Auditory intelligent speed adaptation for long–distance informal public transport in South Africa

N.A. Ebot Eno Akpa, M.J. Booysen and M. Sinclair

***Abstract*—Informal transport refers to the collective passenger road transport industry with little or no regulatory control of its operations, usually characterised by unplanned and ad-hoc service delivery. The notoriously dangerous informal transport industry in South Africa – dominated by minibus taxis – has been shown to disregard the posted speed limit on long-distance trips. Not only do they frequently exceed the differentiated speed limit imposed on minibus taxis, but also the speed limit imposed on normal passenger vehicles. This paper evaluates the impact of an auditory Intelligent Speed Adaptation (ISA) intervention, applied at various intensity levels, on the speeding behaviour of this seemingly intransigent mode of transport. The experiment evaluates the behaviour on the R61 between Beaufort West and Aberdeen. We evaluate the speeding distributions, speeding frequencies, speed percentiles, mean speeds, and the statistical relevance of key metrics. We find that the auditory intervention has a clear impact on speeding behaviour, both when applied at an audible level that can be drowned out by a radio, and even greater impact at a loud level. The impact on speeding is significant, with speeding frequency (both time and distance) reducing by over 20 percentage points.**

Keywords*—Intelligent speed adaptation; Informal public transport; Minibus taxis

I. Introduction

Road transport is an essential element in all societies. Unfortunately, the associated costs of congestion, pollution and traffic accidents are enormous. Systems supporting travellers have the potential to mitigate some of these problems. Examples of such Intelligent Transport Systems are in-vehicle navigation and route guidance utilities as well as real time public transport information provision, monitoring, and active control of traffic flow. One category of such in-vehicle navigation devices are Intelligent Speed Adaptation (ISA) systems aimed at improving safety by ensuring compliance with posted speed limits. These ISA systems can be either mandatory or voluntary and have the ability to continuously inform and enforce compliance with posted speed limits through suitable user interfaces [1].

Research on the impact of ISA systems and their large-scale use dates back to the 1980s. However, developing countries in general and Sub-Saharan Africa (SSA) in particular have lagged behind in the implementation of speed adaptive ITS solutions especially in the public transport sector.

According to the International Association of Public Transport, informal transport refers to the collective passenger road transport industry with little or no control of its operations by an overall regulatory authority, usually characterised by unplanned and ad-hoc service delivery, with insufficient or no respect for routes, and no published or fixed fare structures [2]. The accelerated increase in crash rates, and low compliance with traffic regulations have been identified as the main effects of informal operators on roads across the SSA region [3].

The informal public transport industry in SSA, consisting almost exclusively of minibus taxis has potential for the adoption of effective ISA system solutions to assist with speed compliance and safety improvement. The Economic Development Department of South Africa revealed that there were about 200,000 minibus taxis on South African roads in 2006, with an annual increase of about 23,000 taxis since then [4]. Interestingly, the industry accounts for about 67% of the collective public transport market share [5].

According to South Africa's 2011 Road Traffic Report, minibus taxis account for about 10% of all fatal crashes [6]. The report also states that speeding is the human factor that contributes the most towards fatal crashes by about 36-40%. Many of these taxis engage in local trips on weekdays and long-distance trips on weekends. One long-distance route frequently used is the 1200 kilometre route from Cape Town to Mthatha in the Eastern Cape through the N1 and R61. Manual traffic counts, conducted on a typical weekend during the festive season revealed that over 1700 minibus taxis travelled this route over a twelve-hour period. Given the occasionally high traffic flow rate and high fatalities associated with minibus taxis despite the presence of enforcement, it is imperative to investigate the suitability of alternative safety measures such as ISA systems, which are not common in the minibus taxi industry. The investigation is especially important since this industry does not operate under the same regulations and conditions to public transport in the developed world [7].

II. State-of-the-art

The ultimate objective of all road safety measures is to reduce the number of crashes or injury severity [8]. The relationship between speeding and crash risk/severity has been the topic of many studies over the past decade. Speed is clearly the most important determining factor of crash risk and injury severity, since it affects driver reaction and response time, the energy involved at impact, and the time it takes a vehicle to come to a complete stop [9], [10], [11].

A. Speeding laws and the behaviour of minibus taxis

In South Africa, the speed limit is 60 km/h on public roads within urban areas, 100 km/h on public roads outside urban areas, and 120 km/h on freeways. However, a few exceptions exist, such as the maximum speed limit of 80 km/h for heavy duty vehicles ($\geq$ 9 tonnes), and 100 km/h for minibus taxis. A speed limit tolerance of 10 km/h applies for all speed limits in South Africa which means fines are only issued when the posted speed limit is exceeded by at least 10 km/h.

Limited research has been conducted on the driving behaviour of minibus taxi drivers in SSA. However, it has been established that compliance with maximum speeds is generally low [7]. Although equipment for speed detection and reporting are accurate, effective enforcement remains a problem with regards to prosecution and the timely payment of fines.

Long-distance transport using minibus taxis was investigated in [12]. Data was captured for trips between Cape Town and Mthatha using seven GPS devices configured to upload location, time, and speed every 30 seconds. The data set consisted of 36 return trips. The maximum speeds frequently exceeded 140 km/h, with an absolute maximum recorded speed of 159 km/h. The median of the recorded speeds for different segments of the route was between 120 and 135 km/h.

In [13] the impact of Average Speed Enforcement(ASE) on minibus taxis was investigated on a 71.6 km road between Beaufort West and Aberdeen. Nine taxis were equipped with permanently installed GPS devices, and were monitored along the Cape Town to Mthatha route for over six months. Data was collected for 402 trips. Results showed that the ASE system had little or no impact on driver behaviour of the minibus taxi drivers, with similar speed profiles observed between the enforcement route and three control routes. Of the 402 trips examined, 81% reflected violations of the 100 km/h speed limit, of which 18% also violated the 120 km/h speed limit imposed on light passenger vehicles. It can be observed that speeding behaviour by minibus taxi drivers remains a problem in the region. A behavioural change is therefore needed to reduce the incidence of crashes in the region.

