FINAL ANALYSIS OF THE TAC ISA HEAVY VEHICLE TRIAL: EFFECTS OF ISA AND FUEL EFFICIENCY TRAINING ON SPEED CHOICE

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ABSTRACT

The road safety benefits of Intelligent Speed Assist (ISA) have been demonstrated in passenger car trials. These benefits, however, have yet to be replicated in the heavy vehicle (trucking) industry. This small-scale trial conducted by the Transport Accident Commission (TAC) in collaboration with the Victorian Transport Association (VTA) with the cooperation of several heavy vehicle transport companies sought to assess the relative merits of ISA in terms of driver acceptability, speed choice, and fuel consumption.

The study was a pre-post design. Prior to the installation of the ISA device, a GPS device was fitted to six heavy vehicles and vehicle speed and trip characteristics were continuously recorded. An advisory ISA device was then installed for a period of four to six weeks. Seven drivers participated in the trial and completed a survey before and after the trial. Two drivers also undertook a fuel efficiency training course.

Prior to the study, six of the seven drivers stated they would find a device that would assist their speed choice to be useful, while four believed a device that would prevent them speeding would also be valuable. Following the trial, six drivers reported finding the system helpful in preventing them from speeding, rating it as 5 or above on the 10 point scale. Opinions were more divided in terms of the accuracy of the speed limit map, with two drivers rating it as very poor.

Analysis of speed data indicated an overall 21% reduction in the odds of travelling over the posted speed limit; this was driven entirely by an observed 25% improvement in speed compliance in the 80 km/h and higher speed zones. There was no benefit effect of ISA in the lower speed zones. The drivers that undertook the fuel consumption training course demonstrated an increase in over-limit episodes in the lower end speed zones, although this effect was moderated by the addition of ISA.

Device acceptability appears to play an important role in the effectiveness of advisory ISA systems, however the relationship is complex. Further work that explores the relationship between acceptability of ISA and compliance with the assigned speed limit is required. Further work directly linking the fuel consumption benefits with ISA is also required.

KEY WORDS: Intelligent Speed Assist (ISA), Heavy Vehicles, acceptability, fuel consumption

INTRODUCTION

Speeding is recognised to be a leading contributor to the occurrence of crashes and their associated level of injury severity.[1-4] There is a considerable body of work that examines the factors associated with exceeding the speed limit, and these include personal characteristics (e.g., age, gender), trip purpose, perceived level of detection by police, as well as the perceived credibility of the assigned limits themselves.[5-9]

Compliance with posted speed limits is a critical facet of a safe transport system.[10] As noted by Jiménez and colleagues, and supported by a large number of research studies, the setting of speed limits and associated compliance, leads to more appropriate driving speeds and less variability in travelling speeds, leading to a safer road environment. [11] Speed has been identified as a major factor in heavy vehicle crashes and there has been a push both in Australia and globally to address speeding behaviour as well as a range of other behavioural, organisational and vehicle safety concerns as a means of improving heavy vehicle safety.

Heavy vehicle safety and crashes in Australia

In Australia, for the 12-month period ending June 2010, 258 people died as a result of 212 crashes that involved heavy trucks or buses. One-quarter of those killed were occupants of the truck/bus itself (60% single vehicle crash).[12] Truck-involved fatalities account for approximately one-fifth of those killed on Australian roads, despite representing approximately only 4% of registered vehicles in Australia.

Given their high rates of exposure, transport drivers are unsurprisingly the most frequently involved group in work-related crashes in Australia. This was shown in a study of 13,124 drivers involved in crashes during the period 1997-2002 in New South Wales, Australia. In this study, nearly half of all fatalities resulting from work-related crashes were drivers of heavy vehicles and speeding was associated with 15% of crashes. [13] A study of truck driver fatalities over the decade 1997-2007 in Victoria indicated that speeding was associated with 36% of crashes where the driver of a heavy vehicle was killed.[14]

In Australia the importance of the heavy vehicle industry to the economy and the need for improvements in safety has been recognised by the Australian Transport Council (ATC). In setting a 30% reduction target in heavy vehicle associated crashes, improved speed management was seen to be a key driver.[15] New active safety system technologies, such as Intelligent Speed Assist devices (ISA), offer a potential way to assist the driver and the fleet operator, in ensuring speed limit compliance.

ISA effectiveness studies

Advisory ISA systems are a driver support system that uses knowledge of the road network and GPS technology to improve compliance with the posted speed limit by delivering visual and / or auditory warnings to the driver. More interactive ISA systems actively discourage (via haptic feedback) or prevent the driver from exceeding the speed limit (i.e., intervening, over-rideable or not over-rideable). [16-19]

A number of studies have documented the benefits of ISA technology in 'reducing speed, speed variability and speed violations'.[16, 18, 20-22] Devices that exercise a greater control over the driver are seen to be most beneficial, as opposed to simple advisory systems, however these controlling systems are less likely to be acceptable to drivers.[16, 19] Reductions in mean speed, the 85th percentile speed and percentage of distance travelled over the speed limit have all been documented with the use of ISA.[18, 21] Using these observed reductions in speed, substantial reductions in the number of crashes and of individuals injured have been estimated.[23]

Despite these benefits, a number of negative effects have been observed with ISA. Two key issues are the acceptability of the system warnings [11] and driver adaptation or system over-reliance. [16, 18, 19, 24] System over-reliance is of concern as faster speeds on bends and in approaching intersections have been observed. In addition, young drivers and males appear to be less accepting of the ISA device and it is precisely this group that could benefit most from ISA given their heightened crash risk.[21]

While the beneficial effects of ISA have been demonstrated in passenger cars, no study had demonstrated the value of ISA in heavy vehicles at the time this study was planned. This was despite the findings of a comprehensive review undertaken in 2003 by Regan, Young and Haworth that concluded that ISA systems have the potential to deliver a range of benefits for the heavy vehicle industry, including improved speed control and improved fuel efficiency.[25]

This trial set out to examine whether the potential benefits of ISA observed in passenger cars would translate to heavy vehicles.

