Centre for
Automotive Safety Research

An exploratory study to determine if a critical mass exists for intelligent speed adaptation

DJ Searson, JE Woolley and S Crotty

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Summary

Vehicles equipped with Intelligent Speed Adaptation, or ISA, generally travel slower than vehicles that are not equipped with ISA. This reduces the crash risk of the ISA equipped vehicle. Another benefit of introducing ISA equipped vehicles into the fleet is that by travelling slower, they cause other vehicles in the network to also travel slower.

There may be a ‘critical mass’ of ISA penetration at which the benefits of ISA accrue rapidly for the entire vehicle network, regardless of whether or not they are equipped with ISA. This report seeks to determine if such a critical mass exists.

Micro-simulation software (PARAMICS) was used to simulate a simple traffic scenario. This scenario involved traffic moving at typical urban speed limits along a straight road. The proportion of vehicles with ISA was increased from zero to 100%, at increments of 5%. The network was modified to include different speed limits, traffic volumes, signal densities and multiple lanes.

The results of the simulations suggest that the adoption of ISA does influence the speeds of vehicles both with and without ISA. The benefits of ISA accrued most rapidly for lower ISA penetration. The mean speeds of all vehicles continued to decrease as the proportion of vehicles with ISA was increased to 100%, but at a lower rate. For a basic scenario, at around 30 to 40% ISA penetration, the speed distribution of all vehicles was close to the speed distribution of ISA equipped vehicles.

The speed limit of the urban scenario did not influence the effectiveness of ISA in reducing all vehicle speeds. However, increased traffic volume increased the effectiveness of ISA, and ISA was more effective on a single lane road than a two lane road. The influence of traffic signal density was not straightforward and was confounded by the formation and disaggregation of platoons when caught at a red light.

A higher speed rural road was also simulated, with and without the presence of an overtaking lane. For the rural road, a similar effect on vehicle speeds was observed with increased free speed of ISA. Again, traffic volume increased the effectiveness of ISA at reducing all vehicle speeds. The introduction of an overtaking lane decreased the effectiveness of ISA, by allowing faster travelling non-ISA vehicles to overtake.

The introduction of ISA equipped vehicles into the fleet has benefits for the occupants of those vehicles, but also for the fleet as a whole. No optimal ISA penetration rate was observed however the most rapid reductions in average travelling speeds occurred in the first 40% of ISA penetration.

The modelling revealed the complexity of the relationship between ISA and traffic variables such as average speed. This makes the development of a universal theoretical model difficult to establish and simulations of real world networks would be necessary to account for the range of interactions that occur. This was considered outside of the scope of this current exploratory project.

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Contents

1 Introduction

Intelligent speed adaptation (ISA) is a generic term referring to many different types of devices that aim to assist or force drivers to adhere to a speed limit. Modern devices use Global Positioning System (GPS) technology and on-board maps which are linked to a speed zone database to allow the ISA device to know where the vehicle is and what the speed limit is for the road it is travelling upon.

ISA devices can be divided into three categories: advisory, supportive and limiting. Advisory devices communicate to the driver that they are travelling above the speed limit by using audio and visual signals, but may be ignored by the driver. Supportive devices provide stronger tactile feedback to the driver but can still be overridden. Limiting devices work in the same way as a supportive device except that the driver cannot override them.

The New South Wales Centre for Road Safety conducted a trial of advisory ISA during 2009 and 2010 in the Illawarra region of New South Wales. A total of 114 vehicles were fitted with an advisory ISA device, although only 106 vehicles completed the before and 'during ISA' periods of the trial and only 101 vehicles completed the before, during and after ISA periods. The trial was conducted in three Illawarra local government areas: Wollongong City, Shellharbour City, and Kiama Municipality. The total length of the road network in the trial area was approximately 2,500 km, containing 4,000 speed signs and 932 speed zones that were mapped for the trial. The initial report for the trial was released by the New South Wales Centre for Road Safety in 2010.

Several analyses of this rich source of data have been performed and many more are being planned. The project detailed in this report has the aim of determining if there is a 'critical mass' of ISA penetration at which the benefits of ISA accrue rapidly for the entire vehicle network, regardless of whether or not they are equipped with ISA.

This question cannot be answered directly by examination of the trial database for two reasons. The first being that a range of traffic variables (e.g. signal density) for the entire network are unknown over the period of individual ISA vehicle data collection. The second reason is that nothing is known about the behaviour of non-ISA equipped vehicles in the network during the trial period.

Microsimulation modelling techniques provide a cost effective solution for assessing transport networks in a controlled environment. Such modelling is used on a widespread scale for Intelligent Transport Systems (ITS) impact evaluations and is ideally suited to the investigation of the interaction between ISA penetration levels and overall network performance.

This report explains an exploratory study using microsimulation models to determine the effects of increasing ISA penetration levels on overall network performance.

2 Literature review

A brief literature review was conducted to establish if the concept of a 'critical mass' for ISA penetration levels had been explored previously. Despite numerous international field trials, the most feasible way of exploring the issue is to conduct simulation modelling.

Microsimulation models are well established as tools for conducting evaluations of the impacts of ITS on road networks. Several studies were identified that used microsimulation for modelling the effects of ISA however many were outlines of projects that were just commencing. Frustratingly, no further papers were found that documented the outcomes of these studies.

Archer and Aberg (2000) described the commencement of a project to model the effect of ISA at different implementation levels in order to determine safety and efficiency effects, based on a large field trial in Sweden. The paper highlighted that at the time most research was based on speed and speed variance rather than a focus on how individual road user performance and behaviour is affected for ISA and non-ISA users. The authors also pointed out a strong focus on limiting ISA systems rather than supportive or advisory.

Archer and Aberg hypothesised a relationship between ISA penetration levels and average speed for all vehicles (Figure 1 in their paper). Although the basis or origins of the curve is not explained, the greatest effect of ISA on average speed is assumed to occur at 25 to 30% penetration levels. This point was deemed to represent the situation where there are a sufficient number of ISA equipped vehicles to influence the speed on non-ISA vehicles. This interaction was given the term "contagion". It was further hypothesised that a state of equilibrium is reached probably well before 100% ISA penetration (indicated as approximately 70% on their diagram). It should be noted that these hypotheses were based on urban traffic conditions where up to 50% of the vehicles may be restricted in some way by congestion.

Archer and Aberg also acknowledge the complexities of traffic interactions and noted that it is important to observe the sensitivities of safety and efficiency effects in accordance with different levels of traffic flow, different proportions of free and restricted vehicles, and all this at different traffic sites. Microsimulation made such considerations possible provided that the underlying behaviour model was sufficiently detailed for this purpose. The researchers were using a new micro-simulator based on the Helsinki University of Technology HUTSIM simulation software. At the time of publishing no results had been achieved and further searches have not revealed any concluding papers on the microsimulation aspect of the research project.

Broekx and Panis (2002) detailed some findings for work they conducted for the European PROSPER project: Project for Research On Speed adaptation Policies on European Roads. Microsimulation modelling was conducted for the real world network at Ghentbrugge, Ghent in Belgium. Other modelling sites were to be York in the UK, Stockholm in Sweden and the province of Noord Brabant in The Netherlands. The authors were using a combination of the SATURN and DRACULA traffic models to evaluate the effects of ISA on a network. The modelled network consisted of a 2km by 2km area and had two main roads and several smaller urban roads. The speed limit was 50km/h with the exception of a small section that had a 70km/h limit on a main road. Traffic volume for the network was approximately 2500 vehicles per hour.

Preliminary findings were that at a penetration of 50% ISA vehicles, average speed reduced from 30km/h to 28.7km/h and total travel time increased. Out of 210 total travel time vehicle hours in the morning peak, 105 hours were for queuing delay, so congestion levels in the network were high. This explains why ISA did not have a strong effect on travel times in the study. Several hypotheses were to be tested including the effects of ISA on travel time, urban roads versus motorways, and off-peak versus peak times. No further publications could be found documenting the final outcomes of this study.

Liu and Tate (2004) and (2000) described the results of modelling a road network in Leeds in the UK using the DRACULA software. The network was large with 240 links connecting 120 intersections. Traffic was 18,000 trips per hour in the peak and 12,000 trips per hour in the off-peak periods. Speed limits were a mixture of 30 and 40 mph with a short section of 70 mph. ISA impacts were determined in terms of:

- network travel time
- air emissions
- fuel consumption
- vehicle hours spent at a range of speeds

General results were that the proportion of vehicles exceeding the speed limits (of 30 and 40 mph) decreased with increasing levels of ISA penetration. Although ISA was effective in reducing excessive speeds, it does not induce further congestion. ISA was less effective in congested traffic (morning peak) than uncongested traffic (off-peak). Speed variation was also found to reduce due to ISA, however no effect of ISA could be detected at speeds below the speed limit. Modelling was also conducted on a 60 mph rural two lane road and ISA effects were found to be less significant compared to that in the urban environment. In this situation, the maximum effect of ISA was reached with a 60% penetration. Although this was not stated explicitly for the urban situation, examination of the graphs (e.g. Figure 10) reveals a value of approximately 30% ISA penetration.

Hegeman (2002) performed some modelling to see if platooning caused by ISA could match that of traffic signals. The impact of ISA on gap selection (i.e. headways) indicated that greater road length allows more time for non-ISA vehicles to platoon behind ISA vehicles, however even 200 metres was adequate for this to occur in the simulation. Varying speed limits between 30, 40 and 50 km/h resulted in marginal differences (less than 10%).

Antoniou, Yannis and Golias (2002) performed some microscopic and macroscopic modelling of Driver Assistance Systems including ISA. Microsimulation was performed using the SIMONE, SYSTM and HUTSIM simulation software. The network that was modelled was not explained, but was most likely a freeway system. General findings in relation to ISA include: where the ISA limit was above the average traffic speed, there were minimal traffic effects; ISA did not have a significant impact on the headway distribution and there was a reduction in lane changing. The authors noted that due to the complexity of some of the traffic interactions, straightforward conclusions on the impact of ISA on average speed could not be made.

Servin, Boriboonsomsin and Barth (2006) reported on the effects of ISA penetration rates on emissions according to differing levels of service (i.e. traffic congestion) on freeways. Microsimulation was conducted using the PARAMICS software integrated with a Comprehensive Modal Emissions Model (CMEM). ISA vehicles were found to influence non-ISA vehicles and emissions reductions were most marked in the initial 20% of ISA penetration. In the freeway situation, ISA contributed towards more stable flow and therefore overall reductions in emissions and even travel time. This effect increased with increasing ISA penetration rates.

Ma, Engelson, Lind and Andreasson (2004) reported on the outcomes of their EVITA project: Evaluation of Safety Effects of Various ISA Vehicle Penetration Grades by Microscopic Simulations. The HUTSIM software was used to estimate various safety impacts of ISA but a particular focus of the study was on platooning effects. A two kilometre section of road was simulated for both single lane and dual lane traffic. An attempt was made to quantify the effects of ISA on headway distribution over a range of traffic volumes, ISA penetration and speed limits. The study found that for the single lane road, more ISA vehicles in the network led to less platooning of vehicles. For the dual lane road situation, ISA effects were ambiguous as in some combinations of simulation variables the platoon effect dominated, whereas under others free flow speed prevailed. No further discussion was provided for these observations.