B. ISA and Behavioural change

Most approaches to speed reduction and compliance are either spatially or temporally limited. Camera surveillance, and average speed enforcement systems are only effective at specific sites, while police patrols are only effective for specific periods. On the other hand, ISA systems have the ability to ensure continuous compliance with speed limits. A variety of user interfaces – also known as Human Machine Interfaces (HMIs) – have been implemented in ISA systems in different regions, and may come in the form of haptic intervention systems such as the Active Acceleration Pedal (AAP), visual displays such as dash-mounted LEDs, auditory warnings, or a combination of different interfaces [14]. Some ISA systems are voluntary – allowing the driver the option of customising or switching the system on or off – while others are mandatory with fixed pre-configuration of the main features. ISA system speeds can be fixed, variable, or dynamic in nature. Fixed speed systems are activated at a particular speed limit while variable speed systems are activated based on the posted speed of the current road section. Dynamic speed systems are variable speed systems which also consider weather and traffic conditions in computing the ISA activation speed [15].

Several simulation experiments [16], [17] and field tests [18], [19], [20], [21], [22] have been conducted to evaluate the impact of different ISA systems on driver behaviour [23]. In general, these systems have resulted in speed limit compliance through reduced speed variances, maximum speeds, and the percentage of time spent driving above posted speeds. Previous studies on field trials with instrumented vehicles have shown that ISA systems do not affect average driving speed as much as the percentage of time spent above the speed limit [24].

Spyropoulou et. al [16] investigated the respective effects of advisory, warning and intervening/haptic ISA interfaces on speed compliance compared with a base case in which no ISA was used. The experiment was conducted on 23 participants using a driving simulator. Each interface was tested in four different speed limit areas. At an aggregate level, only the intervening system seemed to have a substantial effect on driving speed. However, its acceptance was comparatively low. The effects of warning systems were more evident at a disaggregate level where drivers were examined individually. With the warning system active on a 60 mph (96.6 km/h) road, 77.3% of the drivers reduced their mean and maximum speeds compared to the base condition. In addition, speeding frequency reduced from 61% for the base condition to 29% for the warning system. Informative systems in contrast, did not seem to affect driving speed.

The INFATI project [18] undertaken by Aalborg University involved road tests around the Aalborg municipality on 24 participants [25]. The system combines visual and advisory interfaces. The visual interface which is the primary interface takes the form of an LED lamp, while the advisory interface supplements the visual interface in the form of a female voice which repeats every six seconds once the posted speed is exceeded. In this study, average speed reduced by 3 – 9 km/h. Higher levels of compliance were observed in urban area with speed limits in the 30 – 60 km/h range than in rural areas with speed limits between 70 and 110 km/h.

Adell *et al.* [20] conducted a real-life study on 20 private vehicles in Hungary and Spain during 2003 and 2004. Each vehicle was equipped with a mandatory variable speed ISA system with two HMIs; an AAP and a warning signal implemented through a buzzer. Test drivers drove the ISA equipped vehicles for one month. Both HMIs reduced mean and 85th percentile speeds but the AAP turned out to be more effective.

One of the largest pioneering large-scale ISA tests was conducted in Sweden between 1999 and 2002 [19]. The Swedish National Road Administration (SNRA) conducted this research in the cities of Umeå, Borlänge, Lidköping, and Lund. Most vehicles used informative or warning interfaces while others used AAPs. Throughout the field trials – mostly carried out in 2001 – about 5,000 vehicles were driven by 10,000 drivers. Average speeds reduced by up to 5 km/h on 70 test roads, speed violations decreased by 10%, and a 20% reduction in road injuries was recorded for all equipped vehicles [19][26].

Several ISA studies have shown that intervention systems are most effective, but that they are also characterised by low user acceptability. The contrary is true for informative or advisory systems which are least effective but most accepted [24], [16]. On the other hand, warning systems are a midway interface in terms of effectiveness and acceptability.

C. Limitations of existing knowledge and research questions

Although research on ISA systems has gained a considerable amount of empirical evidence over the years, their effect on driving behaviour in the informal public transport sector needs to be measured, since previous trials were mostly carried out in the developed world, and exclusively on privately owned passenger vehicles. With regards to speeding, it has been observed that minibus taxis hardly comply with roadside interventions such as average speed enforcement and police patrols. Questions on how auditory ISA systems deployed in minibus taxis affect speeding will be quantified in this paper using relevant metrics and statistical methods. Another important aspect that this paper seeks to address, which is lacking in the existing body of research on auditory ISA systems is to compare the effect of different intensity levels on speed compliance. The rest of this paper presents a detailed discussion on how the experiment was set up for data collection and analyses, followed by a systematic presentation of the results, and the conclusion.

III. Experimental design

Data was obtained from GPRS-enabled GPS tracking devices installed by MiX Telematics in five minibus taxis that operate locally within the Western Cape province of South Africa. The vehicles used were 14-seater 2.5D Toyota Quantum minibus taxis. A once-off financial incentive was made available to the owners at installation. Each device was programmed to provide time stamps, location and speed information at a nominal frequency of 1Hz.

Drivers from the Stellenbosch/Kayamandi Taxi Association were involved in the study. Typically, at least two drivers can drive a specific taxi; the owner and his designated/contracted driver(s) [7], [12]. However, driver identification technologies were not implemented in the system. As a result, disaggregate analysis was limited to trips completed each taxi. The dataset used is availabe at [27].

A. The Evaluation route

Data was collected and analysed for the section of the R61 between Beaufort West and Aberdeen; a 140 km, two lane bi-directional highway with neither separation nor paved shoulders. Fig. 1a shows the route map, while Fig. 1b shows a street view section of the route. This route also hosts one of the province's first average speed enforcement schemes launched in November 2011, covering a distance of 71.6 kilometres, and was chosen because it carries most of the minibus taxi traffic between Cape Town and Mthatha, which excludes the traffic along the busy N1.

Until 1999, the posted speed limit along this route was 120 km/h for both minibus taxis and light passenger vehicles [28]. Due to the high number of fatalities involving minibus taxis, a special maximum speed limit of 100 km/h was set for minibus taxis, and applicable to all highways, though it has been difficult to enforce. In reality, a prosecution speed of 110 km/h (10 km/h higher than the speed limit) applies to minibus taxis.

(a) Route map

(b) Street view section of the route

Fig. 1: Evaluation route on the R61 *(Google maps, 2015)*

B. ISA elements and configuration

The three main ISA elements of user control, system speed, and HMI configuration are presented here. User control and customisation of the system were disabled, making the system mandatory. Mandatory systems were chosen over voluntary systems to apprehend the full effect of having the system running continuously.

