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Efficacy of interventions and incentives to achieve speed compliance in the informal public transport sector

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***Abstract*—The informal public transport industry in South Africa, primarily dominated by minibus taxis is noted for poor compliance and disregard towards posted speed limits. They go as far as driving over the differentiated speed limit of the lighter passenger vehicles used for private transport. This paper compares and evaluates improvements in their speed compliance using two renowned interventions: automated Average Speed Enforcement (ASE), and auditory Intelligent Speed Adaptation (ISA). It also investigates the impact of each intervention on fuel consumption to provide an additional incentive to the most efficient intervention. The main finding was that for minibus taxis, ASE needs ISA as a supplementary intervention. It was discovered that the drivers showed little or no behavioural change while driving on the ASE route, while the introduction of the ISA system resulted in significant changes bringing violation frequencies down to 47.4 % from 81.2 % on the enforcement route. These behavioural changes also resulted in lower fuel consumption rates especially while the ISA system was active. However fuel economy did not seem to work as a self-regulatory incentive for speed compliance.**

I. Introduction

Various on-road countermeasures have been implemented in South Africa to improve road safety by enforcing compliance with posted speeds. These countermeasures include rumble strips, speed humps, and instantaneous speed cameras strategically deployed on roads. In the last decade, there have been a series of on-road Average Speed Enforcement (ASE) systems erected along sections with high crash rates. The use of ASE systems is growing steadily and gaining popularity in South Africa as a novel road safety system. Although it has been effective in general, it has a number of shortcomings specifically associated with the mode of transportation used [1]. Another countermeasure, not common to the informal public transport sector is Intelligent Speed Adaptation (ISA), implemented through in-vehicle Human Machine Interfaces (HMIs). These ISA systems can continuously inform and enforce posted speed limits unlike most on-road countermeasures which are spatially limited. This paper compares and evaluates the efficiency of these two state-of-the-art interventions in improving speed compliance within the informal public transport industry in South Africa. In addition, the paper also investigates fuel savings as an inherent self-correcting incentive.

The informal public transport industry, dominated by minibus taxis, accounts for a significant proportion of the collective transport market in South Africa, and Sub-Saharan Africa (SSA) in general [2]. However, in-vehicle speed adaptive technologies have yet to be widely implemented in this industry [3]. According to the 2011 Road Traffic Report of South Africa, 40% of fatal crashes were attributed to speeding, of which 10% involved minibus taxis [4]. Many of these taxis engage in urban trips on weekdays, and long-distance trips on weekends. Although the logistics of both functions (urban and long-distance) are different, the drivers and vehicles used are the same. The reader is referred to [5] for more information on urban transport, and [6] for more information on long-distance transport.

The focus of this study is on long-distance travel. Figure 1 shows a typical 1200 km long-distance route from Cape Town to Mthatha in the Eastern Cape. Within twelve hours on a weekend during the festive season, manually conducted traffic counts revealed that more than 1700 minibus taxis travelled this route, each taxi carrying about 14 passengers with a trailer. In addition, it was noticed from the data that within seven months, a taxi makes an average of 22 long-distance trips, with some taxis making up to 37 trips over the same seven months period. Each journey to the Eastern Cape usually starts around sunset on Thursday or Friday, and finishes upon arrival in Cape Town on Monday morning before sunrise.

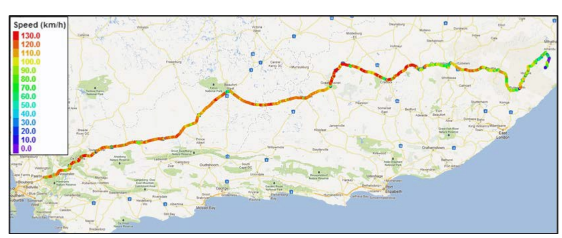

Fig. 1: A journey from Cape Town to Mthatha with colour-coded speeds.

A. Contribution

This paper compares and evaluates the efficiency of on-road ASE and in-vehicle auditory ISA systems in improving speed

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compliance in the minibus taxi industry, and also investigates fuel consumption as an incentive for safe driving. ASE is chosen because it is already installed, but seems ineffective for minibus taxis, while ISA is chosen as an alternative that could work. The impact on fuel consumption is evaluated as an inherent incentive that could act as a self-regulatory method on safety by increasing driver remuneration.