The current study: a real-world trial of ISA in heavy vehicles in Victoria

The Transport Accident Commission (TAC) in collaboration with the Victorian Transport Association (VTA) and with the cooperation of three heavy vehicle transport companies conducted a small scale trial in an attempt to assess the relative merits of ISA in terms of speed choice, driver acceptability and fuel consumption.

A preliminary paper published elsewhere examined in detail the pre-and post-survey (qualitative) responses for all drivers in the trial and used on-road data for two drivers to examine the on-road effect of ISA. The preliminary analysis reported mixed findings with the level of benefit being speed zone dependent[26] while a more recent paper presented the overall speed reduction effects of ISA without consideration of fuel efficiency course participation of fuel consumption patterns[27].

This paper therefore extends previous reported finding to examine the effect ISA on speed choice whilst accounting for participation in the fuel efficiency course for two drivers and driver attitudes toward ISA.

METHOD

Participants

Seven drivers from three transport companies agreed to participate in the trial. The drivers provided informed consent to participate and each completed a questionnaire before and after the completion of the study.

Participating companies/vehicles were selected on the basis of the following criteria:

- they had significant Victorian-based long distance travel undertaken by a number of company vehicles;
- trucks in the study were of similar makes and models and operate repeat trips within Victoria, and
- the company is committed to providing data for evaluation purposes and to allow access to drivers for a briefing session and to complete pre-/post-questionnaires

Design of the trial

The trial was designed as a pre-post study of ISA with the inclusion of fuel efficiency driving simulation training course for two drivers (Table 1).

Phase 1 collected baseline data using a GPS logger while Phase 2 was the ISA trial period. The trial was a simple baseline vs. ISA trial of the effect of ISA in improving speed limit compliance.

Table 1. Design of the ISA trial

DRIVER	Phase 1		Phase 2
A-E	Baseline speed assessment *('baseline')*		ISA trial period *('trial')*
F, G	Baseline (3.5 weeks)	Baseline + fuel efficiency training (4.5 weeks)	ISA + fuel efficiency training (4.5 weeks)

The ISA device for use in the trial

The ISA technology deployed was advisory; that is, it did not limit the speed of the vehicle but simply provided the driver with auditory and visual warnings when the speed limit was exceeded. No data was collected by the advisory ISA device but rather it served purely to advise the driver of the speed limit at each particular moment in time.

The ISA device was programmed to alarm when the driver exceeded the assigned speed limit by 2 km/h for a period of 2 seconds or more. The driver could override and switch the ISA device off if needed. No data was collected from the vehicle speedometer though the ISA device was calibrated to the speedometer.

Data sources

Data collected in the trial included a pre-post participation questionnaire, the logged trip data referred to as the GPS-Enhanced data and the Transport Operator Trip logs. Each is discussed below.

Survey data A *pre-trial survey* was completed by each participating driver with the aim of capturing a range of attitudes to speeding and the likely benefits of 'smart' technology in aiding the driving process. Attitudinal data was collected using either a 5-point Likert scale (1: strongly disagree to 5: strongly agree) or via free text responses. Demographic information was also collected.

A *post-trial survey* was completed to obtain feedback concerning the usability and acceptability of the ISA device, as well as attitudes relating to road safety more generally. A number of attitudinal questions were repeated from the pre-trial survey, permitting a pre-post analysis to be undertaken.

GPS-Enhanced data

In Phase 1, the baseline period, a GPS data logger was installed into the truck to collect speed and associated trip data. Drivers were aware of the data logging capability of the GPS device however they could neither see nor interfere with the device.

The GPS device continually collected detailed information in 15 second cycles. For each cycle, speed (km/h) was captured as were GPS co-ordinates, time and date, distance covered (metres) and bearing / heading.

The GPS logged data was enhanced via linkage with the Victorian road network using Geographic Information System (GIS) software. Vehicle position was established using the longitude and latitude of each cycle. Of particular relevance was the assignment of the speed limit of the road for each recorded cycle. Allowance was given for school day periods associated school speed zones and shopping zones with variable speed signs. The linkage was conducted by the Roads Corporation, Victoria (VicRoads).

Transport Operator Trip Logs

At the conclusion of the trial, companies provided extensive trip logs for each of the trucks involved in the trial. This included the drivers of each trip, the date of vehicle use, destination, odometer readings, load mass, and fuel consumption or fuel refill amount and date. The time of day that the trip was undertaken and completed was not reported in the trip logs.

The trip logs were critical in determining which data cycles to analyse. While two drivers were the sole drivers of their vehicles for the duration of the trial, one truck was driven by five drivers, two of whom were in the study; one truck was driven by 10 drivers (one in trial) 1 truck was driven by 11 drivers (one in trial), while another truck was driven by 19 drivers (one in trial). It was then necessary to link the driver log data to the GPS enhanced dataset to ensure that only those drivers that were enrolled in the trial (i.e., drivers of interest) were included in the analysis. Where multiple drivers drove the truck on a single day, data pertaining to that day was excluded from the analysis.

Fuel efficiency training

Two drivers in the trial completed the fuel efficiency training program run by a third-party provider. The fuel efficiency training course used a truck-based driving simulator with the program having two principal objectives:

1. Improve fuel economy of participant truck drivers through the demonstration of fuel efficient driving techniques, and
2. Reduce vehicle emissions of the trucks driven by participant drivers.