1) The ISA system speed: A fixed ISA speed system was used throughout the experiment. After running a number of trials at different thresholds, the final threshold speed was set at 110 km/h. The speeds were set remotely, with the consent of the taxi owners. Fixed speed systems were used over variable and dynamic systems on the basis of their simplicity, and also to minimise driver distraction and overloading associated with mandatory ISA systems [24][29]. A 110 km/h threshold – though corresponding to the enforcement/prosecution speed – is reasonably high compared to the legal speed limit of 100 km/h. Other motivations behind the use of this fixed speed were two-fold, namely, the managing of acceptability and effectiveness. On one hand, the issue of acceptability cannot be overlooked when dealing with ISA systems. It should be noted that this is a real-life experiment which was not intended to disrupt the logistics of the industry. This study focused on long-distance trips made by minibus taxis which are also involved in urban travel – characterised by lower speeds. As such, the threshold had to be high enough to maximise acceptability and to prevent the system from being triggered during urban trips. On the other hand, as presented in previous sections, most taxis travel at average speeds above 110 km/h, with standard deviations of about 14 km/h for certain sections on the Cape Town to Mthatha route. Setting the device at a threshold speed of 110 km/h thus allowed assessment of the system's effectiveness at realistic travel speeds.

2) The HMI and system configuration: The HMI used was a non-speech warning system implemented with a buzzer attached behind the dashboard of the vehicle, operating at 5 volts with an oscillating frequency of 5 kHz. The warning was a persistent auditory tone that sounded ten seconds after the fixed threshold speed had been exceeded, and stopped immediately after the speed had dropped below the threshold. The loud system was configured at maximum volume with a sound pressure level (SPL) of 90 dB SPL within a 10 cm range, while the soft system was set at a much lower volume with a sound pressure level of 50 dB SPL within a 10 cm range.

C. Experimental procedure

The evaluation was based on the intensity of the warning signal compared with two base conditions (i.e., data collected before and after ISA activation). During ISA activation, two warning intensity levels were tested; 'soft' and 'loud'. Unlike the loud warning, the soft warning was primarily informative, and could be ignored or drowned out by increased radio volume, since its sound pressure level was just under the level sustained at normal conversational speech. Two months' worth of data was used for each of the base conditions and during the soft warning period, while only one month was used for the loud warning period as a result of driver and owner requests to have the system deactivated. The ISA activation was done sequentially, beginning with the soft buzzing system, followed by the loud buzzing system. Although the system was installed in November 2013, ISA activation at 110 km/h was not introduced until December 2014. Of the five equipped minibus taxis, only three were finally considered since two vehicles did not engage in any long distance trips along the evaluation route while the loud buzzing system was active.

D. Data collection and analysis

GPS data was downloaded from Mix Telematics' data server and analysis was done through a Visual Studio interface developed primarily for the minibus taxis. Analysis involved calculating the descriptive statistics of speeding behaviour using metrics such as mean speed, speed variance, speed distribution, speed percentiles, speeding frequency, and travel time. Mean speed was expressed in terms of *Space Mean Speed* – the harmonic mean speed of vehicles through a section of a highway [30]. Speeding frequency (SF) was expressed as the proportion of time or distance covered driving above a certain speed for a given trip. The proportions were added up over consecutive GPS points from an ordered list of N constituting a trip. Some studies have found it to be among the key metrics for quantifying the effects of ISA systems [24][31].

Differences in behaviour due to ISA system activation and buzzing intensity were verified. Further, an assessment was conducted as to whether differences brought about by the ISA system were significant; this was carried out through two sets of t-tests, with a null hypothesis that ISA implementation brings about no change in driving speed. The first were independent (one-sample) t-tests performed to verify the significance of the inactive, soft, and loud intensity periods against observed means obtained from a separate (independent) set of minibus taxi drivers also from the Stellenbosch/Kayamandi Taxi association with vehicles whose ISA functionality was kept inactive throughout the investigation. The second were paired t-tests to performed to verify the significance of ISA deployment on the vehicles, assuming that one driver is linked to a specific vehicle. The t-tests do not indicate the magnitude of the observed effects. In order to gain insight on magnitudes, the effect sizes (EZ) were computed using Cohen's equation [32] as follows:

$$EZ = \frac{M_2 - M_1}{s_{pooled}} \tag{1}$$

where M_2 and M_1 are metric means, and

$$s_{pooled} = \sqrt{\frac{(n_2 - 1)SD_2^2 + (n_1 - 1)SD_1^2}{n_1 + n_2 - 2}} \tag{2}$$

where $n_1 \backslash n_2$ are the number of observations/trips, and $SD_1 \backslash SD_2$ are the metric standard deviations.

IV. Results

Before ISA activation, a total of 33 trips were made, representing a total distance of over 4500 km travelled on the evaluation route, with an average of 1506 km driven per vehicle. At low intensity (soft buzzing), 27 trips were made, with an average of 1211 km driven per vehicle. At maximum intensity (loud buzzing), a total of 20 trips were made, with an average of 920 km driven per vehicle. Nineteen trips were made after ISA deactivation, with an average of 902 km covered per vehicle along the evaluation route.

A. Pre-ISA system activation responses

This section presents preliminary survey results from 21 regular long-distance drivers, all of whom were males. Surveys were designed to compile driver demographics, assess the viability of ISA system deployment, assist in determining the appropriate selection of system settings, and to understand driver attitude to speeding with or without ISA. A summary of responses is shown in Fig.2. Nineteen out of the 21 drivers (about 90% of the participants) knew about the 100 km/h speed limit, while two participants assumed the outdated 120 km/h speed limit to be in place. It is interesting to observe that most of the drivers know the prevailing speed limit but seldom adhere to it. Based on warning ISA system activation, fifteen participants felt that the system was effective, primarily for safety reasons, while six of them were sceptical and felt that the interventions could be a distraction to the normal driving process. Most drivers admitted that they sometimes drive above the speed limit, with eight participants having no particular reasons for speeding while four participants attributed speeding to lateness.

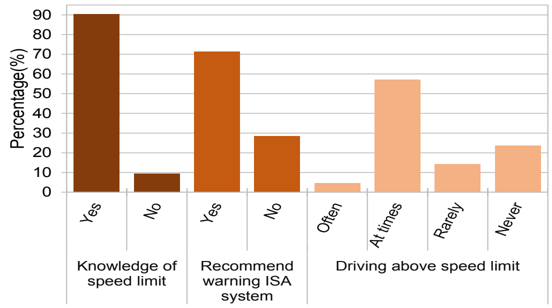


Fig. 2: Survey responses on perception of the speed limit and ISA system

With regards to perceptions on speed severity, participants were grouped in one of five categories for three different speed levels above the 100 km/h speed limit. The results are shown in Fig. 3. Six participants (about 30%) considered driving at 110 km/h on a 100 km/h route of little (minor) or no consequence (very minor), while two participants considered it neither serious nor minor. For most participants, only speeds at or above 120 km/h were considered serious and intolerable. These results show that setting fixed speed ISA systems at the speed limit of 100 km/h will be characterised by low acceptability, justifying the adoption of the actual prosecution speed of 110 km/h as the ISA system speed.