3 Methodology

The PARAMICS microsimulation software was used for the study. Unless otherwise noted, default model values were used for the simulations.

3.1 Network designs

An initial network design was adopted in the form of a symmetrical diamond layout, as shown in Figure 3.1. Horizontal and vertical roads were 12 km in length with diagonals of approximately 3.9 km. Total road length in the network was approximately 40 km. The layout represents a modified form of network commonly used to test traffic routing models.

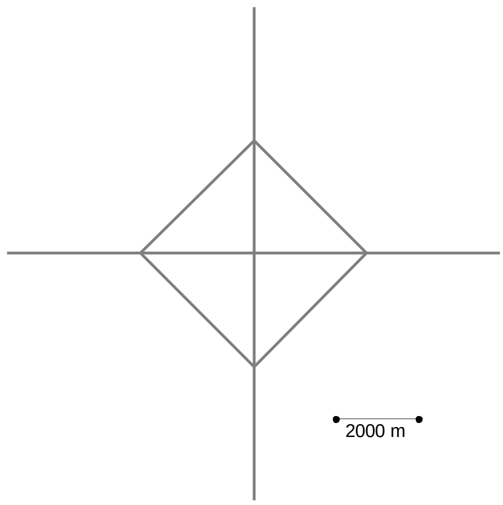

Figure 3.1
Initial diamond shaped road network

Following initial modelling work, the complexity of traffic interactions became apparent. The ability to interpret the effects of ISA were confounded with directions of travel and the cross movement of traffic at junctions. It was found that aggregate network performance measures hid many of these effects and the network was progressively simplified to the extent that a decision was made to conduct modelling with a linear one way road. In the end, the 12 km segment of road (the horizontal line in Figure 3.1) was used for all urban modelling.

This had the advantage that full control could be made over dependent variables and ISA could be more readily analysed as a function of distance along a route.

3.2 Modelling of speed distributions

Only one vehicle type was modelled representing an average passenger car. No heavy vehicles, buses or car derivatives were included in the modelling. ISA control was achieved by introducing a specific ISA vehicle. This vehicle was exactly the same as a non-ISA vehicle, with the exception that certain speed rules related to the vehicle. ISA penetration was achieved by setting the corresponding proportion of the overall vehicle fleet to ISA vehicles.

Two potential features were available within PARAMICS to simulate the behaviour of the advisory ISA vehicles. The first was to impose a different speed limit throughout the network that would only influence ISA vehicles. The second was to limit the top speed of ISA vehicles. Comparison of the speed distributions for these two methods indicated that limiting the top speed of the ISA vehicles resulted in a more realistic speed distribution.

Therefore, non-ISA vehicles were modelled by PARAMICS default behaviour and influenced only by the network speed limit. ISA vehicles were modelled by PARAMICS default behaviour and constrained by a vehicle maximum speed set at the network speed limit. The resulting speed distributions for ISA and non-ISA vehicles can be compared in Figure 3.2 for a 60km/h speed limit.

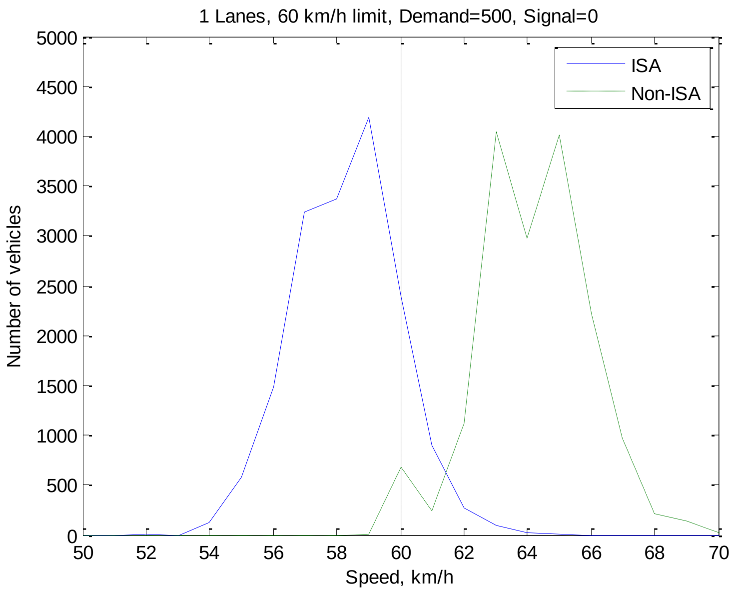

Figure 3.2
Speed distributions for ISA and non-ISA vehicles, 60 km/h speed limit

These default distributions differ from the real world distributions in two ways: the mean for the non-ISA vehicles is well above the posted speed limit and the overall speed variation is not as dispersed.

3.3 Urban network variables

The variables that were investigated in terms of their effect on ISA penetration were:

- speed limit (3 levels – 50 km/h; 60 km/h; 80 km/h)
- traffic volume (3 levels – 250 vehicles/hour; 500 vehicles/hour; 1000 vehicles/hour)
- signal density (4 levels – no signals; 3 signals spaced approx 2500m; 5 signals spaced approx 1250m; 7 signals spaced approx 800m), and
- dual lanes (that permitted overtaking)

A base model was used for comparison. The variables for the base model were a speed limit of 60km/h, traffic volume of 500 vehicles per hour, no signalised junctions and single lane road configuration.

The base model was then repeatedly duplicated, changing one variable each time until eventually 21 scenarios were produced. Each scenario and its settings are detailed in Table 3.1. The signal density levels are illustrated in Figure 3.3.

Table 3.1
List of scenarios used in this project

Scenario Name	Network type	Number of lanes	Speed limit (km/h)	Volume (vehicles/hour)	Signal density
RTA 1 50 500 0	Urban	1	50	500	0
RTA 1 60 500 0	Urban	1	60	500	0
RTA 1 60 250 0	Urban	1	60	250	0
RTA 1 60 1000 0	Urban	1	60	1000	0
RTA 1 60 500 1	Urban	1	60	500	1
RTA 1 60 500 2	Urban	1	60	500	2
RTA 1 60 500 3	Urban	1	60	500	3
RTA 1 80 500 0	Urban	1	80	500	0
RTA 2 60 250 0	Urban	2	60	250	0
RTA 2 60 500 0	Urban	2	60	500	0
RTA 2 60 1000 0	Urban	2	60	1000	0
RTA 2 60 2000 0	Urban	2	60	2000	0
RTA 2 60 500 1	Urban	2	60	500	1
RTA 2 60 500 2	Urban	2	60	500	2
RTA 2 60 500 3	Urban	2	60	500	3
Rural Network 100	Rural	1	100	100	0
Rural Network 100	Rural	1	100	250	0
Rural Network 100	Rural	1	100	500	0
Rural Network OT 100	Rural	1+overtaking	100	100	0
Rural Network OT 100	Rural	1+overtaking	100	250	0
Rural Network OT 100	Rural	1+overtaking	100	500	0

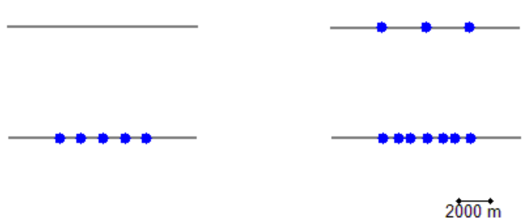

Figure 3.3
Signal locations on the urban network
(a) zero signals, (b) signal density 1, (c) signal density 2, (d) signal density 3

3.4 Simulation and data collection

Each scenario listed in Table 3.1 was simulated 21 times, with each scenario varying the proportion of ISA vehicles from 0% to 100% at 5% increments. PARAMICS allows the use of virtual 'detectors', which record information about the vehicles that pass a particular point in the network. The data recorded by each detector was vehicle type, vehicle speed and vehicle headway.

The detectors were placed with equal spacing of 250 metres along the straight section of road (Figure 3.4). The results of all detectors were collated to provide results for a given scenario.

Figure 3.4
Detector placement on the simulated urban road network

Checks were carried out on detectors located in the vicinity of signalised junctions. It was important not to confound the results by including data that was affected by vehicles either decelerating or accelerating near traffic lights. It was found that excluding one detector on either side of each signalised junction was sufficient to avoid this effect.

Before running a microsimulation model, it is good practice to check that the results are independent of the random 'seed' value. This check was performed, the details of which can be found in Appendix A.

3.5 Rural network

A rural network was constructed to simulate vehicles travelling longer distances on rural roads. The rural network consisted of approximately 80 km of single lane road upon which no overtaking could be performed. Segments were joined with 400 metre radius bends, which did not appear to influence vehicle speed. The speed limit on the rural network was set at 100 km/h.

To demonstrate the influence of an overtaking lane on ISA effectiveness, the rural network was modified to include a 5 km overtaking lane midway along its length (Figure 3.5).

Simulations were run on each rural network at three different levels of traffic volume: 100 vehicles/hour, 250 vehicles/hour and 500 vehicles/hour.

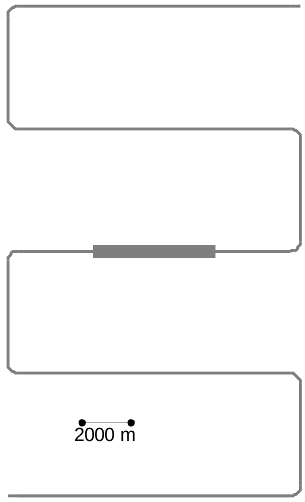

Figure 3.5
Rural road network, overtaking lane shown in centre

4 Results

In this section, the results are presented for different traffic scenarios.

The first set of results is for the 'base model', which was used to examine the general effect of introducing ISA into the vehicle fleet.

Following this are results that examine the effect of changing the speed limit, traffic volume, traffic signal density and number of lanes. These different factors show how the results from the base model may vary for different network and traffic scenarios.

The results from the rural scenario are presented for varying traffic volumes.

4.1 Base model

As described in the methodology section, the base model consisted of a single lane road with a 60 km/h speed limit, a demand of 500 vehicles per hour and no traffic signals. These conditions were chosen to give a reference case to compare with more complicated scenarios.

4.1.1 Analysis of vehicle speeds

Figure 4.1 illustrates the distribution of speed measurements with varying levels of ISA penetration in the vehicle fleet. The plot on the left hand side shows the number of vehicles that were measured at different speeds. The plot on the right hand side shows the cumulative percentage of vehicles at a particular speed.

In the case of 0% ISA vehicles, the left hand plot is centred on the mean speed of approximately 64 km/h. As the percentage of vehicles with ISA is increased, a new peak begins to increase in size, which is centred at a lower speed of around 58 km/h. This new peak represents the ISA vehicles, as well as the non-ISA vehicles that are entering platoons led by slower travelling ISA vehicles. Between 30 and 40% ISA penetration, the higher speed peak has flattened out.

The cumulative distribution of measured vehicle speeds shifts to the left with increasing ISA penetration, indicating a greater proportion of vehicles travelling at lower speeds.