The evaluation route was restricted to the 145 km long section of the R61 between Beaufort West and Aberdeen. The section hosts one of South Africa's first ASE systems launched in November 2011. Although the study focusses on South African public transport, the outcomes will also be relevant to the rest of Sub-Saharan Africa (SSA) since similar methods and means of transportation apply.

II. Related work

As most studies have shown, speed is an important determining factor of crash risk and injury severity [7], [8]. It affects driver reaction and response time, the energy at impact, and the time it takes a vehicle to come to a complete stop [9]. One popular model developed by Nilsson [18] shows an exponential relationship between speed and crash risk/severity. Another model by Aarts shows that a decrease in crash probability of up to 13% can be achieved with a 1% decrease in speed [7].

Although little research has been conducted on minibus taxi driver behaviour in SSA, it has been established that compliance with posted speed limits is generally low [5], [6]. Despite the 100 km/h speed restriction on minibus taxis, they usually drive faster than or at the same average speed with passenger vehicles whose speed restriction is at 120 km/h. In addition, their speed percentile profiles were higher than those of passenger vehicles. In [5], minibus taxis used for long-distance transport were investigated. Data was collected for minibus taxis travelling from Cape Town to Mthatha using GPS tracking devices. Seven tracking devices were modified to connect to the 12V cigarette adapter in vehicles, and were configured to upload GPS information every 30 seconds. It was observed that maximum speeds regularly exceeded 140 km/h, with absolute maximum recorded speeds of about 159 km/h. Similar trends were observed in [6], which investigated minibus taxi driver behaviour on three segments of the same route.

Considering the high crash rates along the N1 and R61, several ASE sections have been deployed within the Western Cape section of the route. They are commonly referred to as Average Speed Over Distance (ASOD) systems which are automated ASE technologies that promote speed management and compliance with posted speed limits. The infrastructure consists of camera pairs strategically placed along the road section, equipped with Automatic Number Plate Recognition (ANPR) technology.

A. ASE, ISA and behavioural change

The effectiveness of each of these interventions in safety improvement depends on several factors including user acceptance, enforcement strategy, and system accuracy. In general, they have both been proven successful in several trials.

ASE was first implemented as a trial system in 1997 in the Netherlands. Since then, Europe has continued to lead in ASE as a transportation intervention, with enforcement sections in many countries, and a number of studies evaluating its impact on speed compliance and other resulting outcomes. Soole et. al. [10] compiled a comprehensive literature survey of ASE studies across Europe with the aim of monitoring speed compliance, driver perception, comparison with instantaneous fixed camera interventions, and conducting cost-benefit analyses. Offence rates were reported to be below 1%, with the proportion of vehicles exceeding the speed limit reduce by up to 90% [11].

The ASE system on the R61 Between Beaufort West and Aberdeen has also had a positive effect on speed compliance. A macroscopic study conducted in 2012 with data captured through the system revealed that no fatal crashes were reported in the first year of ASE operation [12]. In addition, the proportion of vehicles driving below the speed limit increased from 61% to 74%.

Details on fuel consumption within ASE sections in South Africa are yet to be investigated. However, a number of studies have shown that compared with other sections, ASE sections are characterised by lower fuel consumption and emissions [13]. Compared with unenforced sections, for an average car, ASE improved fuel consumption by 2.07 km/L when 70 mph (112.7 km/h) limits were enforced, and by 6.77 km/L when 50 mph (80.5 km/h) limits were enforced.

Simulation experiments [31] and field tests [29], [33], [32], [34], [24] have been conducted to evaluate the impact of different ISA systems on driver behaviour. 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 they affect the percentage of time spent above the speed limit [27].

Spyropoulou et. al [31] investigated the respective effects of advisory, warning and intervening/haptic ISA interfaces conducted on 23 subjects using a driving simulator. Compared with the base case with no ISA intervention on a 60 mph road, the warning system reduced average speed and maximum speed by 77.3%, while speeding frequency declined by 32%.

In another project [29], [30] conducted on 24 subjects in Denmark, the HMI featured an LED display supplemented with an auditory female voice. Average speeds reduced by 3 – 9 km/h, with higher compliance levels observed in urban areas than in rural areas.