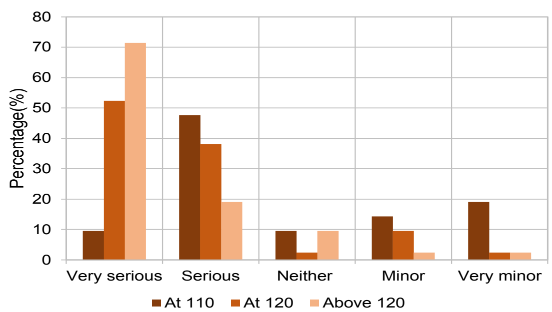


Fig. 3: Perception of the severity of exceeding the 100 km/h speed limit

B. Driving speed

Three metrics of driving speed that illustrate driving behaviour are mean speed, standard deviation and maximum speed. The overall observations are shown in Table I with effect sizes relative to the true behaviour without the introduction of auditory ISA.

Despite a reduction in overall mean speed to 115 km/h with soft buzzing, the improvement is statistically insignificant (p<0.05), suggesting that soft buzzing has little behavioural change with respect to reduction mean speed. This is substantiated by the observation that mean speeds for the inactive and soft buzzing systems were higher than the ISA fixed speed of 110 km/h. On the other hand, both the loud buzzing and post-ISA periods were statistically significant. The mean speed for loud buzzing was just 1 km/h higher than the fixed ISA speed probably due to the ten second time lag before buzzing is triggered, while that after ISA deactivation was at 113 km/h. Although statistically significant, the post-ISA period shows tendencies to revert to normal behaviour.

TABLE I: Driving speed metrics (km/h)

	n	Mean	SD	Maximum	EZ
Independent set	23	119	12.5	154	–
Before	33	118	9.6	147	-0.121
Soft	27	115	11.7	150	-0.463
Loud	20	111*	9.5	138	-1.193
After	19	113*	12.5	141	-0.781

* Statistically significant difference from independent set (p<0.05)

Effect sizes weighted against the number of observations and variances show that loud buzzing can achieve more in terms of mean speed reduction than soft buzzing. The impact due to loud buzzing ($|EZ_{Loud}|$ = 1.193) is almost three times the impact due to soft buzzing ($|EZ_{Soft}|$ = 0.463). Although the collective mean speeds after ISA implementation appear to be statistically significant, it is also observed that $|EZ_{After}|$ is lower than $|EZ_{Loud}|$, showing that drivers begin to revert to normal driving behaviour after the ISA system has been deactivated.

Table II shows disaggregate results for the number of trips (and the percentages) arranged according to mean speed intervals. The general trend shows that the loud buzzing system was more effective with more trips completed at mean speeds below the ISA threshold, 80% of trips below 115 km/h, and no trips above 120 km/h. The contrary is observed before ISA activation with the lowest proportion of trips completed at mean speeds below the ISA threshold, and up to 39% of trips with mean speeds over 120 km/h. On the other hand, during soft buzzing, and after ISA implementation, there seems to be a relatively even non-monotonic distribution in trip proportions over the four intervals. Fig. III gives more information on individual trip mean speeds over time.

TABLE II: Changes in mean speed (number of trips (%)).

		Mean speed intervals (km/h)			
	n	$v > 120$	$115 < v \leq 120$	$110 < v \leq 115$	$v \leq 110$
Before	33	13 (39)	9 (27)	6 (18)	5 (15)
Soft	27	8 (29)	5 (18)	8 (29)	6 (22)
Loud	20	0 (0)	4 (20)	8 (40)	8 (40)
After	19	4 (21)	5 (26)	4 (21)	6 (32)

Fig. 4 shows the disaggrated scatter plots of means trips for all the trips completed during the study, while Fig.5 shows vehicle mean speeds for each evaluation period for each taxi. Coupled with the scatter in Fig. 4, it is observed from Fig. 5

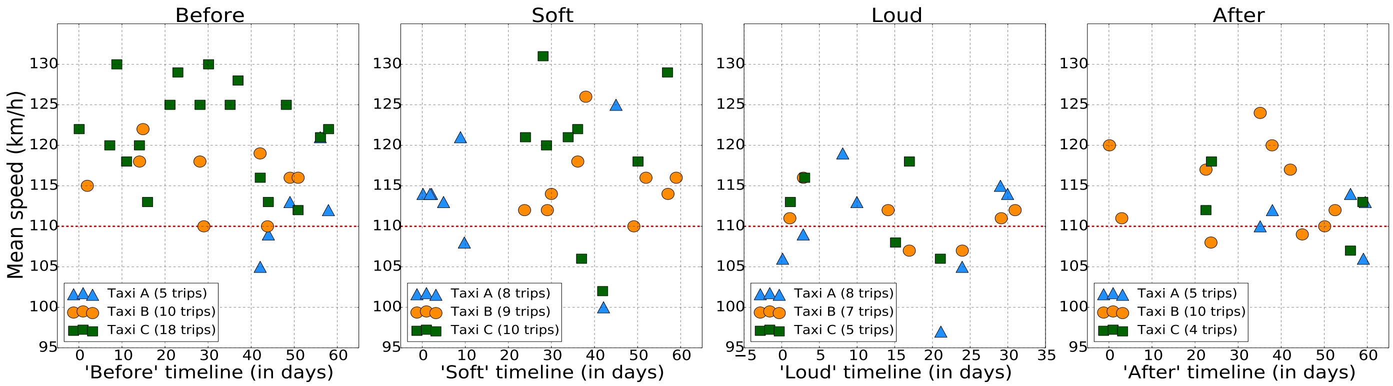


Fig. 4: Mean speed scatter

that drivers of each taxi have different attitudes to speeding even while the ISA system was active. Table III shows paired t-test results and effect sizes for successive evaluation periods. It should be noted that for Table III, the leading diagonal (top left to bottom right) represents the sequence of evaluation adopted in this study. The other entries there are one or tow intermediate evaluation periods.