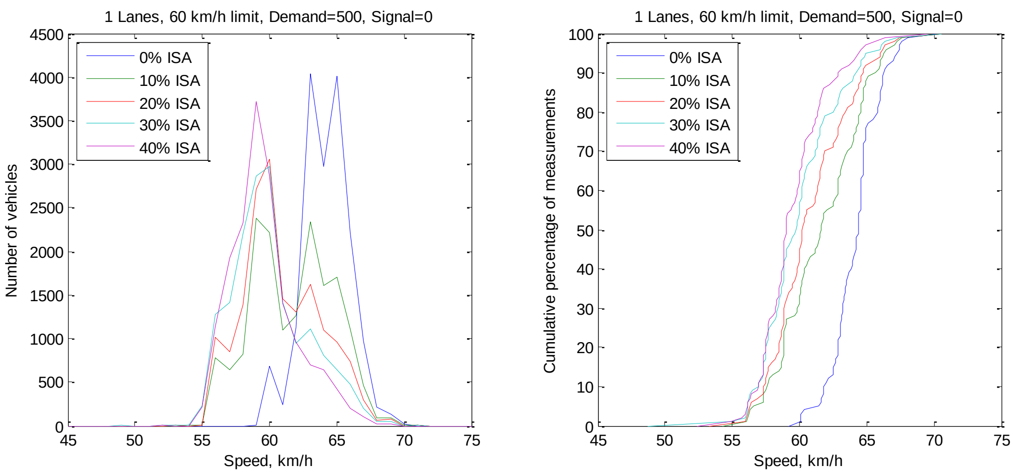

Figure 4.1
Speed distribution for base model: (a) speed density, (b) cumulative distribution

Figure 4.2 illustrates the change in mean speed as the percentage of vehicles with ISA increases from 0% to 100%. The mean speed of all vehicles continues to decrease with increasing levels of ISA penetration, and does not flatten out. This indicates that there was no 'critical mass' value of ISA penetration in the base model.

Note that the mean speeds of ISA vehicles also decreases as ISA penetration increases. This is due to the spread of vehicle speeds: some ISA vehicles still travel slower than others, and may cause faster travelling ISA vehicles to slow down. The likelihood of this occurring increases with higher levels of ISA free speed.

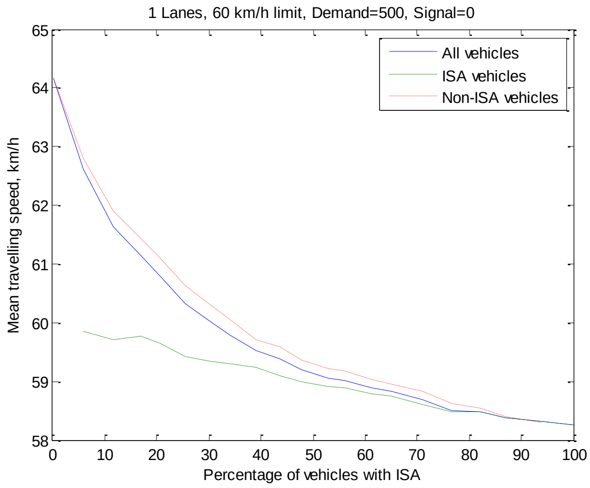

Figure 4.2
Mean travelling speed versus ISA penetration for base model, by vehicle type

However, the degree of curvature of the solid blue line (all vehicles) can be thought of as an arbitrary measure of the effectiveness of ISA in reducing non-ISA vehicle speeds in a particular scenario. If a scenario is not conducive to influence from ISA then we would expect the solid blue line to be virtually linear: the only vehicles being affected by ISA are the ISA vehicles themselves. However, if the ISA vehicles are also affecting non-ISA vehicles, then the solid blue line will begin to curve. The more a scenario is conducive to influence from ISA equipped vehicles, the sharper the curve will be.

4.1.2 Analysis of vehicles at free speed

In order to better understand the effects of ISA penetration, the proportion of vehicles travelling at 'free speed' was also calculated. Free speed suggests that the vehicle driver, in this case simulated, would be choosing their own travelling speed, without being influenced by the vehicle in front. The definition of free speed was a headway measurement of four seconds or more, a commonly adopted definition in traffic engineering.

Figure 4.3 shows the proportion of measured vehicles in the network with a free speed, against increasing levels of ISA penetration. This figure shows that as the percentage of cars with ISA increases, the proportion of cars at free speed stays roughly the same at 35 to 40%. There are two effects at play that may account for this flat line. Although a slower moving ISA vehicle is more likely to cause a non-ISA vehicle to slow down, they are less likely to be slowed down themselves by another vehicle (as they are already travelling at a lower speed). Thus, as the ISA vehicles are introduced in higher proportions, they increase platooning by holding up faster non-ISA vehicles, but also decrease platooning by travelling slower and not being held up themselves.

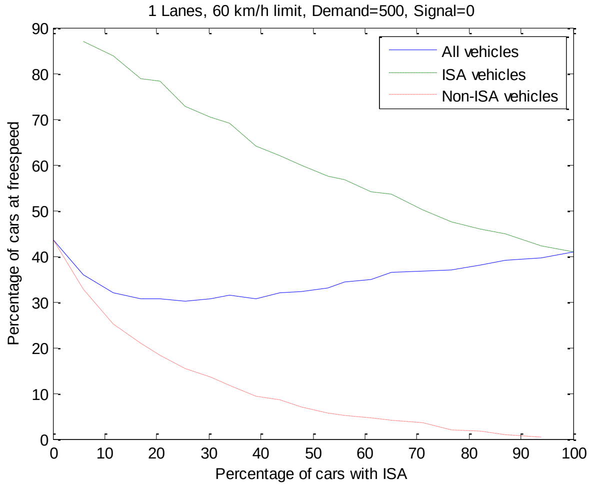

Figure 4.3
Percentage of cars at free speed versus ISA penetration, by vehicle type

4.1.3 Progression of non-ISA vehicles along road

The progression of vehicles along the road was analysed by examining the data recorded by each detector individually.

Figure 4.4 illustrates how the mean speeds of non-ISA vehicles varied as the distance from the start point increased. As the distance increased, more non-ISA vehicles entered platoons behind slower travelling vehicles, causing a reduction in the mean speed. With the introduction of more ISA vehicles, the mean speed was reduced even further, and a greater reduction in mean speed can be seen early on.

Figure 4.5 is a similar plot that shows the proportion of non-ISA vehicles at free speed as the distance from the start point increases. This plot illustrates the effect of platooning: as the non-ISA vehicles progress along the road, they are more likely to catch up to slower travelling ISA vehicles, causing a reduction in the proportion of vehicles at free speed. With increased levels of ISA penetration, the vehicles become less likely to travel at free speed.

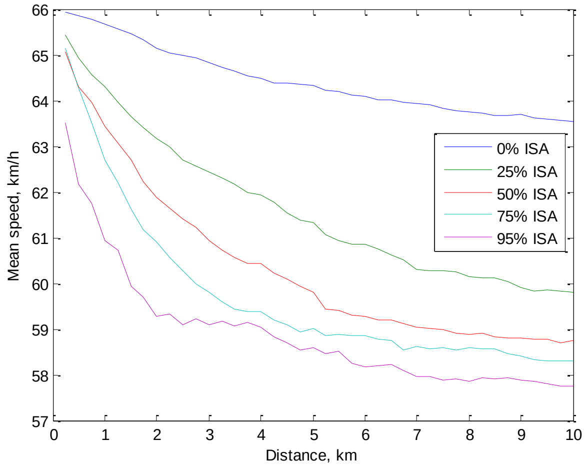

Figure 4.4
Mean measured vehicle speed versus distance along road for the base model, non-ISA vehicles

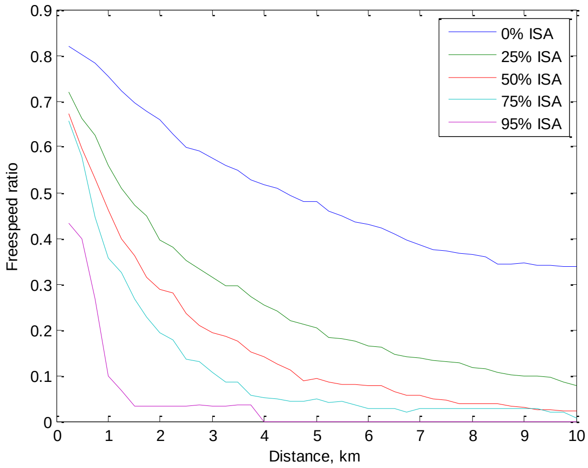

Figure 4.5
Proportion of vehicles at free speed versus distance along road for the base model, non-ISA vehicles

4.2 Comparison of results at different speed limits

The speed limit of the base model was changed to 50 km/h and 80 km/h, to examine how the speed limit may influence the effectiveness of ISA. These speed limits were considered in addition to the base model speed limit of 60 km/h.

Figure 4.6 and Figure 4.7 show the speed distributions for the 50 km/h and 80 km/h speed limits, respectively. In both cases, the left hand plot exhibits a second, lower speed, peak emerging with the introduction of ISA vehicles.

In the case of the 50 km/h speed limit, the higher speed peak flattens out between 30 and 40% ISA. For the 80 km/h speed limit, the higher speed peak is still present at 40% ISA, potentially indicating a reduced effectiveness of ISA in reducing non-ISA vehicle speeds for the given network geometry.

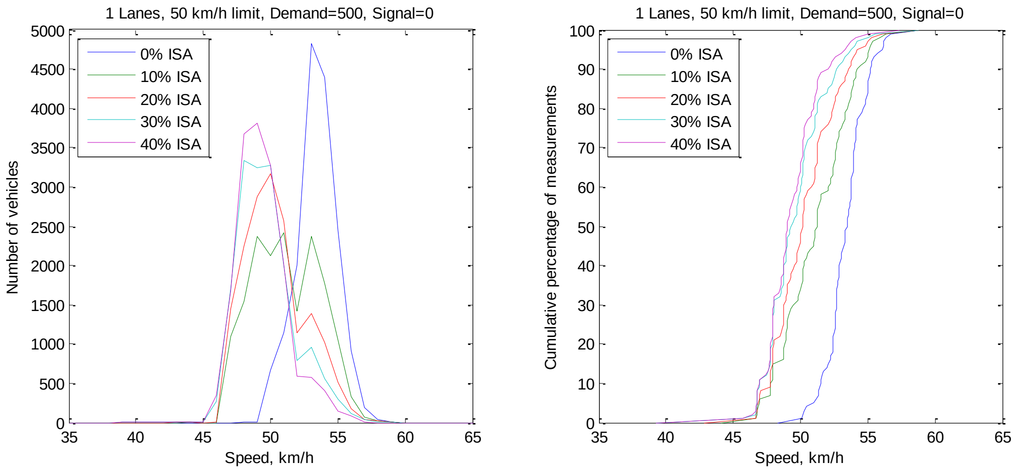

Figure 4.6
Speed distributions for 50 km/h speed limit: (a) speed density, (b) cumulative distribution

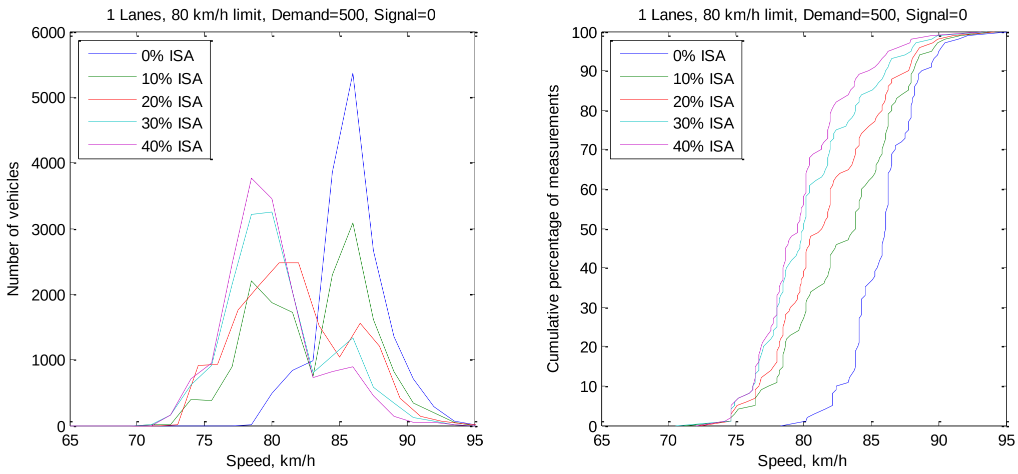

Figure 4.7
Speed distributions for 80 km/h speed limit: (a) speed density, (b) cumulative distribution

Figure 4.8 shows the change in mean speed for different levels of ISA penetration, for the 50 km/h and 80 km/h cases (for comparison, the 60 km/h case can be seen in Figure 4.2).

