISA, risk reduction factors for accidents on different types of road have been estimated in chapter 3. ISA's impact on accidents at different levels of severity (fatal, serious and slight) can be estimated by applying the power model of Elvik et al. (2004).

However, there is not one single ISA future. Various scenarios for ISA implementation are possible. The prediction procedures allow these scenarios to be compared in terms of their impact on safety. Two types of scenario have been considered:

1. Scenarios in which just a single variant of ISA is implemented. Here advisory, voluntary and mandatory ISA are examined separately to indicate how many accidents each would save over the 60-year time period.

2. Mixed scenarios in which more than one variant of ISA is adopted simultaneously. Here two scenarios have been developed: a Market Driven scenario in which users choose to have ISA because they want it, and an Authority Driven scenario in which adoption of ISA, particularly “stronger” forms of ISA is initially encouraged and eventually required.

The first type of scenario is better at indicating the safety potential of different variants of ISA. The second type has the advantage of being more realistic and providing a better indication of the contribution made by the active encouragement of adopting ISA as a road safety measure.

## 5.3 Baseline (no ISA) prediction

The number of accidents in future years was estimated as follows:

(number of accidents in base year) x (traffic growth) x (accident rate reduction factor)

The number of accidents in the base year was the mean number of accidents recorded in the national accident database, STATS19, in the years 2002 through 2006, broken down by severity level. The middle year, 2004, was used as the base year. Traffic growth was obtained from the National Traffic Forecasts (Department of the Environment Transport and the Regions, 1997), Table 3. Zero change is assumed post-2031. The accident reduction factor was obtained from the COBA manual (Department for Transport, 2004), Table 4/1. Zero change is assumed post-2030. The resulting predictions are shown in Figure 19. It can be seen that, according to this procedure, there is a general tendency for accidents to rise after 2010. The upward trends post 2010 shown in Figure 19 are primarily due to the fact that the predicted rate of traffic growth outweighs the rate of accident reduction, as shown in Figure 20.

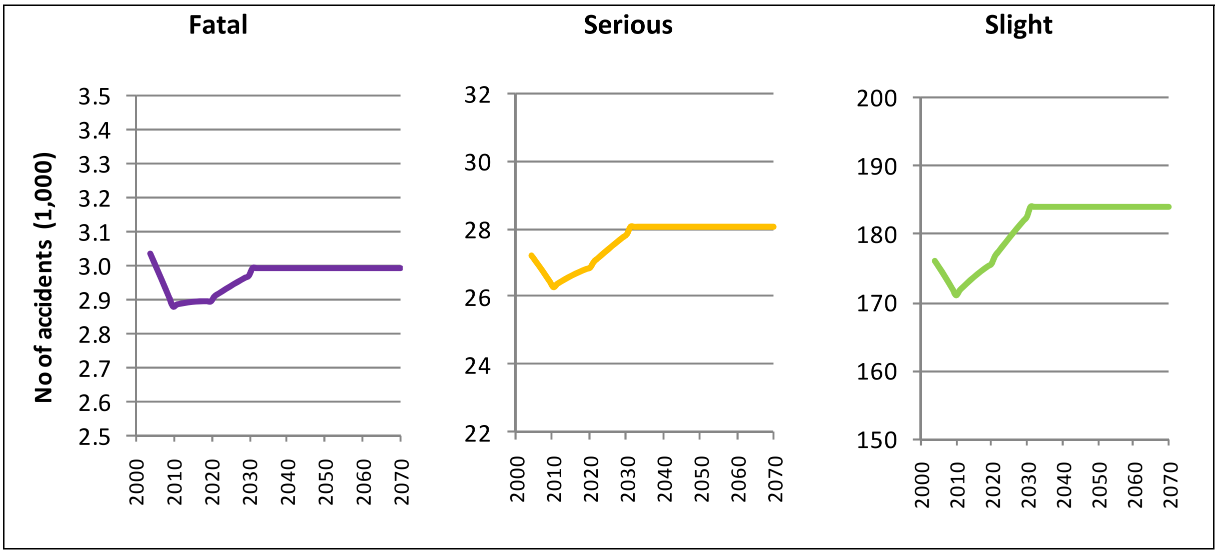



**Figure 19: Predicted number of accidents up to 2070 using COBA procedure**

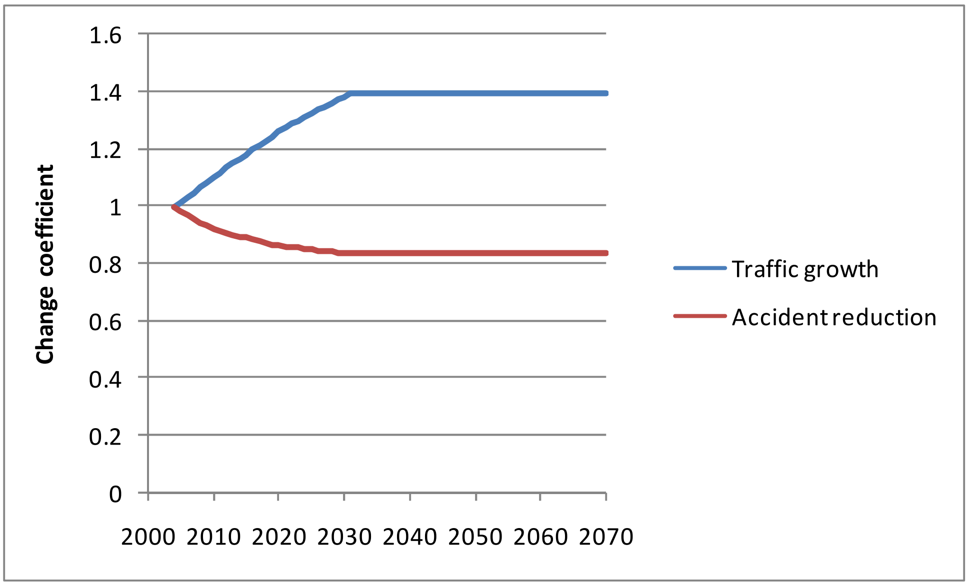



**Figure 20: Traffic growth and accident rate reduction over time**

The annual accident reduction rates specified by COBA are given in Table 22. Urban refers to roads with a 40 mph or lower speed limit; rural refers to roads with a 50 mph or higher speed limit. The COBA manual specifies that the reduction rate for future years should be halved each decade. Zero change is assumed post-2030. It is worth nothing that the COBA manual specifies the accident reduction rate for motorways separately, and here a slight negative reduction (i.e. increase) is specified.

**Table 22: Annual accident reduction specified by COBA (2004)**

| *Period* | *Urban* | *Rural* | *Motorway* |
|---|---|---|---|
| 2000–2010 | −1.6% | −2.7% | 0.1% |
| 2011–2020 | −0.8% | −1.35% | 0.05% |
| 2021–2030 | −0.4% | −0.675% | 0.025% |

Table 23 compares the historical data on the number of accidents from 2000 to 2007, which suggests that the number of accidents actually decreased at a greater rate than the trend specified in COBA. Historical data from accident occurrence on motorways depicted in Table 24 also suggest a declining trend as opposed to the increase specified by COBA.

**Table 23: Historical number of accidents and yearly changes (all roads)**

| | *Number of Accidents* | | | | *Change from Previous Year* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Fatal* | *Serious* | *Slight* | *All* | *Fatal* | *Serious* | *Slight* | *All* |
| 2000 | 3,108 | 32,499 | 198,122 | 320,283 | – | – | – | – |
| 2001 | 3,176 | 31,588 | 194,250 | 313,309 | 2.2% | −2.8% | −2.0% | −2.2% |
| 2002 | 3,124 | 30,521 | 188,106 | 302,605 | −1.6% | −3.4% | −3.2% | −3.4% |
| 2003 | 3,247 | 28,913 | 181,870 | 290,607 | 3.9% | −5.3% | −3.3% | −4.0% |
| 2004 | 2,978 | 26,748 | 177,684 | 280,840 | −8.3% | −7.5% | −2.3% | −3.4% |
| 2005 | 2,913 | 25,029 | 170,793 | 271,017 | −2.2% | −6.4% | −3.9% | −3.5% |
| 2006 | 2,926 | 24,946 | 161,289 | 258,404 | 0.4% | −0.3% | −5.6% | −4.7% |
| 2007 | 2,714 | 24,322 | 155,079 | 182,115 | −7.2% | −2.5% | −3.9% | −29.5% |
| Average | | | | | **−1.8%** | **−4.0%** | **−3.4%** | **−7.2%** |

**Table 24: Historical number of accidents and yearly changes on motorways**

| | *No of Fatal and Serious Accidents* | *Change from Previous Year* |
|---|---|---|
| 2000 | 1,190 | – |
| 2001 | 1,235 | 3.8% |
| 2002 | 1,162 | −5.9% |
| 2003 | 1,166 | 0.3% |
| 2004 | 1,047 | −10.2% |
| 2005 | 1,007 | −3.8% |
| 2006 | 953 | −5.4% |
| **Average** | | **−3.5%** |

Since the historical data show a greater reduction, an alternative set of accident reduction forecasts was developed. The accident reduction rates specified by COBA for urban and rural roads were doubled. For motorways, a rate slightly higher than the recent historical trend of a 3.5% annual reduction was used, in order to ensure a continued decline even with traffic growth. Hence a reduction of 5% was used for 2000–2010 with its magnitude halved every 10 years as specified by COBA. The figures used are shown in Table 25.

**Table 25: Alternative annual rate of accident reduction**

| ***Period*** | ***Urban*** | ***Rural*** | ***Motorway*** |
|---|---|---|---|
| 2000–2010 | −3.2% | −5.4% | −5.0% |
| 2011–2020 | −1.6% | −2.7% | −2.5% |
| 2021–2030 | −0.8% | −1.35% | −1.25% |

The number of accidents for future years were then re-estimated according to the alternative accident reduction rates. The results are illustrated in Figure 21. This alternative set of accident reduction rates seems to provide a more realistic estimation of the number of future accidents. It is worth noting that the predicted numbers of accidents for 2007 are very close to the actual number of accidents reported.

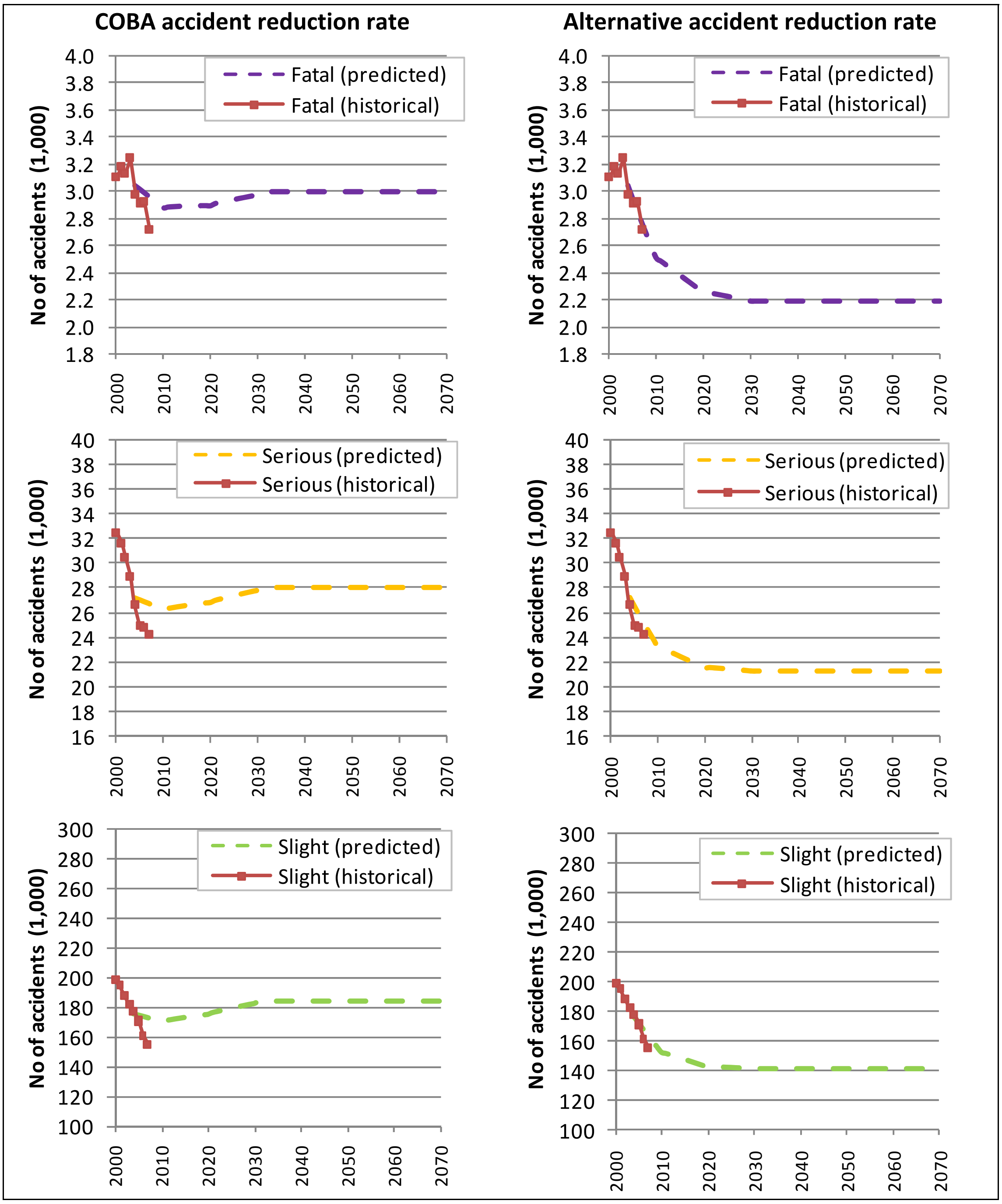



**Figure 21: Comparison of accident predictions with historical numbers**

## 5.4 Results

### *5.4.1 Implementation of a single variant of ISA*

Here it is envisaged that adoption would be as rapid as possible in order to ramp up to 100% ISA penetration. Such deployment would most likely involve legislation or strong incentives to adopt, but this analysis focuses on the potential safety benefits that can be realised with ISA. The assumption is that the vehicle fleet would be equipped with ISA from 2010 starting at 10% of ISA-capable vehicles and increasing by a further 10% each year. The entire vehicle fleet would therefore be equipped with ISA from 2019.

It is recognised that advisory ISA could in reality be deployed at a faster rate than voluntary or mandatory ISA due to the fact that advisory ISA can take the form of a nomadic device (such as a portable satellite navigation system with advisory ISA capability). Voluntary and mandatory ISA require connection to the vehicle's powertrain, and hence professional installation or fitment as original equipment. However, to enable comparison of the three variants on the same basis, the analysis was carried out on the assumption penetration would take place at the same rate.

The predicted impacts by scenario, using the COBA predictions for future accident involvement rates, are provided in Figure 22, Figure 23 and Figure 24. The predicted impacts using the alternative accident reduction predictions are shown in Figure 25, Figure 26 and Figure 27. It can be seen that the predicted impact of advisory ISA on serious and slight injury accidents is minimal. It can also be seen that ISA has a bigger impact on the more severe crashes. Both voluntary and mandatory ISA have a dramatic impact on future accidents.