The two drivers undertook three drives in the simulator. The purpose of each drive was as follows:

- Drive 1: acclimatisation drive
- Drive 2: pre-training drive
- Drive 3: post fuel efficiency driving technique training drive

An overall rating was given for each of the drives, with significant improvement in fuel economy achieved post-training. At the completion of the course drivers rated their satisfaction with ‘*content’, the ‘facilitator’,* and the *‘theory and practical mix’.* One driver rated each sub-item on ‘content’ as a ‘4’ (very good), a rating of ‘5’ (excellent) for each sub-item for the facilitator and a ‘4’ for each of the theory/practical mix items. The second participant driver awarded a rating of ‘5’ for all items. In addition to the 5-point rating scales, participants were asked to note key lessons. One driver noted *‘less gear changes is less work’* while the other noted ‘*be more alert, more fuel efficient’.*

Data Analysis

A single database was constructed that linked the pre-/post-survey data, the trip log data and the GPS Enhanced dataset. This dataset formed the basis of the analysis reported here.

For the survey data, median values and the associated range among respondents were presented due to the ordinal nature of most of the items and the small sample size. Non-parametric statistics were used to examine pre-post survey responses where appropriate.[28]

The principal outcome of interest was the change in the number of cycles that the vehicle travelled over the posted speed limit following the installation of the ISA device compared to the baseline period. Analysis of the effect of ISA only included time cycles where the vehicle was in motion and the speed limit of the road was known. Hence, this excluded cycles: i.) where the vehicle was not in motion (including when stationary at lights or off-road), and / or ii.) where the assigned speed of the road vehicle was unknown.

To examine the change, if any, in the number of timed cycles the vehicle exceeded the assigned speed limit, calculation of the percentage point difference in cycles over the speed limit was determined overall and for each speed zone.

A logistic General Estimating Equation (GEE) regression model was used to assess the effectiveness of the ISA device [29-31]. The logistic GEE model was considered the most appropriate model given the repeated measures nature of the data with speed captured in 15-second cycles and the fact that each subsequent 15-second cycle would be correlated with that immediately prior, with this correlation likely diminishing with every cycle; that is, for repeated observations taken through time, those observations taken more closely to one another in time are likely to be more highly correlated than those taken further apart - this is known as an *autocorrelation.* It is critical to specify the nature of the working correlation matrix in order to account for the within-subject correlations. Ideally an unstructured correlation matrix would be specified as this allows the data to provide an estimate of the correlation between any two cycles of specific time separation. An alternative model uses an autoregressive matrix of the first order (AR(1)) which would be acceptable as the interval length is generally constant between any two observations. Due to computational limitations (i.e., processing power, number of observations) neither the unstructured or autoregressive working correlation matrices could be estimated. As the next best option an exchangeable within-subject correlation matrix was used that assumes that the correlation between any two responses of equal absolute time separation on any one driver is the same. It should be noted that the choice of working correlation matrix did not affect the estimates of ISA effectiveness but did have a bearing on the standard errors of the parameter estimates.

The base main effects model to assess vehicles travelling in excess of the posted speed limit included the design phase of the trial (Baseline, fuel efficiency training alone, ISA-alone, fuel efficiency training + ISA) and the post-ISA device rating of the device usefulness . The repeated measures term was the driver variable. The dependent variable was the vehicle travelling over the posted limit, expressed as a dichotomous outcome. This was repeated for each speed zone.

GEE Analysis was performed in SAS V9.2 of the SAS System for Windows.[32]. Statistical significance was set at $p \leq 0.05$.

Ethics approval

The trial was conducted by the Transport Accident Commission with the data analysis conducted with the approval of the Monash University Human Research Ethics Committee.

RESULTS AND DISCUSSION

Driver characteristics

The characteristics of the drivers are presented in Table 2 below. All of the drivers were male, 4 were aged under 50 years of age, and driving experience ranged from 10 – 45 years (median: 19 years). None of the drivers had heard about ISA prior to the commencement of the trial.

Table 2. Characteristics of the drivers involved in the trial

Characteristics	Number	Percent
Male (%)	7	100
Age category		
30 – 39	2	28.5
40 – 49	2	28.5
50 – 59	2	28.5
60+	1	14.25
Fined for speeding prior 5 years	2	28.5
Heard of ISA before trial	None	None
Driving experience	10 – 45 years, median: 19	

Pre-trial views of speed assist devices and speed behaviour

Drivers were asked a series of questions as to whether they would find a 'smart' speed warning device useful and their awareness of the speed limit when driving (Table 3).

Despite none of the drivers having heard of ISA prior to the trial, 6 of the 7 agreed that they would find a device that told them whenever they exceeded the speed limit useful. These same 6 drivers agreed that they sometimes exceeded the speed limit without realising it, and of these four agreed that they would find a device that stopped them going over the speed limit useful; the other two drivers who agreed that a simple advisory device would be useful altered their view to neutral on the usefulness of a more controlling device after the trial had concluded.

Three of the seven drivers stated they were neutral to *always being aware of the speed limit,* two agreed, and one disagreed. In combination, these findings suggest these drivers might find value in an ISA device. On the other hand, one driver disagreed that any device – advisory or controlling, would be useful, was neutral to 'sometimes going over the limit without realising' and strongly agreed that he was always aware of the speed limit. These divergent views are important to consider in the subsequent findings presented below.