The mean speeds for all vehicles are plotted together for the three different speed limits in Figure 4.9. The second plot shows the mean speeds relative to the speed limit, so that the curvature of the lines can be compared. The degree of curvature for all three speed limits is similar, indicating that speed limit was not a determining factor for the effectiveness of ISA at reducing overall vehicle speeds.

However, the plot of relative speeds seems to show that as the speed limit increased, ISA became marginally less effective at influencing the speeds of non-ISA vehicles. This was likely to be merely a function of the network geometry and not a real effect. Since the length of the road was fixed, as vehicle speed increased, the time that it took a vehicle to travel through the network decreased. Therefore there was less opportunity for ISA and non-ISA vehicles to interact, which would reduce the effectiveness of ISA adoption on overall vehicle speeds.

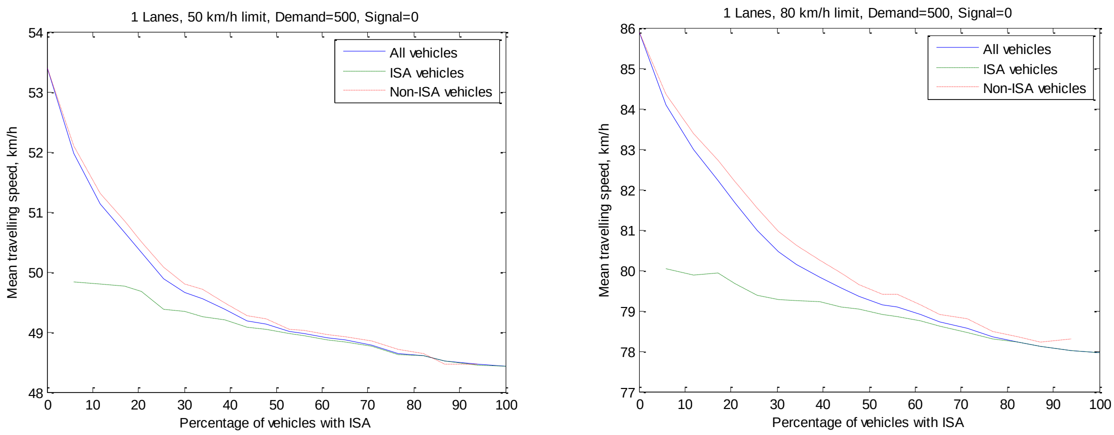

Figure 4.8
Mean speed versus ISA penetration, by vehicle type: (a) 50 km/h limit, (b) 80 km/h limit

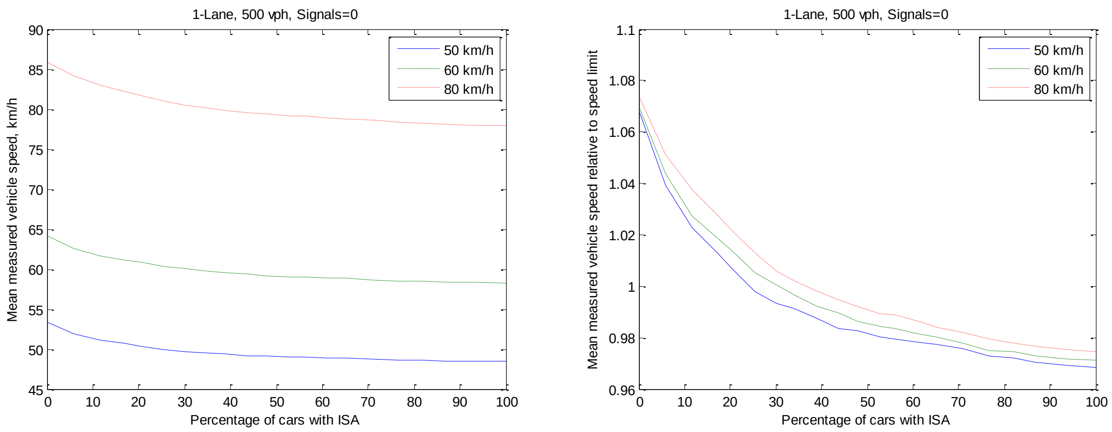

Figure 4.9
Mean speed versus ISA penetration: (a) in km/h, (b) relative to speed limit

4.3 Comparison of results with different traffic volumes

The base model was modified to include traffic volumes of 250 and 1000 vehicles/hour, to examine how the effectiveness of ISA may be affected by traffic volume. These were considered in addition to the base model traffic volume of 500 vehicles/hour.

Figure 4.10 shows the speed distributions for the 250 vehicles/hour scenario. With the reduced traffic volume, the higher speed peak is still present at 40% ISA penetration.

Figure 4.11 shows the speed distributions for the 1000 vehicles/hour scenario. In contrast to the lower traffic volume, this plot suggests a much stronger effect of ISA adoption. The higher speed peak flattens out by around 20% ISA penetration.

Figure 4.12 shows the change in mean speed for different vehicle types with increasing levels of ISA penetration, for the 250 vehicles/hour and 1000 vehicles/hour cases. Figure 4.13 shows the change in mean speed for all vehicles with the three different levels of traffic volume. These figures show that as traffic volume increases, the degree of curvature increases, implying a greater effectiveness of ISA at reducing non-ISA vehicle speeds.

This indicates that traffic volume is a significant factor in determining the effectiveness of ISA adoption on fleet-wide vehicle speeds. Since the effectiveness of ISA is clearly dependent on traffic volume, any estimation of a 'critical mass' must take into account the demand on the network (e.g. peak periods versus off peak). Note that these observations relate to freely flowing traffic conditions and not highly congested queued traffic conditions.

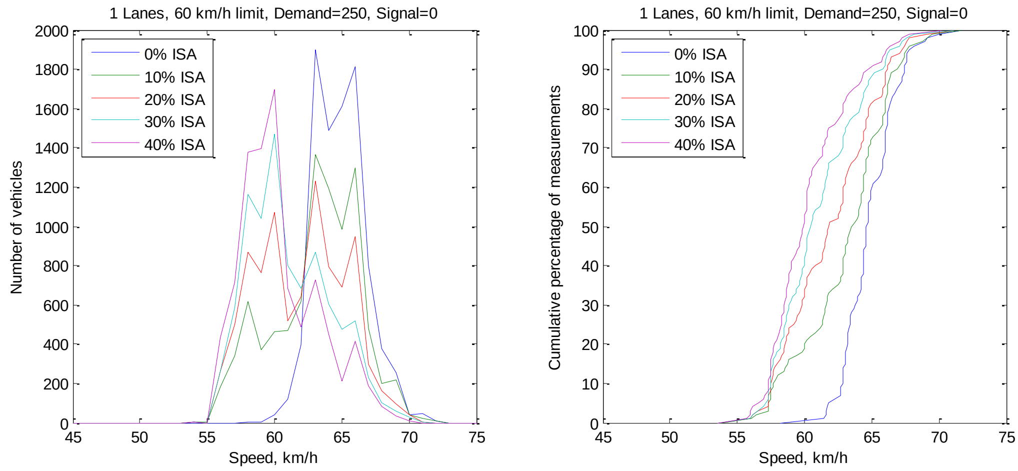

Figure 4.10
Speed distributions for 250 vehicles per hour: (a) speed density, (b) cumulative distribution

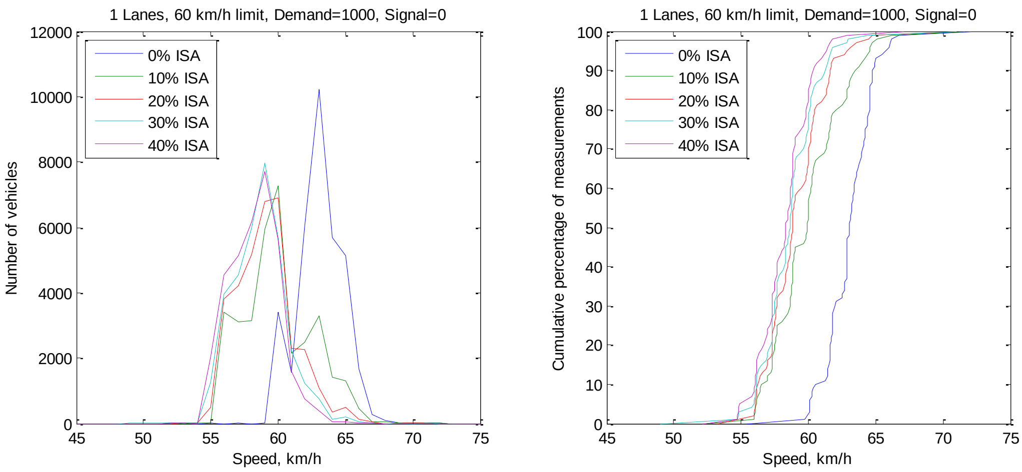

Figure 4.11
Speed distributions for 1000 vehicles per hour: (a) speed density, (b) cumulative distribution

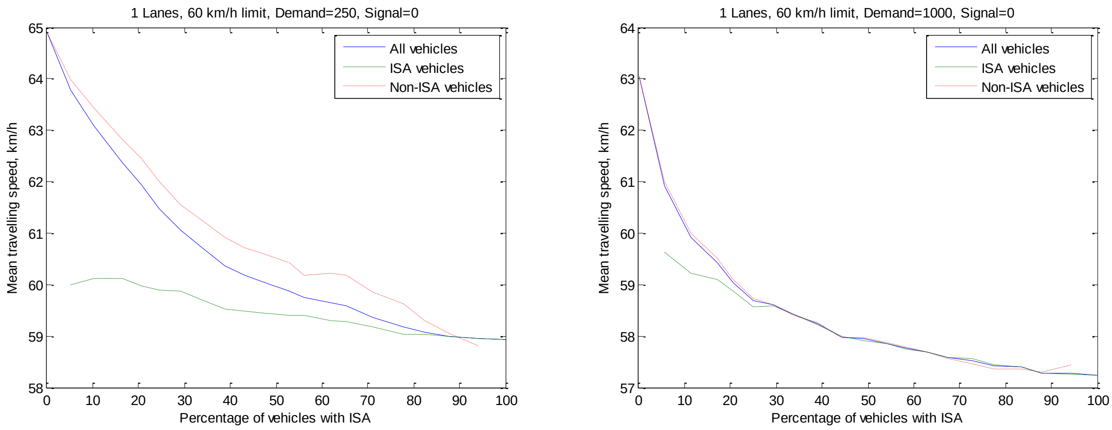

Figure 4.12
Mean speed versus ISA penetration, by vehicle type: (a) 250 vehicles/hour, (b) 1000 vehicles/hour

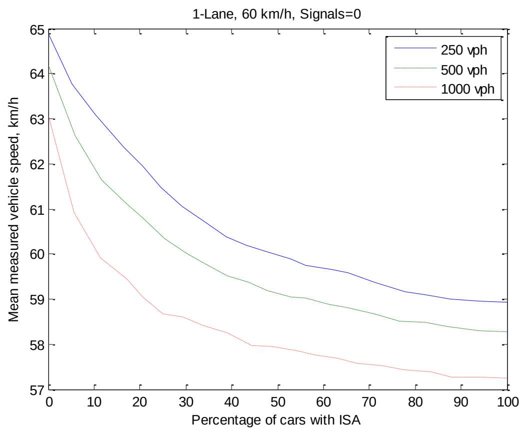

Figure 4.13
Mean speed versus ISA penetration, for different traffic volumes

4.4 Comparison of results with different signal densities

The base model scenario did not include any traffic signals. Three different levels of traffic signal density were considered in addition to the base model, to see if the presence of traffic signals influenced the effectiveness of ISA at reducing fleet-wide vehicle speeds.