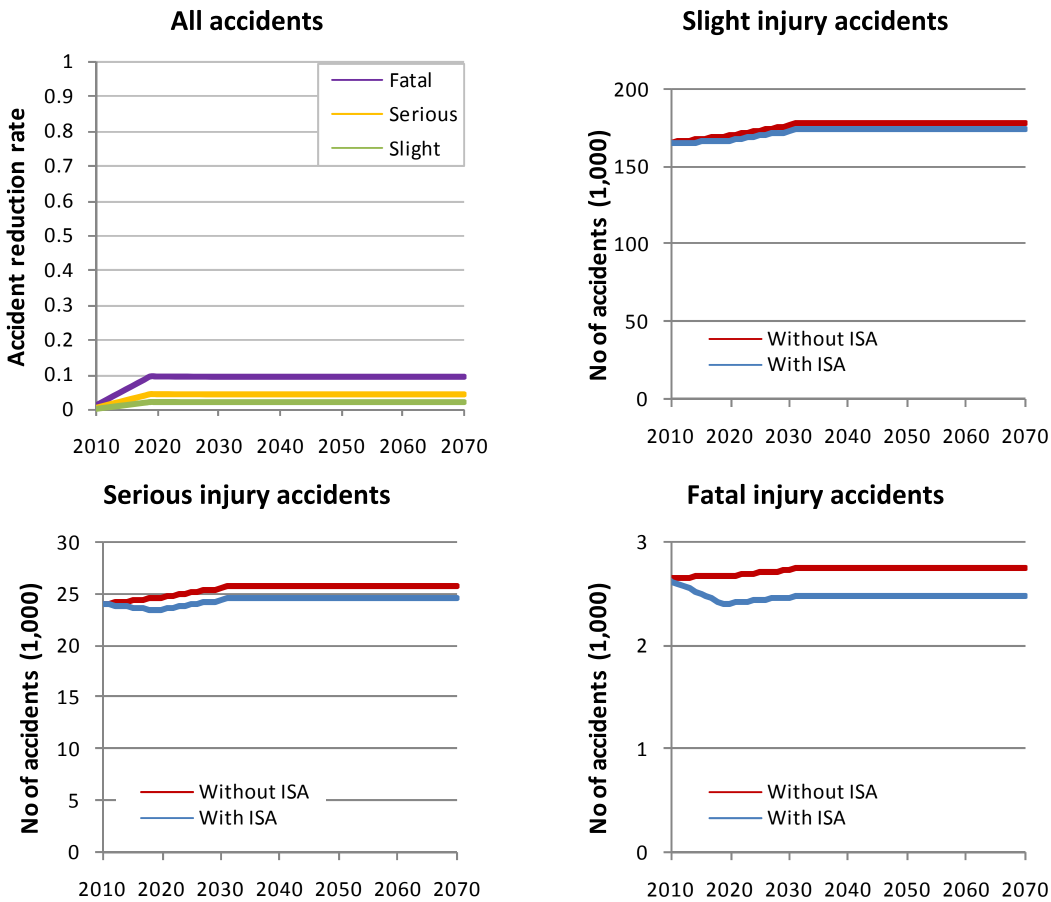



**Figure 22: Predicted accident occurrence for the Advisory ISA scenario using the COBA accident rates**

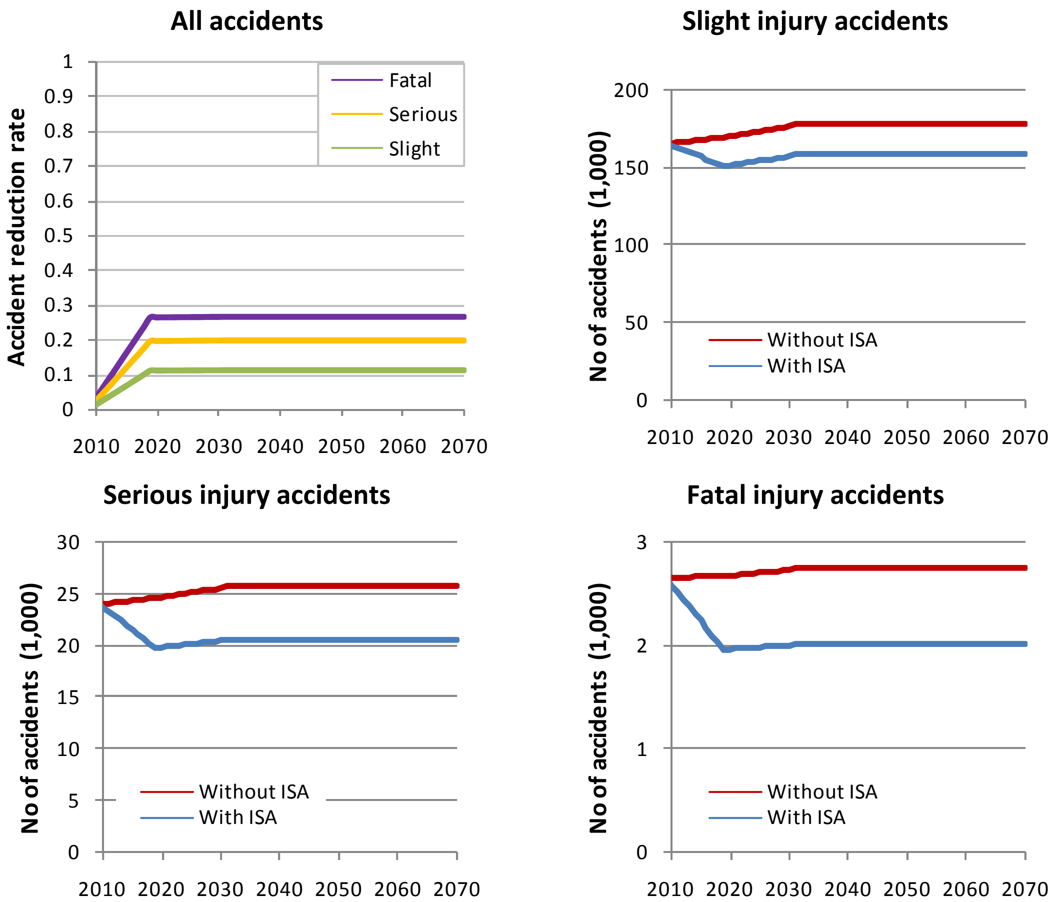



**Figure 23: Predicted accident occurrence for the Voluntary ISA scenario using the COBA accident rates**

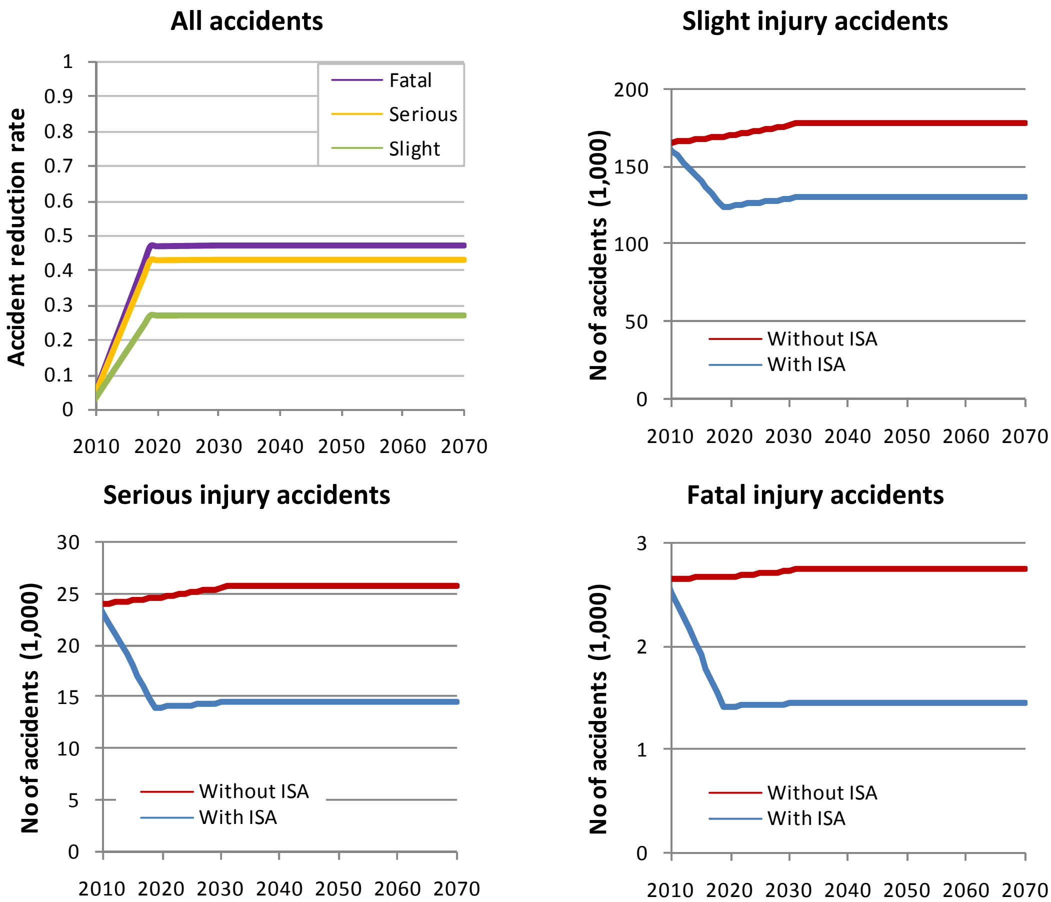



**Figure 24: Predicted accident occurrence for the Mandatory ISA scenario using the COBA accident rates**

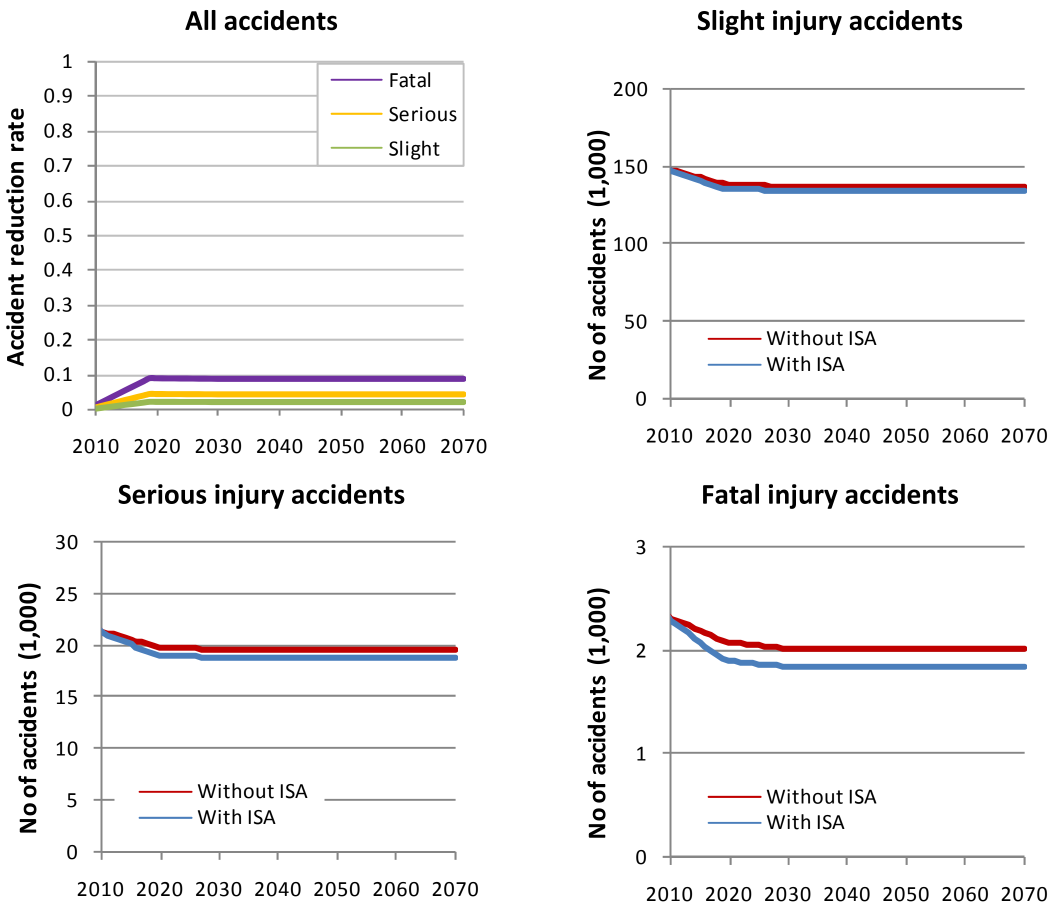



**Figure 25: Predicted accident occurrence for the Advisory ISA scenario using the alternative accident rates**

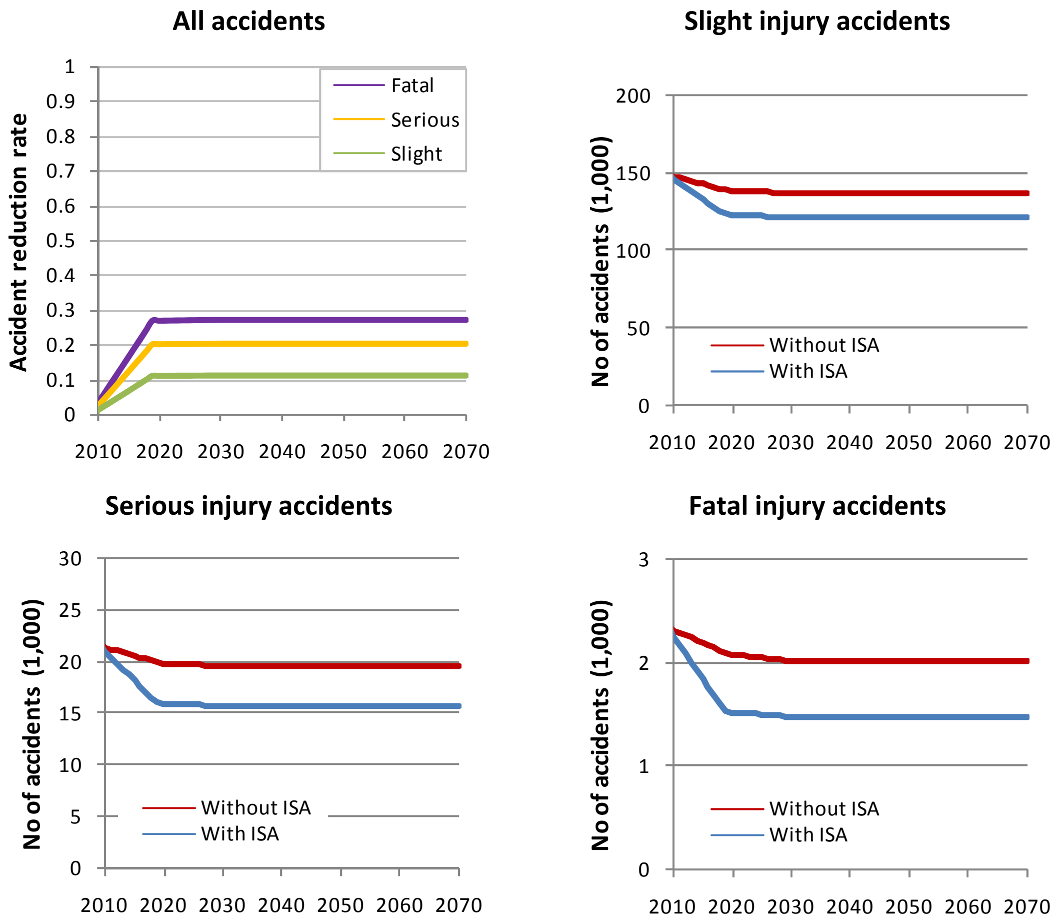



**Figure 26: Predicted accident occurrence for the Voluntary ISA scenario using the alternative accident rates**

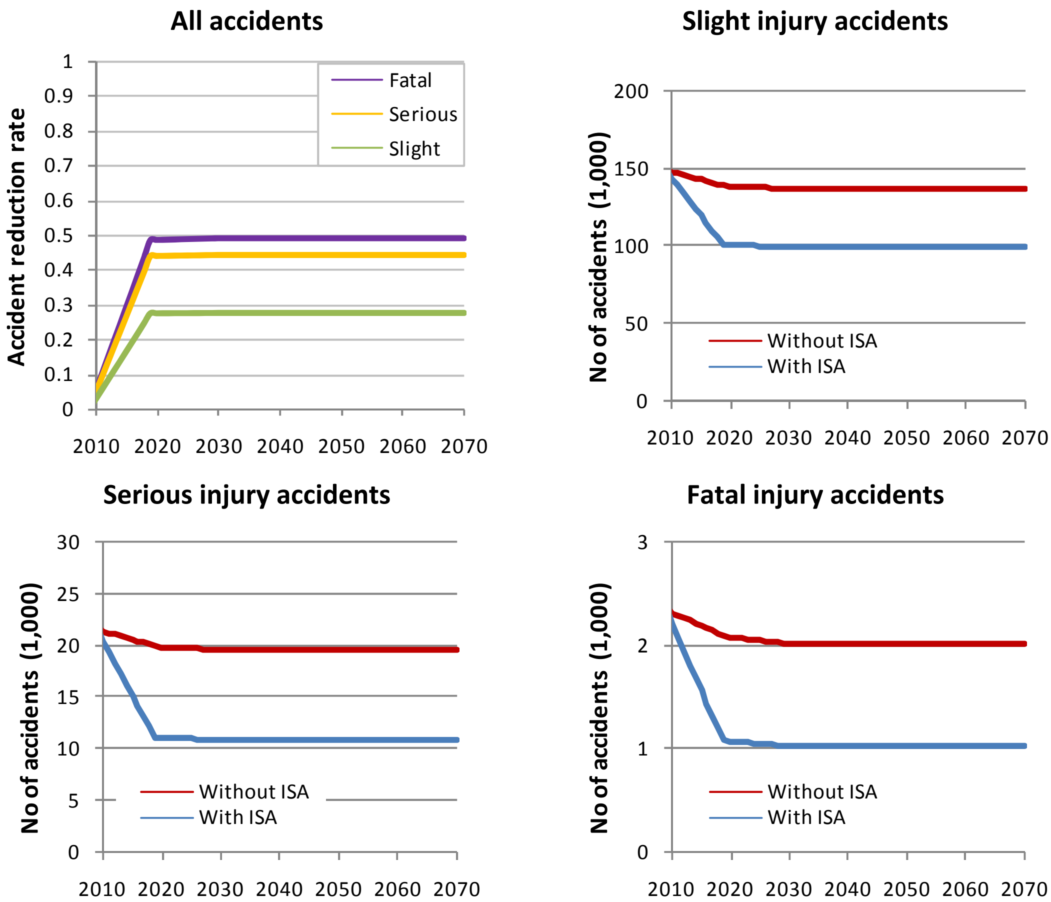



**Figure 27: Predicted accident occurrence for the Mandatory ISA scenario using the alternative accident rates**

### *5.4.2 Mixed scenarios*

In addition to the rather simplified single system scenarios, analysis was also carried out on the two mixed implementation scenarios. These were initially developed in the ISA-UK project (Tate and Carsten, 2008).

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 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, which is achieved by providing ISA-type information on satellite navigation systems. 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 retrofitting 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.

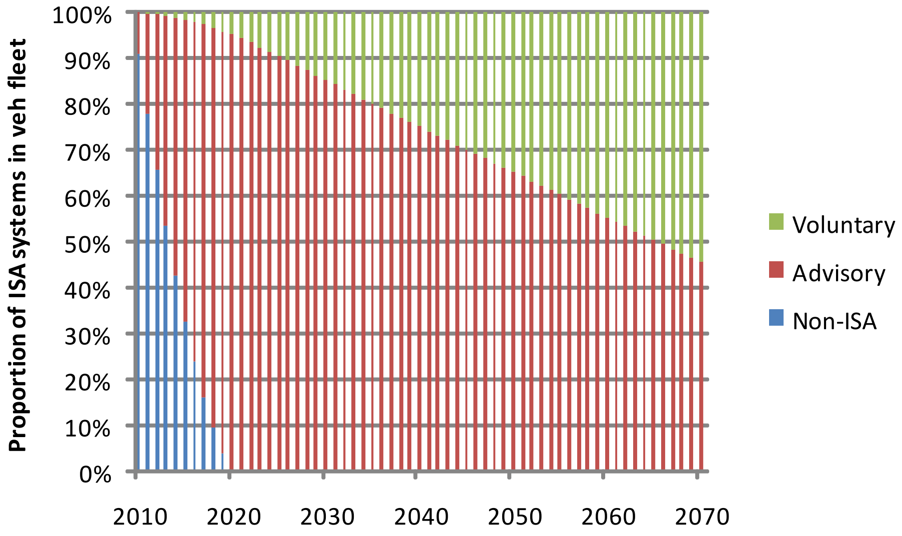