Table 3. Pre-trial views of the perceived usefulness of ISA and speeding behaviour

Rating item	Median †rating	Range†
A device that told me whenever I went over the limit would be useful	4 (agree)	2 - 5
A smart device that stopped me from going over the speed limit would be useful	4 (agree)	2-5
I go over the speed limit sometimes without realising it	4 (agree)	3-4
I am always aware of the speed limit	3 (neutral)	2-5

† Rating scale: 1 – strongly disagree; 2 – disagree; 3 – neither; 4 – agree; 5 – strongly agree

Post trial driver views of ISA captured by the survey

At the conclusion of the trial drivers were asked to rate ISA according to how useful it was, its road safety benefits, how helpful it was, and how accurate it was, using a 10 point scale (with 10 as the highest most positive rating). The responses were as follows:

- Five drivers reported finding the system useful and to have road safety benefits, rating it as 5 or above on a 10 point scale;
- Six drivers reported finding the system helpful in preventing them from speeding, rating it as 5 or above on the 10 point scale
- Four drivers rated the accuracy of the speed limit map as 6 or higher, while one driver gave a rating of 4 while two drivers gave the lowest possible rating of very poor (1)
- Four of the seven stated they needed to over-ride the system or turn it off at some point;
- Six of the seven stated that the default volume for the auditory warnings was acceptable, while one stated it was too loud, although six stated the volume should be controllable, and
- To the question of whether drivers looked at the speedometer less due to the presence of the ISA device, three agreed, two were neutral and two strongly disagreed; of the latter two, one rated the digital speed map as very poor while the other suggested a device to show the speed prior to exceeding the limit – notably, this driver also pointed to the issue of calibration of the device and the difference in reading against the truck speedometer.

Finally, the pre- and post surveys indicated that the drivers held very conservative views of speeding, universally disagreeing to questions such as, *I think it is ok to drive a little bit faster if you are a good driver* and *It is easy to avoid being caught speeding.*

Summary of Driving Time

The GPS recorded vehicle movement and associated information every 15-seconds. Only cycles where the truck was moving were used in the analysis, and those periods where the truck was off-road and stationary or stopped in traffic were excluded. In total, there were 2017 recorded ‘moving’ hours. Of these, 1774 hours were driven by the 5 drivers that participated only in the baseline and ISA component of the trial (baseline hours: 631; ISA hours: 1143)

The two drivers in the fuel efficiency group drove a total of 244 hours under observation, with 91 being in the pre-intervention (baseline period), 83 hours following fuel efficiency training and 70 hours once ISA was installed.

Effect of ISA and fuel efficiency training on the speed profile

The primary purpose of ISA is to promote improved compliance with the assigned speed limit. To set the backdrop to the regression analysis of the effect of ISA and fuel efficiency training alone and in combination on speed limit compliance, it is important to examine the changes, if any, on the speed profile in each of the comparison categories.

Table 4 presents the mean speed, the median and the 85th percentile speed for each of the comparison groups, according to the Phase of the trial. Tables 5 and 6 are divided into whether drivers did or did not receive the fuel efficiency training.

For the 5 drivers in the trial that did not receive fuel efficiency training, it can be observed that across all speed zones, the mean and median speed decreased marginally. In addition, the percent of occasions where the driver exceeded the assigned limit reduced by 21.3%, or alternatively, there was an absolute difference of -3.4% in violations.

For the two drivers that received fuel efficiency training, their mean and median speed increased, although this was accompanied by a reduction in the percent occasions over the posted speed limit. In the fuel efficiency period, there was a -0.9% difference in violations compared to the baseline period, representing a reduction of 12%; the addition of ISA saw mean speed remain higher, but a marked reduction in the percent of over-limit episodes (55% reduction, or an absolute difference of 3.9% less violations). In comparing the PRE-ISA / fuel efficiency training period with the ISA / Fuel efficiency period, there is little difference in the speed profile, but a marked difference in the number of recorded cycles where the speed limit was exceeded (i.e., 48% reduction, or a -3% absolute difference).

Table 4. Speed profile before and during ISA installation, with the percent point difference in speed over-limit violations shown

OMNIBUS – all speed zones	**Mean (SD) (km/h)**	**Median (km/h)**	**85th % km/h**	**Cycles**	**% point diff. over-limit**
STANDARD TRIAL					
BASELINE	82.4 (24.9)	97.0	100	151,365	*reference*
ISA	79.5 (26.2)	92.0	100	274,319	-3.4%
FUEL EFFICIENCY COURSE					
BASELINE	59.3 (31.3)	62.0	97.0	21,723	*reference*
PRE-ISA + FUEL EFFICIENCY TRAINING	62.2 (31.1)	66.0	97.0	19,974	-0.9%
ISA + FUEL EFFICIENCY TRAINING	61.0 (31.9)	63.0	97.0	16,758	-3.9%, -3%†

† reference is pre-ISA+fuel efficiency training

There is reason to believe that ISA and / or fuel efficiency training would influence speed choice. The speed profile of the five drivers that did not receive fuel efficiency training and the two that did is presented in Table 5 and Table 6 respectively.

<u>Speed profile of the five drivers in the simple baseline / ISA comparison</u>

For those drivers involved in the simple baseline / ISA aspect of the trial (Table 8), the following observations can be made:

- 50km/h zone:
  - an increase in the mean (+1.6km/h) and median speed (+3km/h)
  - a marginal increase in the cycles where the speed limit was exceeded (+0.7 percent point difference; 2.6% increase)
- 60km/h zone:
  - no change
- 70 km/h zone:
  - marginal increase in mean (+1.2 km/h) and median speed (+2 km/h)
  - marked increase in cycles where the truck speed exceeded the speed limit (+4.2 percent point difference; 28.2% increase)
- 80 km/h zone:
  - reductions in mean (-1.9km/h) and median speed (-1 km/h)
  - fewer occasions exceeding the assigned speed limit (-2.7% percent point difference; -15% speed violations)

Table 5. Speed profile before and during ISA installation (ISA only drivers), with the percent point difference in speed over-limit violations shown