Figure 4.14, Figure 4.15 and Figure 4.16 show the speed distributions for signal densities 1, 2 and 3 respectively. In all three cases, we can observe the emergence of a lower speed peak as the percentage of vehicles with ISA increases. The higher speed peak appears to flatten out sooner in the case of signal density 1, when compared with the other two scenarios.

Figure 4.17 shows the change in mean speed with increased levels of ISA penetration, split by vehicle type. The lines representing all vehicles are collated on Figure 4.18 along with the base model scenario of no signals. This plot shows that there are some apparent differences in ISA effectiveness between the four different scenarios, but there is no logical progression: signal density 1 is the most effective at reducing all vehicle speeds, followed by 2, zero, then 3. This suggests that the influence of signal density on ISA effectiveness is not clear cut.

Observation of the simulation in progress suggests that there are complex interactions occurring. This is partly because signalised junctions can influence the behaviour of non-ISA vehicles in two conflicting ways. Firstly, a non-ISA vehicle travelling at free speed may queue behind an ISA vehicle at a signalised junction (beneficial to the ISA cause). Secondly, a platoon of non-ISA vehicles headed by an ISA vehicle may be separated by a signalised junction when the following non-ISA vehicle is stopped, thereby allowing the non-ISA vehicles to return to free speed when the signals turn green (detrimental to the ISA cause).

It appears from preliminary observation that the interaction between these two effects is highly sensitive to a number of variables, including ISA proportion, signal frequency, signal spacing and cycle times. To theoretically quantify these effects would require more research. Such theoretical analyses of the effect of signals on ISA is likely to only be relevant if designing a new urban road network. If the interest lies in how ISA can be most effectively implemented with regard to an existing road network then there is not likely to be much flexibility with regard to the location of signalised junctions. It would therefore make more sense to construct a microsimulation model of an existing road network to see how the signalised junctions influence the interactions between ISA and non-ISA vehicles in-situ.

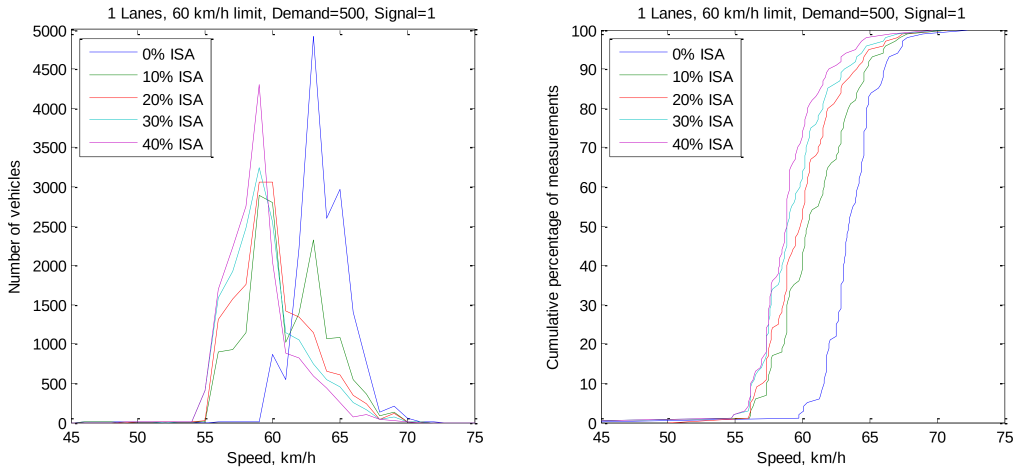

Figure 4.14
Speed distributions for signal density level 1: (a) speed density, (b) cumulative distribution

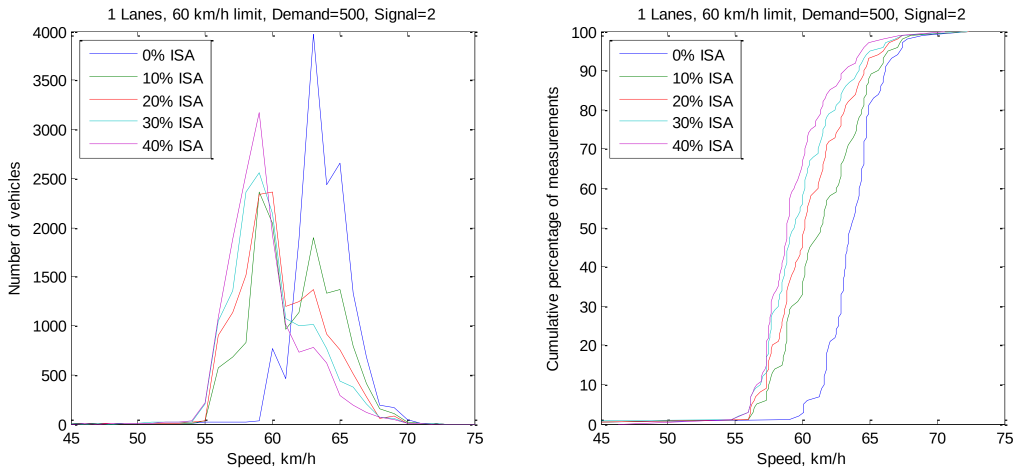

Figure 4.15
Speed distributions for signal density level 2: (a) speed density, (b) cumulative distribution

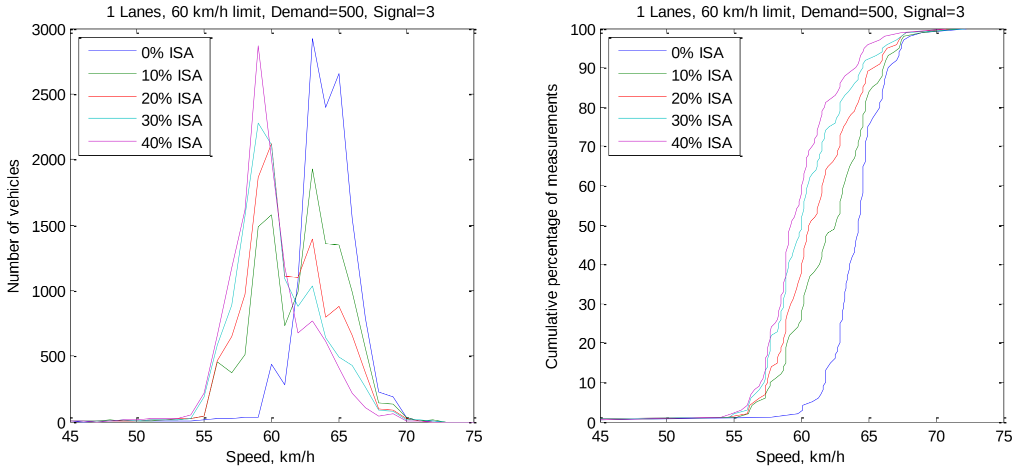

Figure 4.16
Speed distributions for signal density level 3: (a) speed density, (b) cumulative distribution

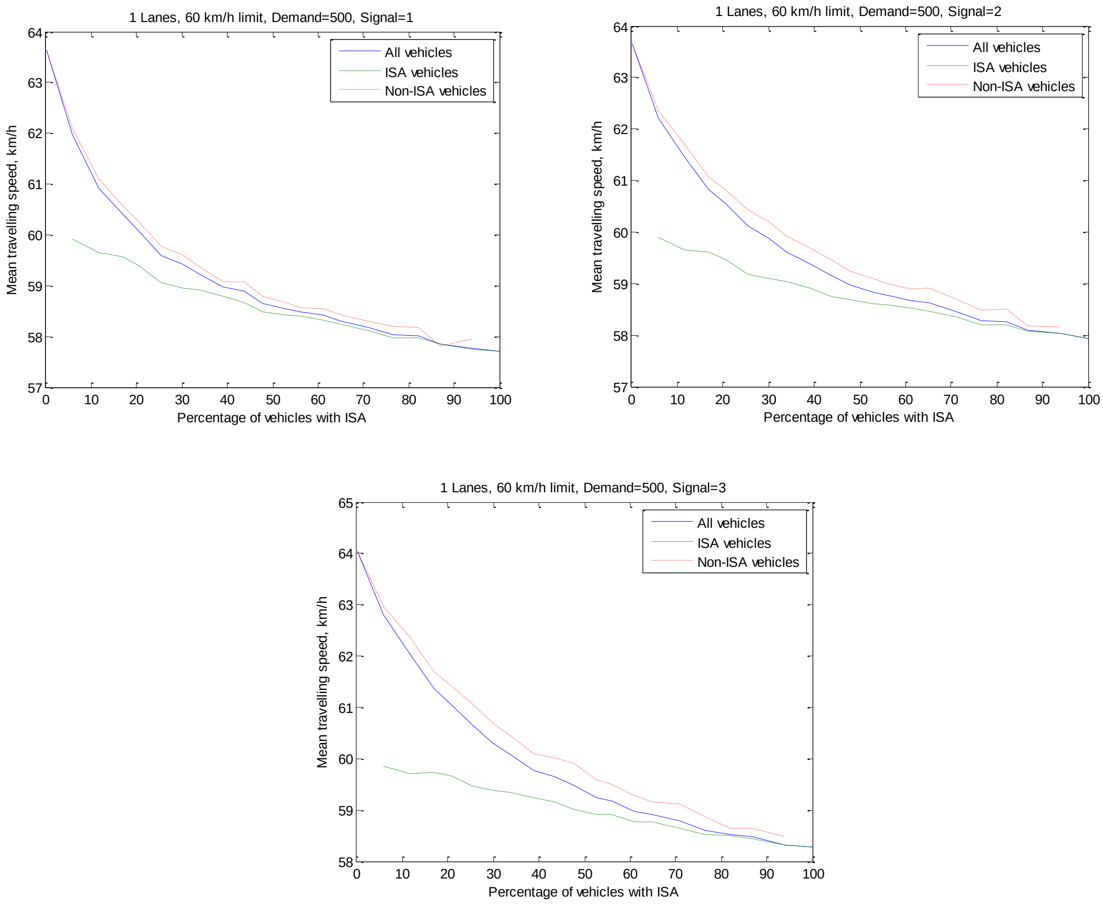

Figure 4.17
Mean speed versus ISA penetration, by vehicle type:
(a) Signal density 1, (b) Signal density 2, (c) Signal density 3