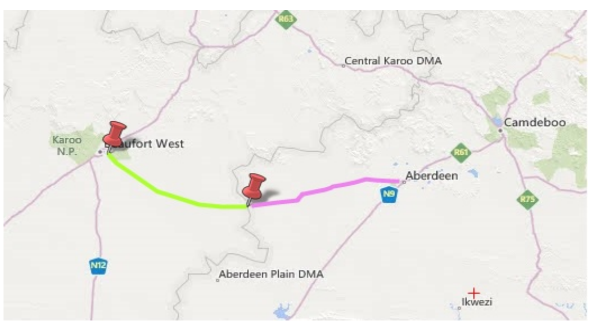
One of the largest pioneering large-scale ISA tests was conducted in Sweden between 1999 and 2002 in the cities of Umeå, Borlänge, Lidköping, and Lund [33]. Most vehicles used informative or warning interfaces. Throughout the field trials – mostly carried out in 2001 – about 5,000 vehicles were driven by 10,000 drivers. Average speeds reduced by up to 5 km/h on 70 test roads, speed violations decreased by 10%, and an average 20% reduction in road injuries was recorded for equipped vehicles [33][26].

One study which estimated the cost savings that can be achieved by implementing ISA systems in South Africa showed that between R18.7 billion and R51.2 billion will be saved annually, with vehicle operating costs (such as fuel and maintenance) and the cost of road accidents being the greatest contributors [35].

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 [27], [31]. On the other hand, warning systems are a midway interface in terms of effectiveness and acceptability, and will be considered in this study through a non-speech buzzer implemented on public transport minibus taxis.

III. Experimental setup and methods

For the study, GPS tracking devices installed by Mix-Telematics in five taxis were used (see [40] for a link to the GPS traces). All the taxis operate locally within the City of Cape Town and the Cape Winelands districts. Owners were incentivised to have the devices installed in their vehicles. The vehicles used were 14-seater Toyota Quantums which run on diesel with Euro II emission technology. The evaluation was centred on the section of the R61 between Beaufort West and Aberdeen; a 145 km, two lane bi-directional highway with no separation. The route map is shown on Figure 2a with the ASE camera locations indicated with push pins, while Figure 2b shows a section of the street view. During the evaluation process, the 71.6 km long Enforcement Route (ER) between the cameras, and the 70.6 km long Control Route (CR) were treated independently. ASE on the enforcement Route has been active since November 2011.



(a) Route map

(b) Street view section of the route

Fig. 2: Evaluation route *(Bing & Google maps, 2015)*

The study involved drivers from the Stellenbosch Taxi Association. Information obtained by surveying 21 regular long-distance drivers is shown in Figure 3. Each minibus taxi is typically driven by the owner and his contracted drivers [6], [5]. Despite the multiple drivers per taxi, driver identification was not activated for this study. In addition, the taxis were not equipped with data-loggers, but they each transmitted the data to an online data server allowing continuous localisation of the vehicle.

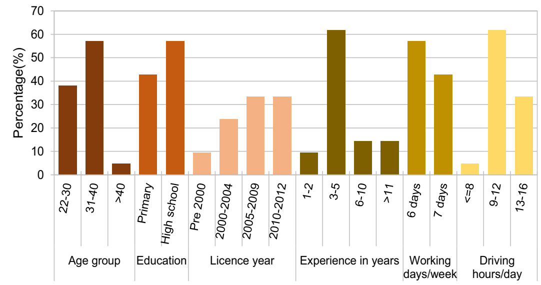


Fig. 3: Driver information

A. Data collection and validation

The tracking devices were programmed to provide information at a nominal frequency of 1Hz. However, due to filtering and data loss, not all successive records were captured at this frequency. Although accurate, the GPS as a measuring device is subject to both systematic and random errors [37]. These errors were minimised by removing GPS records with less than five satellites in view and HDOPs greater than one. In addition, polygons surrounding the route of interest were used to minimise random errors, by only considering records within the polygons.

Trips were identified by probing between departure and arrival points of interest, while stops in each trip were identified using an adapted DJ-Clustering algorithm [38]. For trip identification, due to the relatively low data capturing frequency, a 2km radius was defined around each departure and arrival point of interest to minimise variations in route distance from the actual distance. Trips with no GPS records in the specified radius were excluded from the analysis. This ensured a maximum deviation of 4km in travel distance from the fixed travel distance of the respective routes.

Average speeds captured by the ASE system were compared with average speeds calculated from GPS data for validation. The ASE captured speeds were obtained from speeding fines levied on minibus taxi drivers. Timestamps and average speeds on from the ASE system were mapped to their corresponding GPS timestamps and average speeds. The results were very similar with a measured maximum percentage difference of 0.85%.