Speed zone	Mean (SD) (km/h)	Median (km/h)	85th% (km/h)	Cycles	% point diff. over-limit
50 km/h					
BASELINE	33.6 (23.0)	28	59	5031	*reference*
ISA	35.2 (22.8)	31	59	10,801	+0.7%
60 km/h					
BASELINE	42.5 (18.6)	48	60	13,460	*reference*
ISA	42.9 (18.6)	48	60	29,221	+0.2%
70 km/h					
BASELINE	49.4 (19.9)	54	69	2842	*reference*
ISA	50.6 (20.8)	56	70	6448	+4.2%
80 km/h					
BASELINE	66.3 (18.6)	71	82	22,070	*reference*
ISA	64.4 (20.2)	69	81	42,388	-2.7%
90 km/h					
BASELINE	77.7 (19.3)	82	99	520	*reference*
ISA	79.7 (18.9)	85	99	2710	+4.6%
100 km/h					
BASELINE	92.9 (13.8)	99	101	74,268	*reference*
ISA	92.4 (14.9)	99	100	130,402	-7.7%
110 km/h					
BASELINE	98.2 (7.1)	100	101	32,124	*reference*
ISA	94.9 (12.3)	100	100	50,643	No change
80 km/h plus					
BASELINE	89.6 (17.4)	99	101	128,982	*reference*
ISA	87.6 (19.2)	98.0	100	226,143	-4.3%

*30 km/h, 35km/h and 40km/h speed zones not shown; equates to 3202 15-second cycles due to low cycle numbers across categories; represents 0.67% total 'moving' cycles recorded.

- 90 km/h zone:
    - +2km/h increase in mean and +3km/h increased in median speeds
    - +4.6 percent point difference in cycles over the posted speed limit; 13% increase
- 100 km/h zone:
    - no change in speed profile
    - marked reduction in the percent cycles over the posted speed limit, as seen in a -7.7 percent point difference in cycles over the limit, translating to a reduction of 57%.
- 110 km/h zone:
    - marked reduction in mean speed of 3.3 km/h
    - no change in percent over-limit due to the similarly high degree of speed compliance

- 80 km/h and higher speed zones:
    - lower mean speed in the ISA period (-2km/h) and,
    - an absolute difference of 4.3 percent point fewer violations of the speed limit, representing a 27% reduction in speed violations

Speed profile before and during ISA installation for drivers with fuel efficiency training

For the two drivers that received the fuel efficiency training, a three point comparison of their speed choice can be made. Table 9 provides the complete details, however some findings are particularly noteworthy, these being:

- There is a consistent trend of increased mean speed in the lower speed zones (<=70 km/h) in the fuel efficiency phase, with a subsequent reduction once the ISA phase commences (to the same or below the baseline mean speed);
- In the 80km/h zone, the 110 km/h zone and the 80 km/h plus (combined zone), there was a trend toward a reduction in mean speed in the fuel efficiency phase, with a subsequent increase in the ISA phase, but not as high as in the baseline phase;
- In the 100 km/h zone, the mean speed reduces in each subsequent phase (-2.8 km/h, then -1.2 km/h);
- In the 90 km/h zone, there is a marked reduction in the mean speed (-7.6 km/h), with a slight increase from the fuel efficiency phase to the ISA phase (+1.3 km/h), and
- Considering percent cycles over the posted speed limit
    - With the exception of the 60 km/h and 70 km/h speed zones, there was a reduction in the over-limit episodes in each successive phase, that being fuel efficiency training phase and then ISA;
    - In the 60 km/h zone, there was an increase in the cycles over the assigned speed limit in the post-fuel efficiency training phase (+3.3% to 8.3%), followed by a reduction once the ISA phase commenced (-2.2% to 6.1%) but the percent over-limit episodes was higher than baseline (cf. 5%), and
    - In the 70 km/h zone, there was an increase in violations with fuel efficiency training (to 6.1% from 5.2% [+0.9%]), followed by a dramatic reduction in violations in the ISA phase (to 2.6%)

While the above analysis is important, the regression analysis that follows is the most appropriate way to examine the effect of fuel efficiency training and / or ISA on speed choice. The regression models account for the correlation in speed choice for each driver, and other factors associated with their route and driving style. In addition, these models adjust for the effect of the perceived usefulness of the ISA device. It remains important though to consider the speed profile findings in interpreting the regression analysis.

Table 6. Speed profile before and during ISA installation for drivers with fuel efficiency training, with the percent point difference in speed over-limit violations shown

Speed zone	Mean (SD) (km/h)	Median (km/h)	85th% (km/h)	Cycles	% point diff. over-limit
50 km/h					
BASELINE	20.2 (15.8)	14	38	3135	*reference*
PRE-ISA + FUEL EFFICIENCY	20.4 (15.7)	14	39	2377	-0.9%
ISA + FUEL EFFICIENCY	20.1 (14.4)	14	39	2380	-1.8%, -0.9%
60 km/h					
BASELINE	37.3 (16.9)	39	55	3305	*reference*
PRE-ISA + FUEL EFFICIENCY	38.8 (18.8)	41	56	3193	+3.3%
ISA + FUEL EFFICIENCY	37.2 (18.2)	39	54	2620	+1.1%, -2.2%
70 km/h					
BASELINE	43.6 (19.8)	47	65	2200	*reference*
PRE-ISA + FUEL EFFICIENCY	44.4 (19.9)	47	66	1606	+0.9%
ISA + FUEL EFFICIENCY	41.5 (18.9)	45	61	1353	-2.6%, -3.5%
80 km/h					
BASELINE	63.6 (20.8)	67	82	5421	*reference*
PRE-ISA + FUEL EFFICIENCY	61.3 (21.0)	65	81	4322	-2.5%
ISA + FUEL EFFICIENCY	57.4 (19.9)	61	75	2608	-10.5%, -8.0%
90 km/h					
BASELINE	77.5 (9.1)	77	89	90	*reference*
PRE-ISA + FUEL EFFICIENCY	69.9 (7.0)	71	77	47	-8.9%
ISA + FUEL EFFICIENCY	71.2 (7.8)	71	78	58	-8.9%, no change
100 km/h					
BASELINE	88.2 (19.2)	97	98	6470	*reference*
PRE-ISA + FUEL EFFICIENCY	85.4 (20.3)	94	98	6113	-0.1%
ISA + FUEL EFFICIENCY	84.2 (21.4)	94	97	5805	-0.19%, -0.09%
110 km/h					
BASELINE	93.5 (10.2)	97	98	852	*reference*
PRE-ISA + FUEL EFFICIENCY	95.5 (6.7)	97	98	2159	no change
ISA + FUEL EFFICIENCY	96.0 (6.1)	97	98	1835	no change, no change
80 km/h plus					
BASELINE	79.4 (23.4)	92	97	10,306	*reference*
PRE-ISA + FUEL EFFICIENCY	78.8 (23.1)	89	97	12,641	-2.3%
ISA + FUEL EFFICIENCY	79.4 (23.5)	92	97	10,306	-5.8%, -3.5%