**Figure 28: Penetration of ISA under the Market Driven scenario**

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 retrofitted with advisory ISA simply follows the trend of the Market Driven Scenario which would see all older vehicles retrofitted with Advisory ISA by 2020. No retrofitment 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 retrofitted with voluntary ISA in 2017. While the retrofitment of voluntary ISA would continue, increasing by 5% per year, retrofitting 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 retrofitted with voluntary ISA, and usage of ISA becomes compulsory, so that mandatory ISA is enabled.

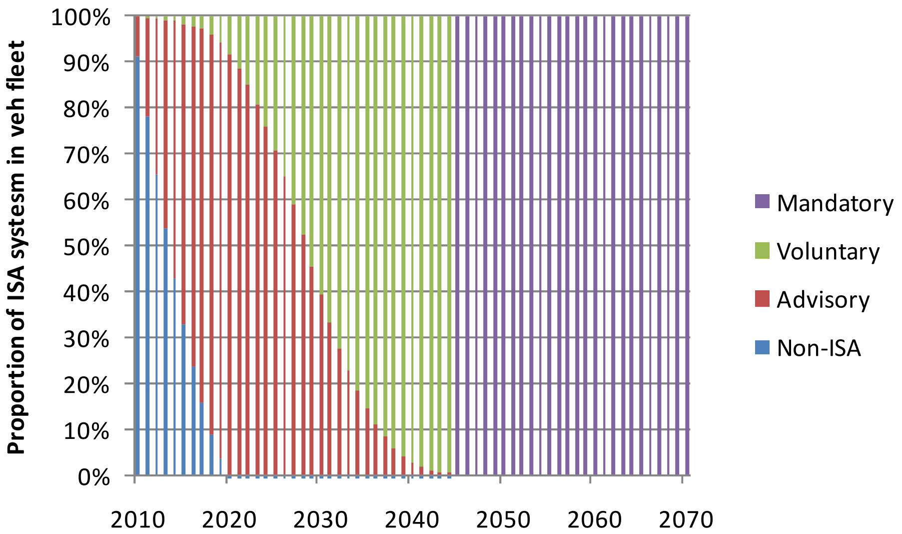



**Figure 29: Penetration of ISA under the Authority Driven scenario**

The results for these two scenarios are shown in Figure 30 and Figure 31 for the COBA predictions of accident involvements rates. Figure 32 and Figure 33 provide the predictions using the alternative predictions of accident involvement rates.

It can be seen that, under the Authority Driven scenario, ISA delivers substantially greater safety benefits than under the Market Driven scenario. However, even the Market Driven scenario — because it incorporates a significant number of vehicles with voluntary ISA — is predicted to deliver considerably greater benefit than the single Advisory ISA scenario shown in Figure 22 and Figure 25.

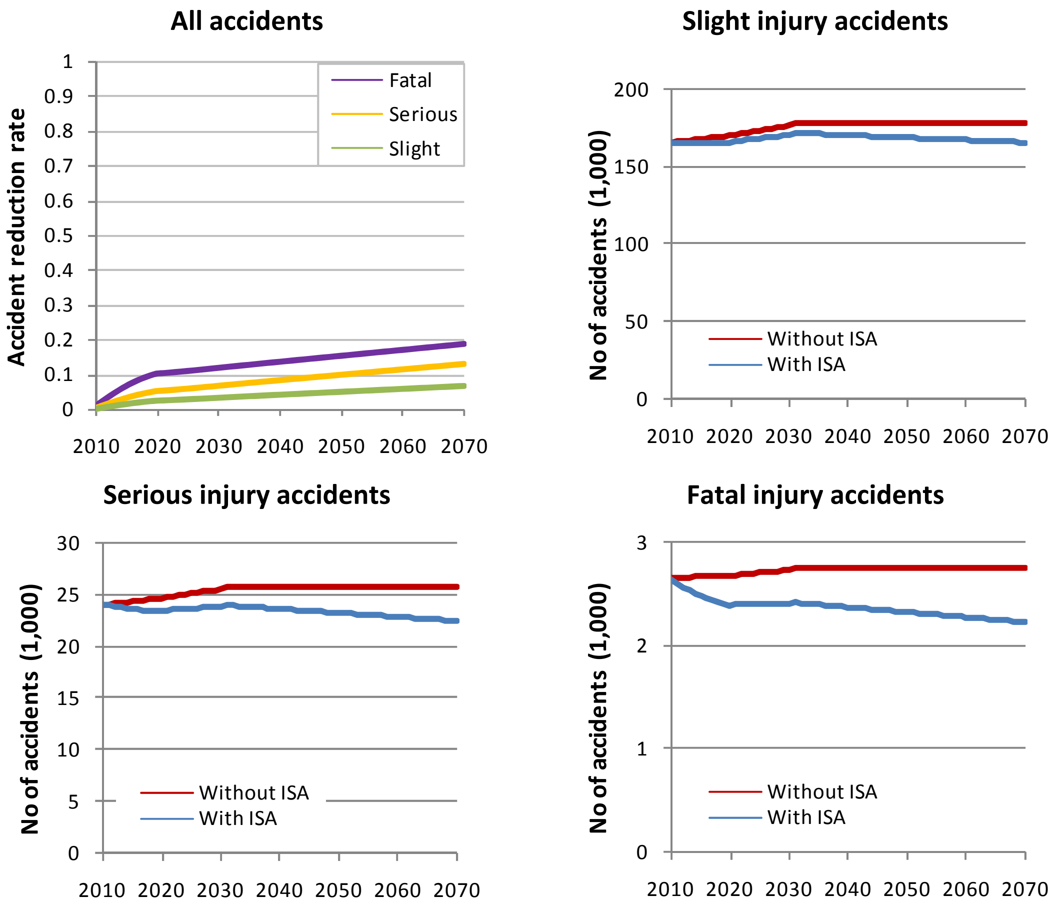



**Figure 30: Predicted accident occurrence for the Market Driven scenario using the COBA accident rates**

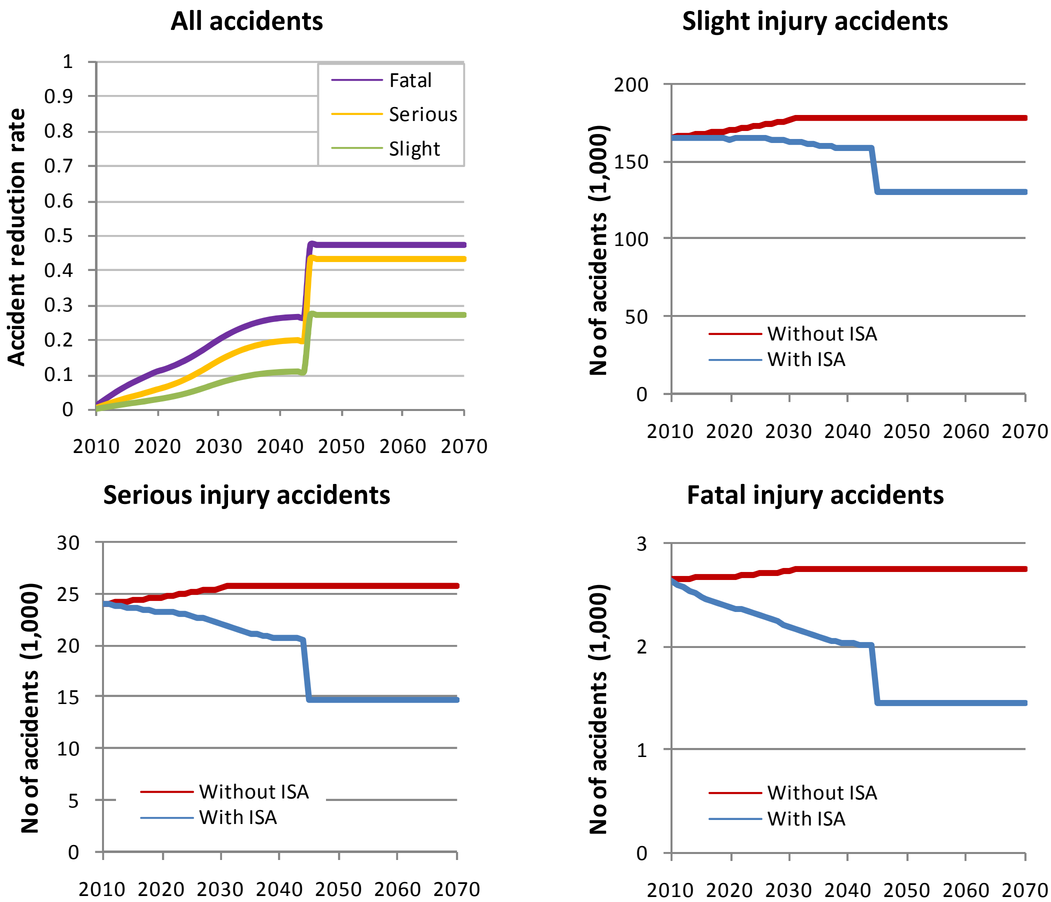



**Figure 31: Predicted accident occurrence for the Authority Driven scenario using the COBA accident rates**

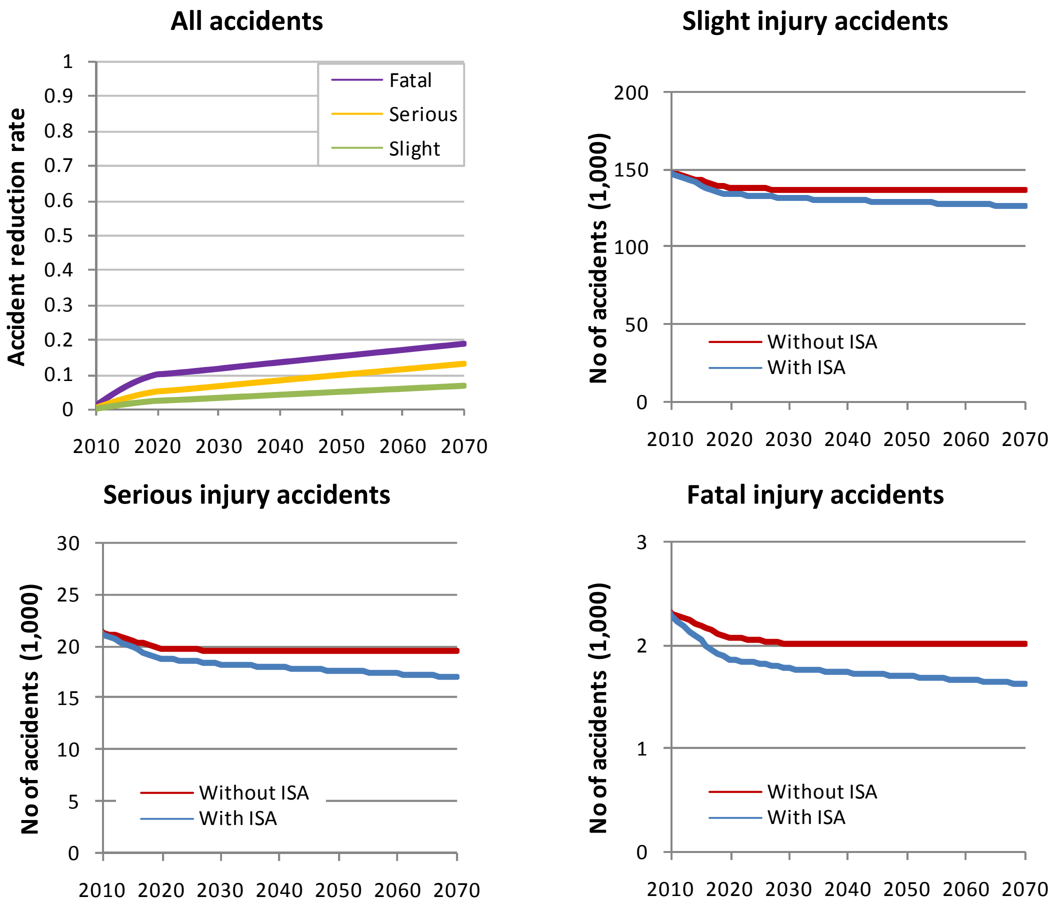



**Figure 32: Predicted accident occurrence for the Market Driven scenario using the alternative accident involvement rates**