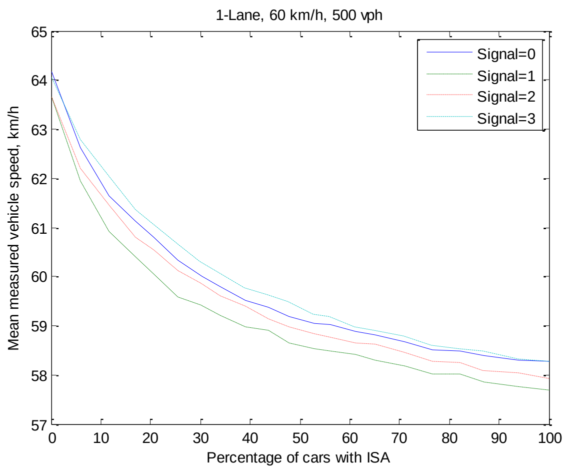

Figure 4.18
Mean speed versus ISA penetration, for different signal densities

4.5 Two lane scenario with varying traffic volumes

The base model scenario was modified to include two lanes travelling in each direction so that overtaking was possible by changing lanes. The effectiveness of ISA on fleet-wide vehicle speeds was not evident when varying the signal density and speed limits. Some ISA effect was observed when traffic volumes were adjusted.

Figure 4.19, Figure 4.20, Figure 4.21 and Figure 4.22 show the speed distributions for the two lane scenario with traffic volumes of 250, 500, 1000 and 2000 vehicles/hour. In all cases, a peak appears at a lower speed as the percentage of vehicles with ISA increases. However, for these cases, the higher speed peak does not flatten out by 40% ISA penetration.

This suggests that when compared with the one lane scenario, ISA is not as effective at reducing overall vehicle speeds for the two lane scenarios. We would expect this result, as the presence of a second lane gives an opportunity for a faster non-ISA vehicle to overtake a slower travelling ISA vehicle.

Figure 4.23 shows the change in mean speed with increasing levels of ISA penetration, for different traffic volumes in the two lane scenario. In the case of 250 and 500 vehicles/hour, the line is almost linear, indicating that only the ISA vehicles themselves are reducing their speed. As the traffic volume increases, the line becomes more curved, suggesting that more of the non-ISA vehicles are reducing their speeds due to the presence of the ISA vehicles. Again, this result is expected: for higher densities of traffic, it becomes more difficult for a faster travelling vehicle to overtake a slower vehicle.

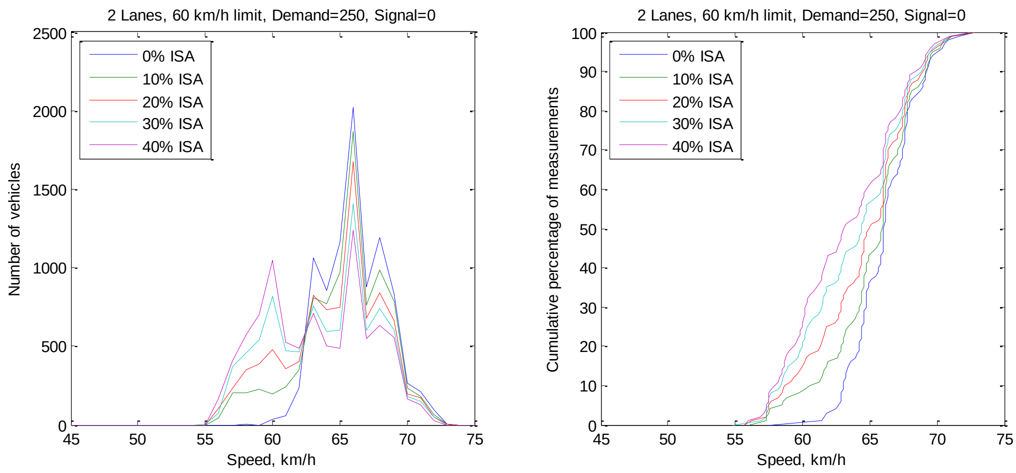

Figure 4.19
Speed distributions for two lanes, 250 vehicles/hour: (a) speed density, (b) cumulative distribution

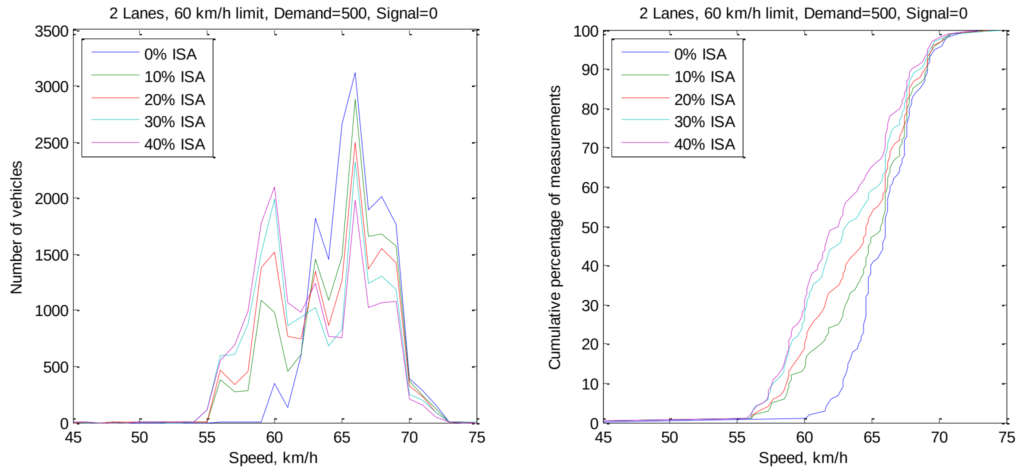

Figure 4.20
Speed distributions for two lanes, 500 vehicles/hour: (a) speed density, (b) cumulative distribution

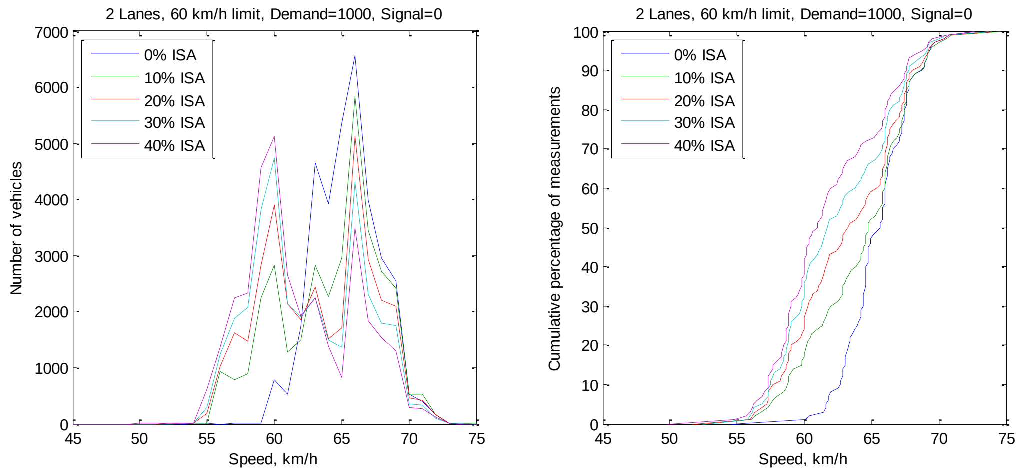

Figure 4.21
Speed distributions for two lanes, 1000 vehicles/hour: (a) speed density, (b) cumulative distribution

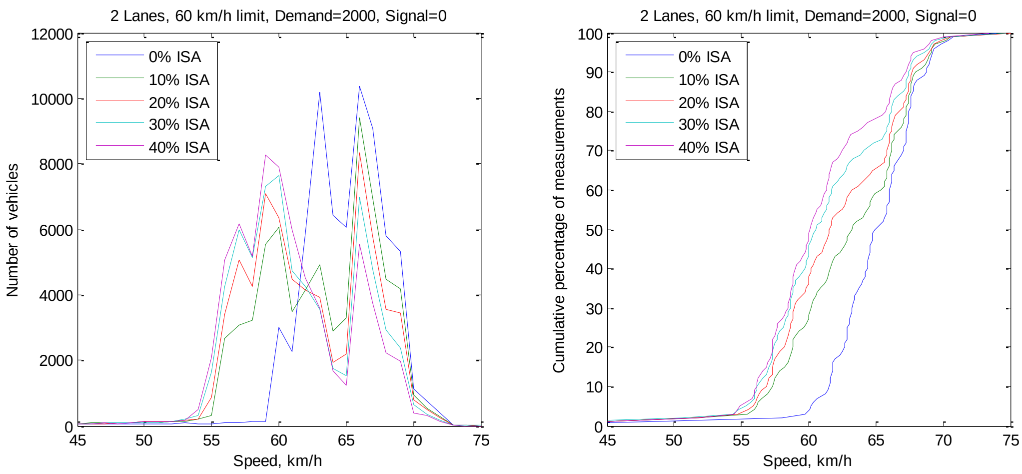

Figure 4.22
Speed distributions for two lanes, 2000 vehicles/hour: (a) speed density, (b) cumulative distribution

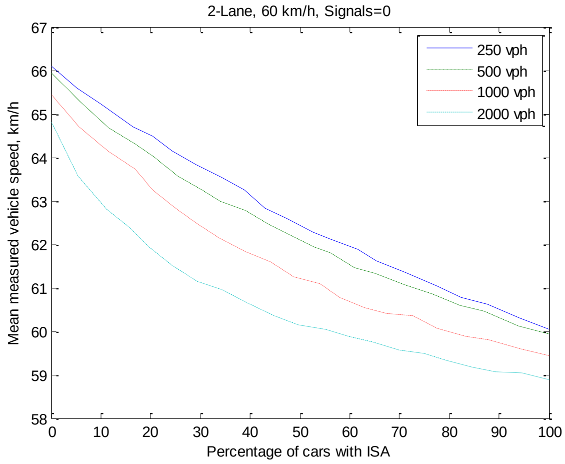

Figure 4.23
Mean speed versus ISA penetration for two lanes, varying traffic volumes

4.6 Rural road

As described in the methodology section, a separate model was constructed to simulate a rural road. The rural road had a speed limit of 100 km/h, and was approximately 80 km in length.

The rural road was first considered with no opportunities for vehicles to overtake each other. The road was then modified to include a 5 km overtaking lane at its midpoint. This enabled any faster travelling vehicles to move ahead of slower vehicles.

Both of these scenarios were considered with traffic volumes of 100, 250 and 500 vehicles per hour.