† reference is pre-ISA+fuel efficiency training

Regression modelling of the effect of ISA and fuel efficiency training

Using the recorded speed and the assigned speed limit of the road, the number of cycles where the vehicle exceeded the posted speed limit was determined. As noted above, for the 5 drivers in the trial that did not receive fuel efficiency training, there was an (unadjusted) 21.3% reduction in the number of recorded cycles where the speed limit was exceeded - alternatively, there was an absolute difference of -3.4% in violations associated with the ISA device.

For the two drivers that received fuel efficiency training, there was a -0.9 percent point difference in speed limit violations compared to the baseline period and the fuel efficiency period, representing a (unadjusted) reduction of 12%. Notably, once ISA was added, there was a marked reduction in the percent of over-limit episodes (55% reduction, or an absolute difference of 3.9% less violations); in comparing the PRE-ISA / fuel efficiency training period with the ISA / fuel efficiency training period, there was a marked difference in the number of recorded cycles where the speed limit was exceeded (i.e., 48% reduction, or a -3% absolute difference).

As noted previously, the above effects do not account for the *driver effect*, that is multiple repeated observations of each driver and the associated unmeasured factors associated with their driving, such as route, speed zones, load haul and attitudes to the ISA device itself, among other factors. It is therefore essential to use appropriate statistical models to tease apart these effects.

The logistic GEE regression model was used to assess the influence of the ISA device and fuel efficiency training, alone and in combination on speed violations however it was not possible to adjust for speed zone in the omnibus model (Table 7). This model simply models the above percent changes across the periods. Table 8 shows the individual and combined effect of ISA and fuel efficiency training for each speed zone. It is important to note that the model that included speed zone could not be processed in SAS due to the small sample of drivers and the complexity of the model itself.

After adjusting for correlated driver outcome data and adjusting for the post-ISA trial rated ‘usefulness’ of the device, the odds of the drivers exceeding the speed limit were reduced by 21% compared to the pre-trial period. This difference was statistically significant (OR: 0.79, 95^{th}% CI: 0.64 – 0.98, p=0.03); this is the same as the ‘unadjusted’ 21% ISA benefit (see Table 4).

Table 7. Effect on ISA and fuel efficiency alone and in combination on speed violations, compared to baseline period

All speed zones	**Reference category**		**95% CI**		
		OR	**LCL**	**UCL**	**P**
PRE-ISA + FUEL EFFICIENCY	Baseline	1.01	0.87	1.18	0.9
ISA only	Baseline	0.79	0.64	0.98	0.03
ISA + FUEL EFFICIENCY	Baseline	0.80	0.61	1.05	0.1

In this model – and without consideration for speed zone, fuel efficiency training had no influence on speed violations (OR: 1.01, 95^{th}% CI: 0.87 – 1.18, p=0.9) relative to the baseline period. There was an indication of some benefit of ISA and fuel efficiency training together, however this was not statistically significant which may be the consequence of low power due to the small sample and / or a ‘washout’ effect of fuel efficiency training (OR: 0.80, 95%CI: 0.61-1.05, p=0.1).

Disaggregation of ISA and fuel efficiency by speed zone

As noted above, it was not possible to include speed zone as a separate parameter in the omnibus model of ISA and fuel efficiency training for technical reasons. There is reason to believe that the effect of ISA and fuel efficiency training on both speed choice and fuel consumption would differ across speed zones. Analysis was therefore conducted separately for each speed zone. It was also necessary for statistical reasons to combine all speed zones inclusive and above 80km/h into a single category.

As can be observed in Table 8, the effects of ISA and fuel efficiency training, alone and in combination differed across speed zone with each being considered in turn.

Fuel efficiency training effect on speed limit violations

The fuel efficiency training comparison is the effect for only two drivers, and is a measure of the episodes above the assigned speed limit relative to the baseline period. While the findings indicate a marginal (1%) benefit in the 50km/h speed zone, this is balanced against the 47% increase in the odds of exceeding the assigned speed limit in 60km/h zone following fuel efficiency training; this does not however extend to higher speed zones. It could be speculated that changes in driver behaviour – manifested as different braking and gear changing patterns, may account for these findings in the lower speed zones. It *could* be the case that in the higher speed zones there are fewer opportunities for fuel efficiency type behaviours to impact upon speed choice due to the already high driving speeds (i.e., a ceiling effect).