B. ASOD system operation

The ASOD system is an automated form of average speed enforcement. It ideally promotes uniform speed and compliance with posted speed limits. The infrastructure consists of camera pairs strategically placed on a road section, with enhanced visibility through roadside notifications at the entry and exit cabinets. Each camera is equipped with Automatic Number Plate Recognition (ANPR) technology. Number plates are captured at an initial camera location, and also at any subsequent camera location. The known distance between both cameras and the travel time between them are used to calculate the average speed of the vehicle. If the calculated average speed is higher than the legal speed limit for the vehicle type on the given road, then the vehicle violates the system. Usually, as is the case in South Africa, a 10 km/h tolerance above the legal speed limit applies.

C. ISA system operation

Three main criteria are used to classify ISA systems [23], [17], namely, the warning/control type, the computation of the threshold speed, and the HMI/user interface. The warning/control types are voluntary, mandatory or advisory. Voluntary and mandatory systems can physically keep the vehicle from exceeding the system threshold speed. However, unlike voluntary systems, Mandatory systems cannot be switched off or overridden by drivers. Advisory systems on the other hand simply provide visual or auditory information when the threshold speed is exceeded.

Fixed threshold speeds were used throughout the experiment. After running a number of trials at different thresholds, the final threshold was set at 110 km/h. Speeds were set remotely with the consent of taxi owners. Fixed speeds were used on the basis of their simplicity and minimal distraction and overloading during the driving process unlike variable or dynamic speed systems [27][28]. A fixed speed threshold at 110 km/h is reasonably high compared with the legal speed limit of 100 km/h imposed on minibus taxis. This choice was made for two main reasons: firstly, to address the effectiveness-acceptability trade-off associated with ISA systems [17]. In addition, data was collected in a real-life trial with no intention to affect the logistics of the industry, but to investigate the effects of ISA systems on minibus taxis in the least disruptive manner. Secondly, the minibus taxis are mostly used for urban travel – characterised by lower speeds compared with long-distance trips. As such, since this study focused on long-distance trips, the threshold was set high enough to prevent system activation during urban travel.

A passive non-speech HMI interface was used in the ISA system. Though an advisory system, it has both mandatory and voluntary properties. Mandatory in that it cannot be switched off by the user, and voluntary in that some levels of loudness can be drowned out by increased radio volume or environmental noise. Mandatory features were allowed to apprehend the full effect of having the system running continuously, limiting driver options to disable or customise the system. The warning was a persistent auditory tone that sounded ten seconds after the fixed threshold speed had been exceeded consistently, and stopped immediately after the speed had dropped below the threshold. At maximum volume, the sound level was set at 90 dB within a 10 cm range, and had a frequency of 5 kHz.

The ISA systems and tracking devices were installed in November 2013, however, ISA system activation at 110 km/h started in December 2014. Driver and owner requests to have the systems deactivated only allowed for the collection of one month worth of data while the ISA system was active.

D. Method of analysis

The absence of minibus taxi fleet data before ASOD deployment in November 2011 did not permit time-based analysis. Effects of the ASOD system on speed compliance were obtained through spatial analysis by comparing results from the 71.6 km Enforcement Route (ER) from Beaufort West to the 70.6 km Control Route (CR) to Aberdeen. Geometric characteristics and traffic conditions of both routes were similar.

The impact of each intervention on driving variables such as average speed, speed percentiles, speeding frequency and travel time was analysed. Significance tests between the ASOD system and the ISA system were investigated through independent samples t-tests. Effect sizes of each intervention were calculated with reference to results obtained along the control route when there was no intervention. The effect sizes (EZ) were computed using Cohen's equation [25] 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 are the number of observations/trips and *SD* are the metric standard deviations.