4.6.1 No overtaking lanes

Figure 4.24, Figure 4.25 and Figure 4.26 show the speed distributions for the rural road with no overtaking, at traffic volumes of 100, 250 and 500 vehicles/hour. With the lowest traffic volume of 100 vehicles/hour, the higher speed peak in the speed density plot does not flatten out by 40% ISA penetration. This indicates that the presence of ISA vehicles on this road did not have a very strong effect on the speeds of all vehicles. This would be expected, as with such a low volume it would be less likely for platoons of vehicles to form behind slower moving ISA vehicles.

With increased traffic volumes of 250 and 500 vehicles/hour, the higher speed peak in the speed density plot does appear to flatten out significantly at around 30 to 40% ISA penetration. This indicates a stronger effect of the ISA vehicles on other vehicles, which would be expected for the higher density of traffic.

Figure 4.27 shows the mean speed versus the percentage of ISA vehicles, for each of the three different traffic volumes. This plot clearly shows that with increased traffic volume, the mean speed of all vehicles is decreased, and the effectiveness of ISA increases (given the increased curvature of the lines for higher traffic volumes).

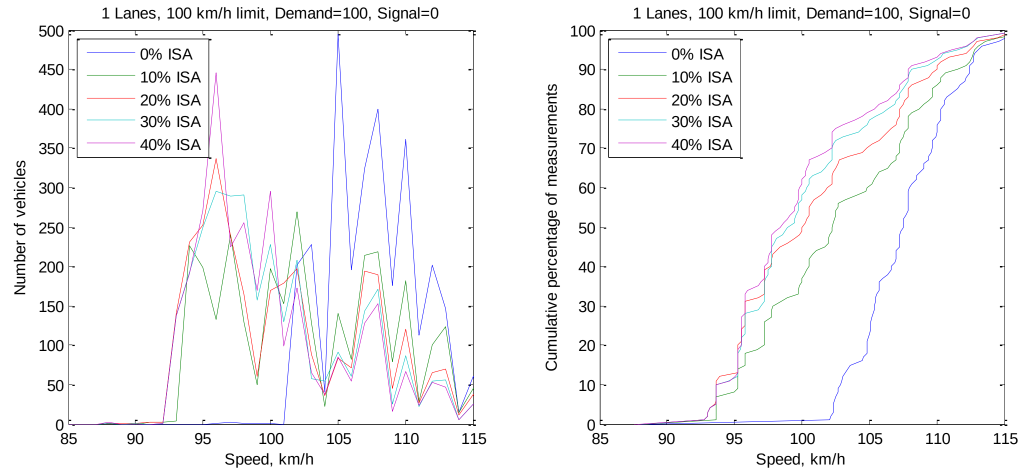

Figure 4.24
Speed distributions for rural road with no overtaking, 100 vehicles/hour: (a) speed density, (b) cumulative distribution

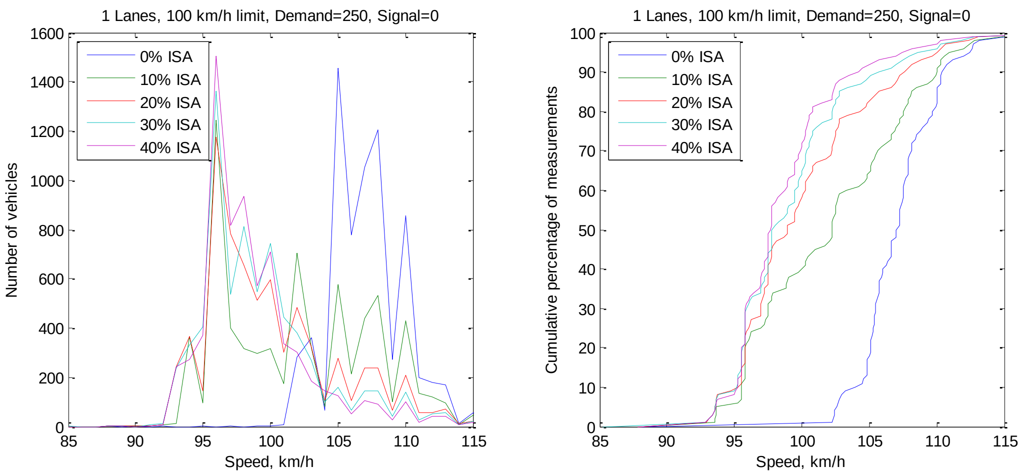

Figure 4.25
Speed distributions for rural road with no overtaking, 250 vehicles/hour: (a) speed density, (b) cumulative distribution

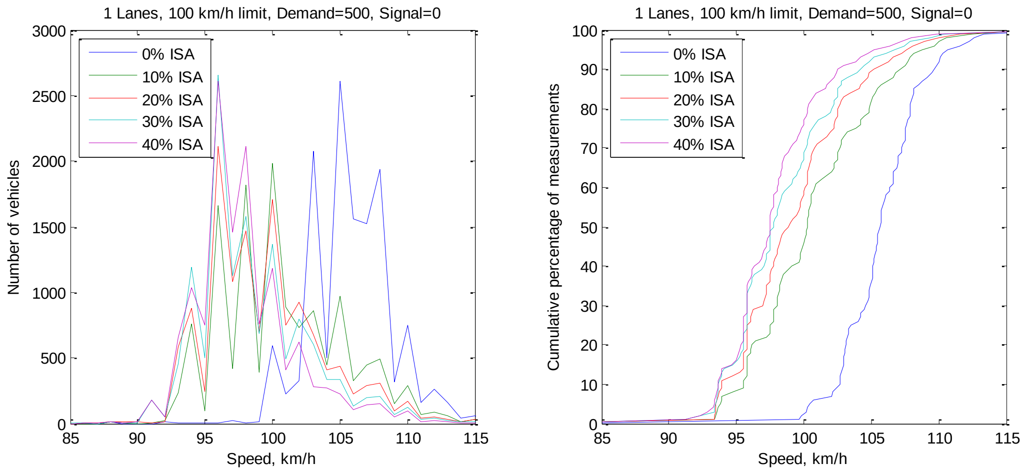

Figure 4.26
Speed distributions for rural road with no overtaking, 500 vehicles/hour: (a) speed density, (b) cumulative distribution

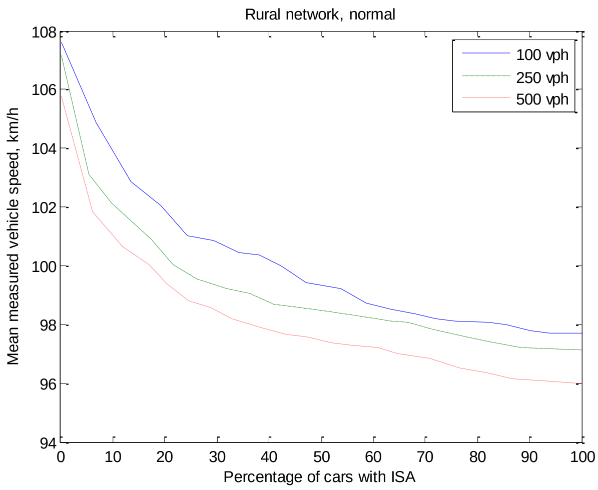

Figure 4.27
Mean speed versus ISA penetration for rural road with no overtaking, with varying traffic volumes

4.6.2 With overtaking lanes

Figure 4.28, Figure 4.29 and Figure 4.30 show the speed distributions for the rural road with an overtaking lane present midway along its length. Again, the plots represent traffic volumes of 100, 250 and 500 vehicles/hour, respectively.

As for the case of no overtaking, the effectiveness of ISA at reducing fleet-wide vehicle speeds appears to increase with increased traffic volume. The presence of the overtaking lane does appear to reduce the effectiveness of ISA in general, with the higher speed peak in the speed density plot still being present for relatively high levels of ISA penetration.

Figure 4.31 compares the three different traffic volumes in terms of the mean speed of all vehicles at different levels of ISA penetration. Again, this plot illustrates that increased traffic volume leads to reduced overall speeds, and increased effectiveness of ISA.

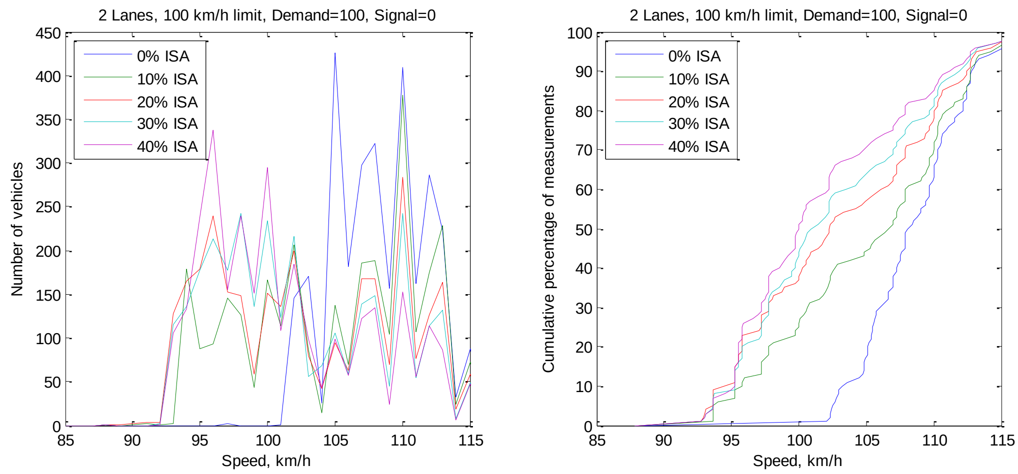

Figure 4.28
Speed distributions for rural road with overtaking lane, 100 vehicles/hour: (a) speed density, (b) cumulative distribution

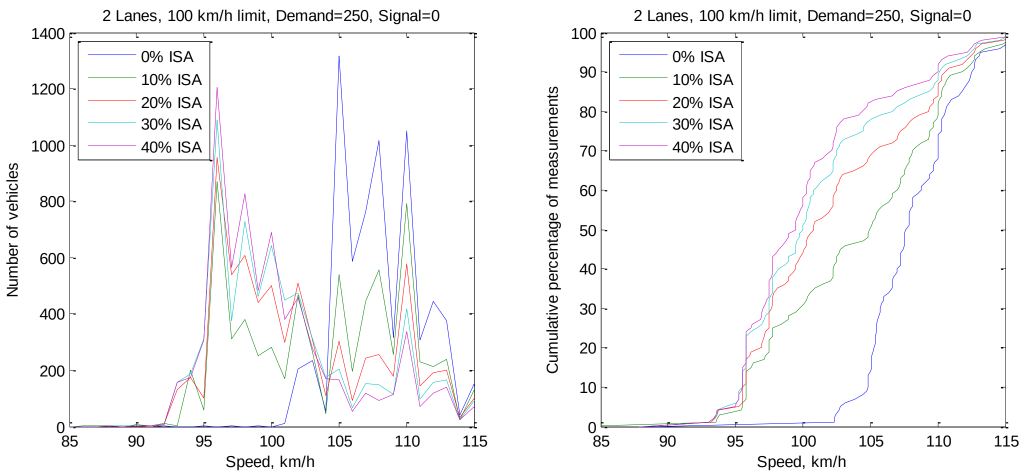

Figure 4.29
Speed distributions for rural road with overtaking lane, 250 vehicles/hour: (a) speed density, (b) cumulative distribution