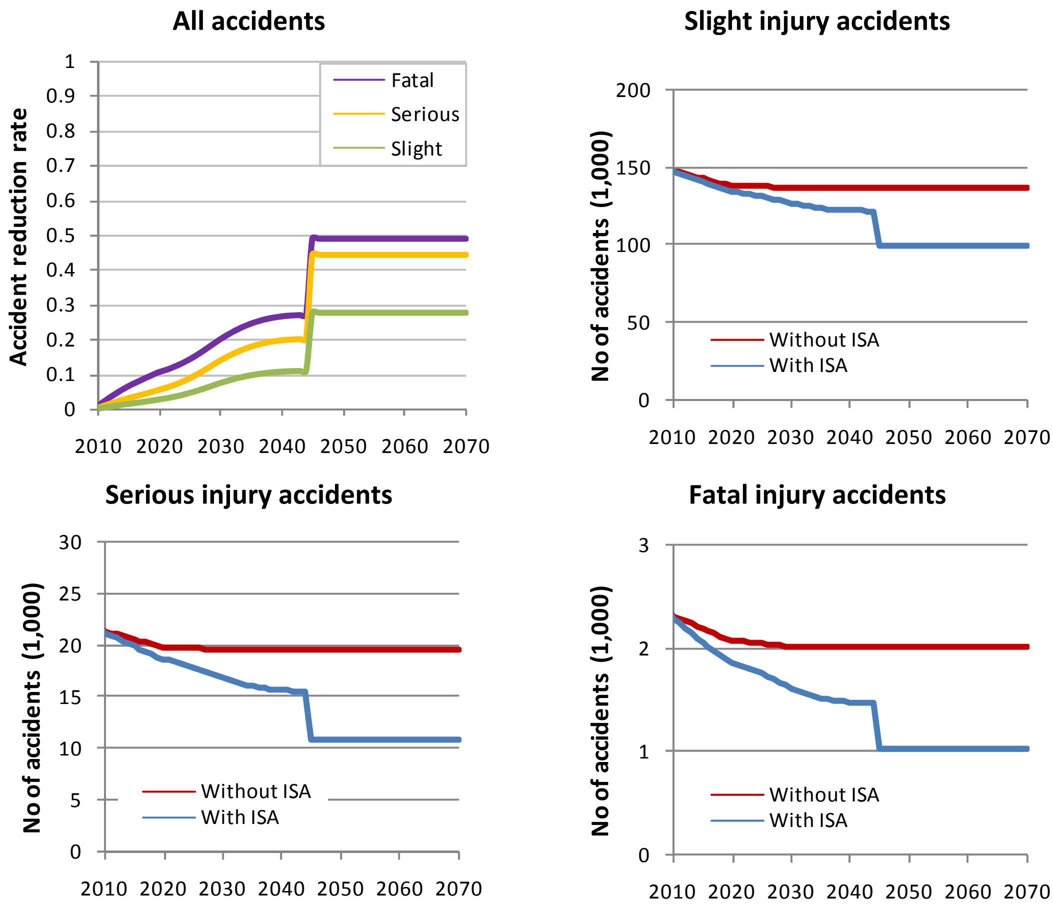



**Figure 33: Predicted accident occurrence for the Authority Driven scenario using the alternative accident involvement rates**

### *5.4.3 Comparison of implementation scenarios*

Table 26 depicts the predicted total number of accidents over the period from 2010 to 2070 under each of the implementation scenarios, using the COBA predictions of accident involvement rates. The Authority Driven scenario is predicted to save 50,000 fatal accidents and 388,000 serious accidents over the 60-year period. This is less than saved under the Mandatory Scenario, but the latter is not a realistic proposition. The Market Driven scenario would save 22,000 fatal accidents and 126,000 serious crashes. These results indicate that, if even some vehicles had voluntary ISA, many serious injuries and fatalities would be prevented.

Applying the alternative prediction of accident involvement rates, as shown in Table 27, produces smaller estimates of the numbers of accidents saved (because the savings are from a lower baseline), but very similar percentage savings to those in Table 26.

**Table 26: Predicted number of accidents for each ISA implementation scenario using COBA predictions of accident involvement rates**

| ***Scenario*** | ***Accident Severity*** | | | ***Total*** |
|---|---|---|---|---|
| | ***Fatal*** | ***Serious*** | ***Slight*** | |
| Baseline (No ISA) | 166,623 | 1,551,485 | 10,721,146 | 12,439,254 |
| Advisory Only | 152,086 (9%) | 1,487,283 (4%) | 10,498,879 (2%) | 12,138,248 (2%) |
| Voluntary Only | 125,198 (25%) | 1,262,964 (19%) | 9,628,839 (10%) | 11,017,001 (11%) |
| Mandatory Only | 93,494 (44%) | 930,436 (40%) | 8,036,446 (25%) | 9,060,376 (27%) |
| Market Driven | 144,633 (13%) | 1,425,308 (8%) | 10,258,576 (4%) | 11,828,517 (5%) |
| Authority Driven | 117,120 (30%) | 1,163,727 (25%) | 9,103,319 (15%) | 10,384,167 (17%) |

Note: percentages in brackets indicate reductions against the baseline

**Table 27: Predicted number of accidents for each ISA implementation scenario using alternative predictions of accident involvement rates**

| ***Scenario*** | ***Accident Severity*** | | | ***Total*** |
|---|---|---|---|---|
| | ***Fatal*** | ***Serious*** | ***Slight*** | |
| Baseline (No ISA) | 125,331 | 1,209,523 | 8,427,059 | 9,761,913 |
| Advisory Only | 114,956 (8%) | 1,162,305 (4%) | 8,264,152 (2%) | 9,541,413 (2%) |
| Voluntary Only | 94,101 (25%) | 984,374 (19%) | 7,571,025 (10%) | 8,649,500 (11%) |
| Mandatory Only | 69,222 (45%) | 718,486 (41%) | 6,295,450 (25%) | 7,083,157 (27%) |
| Market Driven | 109,242 (13%) | 1,113,684 (8%) | 8,074,790 (4%) | 9,297,715 (5%) |
| Authority Driven | 88,062 (30%) | 907,872 (25%) | 7,162,948 (15%) | 8,158,882 (16%) |

Note: percentage in brackets denotes the reduction against the baseline

## 5.5 Conclusions

The clear finding from the predictions of the safety impact of ISA over time is that ISA can have a large effect on future accident number and particularly on the more severe crashes. Not surprisingly, the impact of ISA is increased by strategies that lead to higher level of penetration into the vehicle fleet and also by more rapid introduction of intervening ISA in the form of the voluntary system.

# 6 Cost-Benefit Analysis of ISA

## 6.1 Methodology

The cost–benefit analysis calculates the monetised social costs and benefits of ISA introduction over the 60-year period from 2010 to 2070. This allows the benefit-to-cost ration (BCR) to be calculated. The BCR can be seen as indicating whether there is a case for proceeding with ISA implementation on the grounds that the total benefits that accrue over the period clearly outweigh the costs of investing in ISA.

Once again, the procedures laid out by the Department for Transport in the manual for cost-benefit analysis (Department for Transport, 2004) have been followed. For ISA, it is necessary to consider not only the safety benefits discussed in the previous chapter but also the benefits in terms of reduced fuel consumption and emissions. It is also of course necessary to estimate the profile of ISA equipment costs over the period and to estimate what additional costs might be incurred by for example, the need to supply digital road maps incorporating speed limits.

## 6.2 Costs

The costs of ISA can be broken up into infrastructure costs (those costs need to create the digital map and perhaps to broadcast map updates) and the costs of the in-vehicle equipment. Each is discussed in turn below.

### *6.2.1 Infrastructure costs*

The effort to compile and keep up to date a national speed limit database is considered to be broadly cost-neutral on the grounds that a future process for handling speed limit orders (the legal instruments for making changes in speed limits) would be a replacement for the current manual procedures for processing these. There would be some initial effort required to establish a national speed limit database, which is estimated to be approximately £6 million, as shown in Table 28. This estimate was based on the cost of compiling the London digital speed limit map incurred by Transport for London (£230,000). The lengths of road for London and Great Britain were obtained from Road Statistics 2007 (Department for Transport, 2008).

**Table 28: Estimation of the cost of compiling a national speed limit database**

| | *Road Length (km)* | *Cost of Mapping* |
|---|---|---|
| London | 14,784 | £230,000 |
| GB | 394,879 | £6,143,274 |

However, this national map could be used by many other driver assistance systems in addition to ISA, and would also assist highway authorities in their more general speed management. It is therefore not considered appropriate to ascribe the cost of compiling the initial map to ISA.

Another cost for the government is the transmission over wireless networks of updates to the speed limit map. Without such a service, ISA will soon fall into disrepute. Such broadcast costs are likely to be shared across a range of future traffic management and driver assistance applications. It is therefore not considered appropriate to ascribe them solely to ISA. It should also be noted that the costs are not very likely to be large.

### *6.2.2 In-vehicle costs*

Table 29 identifies the hardware components of advisory and voluntary ISA. A portable satellite navigation system provides a fair basis for the required in-vehicle components of an advisory ISA. It receives a GPS signal, identifies the vehicle's position, links that position to the stored database (i.e. the digital map), and displays the information both visually and by audio. On the other hand, a portable satellite navigation system also receives inputs from the user and provides response accordingly. Although it is recognised that an advisory ISA would not need a colour display, a portable satellite navigation system is considered to be the best candidate for a cost benchmark for an advisory ISA system which would be available for purchase at retail prices.

An entry level brand new TomTom is currently available at £95. The price could go further down due to market competitiveness. Hence the retail price of an advisory ISA is estimated to be £80 in 2010, and £50 in 2015. The price is estimated to be steady thereafter rather than decrease further, since there is always a bottom line in the price trend for consumer electronics: newer models tend to provide additional functionality at similar cost.

**Table 29: Components of in-vehicle ISA equipment**

| *Components of ISA* | *Advisory* | *Voluntary/ Mandatory* |
|---|---|---|
| Processor + RAM | ✓ | ✓ |
| Storage (flash memory card) | ✓ | ✓ |
| GPS chip | ✓ | ✓ |
| HMI (screen, buzzer, and buttons) | ✓ | ✓ |
| Control mechanism (linked to throttle and brake) | × | ✓ |

**Note:** ✓ Required function
× Not applicable
[yellow] Functionality provided by a portable satellite navigation system
[green] Functionality provided by an on-board driver-set speed limiter

Additional items are:

A SIM card (no cost)

An annual cost for speed limits database update (£10 is assumed)

Labour costs for retrofit (where applicable)

An on-board speed limiter provides most of the functionality required by a voluntary (intervening) ISA system, apart from the ability to identify the prevailing speed limit (i.e. recognise the vehicle's location and match it with the speed limit database). A speed limiter has been made available as optional equipment by various car manufacturers. The retail price ranges from £123 (on a Mercedes) to £250 (on a Renault). While it is recognised that car manufactures adopt different pricing strategies, £150 is considered to be a reasonable retail price for a speed limiter in 2010. The price would most likely to decrease further until a reasonable bottom line in line with general price trends for automotive electronics. Hence it is estimated that the price of a speed limiter would be £125 in 2015, £100 in 2020, and would keep steady thereafter.

The cost for the functionality of identifying the prevailing speed limits is estimated through the predicted retail price of an entry level portable satellite navigation system as used for the advisory ISA system, although the cost of HMI components has to be deducted from the complete unit. The cost of the HMI components is estimated to be approximately 50% of the complete unit. This estimation is based on the cost of a replacement screen for a modern mobile phone, which ranges from a mono screen capable of display dot-matrix texts only at £6.50 to a TFT screen capable of displaying full colours in 16.7M depth at £30, in addition to a few buttons and a speaker. Hence the cost of hardware for identification of prevailing speed limits is estimated to be £40 in 2010 and £25 in 2015, and keep steady thereafter (i.e. 50% of the predicted price for a basic TomTom). The resulting costs are shown in Table 30.

**Table 30: Predicted costs of intervening (voluntary or mandatory) ISA**

| | ***Speed Restriction Functionality*** | ***Speed Limit Identification Functionality*** | ***Total*** |
|---|---|---|---|
| 2010 | £150 | £40 | £190 |
| 2015 | £125 | £25 | £150 |
| 2020 | £100 | £25 | £125 |
| : | : | : | : |
| 2070 | £100 | £25 | £125 |

The on-board speed limits database will need to be updated from time to time. A similar functionality of such is provided by TomTom WORK WebFleet, which supports two-way communication between the base and a vehicle through the GSM network. The monthly charge for unlimited text messages ranges from £11.99 for one vehicle to £9.60 for over 250 vehicles. Considering the sheer amount of vehicles equipped with ISA, the cost for this speed limit update service is estimated at £10 per vehicle per annum remaining constant up to 2070. The cost of a GSM SIM card to individual vehicles is considered to be negligible, i.e. absorbed into the annual service charge, as in the cost model adopted by mobile phone service providers.

The cost of fitment of an ISA system is considered to be negligible for new vehicles, as this would be part of vehicle manufacture. As for retrofit, two hours labour is considered to be reasonable. The labour charge is considered to be £75 per hour (Warranty Direct, 2008), which would increase over years along with the value of working time specified by the Department for Transport (Table 3, WebTAG 3.5.6). The resulting labour costs are shown in Table 31.

**Table 31: Labour costs**

| | ***Labour cost (£ per hour)*** |
|---|---|
| 2008 | 75 |
| 2010 | 79 |
| 2015 | 86 |
| 2020 | 95 |
| 2025 | 103 |
| 2030 | 111 |
| 2035 | 122 |
| 2040 | 135 |
| 2045 | 147 |
| 2050 | 160 |
| 2055 | 173 |
| 2060 | 187 |
| 2065 | 203 |
| 2070 | 221 |

Table 32 gives the total estimated costs for ISA hardware over time. Estimates are provided for both original equipment and retrofitted ISA.

**Table 32: Estimated costs for in-vehicle ISA hardware (pounds)**

| | New vehicle | | Retrofit | |
|---|---|---|---|---|
| | *Advisory* | *Voluntary/ Mandatory* | *Advisory* | *Voluntary/ Mandatory* |
| 2010 | 90 | 200 | 247 | 357 |
| 2015 | 60 | 160 | 233 | 333 |
| 2020 | 60 | 135 | 250 | 325 |
| 2025 | 60 | 135 | 266 | 341 |
| 2030 | 60 | 135 | 282 | 357 |
| 2035 | 60 | 135 | 305 | 380 |
| 2040 | 60 | 135 | 330 | 405 |
| 2045 | 60 | 135 | 354 | 429 |
| 2050 | 60 | 135 | 380 | 455 |
| 2055 | 60 | 135 | 406 | 481 |
| 2060 | 60 | 135 | 433 | 508 |
| 2065 | 60 | 135 | 467 | 542 |
| 2070 | 60 | 135 | 503 | 578 |

## 6.3 Benefits of ISA

### *6.3.1 Savings from accident reduction*

The economic benefit of accident reductions expected to be achieved through ISA has been based on the most recent Road Casualties Great Britain (2006). The values have been updated in accordance with the instructions given in Highways Economics Note 1 (HEN1) to provide a base cost for 2008 and increased each year by the expected increase in Gross Domestic Product (GDP), in line with Table 3/4 of the manual for cost-benefit analysis (Department for Transport, 2004). The initial values are shown in Table 33.

**Table 33: Average value of prevention of an accident**

| *Year* | *Fatal* | *Serious* | *Slight* |
|---|---|---|---|
| 2006 | £1,690,370 | £196,020 | £20,120 |
| 2008 | £1,770,056 | £205,261 | £21,068 |

Combining the values in Table 33 with the estimates of numbers of accidents saved with ISA from the previous chapter, one obtains the Net Present Values of accident reduction for the five implementation scenarios as shown in Table 34 and Table 35. The values are somewhat lower when applying the alternative prediction of accident rates.