Fuel consumption is computed using the COPERT model [14]. This model – developed from European fleets – is considered appropriate because South African vehicles have similar emissions to European vehicles [15], [16]. Based on the vehicle characteristics, the following COPERT emission factor equation for fuel consumption (FC) in g/km expressed as a function of speed (v) in km/h applies [14];

$$FC(v) = \begin{cases} 114.34, & v < 10 \\ 0.0198v^2 - 2.506v + 137.42, & 10 \leq v \leq 110 \\ 101.34, & v > 110 \end{cases} \tag{3}$$

Given a list of N ordered GPS records that constitute a trip, the fuel consumption in grams is calculated as follows;

$$FC[in\ grams] = \sum_{n=1}^{N-1} FC(v_{i,i+1}) * d_{i,i+1} \tag{4}$$

where $FC(v_{i,i+1})$ is the emission factor formula in Equation 3, $v_{i,i+1}$ is the average speed between records i and i+1 in km/h, and $d_{i,i+1}$ is the distance between records i and i+1 in km. The fuel consumption estimate in litres was calculated from the fuel consumption in grams and the diesel density constant of 832 grams per litre.

Two methods were used to calculate distances between consecutive records, namely the Haversine distance, and the Route distance queried from Google's Directions server. In most cases, the Route distance was used for its accuracy since it incorporates winding and curves. However, due to its computational payload, Haversine distances were used for consecutive records which were less than 100 metres apart.

Equation 4 is applied based on the assumption that the GPS records defining a trip explain/capture all stops in the course of the trip. If all stops are not captured, which could be as a result of missing data, then the average speed between the consecutive records involved will be inaccurate. The probability of this inaccuracy was minimised by applying a 1 Hz recording frequency to the GPS receiver.

IV. Results and Discussion

A. Driving speed and speeding frequency

This section presents the outcome of each intervention on speed and travel time percentiles, mean speed, and speeding frequency. Mean speed was calculated as the average speed along each route as a function of distance and travel time. Speeding Frequency (SF) was also investigated on the basis of travel time and distance covered. Time-based Speeding frequency is the proportion of the travel time spent driving above the ISA fixed speed, while distance-based speeding frequency is the proportion of the total distance covered driving above the ISA fixed speed.

Table I gives an aggregate summary of key speed variables, and shows significant differences between ASE and ISA, especially on the enforcement route with a 7.7 km/h reduction in mean speed, and a 9 km/h reduction in the 85th percentile speed after ISA is introduced. Average speeding frequency also shows similar trends with ASE having higher values in time and distance-based results for both routes. Effect sizes computed with respect to the intervention-free period on the control route shows higher effect size magnitudes when ISA is introduced.

Speed percentiles in Figure 4 show an increasing divergence between ASE and ISA speed profiles as speed increases, with the ASE system characterised by higher speed profiles on both routes. These results also reflect on the travel time percentile profiles which show longer travel times with the ISA system.

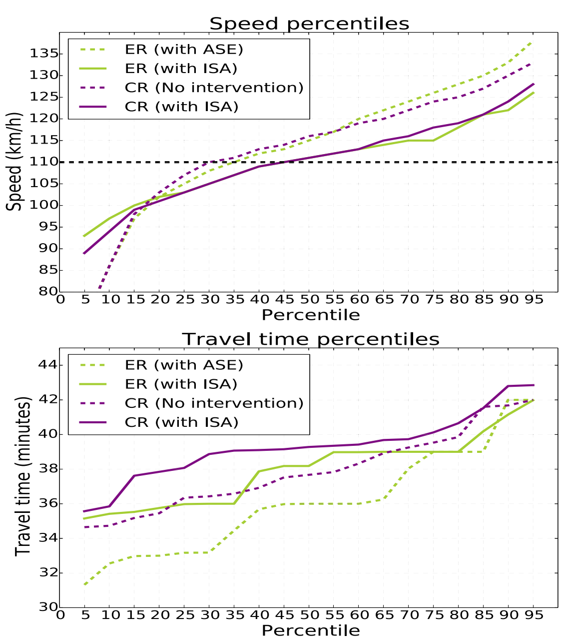


Fig. 4: Speed and travel time percentiles

A more detailed disaggregate analysis of mean speeds is shown in Table II with the 110 km/h violation frequency. These results are further elaborated in Figure 5. The proportion of trips completed with mean speeds above 110 km/h are higher for ASE than for ISA. However, 110 km/h violations on the enforcement route with ASE is at 81.2%; 9.4 percentage points lower than on the control route with no intervention. Considering violations at the legal speed limit of 100 km/h, it is observed that the proportion of trips completed above 100 km/h are above 90% and are the same for both interventions.