Nevertheless changes due to the loud buzzing system were significant and it was more effective at improving mean speed in all vehicles with effect size magnitudes of 1.486 and 1.844 compared with the pre-ISA and soft buzzing periods respectively. For each taxi, reverting to normal behaviour can be observed, and more interesting is the statistically significant difference from loud buzzing to post-ISA activation with an effect size magnitude of 0.951.

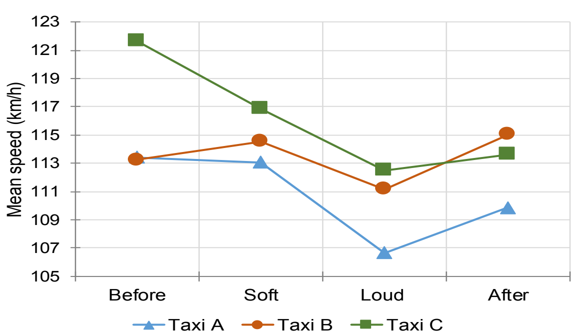


Fig. 5: Vehicle mean speed changes

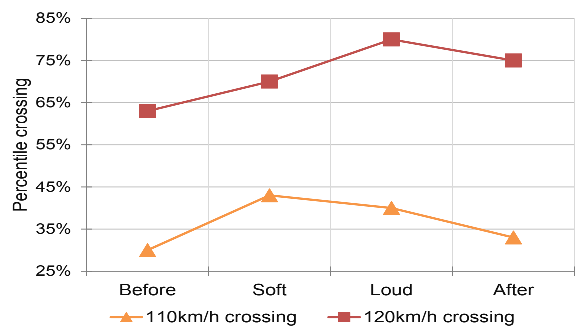
TABLE III: Paired t-test results for mean speed

	Soft	Loud	After
Before	EZ = -0.349	EZ = -1.486*	EZ = -0.836
Soft	–	EZ = -1.844*	EZ = -0.848
Loud	–	–	EZ = 0.951*

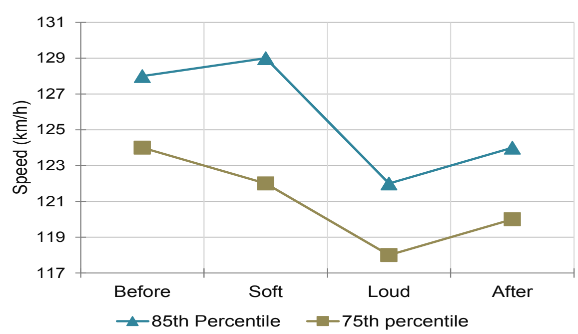
* Statistically significant difference ($p<0.05$)

C. Speed percentiles

Speed percentile rankings are another metric used to quantify driving behavioural changes, and have been used in previous studies to measure the effectiveness of ISA systems [21], [16]. This section presents 85th percentile speeds, and relevant speed percentile crossings for the different warning intensities as shown in Fig. 6.



(a) Percentile crossings



(b) 75th and 85th percentiles

Fig. 6: Speed percentile changes

For soft and loud buzzing, speeding above the fixed ISA speed start at the 43rd and 40th percentiles respectively, while before ISA activation, speeding starts earlier at the 30th percentile before activation and at the 33rd percentile after activation. The largest effect of the loud buzzing system can be observed at higher speeds with a distinctly lower 85th percentile speed. On the other hand, the soft buzzing system records the highest 85th percentile speed. It is observed that once speeding begins (i.e., above 110 km/h), speeds for the soft buzzing system increase abruptly and at higher rates than the other cases. A similar observation was made in [16] where it was found that auditory warnings irritate, and as a result drivers tend to endure the system for much higher speeds once it has been triggered. However, this does not seem to be the case with the loud buzzing system which seems to have a more intervening characteristic probably due to its high sound pressure level.

D. Speed distribution

Another metric that was investigated was the speed distribution obtained for each evaluation period. Kernel Density Estimation (KDE) smoothing using Gaussian kernel functions with a smoothing bandwidth of 0.05 was applied to each distribution. Fig. 7 shows the KDE speed distribution for each evaluation period.

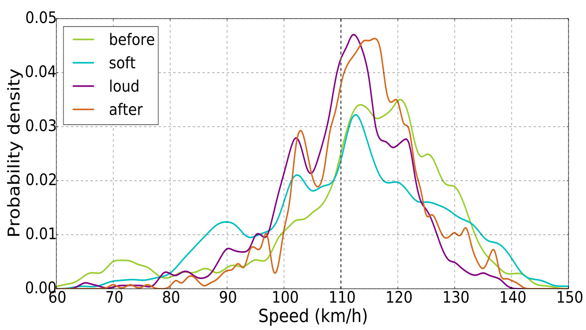


Fig. 7: KDE Speed distribution

Prior to ISA activation, a negatively skewed distribution is observed with a skewness of -1.11, peaking at 120 km/h with a kurtosis of 1.21. Both soft and loud warning system distributions are also negatively skewed with the same peak speed value of 112 km/h. The high kurtosis value observed for the loud buzzing distribution is evidence of a compensation effect from drivers due to the ISA system. Due to the fixed ISA threshold speed of 110 km/h, habitual speeders tend to drive at or around 110 km/h more often than normal, which is clearly demonstrated by the loud buzzing system. Interestingly, effects of the ten seconds delay before buzzing is triggered can be observed from the plateau between 115 km/h and 120 km/h for both soft and loud warning distributions. Although both audible notifications have an impact, the soft warning did not restrict speeding as much as the loud warning system did, especially for higher speeds. Compared with the soft warning distribution, the loud warning distribution has a higher kurtosis value and a more negative skewness, both of which explain the former assertion. The negative skewness values are an indication that minibus taxi drivers are more prone to driving at higher speeds, pushing the distribution curves rightwards. Only after the ISA trials is a more positive skewness value observed with a peak speed of 116 km/h. However, this is coupled with a negative (platykurtic) kurtosis which which indicates a relatively flat distribution.

E. Speeding frequency

Only the loud buzzing system had a statistically significant impact on the overall speeding frequency. The observations are illustrated in Fig. 8, and summarised in Table IV, which shows that soft buzzing reduced time-based speeding frequency to 70%; 11 percentage points less than the 81% prior to ISA activation. Moreover, loud buzzing reduced time-based speeding frequency by 21 percentage points with an effect size magnitude of 0.944; almost twice the 0.484 effect size magnitude due to soft buzzing. Effects of the ISA system can be further appreciated from the increase in overall speeding frequency observed after deactivation. The perceived uniformity between time and distance-based speeding frequency changes indicates that for each intensity level (including the pre and post-ISA activation periods), epochs of average speeds above the ISA threshold computed between consecutive records were similar.