**Table 34: Net Present Value of accident reduction by implementation scenario using the COBA accident rates**

| *Implementation scenario* | *Net Present Value (£m in 2008 prices)* |
|---|---|
| Market Driven | £43,904 |
| Authority Driven | £110,909 |
| Advisory ISA only | £27,049 |
| Voluntary ISA only | £96,365 |
| Mandatory ISA only | £194,240 |

**Table 35: Net Present Value of accident reduction by implementation scenario using the alternative accident rates**

| *Implementation scenario* | *Net Present Value (£m in 2008 prices)* |
|---|---|
| Market Driven | £32,808 |
| Authority Driven | £85,122 |
| Advisory ISA only | £19,681 |
| Voluntary ISA only | £74,480 |
| Mandatory ISA only | £152,660 |

### *6.3.2 Fuel savings*

As discussed in section 3.3, the overall finding from the emissions modelling is that both voluntary and mandatory ISA would have a significant effect on $CO_2$ emissions from cars on 70 mph roads. The same proportionate savings can be predicted for fuel consumption. It is assumed that other light vehicles have the same fuel and emissions savings as cars, and it is also assumed that there is no fuel or emissions savings for heavy goods vehicles, coaches or buses. Other emissions savings, apart from $CO_2$, were considered to be negligible, as were reductions in noise.

To calculate the value of fuel saved from vehicles having ISA, it is necessary to predict the cost of fuel over the period from 2010 to 2070. Retail fuel prices generally move in line with the price of crude oil. A crude oil price forecast issued recently by the government (BERR, 2008) envisages four possible future scenarios: Low, Central, High and High High. The estimates over time for each scenario are shown in Table 36.

**Table 36: Crude oil price in US$ per barrel (BERR, 2008)**

| | *Low* | *Central* | *High* | *High High* |
|---|---|---|---|---|
| 2007 | 73 | 73 | 73 | 73 |
| 2010 | 45 | 65 | 85 | 107 |
| 2015 | 45 | 68 | 90 | 150 |
| 2020 | 45 | 70 | 95 | 150 |
| 2025 | 45 | 73 | 100 | 150 |
| 2030 | 45 | 75 | 105 | 150 |

Indexing these predicted prices to the 2010 predicted price gives the values shown in Table 37. Again it is assumed that beyond 2030 costs are stable.

**Table 37: Price index for crude oil relative to the 2010 price (2010 price = 1)**

| | *Low* | *Central* | *High* | *High High* |
|---|---|---|---|---|
| 2010 | 1 | 1 | 1 | 1 |
| 2015 | 1 | 1.05 | 1.06 | 1.40 |
| 2020 | 1 | 1.08 | 1.12 | 1.40 |
| 2025 | 1 | 1.12 | 1.18 | 1.40 |
| 2030 | 1 | 1.15 | 1.24 | 1.40 |

Fuel savings were estimated at the national level. The steps in the estimation were as follows:

1. The volume of fuel used on motorways by cars and vans was obtained, split between petrol and diesel (Office of National Statistics, 2008). This gives total litres used by cars and by vans.

2. Future fuel consumption was calculated based on the forecast increase in travel by cars and vans on motorways from the figures given in the DfT publication 'Road Transport Forecasts for England 2007'.

3. An adjustment was made to account for the expected improvement in fuel efficiency in the future vehicle fleet. This adjustment was based on WebTAG 3.5.6 Table 13 (published by DfT). According to WebTAG, the proportion of petrol and diesel vehicles in the future fleet has been built into the efficiency factors.

4. The forecast future fuel prices were calculated for petrol and diesel in terms of a resource cost, which is net of fuel duty and VAT, and the price was applied to the amount of fuel each year to get the total monetary value.

5. The estimated savings in consumption with voluntary (3.4.%) and mandatory ISA (5.8%) were applied to the yearly cost to get savings for 100% penetration.

6. The savings were adjusted to the size of the fleet equipped with ISA in each year.

Table 38 shows the predicted savings in $CO_2$ emissions and fuel over the 60 year period as calculated at step 3 in the above procedure. The full process gives the values for the 60-year period shown in Table 39.

**Table 38: Savings in emissions and fuel by ISA implementation scenario**

| *Implementation scenario* | *$CO_2$ (tonnes)* | *Fuel (litres)* |
|---|---|---|
| Market Driven | 4,139,311 | 6,459,505,951 |
| Authority Driven | 16,303,642 | 25,436,233,731 |
| Advisory ISA only | 0 | 0 |
| Voluntary ISA only | 15,009,557 | 23,470,842,292 |
| Mandatory ISA only | 25,604,538 | 40,038,495,675 |

**Table 39: Net Present Value of fuel saving by implementation scenario (£m in 2008 prices)**

| *Implementation Scenario* | *BERR Fuel Price Scenario* | | | |
|---|---|---|---|---|
| | *Low* | *Central* | *High* | *High High* |
| Market Driven | £436 | £446 | £545 | £624 |
| Authority Driven | £1,703 | £1,740 | £2,139 | £2,439 |
| Advisory ISA only | – | – | – | – |
| Voluntary ISA only | £2,228 | £2,267 | £2,690 | £3,155 |
| Mandatory ISA only | £3,800 | £3,867 | £4,589 | £5,383 |

### 6.3.3 $CO_2$ savings

$CO_2$ savings were calculated based on the estimated fuel savings. These figures were based on the Central fuel price scenario. They are not sensitive to changes in fuel prices. The valuation of the social cost of $CO_2$ emissions was obtained from WebTag (DfT). The resulting estimate of the savings from the various ISA implementation scenarios is shown in Table 40.

**Table 40: Net Present Value of $CO_2$ emissions reduction by implementation scenario**

| *Implementation scenario* | *Net Present Value (£m in 2008 prices)* |
|---|---|
| Market Driven | £196 |
| Authority Driven | £773 |
| Advisory ISA only | £0 |
| Voluntary ISA only | £802 |
| Mandatory ISA only | £1,369 |

## 6.4 Benefit Cost Ratio

Table 41 and Table 42 give the benefit-to-cost ratios (BCRs) over time for each of the implementation scenarios. The tables are based on the BERR Central scenario for fuel prices. The cells highlighted in green indicate the years in which the accumulated benefits start to outweigh the accumulated costs. It can be seen that the payback time is generally not very long. In less than 15 years, under virtually every scenario, ISA has recovered its implementation costs. Over the whole period considered the BCRs are large, with the smallest being the Advisory ISA Only scenario, which is not considered particularly realistic.

**Table 41: Cumulative benefit-to-cost ratios over time for each implementation scenario using the COBA accident rates**

| | *Market Driven* | *Authority Driven* | *Advisory* | *Voluntary* | *Mandatory* |
|---|---|---|---|---|---|
| 2010 | 0.16 | 0.15 | 0.18 | 0.38 | 0.77 |
| 2011 | 0.21 | 0.20 | 0.22 | 0.46 | 0.93 |
| 2012 | 0.27 | 0.27 | 0.27 | 0.58 | 1.17 |
| 2013 | 0.34 | 0.34 | 0.33 | 0.71 | 1.43 |
| 2014 | 0.42 | 0.41 | 0.39 | 0.84 | 1.69 |
| 2015 | 0.49 | 0.49 | 0.45 | 0.98 | 1.97 |
| 2016 | 0.57 | 0.56 | 0.52 | 1.13 | 2.27 |
| 2017 | 0.65 | 0.64 | 0.59 | 1.28 | 2.58 |
| 2018 | 0.73 | 0.73 | 0.66 | 1.44 | 2.90 |
| 2019 | 0.81 | 0.81 | 0.74 | 1.62 | 3.25 |
| 2020 | 0.90 | 0.91 | 0.84 | 1.81 | 3.65 |
| 2025 | 1.43 | 1.52 | 1.32 | 2.76 | 5.54 |
| 2030 | 1.93 | 2.26 | 1.72 | 3.54 | 7.10 |
| 2035 | 2.42 | 3.15 | 2.08 | 4.23 | 8.48 |
| 2040 | 2.92 | 4.06 | 2.42 | 4.87 | 9.77 |
| 2045 | 3.44 | 5.16 | 2.75 | 5.48 | 10.98 |
| 2050 | 3.96 | 7.07 | 3.06 | 6.07 | 12.17 |
| 2055 | 4.51 | 8.83 | 3.37 | 6.65 | 13.32 |
| 2060 | 5.08 | 10.48 | 3.68 | 7.22 | 14.47 |
| 2065 | 5.67 | 12.08 | 3.98 | 7.79 | 15.61 |
| 2070 | 6.29 | 13.63 | 4.28 | 8.36 | 16.75 |
| **OVERALL** | **6.3** | **13.6** | **4.3** | **8.4** | **16.7** |

**Table 42: Cumulative benefit-to-cost ratios over time for each implementation scenario using the alternative accident rates**

| | *Market Driven* | *Authority Driven* | *Advisory* | *Voluntary* | *Mandatory* |
|---|---|---|---|---|---|
| 2010 | 0.13 | 0.13 | 0.15 | 0.33 | 0.66 |
| 2011 | 0.17 | 0.16 | 0.18 | 0.39 | 0.80 |
| 2012 | 0.22 | 0.22 | 0.22 | 0.49 | 1.00 |
| 2013 | 0.28 | 0.27 | 0.27 | 0.60 | 1.22 |
| 2014 | 0.33 | 0.33 | 0.32 | 0.71 | 1.44 |
| 2015 | 0.39 | 0.39 | 0.37 | 0.82 | 1.67 |
| 2016 | 0.45 | 0.44 | 0.41 | 0.94 | 1.91 |
| 2017 | 0.51 | 0.50 | 0.46 | 1.06 | 2.15 |
| 2018 | 0.56 | 0.56 | 0.51 | 1.18 | 2.40 |
| 2019 | 0.62 | 0.63 | 0.56 | 1.31 | 2.67 |
| 2020 | 0.68 | 0.69 | 0.64 | 1.47 | 2.99 |
| 2025 | 1.05 | 1.13 | 0.96 | 2.17 | 4.43 |
| 2030 | 1.36 | 1.63 | 1.21 | 2.69 | 5.49 |
| 2035 | 1.65 | 2.17 | 1.41 | 3.11 | 6.33 |
| 2040 | 1.92 | 2.69 | 1.59 | 3.46 | 7.06 |
| 2045 | 2.18 | 3.29 | 1.74 | 3.78 | 7.70 |
| 2050 | 2.44 | 4.31 | 1.89 | 4.07 | 8.29 |
| 2055 | 2.70 | 5.21 | 2.03 | 4.34 | 8.84 |
| 2060 | 2.95 | 6.00 | 2.15 | 4.59 | 9.34 |
| 2065 | 3.19 | 6.72 | 2.27 | 4.82 | 9.82 |
| 2070 | 3.44 | 7.39 | 2.38 | 5.04 | 10.28 |
| **OVERALL** | **3.4** | **7.4** | **2.4** | **5.0** | **10.3** |

It is interesting to note what are the drivers behind the benefits. The attribution of the benefits using the alternative prediction of accident rates is shown in Table 43.

**Table 43: Source of ISA benefits**

| *Implementation Scenario* | *ISA Benefits (£1m)* | | | | *Proportion of Benefits Due to Accident Savings* |
|---|---|---|---|---|---|
| | *Fuel* | *$CO_2$* | *Accidents* | *TOTAL* | |
| Market Driven | £446 | £196 | £32,808 | £33,450 | 98% |
| Authority Driven | £1,740 | £773 | £85,122 | £87,636 | 97% |
| Advisory ISA only | £0 | £0 | £19,681 | £19,681 | 100% |
| Voluntary ISA only | £2,267 | £802 | £74,480 | £77,549 | 96% |
| Mandatory ISA only | £3,867 | £1,369 | £152,660 | £157,895 | 97% |

## 6.5 Conclusions

It can be concluded that implementation of ISA is clearly justified from a social cost and benefit perspective. Intervening forms of ISA (i.e. the voluntary and mandatory variants) deliver greater benefits than advisory ISA. Therefore strategies that promote the adoption of those intervening systems will deliver enhanced benefits. This is not altogether surprising as the benefit side is dominated by the accident savings where voluntary ISA is far more effective than advisory ISA.

# 7 Encouraging the Adoption of ISA

## 7.1 Methodology

Whatever the benefits of ISA, they will not be realised without actual adoption and use by members of the public and fleets. Three successive approaches were used to examine how to encourage adoption. The first step was a **literature review**. The second step was a set of **focus groups** — four with private motorists and one with fleet managers. The focus group with fleet managers was conducted because of their potential to play a key role in accelerating the market penetration of ISA and raising awareness of ISA systems in the wider market.

Because the project was interested in factors influencing vehicle purchase, the private motorists consisted of drivers who were intending to buy a new car within the next two years. Four groups of participants took part in a 90-minute discussion:

1. Male (50% high mileage-drive as part of work, 50% leisure and commuting)
2. Female (50% high mileage-drive as part of work, 50% leisure and commuting)
3. Male (50% high mileage-drive as part of work, 50% leisure and commuting)
4. Female (50% high mileage-drive as part of work, 50% leisure and commuting)

The single-gender group format provided the opportunity to explore potential differences in attitudes towards ISA technologies. As the discussion focused on driving behaviour, it was also important that participants were not tempted to debate the differences between male and female drivers at the expense of the focus of the research. Recruiting high mileage participants who drove as part of their work in addition to 'average' leisure and commuting drivers ensured a spectrum of driving exposure.

Following a warm-up exercise, participants were introduced to the topic of ISA and provided with a fact sheet describing mandatory and voluntary ISA. Discussion in the first half of the focus group focused on participant's reasons for buying or not buying a vehicle fitted with voluntary or mandatory ISA system and the type of incentives required to encourage drivers to purchase such vehicles (e.g. reduction in insurance, tax exemption, preferential treatment). Following a short break, participants discussed how much they would use a voluntary ISA system if it were installed in their vehicle and the how best to increase system use through incentives (e.g. pay as you speed, coupons, insurance rebates.

The fleet manager focus group involved four participants and lasted two hours. Two of the participants, while still working in fleets (as a fleet risk consultant and a director of a fleet management company), were no longer acting directly as fleet managers. As part of a warm-up exercise, the participants were asked to name the three main factors influencing their purchasing/leasing decisions and the information sources used to make that decision. Discussion then explored various policies and road safety management procedures in place within the fleet managers' companies, exploring their approach towards speeding violations and accidents. Following a short break, participants were introduced to the topic of speed control and provided with a fact sheet describing voluntary and mandatory ISA. Discussion focused on participants' reason for buying or not buying a vehicle fitted with a voluntary or mandatory ISA system and the type of incentives required to encourage drivers to purchase such vehicles (e.g. reduction in insurance, tax exemption, preferential treatment). Participants also discussed how much they would use a voluntary ISA system if it were installed in their vehicles and how best to increase system use through incentives (e.g. pay as you speed, coupons, insurance rebates). The focus groups closed with an exercise which sought to explore the implementation of ISA within a fleet, examining key stakeholders, their likely concerns and potential incentives/information which could appease these concerns.

The final stage, with the issues investigated being informed by the results of the focus groups with private motorists, was a **Stated Preference (SP) survey** of drivers. SP is a survey technique used to understand individuals' preferences and how they use those preferences to make choices. The aim of SP is to explore how individuals respond to a range of hypothetical choice settings in order to establish a willingness to pay for a particular desirable attribute (i.e. a benefit) or the willingness to accept payment in return for accepting an undesirable attribute (i.e. a disbenefit). Typically, individuals are presented with a number of choice sets, or scenarios, and asked to choose one option from each of the choice sets. The approach involves the description of goods or services in terms of underlying attributes (such as cost, style, features, etc.). The method is referred to as "stated preference" methods, because individuals are asked directly to state their choices, rather than revealing them in a real world setting. Since SP does not depend on actual decisions made in the past, it can be applied to a range of hypothetical contexts and choices. Thus by creating hypothetical (but realistic) scenarios, it is possible to explore those factors influencing choices related to a product, such as ISA, that is not currently available on the public market, and also to identify any important differences between sub-groups in their preferences.