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

Route	Intervention	Mean speed intervals (km/h) $s > 120$	$110 < s \leq 120$	$s \leq 110$	Violations
ER	ASE	13 (40.6)	13 (40.6)	6 (18.8)	26 (81.2)
	ISA	1 (5.3)	8 (42.1)	10 (52.6)	9 (47.4)
CR	Neither	15 (46.9)	14 (43.7)	3 (9.4)	29 (90.6)
	ISA	2 (10.5)	8 (42.1)	9 (47.4)	10 (52.6)

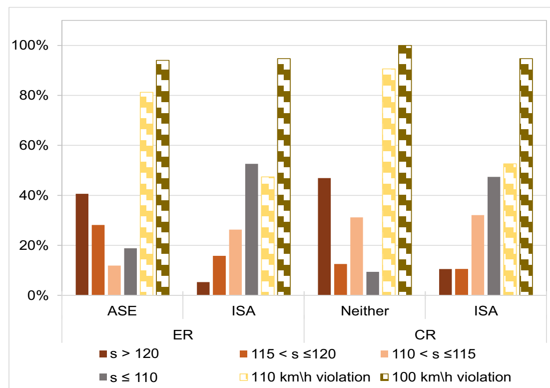


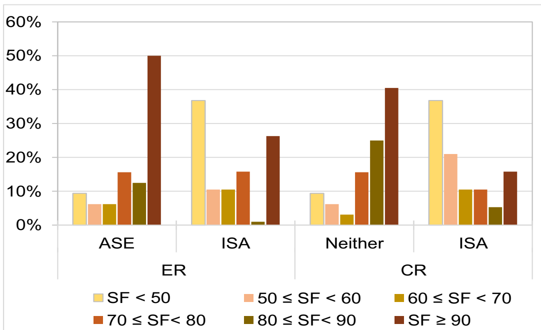
Fig. 5: Speeding and system violation rates

Time and distance-based speeding frequency results are shown in Figures 6a and 6b respectively, with six intervals of interest for each intervention and route. The results show that with ASE alone, high speeding frequencies are more prominent on both the enforcement and control routes, but less prominent when ISA is introduced. Similarly, low speeding frequencies are more prominent when ISA is introduced, than with ASE alone. Uniformity between time and distance-based speeding frequency results is also observed which shows that average speed instances above 110 km/h computed from consecutive GPS records were similar.

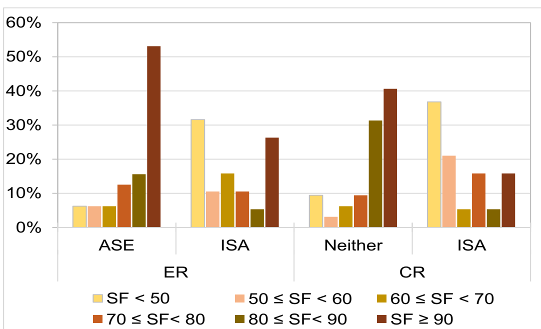
Furthermore the relationship between mean speed and time-based speeding frequency is explored. In Figure 7 the scatter plots and regression lines on the enforcement and control routes for each intervention are shown. Individual trips are plotted as separate points. These plots show that the drivers are generally habitual speeders even in the presence of an intervention. This is evident from the presence of many points situated on the top right quadrant of the graph. On the enforcement route the ASE intervention has a steeper slope indicating that introducing ISA is more effective in ensuring speed compliance. Similarly, on the control route, with no intervention, the slope is slightly higher than that of the ISA system. This occurs because with no intervention, the control

TABLE I: Speed and speeding frequency metric summaries

				Speed metrics (km/h)				Average Speeding Frequency (%)	
Route	Intervention	Trips	EZ	Mean	SD	Maximum	85th percentile	Time	Distance
ER	ASE	32	0.07	118.3	11.2	147	130	82	84
	ISA	19	-0.46	110.6	9	138	121	59	61
CR	Neither	32	–	117.3	17	141	127	79	81
	ISA	19	-0.40	110.8	15.2	138	121	57	60