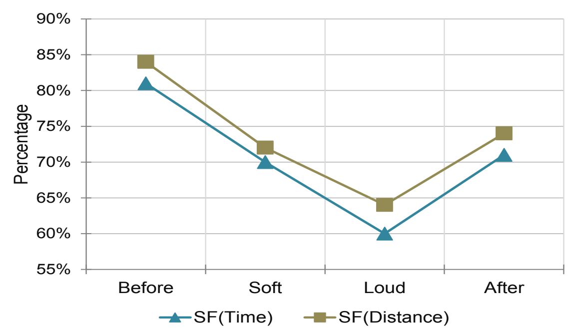


Fig. 8: Speeding frequency changes

TABLE IV: Speeding frequency

		Time			Distance		
	n	SF (%)	SD	EZ	SF (%)	SD	EZ
Independent set	23	82	21.1	–	84	20.7	–
Before	33	81	20.5	-0.014	84	19.4	0.001
Soft	27	70	27.7	-0.484	72	27.5	-0.459
Loud	20	60*	24.6	-0.944	64*	25.4	-0.871
After	19	71	22.9	-0.486	74	22.4	-0.467

* Statistically significant difference from independent set ($p<0.05$)

Previous results have shown that driver compliance with posted speed limits depends on the value of the speed limit. Irrespective of the ISA system used, lower posted speeds result in higher speeding frequencies, while higher posted speeds result in lower speeding frequencies [33], [16]. In this study, a similar trend was seen whereby the fixed ISA speed of 110 km/h – which happens to be 8 km/h less than the mean speed before ISA activation – resulted in fairly high speeding frequency changes for both soft and loud buzzing systems.

In Table V, the percentage of trips are shown in six speeding frequency intervals. Results indicate that the ISA system affected most drivers, with the loud system being more effective. In the time-based results, 45% of trips before activation have speeding frequencies above 90%, compared with 22% and 10% for soft and loud buzzing systems respectively. There is a noticeable jump in speeding frequencies before ISA activation between the 80-90% speeding frequency interval; 72% (27+45) of trips stay above the ISA fixed speed of 110 km/h at least 80% of the time. Introducing the ISA system reduced this percentage to 48% for soft buzzing, and 20% for loud buzzing. Furthermore, a comparatively higher proportion of trips with the loud buzzing system spend less than 50% of the time above the ISA speed. On the other hand, while the soft buzzing system shows improvement compared with the period before ISA activation, most of its trips are still characterised by high speeding frequencies.

TABLE V: Percentage of trips per speeding frequency interval

Interval (%)	Time-based (%)				Distance-based (%)			
	Before	Soft	Loud	After	Before	Soft	Loud	After
$SF < 50$	9	18	30	21	9	18	25	21
$50 \leq SF < 60$	3	4	15	11	0	0	15	0
$60 \leq SF < 70$	9	18	20	11	9	11	20	11
$70 \leq SF < 80$	6	11	15	11	3	22	10	11
$80 \leq SF < 90$	27	26	10	31	27	22	15	41
$SF \geq 90$	45	22	10	15	51	26	15	15

Fig. 9 shows vehicle speeding frequency for each evaluation period, while Table VI shows paired t-test results and effect sizes for successive evaluation periods. Similar to mean speeds, it is observed that drivers for each taxi portray different attitudes to speeding even while the ISA system was active. More than the soft buzzing system which shows improvement for only two taxis, the loud buzzing system results stand out with effect size magnitudes of 2.372 and 1.272 compared with the pre-ISA and soft buzzing periods respectively. Reverting to normal behaviour can be observed for each taxi after ISA deactivation, having a significant difference from loud buzzing with an effect size magnitude of 1.687.

TABLE VI: Paired t-test results for speeding frequency

	Soft	Loud	After
Before	EZ = -0.939	EZ = -2.372*	EZ = -0.652
Soft	–	EZ = -1.272*	EZ = 0.308
Loud	–	–	EZ = 1.687*

* Statistically significant difference ($p<0.05$)

F. Travel time

In this section, the ISA system effects on travel time were quantified. An average travel time of 70 minutes was obtained prior to ISA activation. During the activation period, the computed average travel time was 73 minutes for soft buzzing and 76 minutes for loud buzzing. Table VII shows these results in more detail. Similar to the mean speed results, the t-tests revealed that the loud buzzing and post-ISA travel times had a statistically significant difference, with effect size magnitudes of 0.765 and 0.424 respectively.

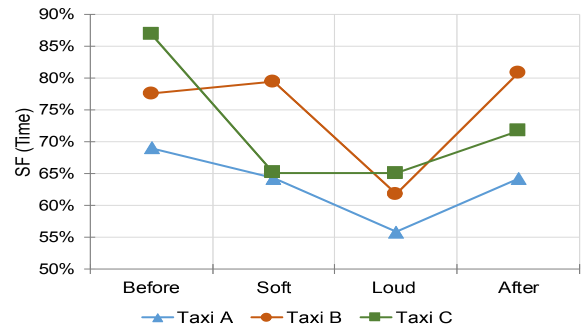


Fig. 9: Time-based speeding frequencies for each vehicle

TABLE VII: Travel time results

	n	Time (in Minutes) Mean	SD	Minimum	EZ
Independent set	23	72	4.84	61.77	–
Before	33	70	5.81	62.05	-0.331
Soft	27	73	6.04	62.48	0.264
Loud	20	76*	5.98	66.92	0.765
After	19	74*	4.99	67.17	0.424

* Statistically significant difference from independent set ($p<0.05$)

Together with the computed mean speeds, these results suggest that auditory ISA systems can improve road safety and speed compliance at the 110 km/h threshold with an increase in travel time of about six minutes (5.6%). Considering the fact that under 20% of participants attributed speeding to time restrictions, the 5.6% increase in travel time should not be a significant trade-off to speed and safety.

Moving on to more specific results, Table VIII shows the statistical significance and effect sizes based on the impact of successive ISA implementations on each taxi. Results show that the subsequent implementation of the loud warning from the soft warning had a significant impact on travel time with an effect size magnitude of 1.209, while the soft warning system implemented after the pre-ISA activation period does not result in a significant difference.