Recognising that some drivers are more safety-inclined than others (and indeed that some would be willing to pay for a safety device), separate survey designs were created for three types of vehicle purchaser:

1. Those who would buy a mandatory ISA system — these drivers received an SP survey where both systems were offered at a cost to the driver (Group 1 with 490 respondents).

2. Those who would buy a voluntary system — here drivers were required to pay for voluntary system but received incentives to buy a mandatory system (Group 2 with 503 respondents).

3. Those who like neither system — both systems were offered with discounts and incentives to encourage drivers to purchase an ISA vehicle (Group 3 with 466 respondents).

The segmentation of respondents into these three groups was based on an initial screening question. Thus the number of respondents falling within each group was a reflection of the spread of opinion across the sample, rather than a predetermined quota sample. The allocation of respondents into these initial groups provides early indication that 64% of the sample were willing to consider purchasing an ISA-equipped vehicle.

Factors influencing decisions to buy that were investigated were purchase price, insurance discount and annual tax discount. Incentives to use Voluntary ISA that were studied were a fuel rebate or cash back on a driver’s insurance premium for every mile travelled with the system activated. Six other factors were also investigated: the percent of other equipped vehicles on road; free optional extras on a new car; varying the penalty administered for committing a speeding offence; and varying the length of time speeding endorsements remain on a driver’s licence. Respondents also supplied demographic information and information on their driving history. Interviews were conducted with 1487 drivers at their homes (1459 of the interviews were usable for analysis). The interviews were carried out across Great Britain in randomly selected areas and at addresses randomly selected within each area. Only one driver was interviewed per household.

Depending on the part of the sample, different designs of the survey were used. The survey design is summarised in Table 44. In Group 1, which contained respondents who expressed a preference for the mandatory system, respondents had to pay for either of the systems, with the price being a function of vehicle price, with a range between 0% and 9% for the mandatory system, and between 4% and 9% for the voluntary system. These values were varied according to an experimental design aimed at encouraging respondents to trade between attributes. The prices for cars used cut-off points of £5,000 and £15,000. Additionally, respondents were given an incentive to use the voluntary system, ranging from no incentive to 2 pence per mile (up to 20,000 miles) and where depending on the design, this was used for fuel rebates or insurance rebates.

In Group 2, which contained respondents who expressed a preference for the voluntary system, a discount on car price was offered in return for choosing the mandatory system (ranging from 5% to 50% of vehicle price), while the respondents had to pay for the voluntary system (ranging from 0.5% to 8% of the vehicle price). The same incentives to use the voluntary system were again offered.

In Group 3, which contained respondents who expressed a dislike for both systems, two approaches were used. In the first approach, discounts on car price are offered in return for choosing either system, ranging from 15% to 40% for the mandatory system, and from 0% to 20% for the voluntary system. In the second approach, these discounts are replaced by tax rebates, ranging from £750 to £950 for the mandatory system and from £0 to £200 for the voluntary system. Finally, incentives to use the voluntary system are again offered, but these have now increased, with a range between 1 penny per mile to 2.5 pence per mile (again with an upper limit of 20,000 miles).

**Table 44: Design of stated preference survey**

| *Group* | *Group Characteristics* | *Form of SP Survey* | *Cost of ISA* | *Incentive to Use Voluntary System* |
|---|---|---|---|---|
| Group 1 (490) | Those who would buy a mandatory ISA system | Survey where both systems were offered at a cost to the driver | Price of system ranges from 0% to 9% of vehicle price for the mandatory system, and from 4% to 9% for the voluntary system | Ranged from 0p to 2p per mile (up to 20,000 miles). Incentive could be fuel rebates or insurance rebates. |
| Group 2 (503) | Those who would buy a voluntary ISA system | Requirement to pay for voluntary system but incentives to buy a mandatory system | Discount on car price offered in return for choosing the mandatory system (ranging from 5% to 50% of vehicle price).<br><br>Respondents had to pay for voluntary system (ranging from 0.5% to 8% of the vehicle price). | Same |
| Group 3 (466) | Those who like neither system | Both systems offered with discounts and incentives | Two approaches tested:<br>(1) discounts on car price offered in return for choosing either system, ranging from 15% to 40% for the mandatory system, and from 0% to 20% for the voluntary system; (2) these discounts were replaced by tax rebates, ranging from £750 to £950 for the mandatory system and from £0 to £200 for the voluntary system | Ranged from 1p per mile to 2.5p per mile (up to 20,000 miles) |

## 7.2 Results

### *7.2.1 Literature review*

The literature review suggested that the benefits potentially associated with ISA (such as improved safety, lower fuel consumption and reduced emissions) can provide a motivating influence behind a driver's purchasing decision. However, attributes such as price, styling and reliability remain drivers' primary considerations when buying a new vehicle. Research has therefore suggested that the key to enhancing market penetration of systems such as ISA lies in promotional activities and deployment initiatives. Promotional activities such as demonstrations, campaigns and field operational tests (large-scale trials) serve to enhance consumers' awareness and understanding of systems. Deployment initiatives are designed to increase a consumer's willingness to buy and include measures such a tax rebates and reduced insurance premiums. Together, successful promotion and deployment activities should lead to increased numbers of ISA equipped vehicles. Drawing from existing literature the review identified a number of incentives that could potentially be used to encourage take-up of ISA. These included tax rebates, vehicle insurance discounts, vehicle purchase price discounts, reward vouchers and free optional extras added to vehicle (e.g. an in-car DVD player).

### *7.2.2 Focus groups*

In general the effectiveness of the voluntary system was questionable, given the types of (safe) people who are likely to purchase it.

> "I would not see any point in applying the voluntary one, because it's kind of like a waste of technology because those people who have it would choose not to use it." [Group 3, female h]

The voluntary system was most attractive in areas where participants felt it was important to drive within the speed limit. For example, participants appreciated the value of ISA in built-up areas where hazards such as pedestrian were more likely, in unfamiliar areas, near speed cameras, motorway exits and on confusing stretches of road.

> "I do not think I would [engage] it on motorway but I would in built up areas." [Group 1 female i]

A system which was mandatory in town, but overridable elsewhere was attractive to some:

> "Villages, towns and city centres, I would not mind it being mandatory there, but on the open roads I would not want it… I have not had accidents on the open road so I am aware of traffic to be able to manage it myself." [Group 2, male i]

There was a general resistance to mandatory ISA (although this was to a lesser extent amongst some female participants). As participants did not believe that they were part of the current safety problem on UK roads, they did not see the potential for ISA.

> "I think the majority of us in this room are mature enough to drive safely." [Group 2, male a]

When discussing the system participants expressed concerns regarding safety, suggesting that mandatory ISA may be dangerous in situations where they need to accelerate out of danger or frustrating when they wanted to overtake.

> "I think it is dangerous… If you are driving a car you like to be in control of the car… There can be times where you might want to put your foot down a little bit and the car will not respond and it could be more dangerous." [Group 4, male g]

However, many participants did think that the technology could be introduced for young/inexperienced drivers. This was an opinion that emerged in all four focus groups. Parents in particular appreciated the potential of ISA for their teenage children.

> "The only time I would buy a car [with mandatory ISA] is if I had kids that were old enough to drive and I would limit them for the first three or four years" [Group 4, male e]

Similarly, mandatory ISA was an attractive option for convicted speeders.

> "If someone gets up to their limit on their penalties I think they should be told that they can only have a mandatory car to prevent them from doing it again. Or they can only be insured to drive a mandatory car." [Group 1, female d]

There was quite a lot of acceptance of compulsory fitment of ISA. This was an unprompted discussion in three out of four of the groups. It was felt by some that compulsory fitment would be fairer and more effective than any incentive schemes designed to encourage take-up. Participants admitted that they would not necessarily like the implementation of ISA but stated that they would accept the legislation and learn to live with it. Indeed many compared the scenario to that of the introduction of seat belts.

> "I probably would contradict myself by saying I would not go out and buy one but I think it should be mandatory on all cars." [Group 2, male c]

> "It will really annoy me and I will hate it but I will get over it. I will really hate it." [Group 3, female c]

> "You don't sell it. It has to be like seat belts." [Group 3, female a]

Some participants went as far to say that, if this was something that the Government believed would dramatically reduce accidents, then offering incentives undermined the importance of this technology.

> "But if it is that important and they (the government) believe in it they seem to be throwing so much at it, they give you this, they give you that and the other. But to me it just seems like they are giving too much away, they should just say it is this good do you want it on your car. But it is just we will give you this, we will give you that. It is desperate." [Group1, female h]

Participants' cynicism regarding the effectiveness of fiscal incentives was also reflected in their belief that increasing the penalty for speeding was a viable incentive to encourage take-up (a belief echoed across three of the four focus groups). It seemed that the public held more confidence in legislation changing behaviour than incentives.

> "If the government change it and said you do not get three points you get six points, and all of a sudden the size of the prize is completely different now because you go across that line. Because at the moment you can afford to take the risk. I am not saying it is fair. It is just creating a situation where you cannot afford to take the risk." [Group 4, male g]

When considering the fiscal incentives proposed to encourage take-up and use discussion suggested that complicated rebate or bonus schemes should be avoided and lump sum incentives were generally preferred to monthly cumulative ones.

> "A percentage every year is a better idea…and you know where you are….a yearly one to get the benefit." [Group 3, female h]

Participants also expressed more trust in rebates or discounts that are transparent and government led (such as fuel rebates) and any discounts offered on the vehicle purchase price would have to be government subsidised and bear no relation to the forecourt "haggling" process. Furthermore, purchase price discounts would have to substantial (i.e. thousands of pounds rather than hundreds) to persuade participants to buy an ISA-equipped vehicle.

> "If you told us that the money was coming from the government that would be more believable than if you send it off for the refund to the [car dealership] head office." [Group 2, male h]

There was some support for a discount on road tax and insurance, although the likelihood of insurance discounts was also questioned by some and in general participants would require large discounts.

> "Yes your road tax. I would rather have money off your insurance but I would do money off your road tax. I would not want high street vouchers." [Group 3, female d]

> "Annual discount insurance would have to be substantial." [Group 2, female c]

Among the fleet managers, there was a general lack of support for the ISA systems. There was concern, particularly for the mandatory system, that their drivers would be hostile.

> "We would not get it through to be honest because people don't drive within speed limits, especially on motorways." [c]

They did not believe that exceeding the speed limit necessarily reduced a driver's safety. Rather they felt that driving at inappropriate speeds increased risk, which ISA itself may not be able to tackle. The overwhelming message from the group was that the safety benefits associated with ISA were questionable.

> "I don't know what the case is that this will increase or improve safety." [a]

Thus all the participants stressed that ISA would only be adopted if it was proven to save costs, namely a tangible decrease in fuel costs across the fleet.

> "You would have to demonstrate that the system gave a cost saving more than it cost because it would have to be self-funding." [d]

Other potential cost savings included reduction on wear and tear and repairing accidental damage. If such could be proven by means of fleet-based field trials, there was little doubt that they would adopt this technology.

### *7.2.3 Survey*

The Stated Preference survey to investigate choice by drivers in purchase and use of ISA was analysed using a set of models known as Random Utility Models. These can be used to analyse situations in which respondents are faced with choices between a limited number of alternatives. Models were developed to examine:

1. The choice between the two types of ISA system (voluntary and mandatory) — respondents had to choose one or the other under various scenarios
2. Purchase decisions for buying the voluntary system and buying the mandatory system

The modelling approach allowed for the fact that choice might be influenced by the socio-demographic and driver sub-group to which a respondent belonged. For example, respondents with higher income might be less sensitive to cost. It will be recalled that there were three groups of respondents:

> Group 1 with 490 respondents: they would buy a mandatory ISA system, and in the survey these drivers received an SP survey where both systems were offered at a cost to the driver.
>
> Group 2 with 503 respondents: they would buy a voluntary system, and in the survey these drivers were required to pay for the voluntary system but received incentives to buy a mandatory system.
>
> Group 3 with 466 respondents: they like neither system, and in the survey both systems were offered with discounts and incentives to encourage drivers to purchase an ISA vehicle.

**The choice between the two types of ISA**

The results for models estimated on the stated choice data are presented first, and are summarised in Table 45. These results examine individuals' responses as to which of the two systems they preferred in a certain scenario. One useful way to look at the results is what it would take for the two systems to have equal probability of being chosen, i.e. the tipping point beyond which one of the two systems becomes more attractive than the other. Respondents in *Group 1* were given a set of situations in which they had to pay for both types of ISA, but some incentives to use the voluntary system were offered. The overall finding for this group was that at a price of £600 together with a 1p per mile fuel rebate, the voluntary system was equivalent in attractiveness to a mandatory system sold at a price of £636. This shows that this Group were willing to pay more for mandatory ISA. If the price for the mandatory system increases beyond £636 with the attributes for the voluntary system kept fixed, the latter would become more attractive, and vice versa. Further analysis showed that Group 1 was quite heterogeneous in the location of this tipping point, with four identifiable sub-classes:

- A sub-class for whom a price of £423 for the mandatory system was equivalent to the £600 and 1p fuel rebate for voluntary ISA. This class, which had a share of 36% in the group, thus had a tipping point that is lower (in terms of the cost for the mandatory system) than the overall value for Group 1.
- A sub-class for whom mandatory ISA at £1296 was equivalent. This class, which had a share of 34% in the group, thus had a much higher tipping point, i.e. a higher relative willingness to pay for the mandatory system.
- A sub-class for whom mandatory ISA at £323 was equivalent. This class, with a share of 24% in the group, thus again has a lower than average tipping point.
- A sub-class for whom mandatory ISA even when free was not equivalent. This class, with a share of 6% in the group, thus captures respondents who are only willing to choose the mandatory system if it is substantially (more than £600) cheaper than the voluntary system.

These results show the presence of significant levels of heterogeneity. The existence of the fourth sub-class shows that, even within a group who initially indicated a preference for the mandatory system, there were a few respondents who were only willing to do so in return for a large reduction in its cost relative to the voluntary system. Overall, with the values presented in the survey and with the current sample of respondents, the mandatory system was chosen in 76% of cases. This would suggest that increases in cost for the mandatory system above those presented in the survey would be acceptable while still maintaining a better than even probability for the mandatory system.

The respondents in *Group 2* obtained a hypothetical discount to sway them into choosing mandatory ISA, while still paying for the voluntary version. Again there were incentives to use the voluntary system. To obtain reasonable quality models, it was necessary to divide this group into sub-classes. Again four sub-classes emerged:

- A sub-class with a preference for the mandatory system for whom a discount for the mandatory system was only required to make it equally attractive if the voluntary system were sold at less than £530 with a 1p per mile fuel discount. This sub-class had a share of 31% in the group.
- A sub-class whose dislike of the mandatory system was so extreme that any realistic levels for the discount would not be sufficient for the mandatory system to be as

likely to be chosen as the voluntary system. This sub-class had a share of 28% in the group.

- A sub-class where the choices seemed to be related to inherent preferences rather than being explained by the modelled factors. This group, with a share of 23% in the group, showed a slight preference for the mandatory system.

- A sub-class where equal probability of choosing either system was at a cost for the voluntary system of £600 and a discount of £1450 on the mandatory system. This group had a share of 18% in the group.

The results thus show that while Group 2 indeed contained respondents with a preference for the voluntary system over the mandatory system, there are also sub-classes where, with the presented values, respondents have a preference for the mandatory system. This would suggest that, for at least part of the sample, the presented characteristics for the mandatory system were better than expected. Overall, in this sample, the mandatory system has a probability of 54%. While this is lower than in the first group (a combination of different preferences as well as different attribute levels), it suggests that the incentives presented in this part of the survey were sufficient to get a better than even probability of choosing mandatory over voluntary.