(a) Time-based



(b) Distance-based

Fig. 6: Speeding frequency

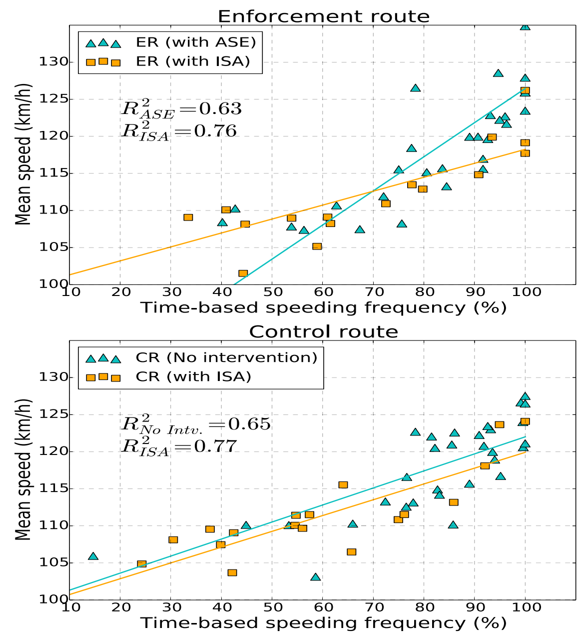


Fig. 7: Mean speed versus time-based speeding frequency

route has a higher proportion of trips with low speeding frequencies than the ASE intervention on the enforcement route.

B. Speed distribution

Using Gaussian kernel functions, Kernel Density Estimation (KDE) was applied to estimate speed distributions. The Scott smoothing bandwidth [21] was used for each distribution. From the results in Figure 8, it is observed that all four distributions are negatively skewed, with the ASE distributions being more negatively skewed, while all kurtosis values are leptokurtic (more positive than that of a normal distribution). More interestingly, it is observed that with the introduction of ISA, the distribution means reduce on both routes, showing that ISA contributes towards speed compliance more than ASE.

On the enforcement route, the skewness values are -0.9 for ASE and -0.6 with ISA, and the kurtosis values are 0.4 for ASE and 1.2 with ISA. On the control route, the skewness values are -2.2 for ASE and -2.7 with ISA, and the kurtosis values are 5.9 for ASE and 11.4 with ISA. On each route, kurtosis values for ASE are lower than those with ISA, indicating the impact of the ISA system causing drivers to spend more time around the ISA speed. The high peak and consequent high kurtosis of both ISA distributions show that the system had a compensation effect on driving especially around the ISA speed of 110 km/h. The slight deviation of the ISA distribution peaks from the 110 km/h mark is also evidence of the effect of the ten seconds time lag before buzzing starts. Results show that the ISA system was more effective at achieving speed compliance than ASE in the enforcement and control routes.

C. Fuel consumption

Studies have shown that driving speed plays a significant role in fuel consumption [39]. The ability of interventions to promote speed compliance implies that they can also reduce fuel consumption, especially for habitual offenders. Using the COPERT model, fuel consumption estimates were computed for each trip through the control and enforcement routes. On the enforcement route, the computed average fuel consumption estimates were 8.35 km/L for ASE and 8.58 km/L with the ISA system. On the control route, the computed average fuel consumption estimates were 8.36 km/L for no intervention and 8.63 km/L with the ISA system. Compared with the control route with no intervention, ASE shows little or no change in

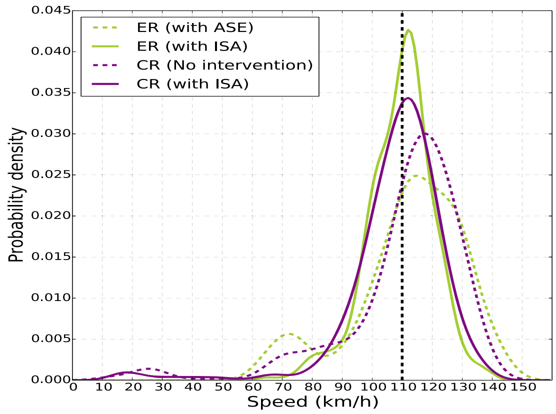


Fig. 8: KDE Speed distribution

the fuel consumption rate. However with the ISA system, fuel consumption on the enforcement route improved by 3%.