TABLE VIII: Paired t-test results for travel time

	Soft	Loud	After
Before	EZ = 0.875	EZ = 1.604*	EZ = 1.921
Soft	–	EZ = 1.209*	EZ = 1.921
Loud	–	–	EZ = 0.108

* Statistically significant difference ($p<0.05$)

According to the TomTom on-line route planner, without any traffic delays or stops, it takes normal passenger vehicles

84 minutes to travel this route, corresponding to an average speed of 100 km/h [34]. Assuming that vehicles adhere to a speed limit of 110 km/h on this route, travel times should not be less than 76 minutes, which corresponds to the mean travel time achieved with the loud ISA system. This result shows that the ISA system had an effect on driver behaviour, causing them to drive around the ISA threshold speed.

V. Discussion and conclusion

This paper evaluated the impact of auditory ISA on the informal public transport industry in South Africa which predominantly consists of minibus taxis. The effect of two sound intensity levels (soft and loud) were investigated, and compared with the outcomes before and after ISA activation. This section discusses the theoretical and policy implications of the empirical findings, and rounds up with concluding remarks stating strategies for future implementation and investigation.

A. Summary of empirical findings and contributions

At an aggregate level, both soft and loud ISA intensity levels were effective at reducing mean speed and speeding frequency, with even the soft buzzing system decreasing the percentage of trips completed at high mean speeds such as 120 km/h which was common before ISA activation. However, after statistical analysis, it was observed that the loud system was more effective showing significant differences compared with typical driving behaviour on the evaluated route, the preceding soft buzzing system, and the subsequent post-ISA activation outcomes. For one of the taxis, mean speed and speeding frequency were higher during soft buzzing than before ISA activation, while this was never the case with the loud buzzing system. In addition, the soft ISA system appeared to be least effective at higher speeds, having the highest 85th percentile speed throughout the investigation, while the loud buzzing system recorded the lowest 85th percentile despite its similarity to percentile speeds measured before ISA activation at lower speeds.

Although the loud buzzing system was more effective in improving speed compliance, the soft buzzing system was readily accepted by the drivers. No complaints were raised while the soft buzzing system was active. However, the loud buzzing system began to encounter some resistance three weeks into its deployment.

Another interesting trend from the findings is that drivers began to revert to normal driving after the ISA system was deactivated,as was evident from the statistically significant differences and high effect sizes from loud buzzing to post-ISA activation. Moreover, this reversion was not sudden as it was observed that speeding frequencies were substantially less than those before ISA activation. However, on several occasions (specifically during disaggregate analysis), patterns observed after ISA deactivation were similar to those observed while the soft buzzing system was active.

B. Theoretical implications

The generally positive effects of auditory ISA systems on speed compliance in the minibus taxi industry, inherently mean that road safety can be improved as per Nilsson [35] and Aarts' [9] mathematical models which suggest that achieving a decrease in driving speed culminates in a decrease in crash risk and severity.

The soft buzzing system used in this study relates to previous warning ISA systems in many ways, while the loud buzzing system has similar effects with active intervening systems (such as AAPs [36], [37]) especially as it caused drivers to drive around the ISA speed more often, with lower variations in speed. These differences between the soft and loud buzzing systems can only be attributed to the differences in their sound intensities. Similar to warning systems in [16], the soft buzzing system was less effective at high speeds since drivers will prefer to endure the warning for speeds that are much higher than the threshold speed once the ISA system has been triggered. In addition, the soft buzzing system seemed to have a high level of acceptance [1]; unlike the loud buzzing system, no driver complained about it during system activation.

With regards to patterns after ISA activation, outcomes of this study agree with findings in [20], where field tests were conducted on instrumented vehicles. After ISA activation, speeds were not as high as before ISA activation, and neither were they as low as during loud buzzing.

C. Policy implications

High mean speeds computed in this study (even with the ISA system) agree with [28] that the differentiated 100 km/h speed limit of minibus taxis will be difficult to enforce. Nevertheless, improvements with the loud system have shown that it can mitigate this difficulty especially if more minibus taxis adopt the system, seeing that existing interventions were not as effective. ISA penetration in the minibus taxi industry can be ensured by installing the system during vehicle manufacture where other ISA variants such as AAPs can also be introduced in minibus taxis to complement auditory ISA systems for better results.

D. Future work and Concluding remarks

The sequence of activation was fixed whereby the soft warning was tested before the loud warning. Effects due to a swap in sequence also needs to be investigated. However, the reverts observed after deactivation can also be expected if the soft system is preceded preceded by the loud system since it showed similar results after deactivation.

A fixed ISA system was used, configured at the highway prosecution speed of 110 km/h for minibus taxis. This was specifically for the purposes of this study since only long-distance trips were evaluated. The effect of variable speed systems on minibus taxis operating within cities where speed limits vary also needs to be investigated.

It has been shown that drivers tend to revert once the ISA system is deactivated. To maintain the advantages of the ISA system, it will therefore be required to run continuously. On this note, another aspect to investigate further is whether the positive impact of the loud buzzing system can be sustained over a long-term. Besides the low acceptability associated with the loud buzzing system, questions regarding the continuity of its impact need to be addressed if it were to be instituted, in which case driver experience and acceptability also need to be examined comprehensively.

The overall effect of auditory ISA systems on speed compliance can be seen from its ability to reduce speeding. It is evident from this study that for minibus taxi drivers, soft auditory ISA systems will not improve speed compliance as much as loud ISA systems. Although the loud system did not fully ensure absolute speed compliance, it proved to be a better solution than existing safety measures (e.g. average speed enforcement).

Acknowledgment

The authors would like to acknowledge MTN and MiX Telematics for their financial and technical support.

References

[1] J.J. Blum, A. Eskandarian, “Managing Effectiveness and Acceptability in Intelligent Speed Adaptation Systems,” *Proceedings of the IEEE ITS conference*, pp. 319-324, 2006.

[2] International Association of Public Transport - (UITP), “Public Transport in Sub-Saharan Africa: major trends and case studies”, Brussels, Belgium, 2010.

[3] F. Kassa, “Informal transport and its effects in the developing world: a case study of Addis Ababa, Ethiopia”, *Journal of Transport Literature*, vol. 8, pp. 113-133, 2014.

[4] Economic Development Department, “South Africa opens second minibus taxi assembly plant”, Available at http://www.economic.gov.za (25/08/2015), 2012.

[5] Trans-Africa Consortium, “Overview of public transport in Sub-Saharan Africa.” 2008.