*Group 3* respondents obtained a hypothetical discount for purchasing either system and also received incentives to use the voluntary system. Group 3, like Group 2, was heterogeneous so that a single overall model could not be obtained. More detailed modelling identified three sub-classes:

- A sub-class with a strong preference for the voluntary system. The preferences in the group were so extreme that no reasonable shift in discounts would lead to equal probabilities for the two systems. This sub-class had a share of 50% in the group.

- A sub-class with a strong preference for the mandatory system. The preference for the mandatory system was so large that, with no discount for that system, a discount of £769 for the voluntary system along with a 1p per mile fuel discount was required to obtain equal probabilities of choosing one or the other. This sub-class had a share of 28% in the group.

- A sub-class for which, with no price discount on the voluntary system but a 1p per mile fuel discount, a discount of £2040 was required for the mandatory system to obtain equal probabilities of choice for the two systems. This sub-class had a share of 22% in the group.

Overall, with the presented attribute combinations, the mandatory system had a probability of 35% of being chosen in this sample. This shows that larger discounts than those presented are required for the mandatory system to have a better than even probability of being chosen over the voluntary system. Nevertheless, the presence of the second sub-class again suggests that the attribute levels presented exceeded at least some respondents' a priori expectations.

**Table 45: Results of choice models**

| *Group* | *Group Characteristics* | *Overall rate of choice* | *Tipping point comparison* | *(Sub) Class* | *Class Size as % of Group* | *Tipping Point to Get Equal Choices of the 2 Systems* | *Characteristics of Class* |
|---|---|---|---|---|---|---|---|
| Group 1 | Those who would buy a mandatory ISA system | Chose mandatory 76%<br>Chose voluntary 24% | With voluntary charged at £600 and 1p fuel rebate | Class 1 | 36% | Mandatory charged at £423 | About equal |
| | | | | Class 2 | 34% | Mandatory charged at £1,296 | Extremely pro mandatory |
| | | | | Class 3 | 24% | Mandatory charged at £323 | Slightly pro voluntary |
| | | | | Class 4 | 6% | Need incentive for mandatory | Extremely pro voluntary |
| Group 2 | Those who would buy a voluntary ISA system | Chose mandatory 54%<br>Chose voluntary 46% | With voluntary charged at £600 and 1p fuel rebate | Class 1 | 31% | Discount only required if voluntary charged at less than £530 | Slightly pro voluntary |
| | | | | Class 2 | 28% | No realistic levels of discount will lead to equal shares | Extremely pro voluntary |
| | | | | Class 3 | 23% | Little sensitivity to attributes; choices determined by inherent preferences | Slightly pro mandatory |
| | | | | Class 4 | 18% | Discount of £1,450 required on mandatory system | Pro voluntary |
| Group 3 | Those who like neither system | Chose mandatory 35%<br>Chose voluntary 65% | With 1p fuel rebate for voluntary | Class 1 | 50% | No reasonable differences in discounts will lead to equal shares | Extremely pro voluntary |
| | | | | Class 2 | 28% | With no discount for mandatory, need discount of £769 on voluntary | Extremely pro mandatory |
| | | | | Class 3 | 22% | With no discount for voluntary, need discount of £2,040 on mandatory | Extremely pro voluntary |

**Purchase decisions**

This part of the analysis focuses on individuals' responses in terms of their decision to buy either of the two systems. The results are summarised in Table 46. The information on purchase decisions was captured alongside the stated choice data analysed above. In each choice situation, respondents were asked to indicate for either system whether they would be willing to buy it, while being given the option to buy neither or both of the systems. Separate models were estimated for the two systems. However, it was recognised that, given the joint presentation, the attributes of one system potentially had an effect on the stated intention to buy the other system. Therefore the attributes of both systems were included in both sets of models. The alternatives examined are the decision to *buy* or *not buy* each system.

In general, overall models by respondent group worked well. Sub-classes within the groups could be identified, but the overall findings were consistent with those of the more aggregate modelling. Increases in cost have a decreasing effect on the probability of buying a specific system, but have an increasing effect on the probability of buying the alternative system.

For *Group 1*, model fit was better for the (preferred) mandatory system than for the voluntary system. The cost of the mandatory system plays a much bigger role than does the cost of the voluntary system. Fuel rebates and insurance cash backs as an incentive to using the voluntary system have a positive impact on the probability of buying the voluntary system but have the opposite effect on the probability of buying the mandatory system. Even if the voluntary system were free with a fuel rebate of 1p per mile, the mandatory system could cost up to £273 before the probability of buying it would drop below 50%. However, with costs of the voluntary system at £600 and £1200, the maximum acceptable price for the mandatory system is below that of the voluntary system, at £541 and £810 respectively. This is a result of the asymmetry in the sensitivity to costs for the two systems. Looking at the probability of buying the voluntary system, again at no cost and with a fuel rebate of 1p per mile, the mandatory system would have to cost more than £775 before the probability of buying the voluntary system exceeds 50%. At costs of the voluntary system at £600 and £1200, the minimum price for the mandatory system is at £987 and £1199 respectively. This means that up to a price of £1200, the cost of the voluntary system needs to be below that of the mandatory system for it the probability of buying it to exceed 50%. With the values used in the survey, the probability of buying the mandatory system was 70% in this group, with the probability of buying the voluntary system being 34%. The probability of buying both systems was 22%, and the probability buying neither of the two systems was 18%.

Looking at *Group 2*, it can be calculated that, if the voluntary system was free with a fuel rebate of 1p per mile, the mandatory system would have to come with a discount of at least £2818 before the probability of buying it rise above 50%. This drops to £1788 and £757 when the cost of the voluntary system is increased to £600 and £1200 respectively. On the other hand, looking at the probability of buying the voluntary system, again at no cost and with a fuel rebate of 1p per mile, if the mandatory system were to come with a discount of less than £140, then the likely decision is to purchase the voluntary system. With higher costs for the voluntary system, the probability of purchase is less than 50% even without discounts for the mandatory system. These values change significantly with higher rates of fuel rebate. With the values used in the survey, the probability of buying the mandatory system was 52% in this group, with the probability of buying the voluntary system being 35%. The probability of buying both systems was 7%, with a probability of 19% for buying neither of the two systems.

**Table 46: Results of purchase models**

| ***Group*** | ***Group Characteristics*** | ***Tipping Point Comparison: Voluntary Price with 1p Fuel Rebate*** | ***Buy Mandatory[1]*** | ***Buy Voluntary[2]*** |
|---|---|---|---|---|
| Group 1 | Those who would buy a mandatory ISA system | £0 | £273 | £775 |
| | | £600 | £541 | £987 |
| | | £1,200 | £810 | £1199 |
| Group 2 | Those who would buy a voluntary ISA system | £0 | £2,818 | £140 |
| | | £600 | £1,788 | Any discount will lead to <50% of buying voluntary |
| | | £1,200 | £757 | Any discount will lead to <50% of buying voluntary |
| Group 3 | Those who like neither system | NA | With no discount on voluntary, and no fuel rebate, a minimum discount of £7936 is required | A minimum discount of £2838 is required |

[1]Maximum price for the mandatory system before the probability of buying it drops below 50%

[2]Minimum price for the mandatory system before the probability of buying the voluntary system drops below 50%

Finally, for *Group 3* (who like neither system), the probability to buy either system was very low. However, it can be seen that, with no discount for the voluntary system and no fuel rebate, a discount of £7936 would be required for the mandatory system to have a probability of 50% or more to be purchased. If a free entertainment system were provided, the required discount dropped to £5566. This drop is higher than expected, and gives an indication of the high protest vote associated with the mandatory system. For the voluntary system, the discount offered for the mandatory system is irrelevant, and a discount of £2838 would be required for the probability of buying the voluntary system to exceed 50%, where fuel rebates and insurance cash-backs have no statistically significant effects. With the values used in the survey and the present sample, the probability of buying the mandatory system was 24% in this group, with the probability of buying the voluntary system being

26%. The probability of buying both systems was 7%, and the probability of buying neither of the two systems was 56%.

This analysis has again highlighted significant differences across the three groups in their attitudes. These differences are illustrated by the variation in the required incentives but also the gradual reduction of the probability of buying either system (e.g. from 70% to 52% to 24% for the mandatory system) and the gradual increase in the probability of buying neither system (from 18% to 19% to 56%).

**Attitudes towards the compulsory fitment of ISA**

In response to comments made in the private driver focus groups, respondents were asked whether all new vehicles should be fitted with each system. Across all groups 43% of respondents believed that the voluntary ISA system should be fitted to all new vehicles, 25% were undecided and 32% were against this policy. Only 29% of respondents believed that the mandatory should be fitted to all new vehicles, compared to 14% who were undecided and 57% opposed this measure. Figure 34, Figure 35 and Figure 36 show responses by the three groups. As expected, Group 1 show a stronger preference for the compulsory fitment of mandatory ISA to all new vehicles, whereas those from Group 2 favour the voluntary system and those from Group 3 show opposition to the fitment of both systems.

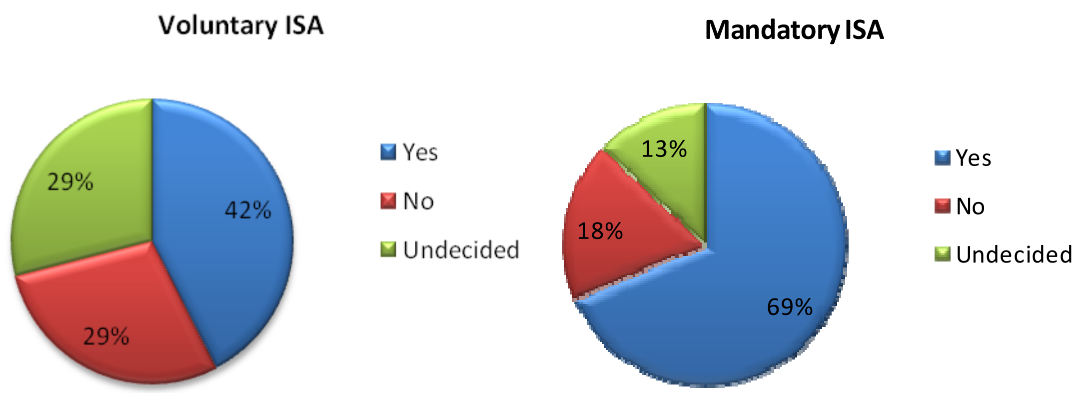



**Figure 34: Group 1 response to compulsory fitment of ISA systems to all new vehicles (preference for mandatory ISA)**

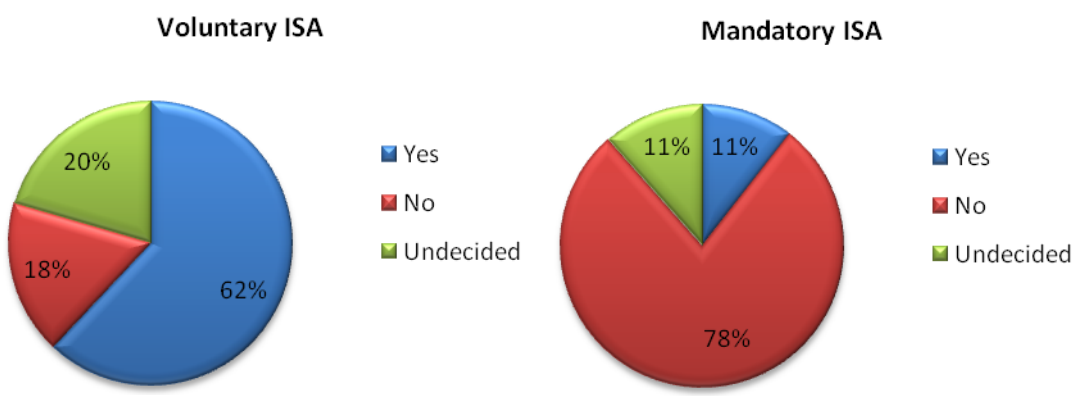



**Figure 35: Group 2 response to compulsory fitment of ISA systems to all new vehicles (preference for voluntary ISA)**

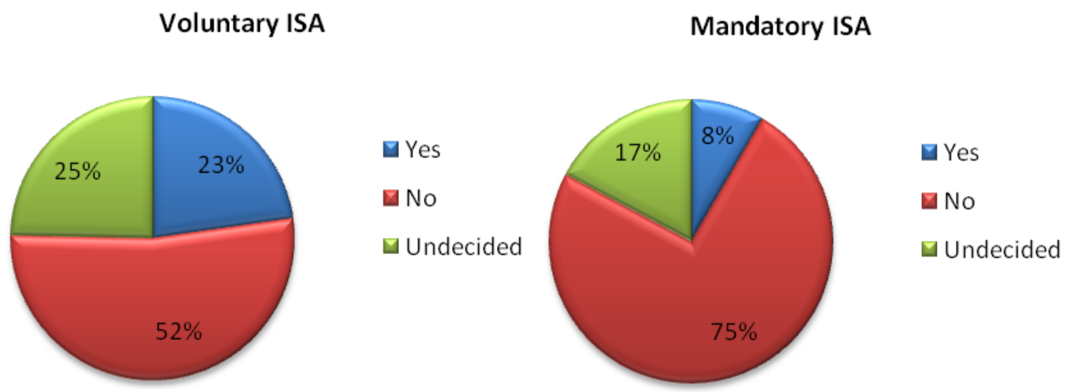



**Figure 36: Group 3 response to compulsory fitment of ISA systems to all new vehicles (no preference for ISA)**

## 7.3 Conclusions

Four focus groups involving private drivers were undertaken to explore attitudes towards ISA technologies and the feasibility of the incentive schemes drawn from the literature review. The discussions revealed that many were sceptical or opposed to this type of technology, although there was greater acceptance for its use on urban roads. In spite of this opposition, it was felt that the most effective method to increase the market penetration of ISA would be through enforcement and legislation making fitment compulsory rather than fiscal incentives. When incentives were considered, it was clear that substantial rebates and discounts would be needed to influence purchasing behaviour. The public favoured transparent and simple incentive schemes designed to address basic costs associated with motoring such as rebates on insurance, road tax and fuel, and showed little enthusiasm for reward schemes such as preferential parking or leisure vouchers.

The focus group with fleet managers indicated a general lack of support for the ISA systems as the managers did not believe that exceeding the speed limit necessarily reduced a driver's safety. They felt that risk was more affected by driving at inappropriate speeds, which ISA may not be able to tackle. The overwhelming message from the group was that the safety benefits associated with ISA were questionable. ISA would only be adopted if it was proven to save costs particularly in the form of a tangible decrease in fuel costs across the fleet. Other potential cost savings included reduction on wear and tear and repairing accidental damage. If such savings could be proven by means of fleet based field trials, there little doubt that they would adopt this technology.

The survey results revealed that there were considerable variations in sensitivities and preferences in the sample. The main differences were between the three groups already identified prior to the administration of the survey questionnaire. However, even within the groups, there were major variations such that models of choice between the two systems performed much better when sub-classes within the groups were considered.

Group 1, who preferred the mandatory system, were willing to pay considerably more for a mandatory ISA than for a voluntary one. Group 2 would generally be willing to purchase voluntary ISA for only modest subsidy, provided the cost is not very large. Within Group 2, who were supposed to prefer the voluntary system, one sub-class actually preferred the mandatory one without a discount even against voluntary ISA with a considerable incentive. Another sub-class could not be persuaded to choose mandatory ISA under virtually any realistic subsidy. And a final sub-class would choose either system at equal probability when voluntary ISA costs £600 and mandatory ISA is provided with a payment of £1450 — so that they hugely prefer the voluntary system. Group 3, who nominally like neither system, is also heterogeneous. Their general probability of buying either was confirmed to be low. But when they had to choose one version over another, three sub-classes emerged. One would always choose voluntary ISA, one had a very strong preference for mandatory ISA (perhaps indicating that if one had to have ISA, one might as well have the stronger form), and one had roughly equal propensity for the two variants.