Assuming that drivers keep to a 110 km/h speed limit, the maximum fuel consumption rate will be 8.2 km/L (101.34 g/km), which happens to be the maximum rate for light duty vehicles based on the COPERT model. This also explains why the ISA speed fixed at a 110 km/h does not result in remarkable reductions in fuel consumption rates. However, comparing the fuel consumption of speed compliant trips with the worst non-compliant trips reveals interesting results. With the ISA system active, some drivers were able to keep fuel consumption rates on the enforcement route as low as 10.1 km/L, corresponding to a 1.74 km/L (17.2%) improvement compared with the 8.36 km/L average, and a 1.9 km/L (18%) improvement compared with the 8.2 km/L maximum rate. On the other hand, the minimum fuel consumption rate observed on the enforcement route with ASE is 8.76 km/L which corresponds to a 5% improvement compared with the 8.36 km/L average on the control route without enforcement, and a 6% improvement compared with the 8.2 km/L maximum rate. For each trip, a driver typically gets R500 as payment, and a fixed fuel budget of R3500 from the owner of the taxi. The 17.2% improvement in fuel consumption with the ISA system could result in an increase in driver remuneration by about 120% from the fuel budget. Also, the 5% improvement in fuel consumption with the ASE system could result in an increase in driver remuneration by about 35% from the fuel budget.

V. Conclusion

The aim of this paper was to compare and evaluate the efficiency of automated average speed enforcement, and auditory intelligent speed adaptation on informal public transport, while evaluating the fuel economy as an inherent incentive. This was established by running analysis tools on GPS data collected on an ASE route, and an adjacent control route without ASE. A buzzing auditory ISA was remotely activated at a fixed speed of 110 km/h for a month. Data analysis algorithms and tools were then used to to collect and compare results.

The main finding was that with regards to the informal yet vibrant minibus taxi industry, speed compliance can be achieved with ISA systems than through ASE. With the known proportionality between speed compliance and crash risk [7], [8], this also implies that road safety can be improved with ISA systems than through ASE systems for this same industry. Previous investigation into the low compliance associated with average speed enforcement showed that most minibus taxi drivers did not understand how the system operated and what was expected of them within the enforcement zone [36].

Mean speeds, percentiles, speeding frequencies, and speeding distributions measured on both the enforcement and control routes were similar while ASE was active on the enforcement route. Not only were they similar, but were characterised by high speed violation frequencies. Violation frequencies of 81.2% and 90.6% were measured on the enforcement and control routes respectively. This also shows that despite the high violation frequencies, vehicles were more compliant on the enforcement route than on the control route as would be expected. On the other hand, speed variables measured on both the enforcement and control routes were equally similar while the ISA system was active. However, in addition to the similarity, unlike the ASE intervention, average speed violation frequencies decreased, and were shown to comply closely with the ISA speed of 110 km/h. Violation frequencies of 47.4% and 52.6% were measured on the enforcement and control routes respectively. This is 33.8 percentage points less than violation frequencies with ASE on the enforcement route, and 38 percentage points less than violation frequencies on the control route. Over 90% of trips violated the 100 km/h legal speed limit for both ASE and ISA interventions. The speed compliance results observed with the ISA system set at a 110 km/h threshold suggest that ISA systems set at 100 km/h could also be influential in improving speed compliance and safety at the legal speed limit.

Furthermore, the introduction of the ISA system not only improved speed compliance, but also reduced fuel consumption, hence for minibus taxis, it does not just provide safety as an incentive, but fuel economy as well. With the ISA system, fuel consumption rates as low as 10.1 km/L (9.9 L/100km) were observed, while with the ASE system, low fuel consumption rates were around 8.76 km/L (11.4 L/100km). Moreover, drivers can increase their remuneration by over 100% from the fixed fuel budget if they adhere to the speed limit. However, this does not seem to work as a self-regulatory incentive for compliance with speed limits and safe driving probably because they are unaware of how much they could save, or simply because they are habitual speeders.

According to [10], to ensure high speed compliance, ASE systems cannot exist as the sole intervention. The results in this paper also confirm this. In addition, findings in [36] identified poor driver understanding of the ASE system operation as the main factor behind low speed compliance. The Western Cape government in South Africa [12] discovered huge improvements in speed compliance as a result of this ASE system on the R61. However, from this study, it is likely that minibus taxis which frequent this route do not contribute significantly to this observed improvements in compliance. This therefore suggests ISA technologies as a supplementary intervention to existing ASE interventions, in addition to the need for driver education on how the ASE systems operate, especially for minibus taxis. Moreover, implementing ISA technologies come with many advantages due to the ubiquitous nature of GPS data, and opens doors for more advanced implementation solutions. However, the hurdles of user acceptance of ISA systems need to be transcended, and further research needs to be done to narrow down on system requirements which may lead to driver overloading or distraction. Nevertheless, the prospects of simplified auditory ISA technologies in the informal public transport sector are high, considering the advantages observed in this small-scale study.

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