Using the baseline period as the comparison group, the following observations can be made:

- 50km/h: a statistically significant 1% lower odds of exceeding the speed limit (OR: 0.99, 95^{th}% CI: 0.98 – 0.998, p=0.047).
- 60 km/h: a 47% increase in the odds of exceeding the speed limit, as measured by the number of 15-second cycles of the posted limit (OR: 1.47, 95^{th}% CI: 1.29 – 1.66, $p\leq 0.001$).
- 70 km/h: no difference in the episodes above the posted limit
- 80 km/h plus: no difference in the episodes above the posted limit

ISA effect on speed limit violations

Examining the effect of ISA alone – this includes five drivers, the benefit effects can be seen in the higher speed zones. That is, there was a 25% lower odds of exceeding the assigned speed limit in the 80km/h plus speed zones (OR: 0.75, 95^{th}% CI: 0.60 – 0.93, p=0.01). There was no effect on speed violations in the other speed zones.

Using the baseline period as the comparison group, the following observations can be made:

- 50km/h: no difference in the episodes above the posted limit
- 60 km/h: no difference in the episodes above the posted limit
- 70 km/h: no difference in the episodes above the posted limit
- 80 km/h plus: 25% lower odds of exceeding the assigned speed limit (OR: 0.75, 95^{th}% CI: 0.60 – 0.93, p=0.01).

Combined effect of ISA and fuel efficiency training on speed limit violations

For the two drivers where ISA and fuel efficiency training could be assessed, relative to the pure baseline, there was a significant reduction benefit in the 70km/h speed zone.

While there was an indicative 22% increase in speed violations (OR: 1.22, 95th% CI: 0.99 – 1.51, p=0.07) in the 60 km/h speed zones, however this must be referenced against the 47% increase observed in the fuel efficiency training alone period, indicating a moderating effect of ISA.

Using the baseline period as the comparison group, the following observations can be made:

- 50km/h: no difference in the episodes above the posted limit
- 60 km/h: a non-statistically significant 22% increase in the odds of exceeding the speed limit, as measured by the number of 15-second cycles of the posted limit (OR: 1.22, 95th% CI: 0.99 – 1.51, p=0.07).
- 70 km/h: 30% lower odds of exceeding the assigned speed limit (OR: 0.70, 95th% CI: 0.66 – 0.75, p≤0.001).
- 80 km/h plus: a non-significant 35% reduction in the odds of exceeding the assigned speed limit (OR: 0.65, 95th% CI: 0.35 – 1.18, p=0.1).

Table 8. Effect of ISA device overall and by speed zone on the number of recorded violations of the speed limit, compared to baseline period

Speed zone	Reference category	OR	95% CI		P
			LCL	UCL	
50 km/h					
PRE-ISA + FUEL EFFICIENCY	Baseline	0.99	0.98	0.998	0.047
ISA only		0.89	0.77	1.03	0.1
ISA + FUEL EFFICIENCY		1.00	0.93	1.06	0.3
60 km/h					
PRE-ISA + FUEL EFFICIENCY	Baseline	1.47	1.29	1.66	≤0.001
ISA only		0.99	0.70	1.39	0.9
ISA + FUEL EFFICIENCY		1.22	0.99	1.51	0.07
70 km/h					
PRE-ISA + FUEL EFFICIENCY	Baseline	1.11	0.79	1.56	0.5
ISA only		1.24	0.65	2.38	0.5
ISA + FUEL EFFICIENCY		0.70	0.66	0.75	≤0.001
80 plus km/h					
PRE-ISA + FUEL EFFICIENCY	Baseline	0.93	0.67	1.28	0.6
ISA only		0.75	0.60	0.93	0.01
ISA + FUEL EFFICIENCY		0.65	0.35	1.18	0.1

Further analysis not presented in tabular format indicates that for all speed zones, those participant who received fuel efficiency training had significantly higher (+27%) recorded 15-second cycles above the posted speed limit once they had the training but before the ISA was active, compared to the period when the ISA was active (OR: 1.27, 95%CI: 1.10-1.47, $p \leq 0.001$). This effect was not observed in the 50km/h or 60km/h zones, but the difference in speed violation episodes between fuel efficiency vs. fuel efficiency + ISA was strongly evident in the 70km/h (OR: 1.58, 95%CI: 1.06-2.36, p=0.03) and the 80 plus km/h speed zones (OR: 1.44, 95%CI: 1.06-1.94, p=0.02). The findings indicate a significant moderating effect of ISA on speed violations; however whether this can be directly translated into fuel efficiency savings cannot be determined.

Post-trial attitudes to the usefulness of the ISA device

Of interest was the association between attitudinal responses to the acceptability and usefulness of the ISA device and travelling over the posted speed limit. This was modelled in the same GEE models presented in Table 8.

Table 9 shows that for driver responses as to the usefulness of the ISA device (rated on a 1, not at all to 10, extremely useful), there was little association with the percentage of over-limit episodes overall. However it can be seen that for every 1-point increase in perceived usefulness of ISA there was a 18% lower odds of exceeding the speed limit in the 60 km/h (OR: 0.82, 95% CI: 0.74-0.90) and 70km/h zones (OR: 0.82, 95% CI: 0.68-0.98).

This finding could be a manifestation of drivers relying on the ISA system and hence there is no change in the vehicle over-limit episodes. This is supported by marginally higher mean speeds in these zones in the ISA trial compared to baseline. It is possible the truck drivers take more immediate preventative action in these road contexts when the device alarms given the increased complexity of the environment. As the ISA device was calibrated to the speedometer and drivers rely on the device to monitor their speed, and this has the effect that there was no difference in vehicle over-limit episodes between the two periods; this perhaps explains nicely why there is a relationship between perceived usefulness of ISA in these speed zones with respect to a reduced likelihood of exceeding the assigned limit.