The picture is therefore one of some groups with very entrenched positions (both pro and con) who are not really amenable to persuasion by means of incentives. On the other hand, there are other groups who are amenable to subsidy, particularly on purchase price and fuel cost, or who would be willing to purchase an ISA system if the cost were not too high. It is interesting to note that the analysis revealed that, while there are very significant variations in sensitivities and preferences, these cannot easily be linked to socio-demographic attributes of the respondents. As such, it is not necessarily the case that young male respondents have a strong objection to ISA while older respondents with more expensive cars have a more positive attitude. This observation would suggest that people have strong inherent views on installing an ISA in their car, where these are independent of their socio-demographic characteristics, and that, as a consequence, it is not easy to target one specific part of the population in a campaign to increase the uptake of such systems.

# 8 Conclusions and Recommendations

The study has predicted substantial benefits from the introduction of ISA. These benefits consist principally of the savings in accidents and in particular in more severe accidents. The savings are substantial under all the scenarios examined, and strategies that promote higher penetration of ISA and earlier adoption of intervening forms of ISA lead to greater impact. Thus ISA can be considered as a system with major safety potential.

The environmental benefits of ISA are real but less considerable. They consist mainly of reductions in fuel consumption and in consequent $CO_2$ emissions. The more detailed second-by-second analysis of the speeds recorded in the field trials with ISA is considered more reliable and leads to larger estimates. It also hints that there may be benefits on roads other than 70 mph roads.

The attitudinal work revealed that the public is segmented into three major groups, which are estimated to be of roughly equal size. There are those who are extremely hostile to ISA and who declare that no amount of incentive would sway them to purchase or use ISA. There is a group of non-committed who indicate that they would be persuaded by the right kind of incentives. And there is a group who appreciate the safety potential of ISA and who do not require any incentives to adopt it. Thus there is the potential for incentive to be wasted on those who do not need them, and a danger that, if adopted, there would be a considerable minority of refusers.

Interestingly, there was significant support in the focus groups for the government moving ahead not only with requiring fitment but also in the longer run with requiring usage. The analogy was drawn with the history of seatbelt wearing. Even among the strong opponents of ISA, there were statement that it they were required to use it, they would comply.

The level of support for ISA can be viewed as being notable as there has been no real public debate about its merits. There is a large body of literature on resistance of change, including resistance to the introduction of new products and new technologies (e.g. Moldovan and Goldenberg, 2004; Jermias, 2001). One conclusion from the observation of support for ISA is that an initial media campaign to explain the system to the public, followed by encouragement to fit and use could persuade a lot of drivers.

On the other hand the generally negative views of the fleet managers are somewhat surprising as it might be expected that they would be among the first to see the benefits of ISA, particularly in terms of reducing operating costs. There is a clear need for a campaign directed at this group.

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# Appendix 1: Summary of Car Types Used for GAM Model Development

| ***Vehicle*** | ***Source*** | ***Fuel*** | ***Euro Class*** | ***Engine Size (cc)*** | ***Odometer (km)*** |
|---|---|---|---|---|---|
| Fiat Punto | VCA | diesel | IV | 1300 | 46628 |
| VW Polo | Ricardo | diesel | III | 1422 | 34552 |
| Mercedes A170 | VCA | diesel | IV | 1700 | 31768 |
| Ford Focus | Ricardo | diesel | III | 1753 | – |
| Audi A3 | Ricardo | diesel | III | 1896 | 25004 |
| BMW 320 | VCA | diesel | IV | 2000 | 31717 |
| Mazda 6 | VCA | diesel | IV | 2000 | 24098 |
| Toyota Corrola | VCA | diesel | IV | 2000 | 28666 |
| VW Golf | VCA | diesel | IV | 2000 | 36545 |
| Nissan Almera | Ricardo | diesel | III | 2184 | 25455 |
| Volvo S60 | Ricardo | diesel | III | 2401 | 29462 |
| Audi A4 | Ricardo | diesel | III | 2496 | – |
| MCC Smart | Ricardo | petrol | III | 599 | 50907 |
| Toyota Yaris | Ricardo | petrol | III | 998 | 44381 |
| Fiat Punto | Ricardo | petrol | III | 1242 | 43636 |
| Volkswagen Polo | Ricardo | petrol | IV | 1390 | 27575 |
| Nissan Almera | Ricardo | petrol | III | 1498 | 25455 |
| Ford Fiesta | VCA | petrol | IV | 1600 | 26970 |
| Mitsubishi Spacestar | VCA | petrol | IV | 1600 | 36063 |
| Vauxhall Zafira | VCA | petrol | IV | 1600 | 39347 |
| Peugeot 306 | Ricardo | petrol | III | 1761 | 31195 |
| Rover 45 | Ricardo | petrol | III | 1796 | 22360 |
| Vauxhall Vectra | VCA | petrol | IV | 1800 | 28877 |
| Mitsubishi Carisma | Ricardo | petrol | III | 1834 | 29771 |
| Seat Leon | Ricardo | petrol | III | 1896 | 19409 |
| Skoda Octavia | Ricardo | petrol | IV | 1984 | 15662 |
| Audi A4 | VCA | petrol | IV | 2000 | 30485 |
| Ford Galaxy | Ricardo | petrol | III | 2259 | 50907 |
| BMW 525i | Ricardo | petrol | III | 2494 | 61646 |
| Mercedes C240 | Ricardo | petrol | III | 2597 | 35594 |
| Kia Magentis | Ricardo | petrol | III | 2493 | 34663 |

# Appendix 2: Details of Speed-Accident Models

## U2

Taylor and colleagues have developed models relating speed to accident risk models for UK urban roads (Taylor et al., 2000). One of these models, the U2 model, 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:

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

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 the ISA-UK trials 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. There is no problem with applying the model for voluntary ISA.

## Kloeden Urban

The research by Kloeden and colleagues has examined the risk associated with individual drivers' speed choices on urban roads (Kloeden, McLean and Glonek, 2002). The data collection was carried out on 60 km/h roads in Adelaide, South Australia. A team of accident investigators used crash reconstruction to estimate the speed of vehicles involved in crashes where at least one occupant was transported by ambulance to hospital. A case-control methodology was applied to compare the observed traffic speeds at the same locations with the speeds of the accident-involved vehicles and set of models were developed for the relationship between speed and risk. Figure 37 shows the modelled relationship for risk at a given speed as compared with risk at the 60 km/h speed limit.

The model equation behind Figure 37 is:

$$\text{relative risk (V)} = e^{(-0.822957835 - 0.083680149V + 0.001623269V^2)}$$

where V = free travelling speed in km/h

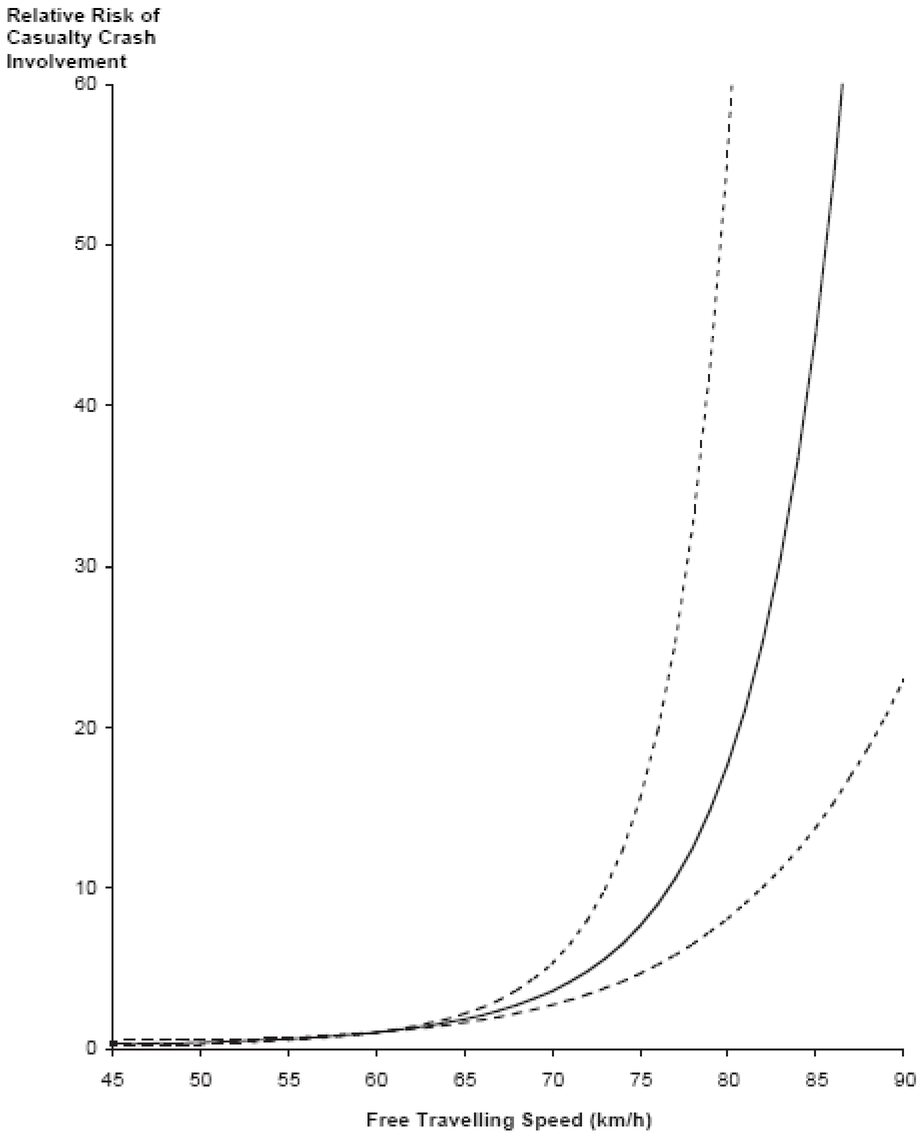


**Figure 37: Modelled relationship between free travelling speed on 60 km/h roads and the risk of involvement in a serious crash showing 95% confidence interval (source: Kloeden, McLean and Glonek, 2002)**

The Kloeden models are based on data collected in South Australia. As can be observed from Figure 37, the confidence intervals associated with these relationships become very large toward the upper extremes.

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 urban study.

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 associated with pre-crash speeds more than 20 km/h greater than the mean speed. For the analysis in this project, the version of the Kloeden model which uses absolute (as opposed to relative) speed has been applied. Since the model was developed for 60 km/h roads, applying it for 30 mph (50 km/h) roads will result in relatively lower risks. In addition, the model has been capped for speeds above 80 km/h and below 45 km/h, resulting in significantly lower, more conservative, predicted crash risk reductions for ISA. It has also been adjusted by applying the Elvik et al. (2004) Power Model (see below), to adjust for the fact that the Kloeden data were obtained for serious crashes, whereas the initial modelling here is for all injury accidents.

## Kloeden Rural

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, Ponte and McLean, 2001). Given the range of speed limits, the resulting relationship is presented in terms of risk by deviation from mean speed as shown in Figure 38. The equation fitted to the data by Kloeden et al. (2001) for relative risk of involvement in a crash is:

$$\text{relative risk (speed difference)} = e^{(0.07039V + 0.0008617V^2)}$$

> where V = difference in travelling speed in km/h

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 model. However, it does have the advantage of fully considering the impact of intervening ISA on the shape of the speed distribution. The rural model has therefore been applied, but risk has been capped at a deviation of +30 km/h. As with Kloeden's urban model, a severity adjustment has been applied.

The model illustrated in Figure 38 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 in the ISA-UK trials when using voluntary ISA. Similarly, the risk profile for mandatory ISA is based on the mean speeds recorded in the ISA-enabled period when drivers did not override the ISA system.

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.

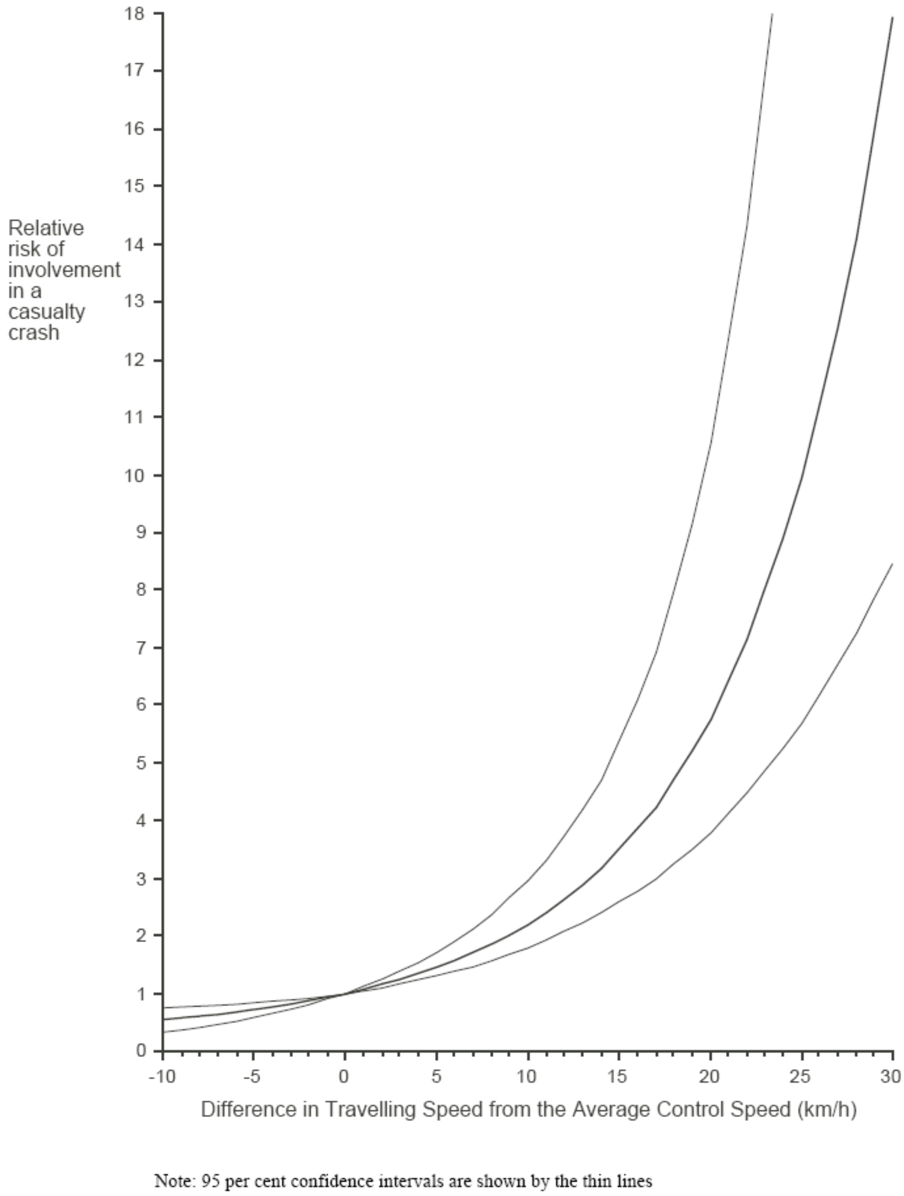


**Figure 38: Modelled relationship between deviation from mean speed on rural roads (speed limit 80 km/h to 110 km/h) and the risk of involvement in a serious crash showing 95% confidence interval (source: Kloeden, Ponte and McLean, 2001)**

## Power Model

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 47 shows the coefficients determined by their analysis.

**Table 47: Coefficients of power model (Elvik et al., 2004)**

| ***Metric of Interest*** | ***Accidents*** |
|---|---|
| Fatal | 3.6 |
| Serious Injury | 2.4 |
| Slight Injury | 1.2 |
| All Injury | 2 |
| Property Damage Only | 1 |

The work of Nilsson and the meta analysis of Elvik et al. (2004) 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 47 have been applied to translate predictions at the all injury level generated by various models into separate predictions for slight crashes, serious crashes and fatal crashes.

The results of Elvik et al. (2004) also provide a general model (i.e. a model not specific to any particular road category) relating speed to accident risk. This model has therefore been applied when a more appropriate specific model could not be found. Such cases are 70 mph roads and motorways, as well as the 60 mph unclassified roads.