[6] Road Traffic Management Corporation, “Road Traffic report.” *Department of Transport: Republic of South Africa*, March 2011.

[7] M.J. Booysen, N.A. Ebot Eno Akpa, “Minibus driving behaviour on the Cape Town to Mthatha route.” *Southern African Transport Conference*, 2014.

[8] R. Elvik, A. Hoye, T. Vaa, M. Sorensen, ”The handbook of road safety,” *Emerald Group Publishing Limited*, 2nd ed., Bingley, UK, 2009.

[9] L. Aarts, I. van Schagen, “Driving speed and the risk of road crashes:a review.” *Accident Analysis and Prevention*, 38 (2), 215-224, 2006.

[10] D. Richards, R. Cuerden, and G. Britain. “The relationship between speed and car driver injury severity.” *Road Safety Web Publication*, 2009.

[11] M.M. Minderhoud, & P.H. Bovy. “Extended time-to-collision measures for road traffic safety assessment.” *Accident Analysis & Prevention* 33, no. 1, 89-97, 2001.

[12] M.J. Booysen, S.J. Andersen, and A.S. Zeeman, “Informal public transport in Sub-Saharan Africa as a vessel for Novel Intelligent Transport Systems.” *16th International IEEE Conference on Intelligent Transport Systems*, 6-9 Oct. 2013, The Hague, The Netherlands

[13] N.A. Ebot Eno Akpa, M.J. Booysen, and M. Sinclair. “The impact of average speed over distance (ASOD) systems on speeding patterns along the R61.” *Proceedings of the first International Conference on the use of Mobile Informations and Communication Technology (ICT) in Africa UMICTA*, 12 2014, pp 78-82, ISBN: 978-0-7972-1533-7.

[14] H.L. Oei, P.H. Polak, “Intelligent speed adaptation (ISA) and road safety,” *IATSS research*, vol. 26, no. 2, pp.45-51, 2002.

[15] O.M.J. Carsten & F.N. Tate, “Intelligent speed adaptation: Accident savings and cost-benefit analysis”, *Accident Analysis and Prevention,* vol. 37, no. 3, pp. 407-416, 2005.

[16] I. K. Spyropoulou, M. G. Karlaftis, and N. Reed, “Intelligent speed adaptation and driving speed: Effects of different system HMI functionalities.” *Transportation research part F: traffic psychology and behaviour*, 24:39–49, 2014.

[17] C.N. van Nes, I.N.L.G van Schagen, M. Houtenbos, and P.L.J Morsink, “De bijdrage van geloofwaardige limieten en ISA aan snelheidsbeheersing: een rijsimulatorstudie,” Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam, 2007.

[18] INFATI.dk, Intelligent Speed Adaptation, [online] May 2015, Available:http://www.infati.dk/uk/index.htm (Accessed: 5th May 2015).

[19] T. Biding, G. Lind. “Intelligent speed adaptation (ISA): results of large-scale trials in Borlänge, Lidköping, Lund, and Umeå during the period 1999-2002”, *VAEGVERKET PUBLIKATION 2002*, 89E, 2002.

[20] E. Adell, A. Várhelyi, and M. Hjälmdahl. “Auditory and haptic systems for in-car speed management A comparative real-life study.” *Transportation research part F: traffic psychology and behaviour*, 11(6): 445-458, 2008.

[21] S. Vlassenroot, S. Broekx, J. De Mol, L. Int Panis, T. Brijs, and G. Wets. “Driving with intelligent speed adaptation: Final results of the Belgian ISA-trial.” *Transportation Research Part A: Policy and Practice* 41, no. 3: 267-279, 2007.

[22] M. Hjålmdahl and A. Várhelyi, “Speed Regulation by In-car Active Accelerator Pedal: Effects on Driver Behaviour.” *Transportation Research, Part F*, vol. 7, pp. 77-94, 2004.

[23] S.M.R. Ghadiri, J. Prasetijo, A.F. Sadullah, M. Hoseinpour and S. Sahranavard. “Intelligent speed adaptation: Preliminary results of on-road study in Penang, Malaysia”, *IATSS Research,* vol. 36, no. 2, pp. 106-114, 2013.

[24] M. Päätalo, H. Peltola, and M. Kallio, “Intelligent Speed Adaptation Effects on Driver Behaviour.” presented at *European Working Group on Speed Control*, Aalborg, 2001.

[25] H. Lahrmann, J. R. Madsen, and T. Boroch. “Intelligent Speed Adaptation-Development of a GPS Based ISA-System and Field Trial of the System with 24 Test Drivers.” *8th World Congress on Intelligent Transport Systems.* 2001.

[26] R. Bishop, *Intelligent vehicle technology and trends*, 2005.

[27] N.A. Ebot Eno Akpa, M.J. Booysen, and M. Sinclair. Publicly available annotated dataset of tracked taxis, at: http://goo.gl/EIXTSo.

[28] C.J. Bester, ”Differentiated speed limits that will work”, *South African Transport Conference*, CSIR, Pretoria, July 2012.

[29] S. Gray, “Community perceptions of ITS technologies,” presented at *World Congress on Intelligent Transport Systems*, Sydney, Australia, 2001.

[30] N. Garber, and L. Hoel, “Traffic and highway engineering”, *Cengage Learning*, 2014.

[31] H.W. Warner and L. Aberg, “The long-term effects of an ISA speed-warning device on drivers’ speeding behaviour.” *Transportation research part F: traffic psychology and behaviour*, 11(2), 96-107, 2008.

[32] J. Cohen, *Statistical Power Analysis for the Behavioural Sciences*, 2nd edition. Erlbaum, Hillsdale, NJ, 1988.

[33] D. Finch, P. Kompfner, C. Lockwood & G. Maycock, “Speed, speed limits and accidents”, *TRL project report*, PR 58, 1994.

[34] Beaufort West to Aberdeen, *TomTom Route Planner*, [Online]. Retrieved from: http://routes.tomtom.com/#/route (Accessed: 1st June 2015).

[35] G. Nilsson, “Traffic safety dimensions and the power model to describe the effect of speed on safety.” PhD thesis, Lund University, 2004.

[36] H. Lahrmann, J Runge & T. Boroch. “Intelligent Speed Adaptation-Development of a GPS Based ISA-System and Field Trial of the System with 24 Test Drivers.” *8th World Congress on Intelligent Transport Systems,* 2001.

[37] A. Várhelyi, M. Hjålmdahl C. Hydén & M. Draskóczy, “Effects of active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas,” *Accident Analysis and Prevention,* 2004.