Table 9. Association between rated ISA device usefulness and over-limit episodes

Speed zone – driver rated device usefulness	OR	95% CI LCL	95% CI UCL	P
Omnibus	0.73	0.40	1.32	0.3
50 km/h	1.14	0.91	1.43	0.3
60 km/h	0.82	0.74	0.90	≤0.001
70 km/h	0.82	0.68	0.98	0.03
80 km/h plus	0.72	0.38	1.36	0.3

Summary of ISA and fuel efficiency findings on speed choice, and the role of attitudes toward ISA

The key finding was the overall 21% reduction in the number of speed violation episodes. This effect manifested in speed zones of 80 km/h and higher (25% reduction). ISA had little beneficial effect in the lower speed zones (<=70 km/h).

The effect of fuel efficiency training was mixed. While having a percentage-wise marginal (1%) but statistically significant benefit in the 50km/h zone, this was countered by a 47% increase in the odds of exceeding the 60 km/h speed limit; once ISA was provided to these drivers their violations were moderated to a non-statistically significant but nonetheless important +22% increase over baseline violations. Only in the 70 km/h speed zone did the ISA / fuel efficiency training combination have a speed violation reduction effect relative to baseline. There was no benefit effect for the ISA-alone group in this speed zone (relative to baseline). Importantly, in the 70 km/h and 80 km/h plus zones, fuel efficiency training alone was associated with significantly increased odds of speed limit violations compared to when ISA was present, although this effect was absent from the 50 km/h and 60 km/h zones where there was no benefit of ISA in any case.

These results indicate that while fuel efficiency training has little demonstrable effect overall, there was a speed violation disbenefit in the 60 km/h speed zone. Importantly though, the addition of ISA resulted in significantly fewer violations for the fuel efficiency trained drivers. Whether this impacts upon actual fuel consumption cannot be determined as multiple drivers operated the truck on a single day, and in many instances 'shared' the same fuel load; consequently the fuel consumption patterns for the two drivers of interest could not be determined.

It is notable too that the only speed zones where the drivers' attitude to ISA had an effect was in the 60 km/h and 70 km/h speed zones. The attitudinal response analysis indicates that for each one point increase in the driver rated 'usefulness' of ISA, there was a 18% reduction in the odds of exceeding the limit. There was however little change in the mean and median speeds in these speed zones for the two sets of drivers (fuel efficiency trained; not fuel efficiency trained). These results could indicate a reliance on ISA, but this was accompanied by small changes in mean speed.

Limitations and Lessons

In the analysis of the trial two key technical matters came to light, the first relating to the matching of the GPS co-ordinates to the exact location and hence speed zone, and the second concerns the statistical analysis methods utilised for this type of data.

The first issue is a technical concern that relates to the imperfect matching of the longitude and latitude co-ordinates of the road on which the vehicle was travelling with respect to assignment of the speed limit. This appears to be due to a lack of precision and ability to differentiate the speed zones at certain locations, for instances on bridges and service/slip roads. Our investigations do however indicate that i.) the error rate is low, and ii.) the error would be systematic and hence unbiased with respect to the pre-post installation period of the ISA device. We are further benefited in this trial by the truck drivers in the study driving consistent routes, commencing each day at largely the same point of origin and driving a consistent pattern of destinations. Consequently we consider that our percentage difference of cycles and Odds Ratio values comparing baseline to the ISA trial period would not be biased by this problem.

The repeated measures nature of the data collected and the dichotomous outcome (i.e., vehicle over-limit) presented a considerable analytical challenge, particularly as the relatively new logistic GEE model was used in this analysis. Despite having over 500,000 records, we were limited in the number of covariates that we could model largely due to having only seven drivers, while the modelling of interactions proved extremely difficult. The inclusion of covariates in addition to the day of week and a single attitudinal measure of acceptability such as time of day, weather conditions, and additional demographic, route and vehicle characteristics would be ideal, however vast number of observations would be required and the associated computing power required would be immense.

As already noted, we report the difference in the percentage of cycles over the assigned speed limit. This is an important methodological consideration as the 15 second interval, while used to capture cycles over the assigned speed limit, is unlikely to represent a singular speed violation episode, particularly given the mass, and hence momentum of the truck. That is, it is most probable that a number of sequential 15-second cycles represent a singular speed violation episode. Future analysis will need to determine an appropriate algorithm in order to discriminate 'speeding' behaviour associated with throttle control from braking and gliding as a means of slowing down once an ISA speed alert has activated.

Finally, the inability to examine the effect of the fuel efficiency training program on fuel use represents a significant limitation of the study. As noted above, this occurred purely as a consequence of the operational aspects of the truck company and the need to employ multiple drivers to operate the vehicle across the established shift pattern. This is an important design issue that future ISA field trials would be well served to take heed of when implementing their field trial. The question then remains unanswered as to the effect of fuel efficiency training on both on-road fuel consumption and speed compliance, and the interactive effect of ISA.

CONCLUDING COMMENT

In summary, the TAC in collaboration with the Victorian Transport Association (VTA) and with the cooperation of several heavy vehicle companies conducted a small scale trial to assess the relative merits of ISA in terms of driver acceptability and speed choice. By the conclusion of the trial, there was a divergence of opinion with respect to driver acceptability of the device with some key issues emerging that require further investigation. In particular, further work is required on this dataset before a complete understanding of the relationship between acceptability and the effectiveness of ISA in mitigating speed among this group of drivers can be gained.

Overall, there was a significant 21% reduction in the odds of drivers exceeding the speed limit in the ISA trial period compared to the baseline period, and this effect was driven by ISA effectiveness exclusively in the higher speed zones. Despite a number of significant challenges both in the conduct of this research and the analysis of the collected data, the positive results encourage the initiation of larger-scale trials of active safety technology in the heavy vehicle industry. Further analysis is required to determine whether the differences in speed compliance result in fuel consumption benefits, as well as the overall effect of fuel efficiency training on on-road fuel use.

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NOTE

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