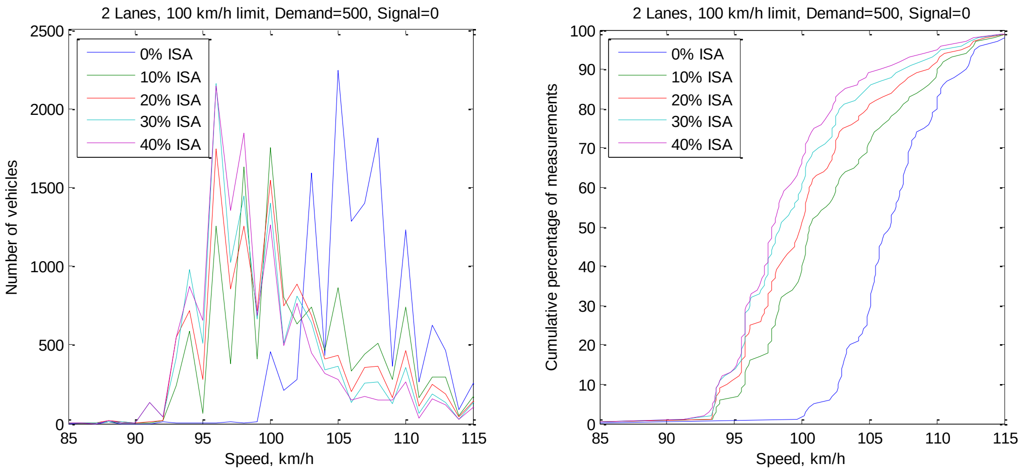

Figure 4.30
Speed distributions for rural road with overtaking lane, 500 vehicles/hour: (a) speed density, (b) cumulative distribution

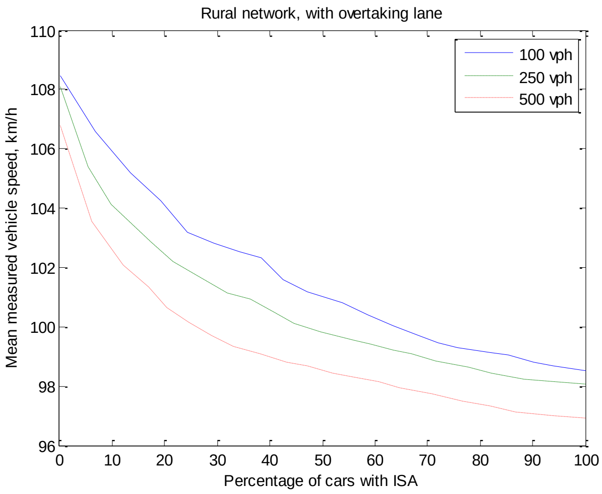

Figure 4.31
Mean speed versus ISA penetration for rural road with an overtaking lane, with varying traffic volumes

4.6.3 Comparison with and without an overtaking lane

Figure 4.32 compares the mean speed of all vehicles, with and without the presence of an overtaking lane. This plot illustrates that without an overtaking lane, the effect of ISA on fleet-wide vehicle speeds is stronger (shown by the increased curvature of the solid line) and the mean speed of all vehicles was lower. This result is to be expected: without an opportunity to overtake, faster travelling non-ISA vehicles are more likely to form platoons behind slower travelling ISA vehicles.

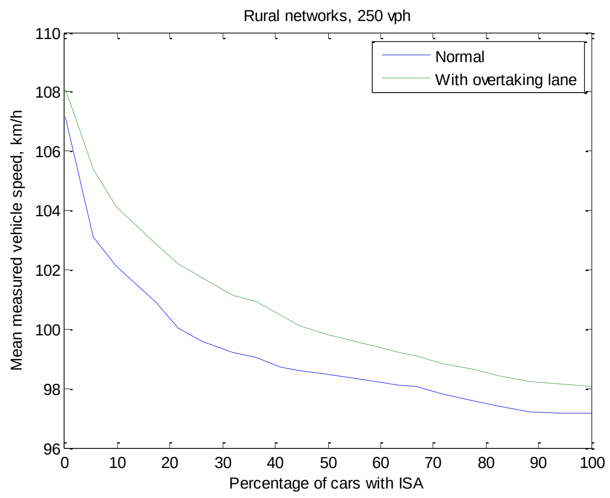

Figure 4.32
Mean speed versus ISA penetration for rural road with and without overtaking lane, 250 vehicles/hour

5 Discussion

In general, the introduction of ISA equipped vehicles into the simulated networks reduced the mean measured vehicle speed. There are two reasons for this reduction in speed. The first is that the ISA vehicles themselves are more likely to travel slower than non-ISA vehicles. The second is that faster travelling non-ISA vehicles may catch up to slower travelling ISA vehicles, and be required to match their speed.

If only the first effect were present, then we would expect to see a linear decrease in mean speed with increasing ISA penetration. This was observed for the two lane road with a low volume of traffic. If both effects were present then we would expect to see a steeper drop in mean speeds when ISA is introduced at low levels, which gradually levels out as ISA is adopted by more and more vehicles. This behaviour was observed for most of the scenarios considered, with increased curvature generally implying a higher effectiveness of ISA in slowing non-ISA vehicles.

Generally, the greatest reduction in average speed was achieved up to approximately 30 to 40% ISA penetration. This is broadly consistent with results reported in other studies of urban areas outlined in the literature review. The complexity of traffic interactions means that comparisons with other studies have to be treated with some caution, especially when differing road geometries, cross sections and density of traffic signals are involved. The extent of congestion on the road network also has an effect on ISA effectiveness and care was taken in this study to eliminate this effect so as to not confound the interpretation of results.

Only one other study involved the modelling of rural road networks but comparison is difficult as neither the modelled traffic flows nor distance were revealed and overtaking was modelled in a different manner.

If a 'critical mass' of ISA vehicles implied an optimal level of ISA penetration, no such point was found in any of the scenarios considered. That is, there was no point at which no more reduction in mean speed was achieved by introducing even more ISA equipped vehicles into the fleet. The relationships observed with this modelling work suggested a continuum: the mean speed continued to decrease until the network consisted of 100% ISA vehicles.

The mean speed versus ISA penetration relationship was generally nonlinear. Depending on the cost-benefit relationship of ISA penetration, there may be a critical point at which the cost of further ISA penetration outweighs the benefits of doing so.

Determination of this critical point would depend on the cost-benefit relationship, but would also be dependent on the road network being considered. Different aspects of the road network have been shown to influence the effectiveness of increased ISA penetration. These factors include how many lanes are available, the traffic volume and the signal density.

The complexity of the problem is evident, and there are many interactions and factors in the road network that can influence the results. The results presented in this report represent an examination of each network factor in isolation. In a real world traffic network, it would be much more difficult to isolate these effects. This appears to be consistent with occasional brief commentary in the literature on the complexity of the traffic interactions.

6 Conclusions

In conclusion, the introduction of ISA equipped vehicles into the road network has been shown, using microsimulation, to reduce the speed of other vehicles that are not equipped with ISA. The largest reductions in speed were achieved with ISA penetrations of up to 30 to 40%, after this the mean speeds generally continued to decrease but at slower rates.

The effectiveness of ISA vehicles in reducing the speeds of vehicles without ISA was not influenced by the speed limit, but was affected by other network factors.

With increased traffic volume, the effectiveness of ISA increased, due to a greater chance of a non-ISA equipped vehicle catching up to an ISA equipped vehicle. This was observed on both an urban style road, and a rural road.

The effectiveness of ISA was higher for a single lane road than a road with two lanes, or with an overtaking lane available. The presence of a second lane enabled faster non-ISA vehicles to pass ISA vehicles, instead of forming a platoon.

The influence of traffic signal density on ISA effectiveness was not clear cut. While a moderate number of traffic signals appeared to increase ISA effectiveness, a greater increase in signal density appeared to decrease ISA effectiveness. There are two effects at play: (1) traffic signals are likely to increase platooning behind ISA equipped vehicles, (2) traffic signals may break up platoons that have already formed behind ISA equipped vehicles. These two effects are thought to account for the ambiguity on the influence of increased signal density.

7 Future work

One limitation of this study is the accuracy of the natural speed distributions for ISA and non-ISA equipped vehicles (See Figure 3.2). A real world speed distribution is generally wider and less aggressive than the default speed distributions given by PARAMICS. As such, a future study would benefit from better fine tuning of the speed selection of ISA and non-ISA vehicles, in order to match real world distributions more closely.

Due to the uncertainty of the effect of traffic signals, and the potential cross over effects of speed limit, traffic volume and lane availability, it may be best to model a real world network in the future. This would mean that the results would have a direct meaning, and could be later compared with a measured effect.

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The views expressed in this report are those of the authors and do not necessarily represent those of the University of Adelaide or the funding organisations.

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Appendix A – Seed value sensitivity

Microsimulation software packages use complex stochastic processes to generate simulation results. A seed number must be specified by the user for each simulation which acts as a starting point for the random number generator within the software. If the seed number is kept consistent for a particular network then the results of repeated simulations will be identical (assuming all other parameters are invariant). Changing the seed number will produce a different set of results in any subsequent simulation.

Testing the network using a variety of seed numbers selected at random must be done to ensure the reliability of results. It is important that changing the seed value should not result in stark contrasts between simulation results.

A network simulation for the base scenario was run using ten randomly selected seeds. Figure A1 shows the dependency of mean speed on the proportion of vehicles with ISA. For clarity only five of the different seed values are displayed.

Although differences exist, the same general trend was observed for each seed value. Given the exploratory nature of the project, multiple seed runs were not conducted for each scenario, and the same seed value established in the original sensitivity test was used for all scenarios. Given the simplicity of the scenarios and the results of the sensitivity tests, it was assumed that the simulation was not sensitive to the selection of a random number generator seed value.

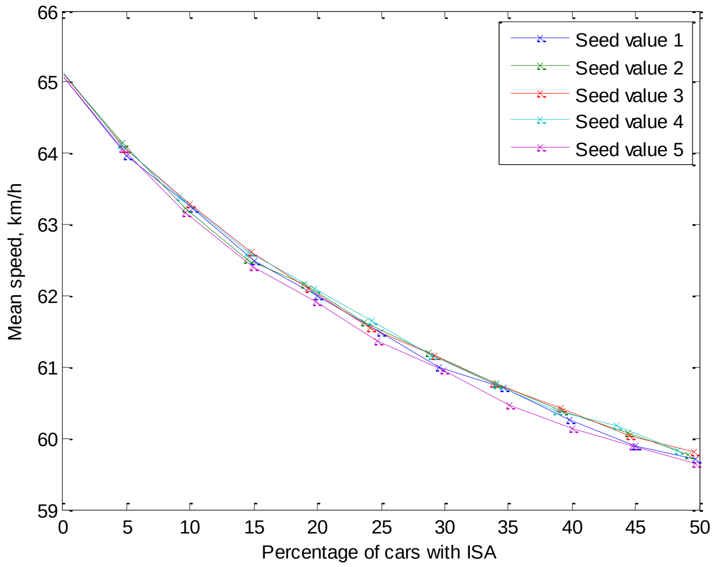

Figure A1
Mean speed versus ISA penetration, using different random number generator seeds

Although the network was found to be insensitive to seed variation it is still important to keep the seed number consistent when generating data for analysis. For this reason a seed number of 3177 was selected (at random) and used in all further simulations.