The impact of average speed over distance (ASOD) systems on speeding patterns along the R61.

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***Abstract*—Speeding is considered to be a major contributing cause of road fatalities in Sub-Saharan Africa and South Africa in particular. The minibus taxi industry is a vibrant yet partly informal sector of public transport in South Africa, which has been associated with speed-related road fatalities. Although countermeasures have been implemented to address speeding, they have not led to significant reduction in road fatalities and adherence to legal speed limits. Among the countermeasures deployed on some highways is the Average Speed Over Distance (ASOD) system which uses cameras to enforce speed limits. In this paper, historical probe data is used to evaluate the impact of the ASOD system on speed profiles of passenger vehicles. The data also consists of speed, time and location information gathered by navigation and fleet management devices that were installed in minibus taxis. The evaluation is based on spatial differentiation (the impact on the enforcement site with ASOD versus the control site without ASOD) and time differentiation (the impact before and during ASOD enforcement). For passenger vehicles, the results show that the presence of ASOD systems caused a reduction in mean speeds and ensured compliance with speed limits at enforcement and control sites. On the other hand, the system appears to have no influence on minibus taxis, with high, yet similar average speeds measured in the enforcement and control sites during ASOD enforcement.**

I. Introduction

Various speed reduction countermeasures have been used in South Africa to reduce speed-related fatalities and injuries. While some countermeasures such as rumble strips and speed humps are aimed at managing vehicle speeds, other countermeasures such as instantaneous speed cameras are aimed at enforcing compliance with posted speed limits [1]. This paper focuses on the Average Speed Over Distance (ASOD) system implemented on the R61 between Beaufort West and Aberdeen in South Africa. ASOD is a form of automated speed enforcement, which ideally promotes both speed management and compliance with posted speed limits through Average Speed Enforcement (ASE). It is usually referred to as Point-to-Point speed enforcement in parts of Europe. A number of studies have proven the effectiveness of ASODs in Australia and Europe with a significant reduction in crash rates by about 24% over a period of three years during enforcement [6][7]. The size of its effect on crash rates and speed violation may vary from region to region as [2] suggests.

The infrastructure involves the installation of Automatic Number Plate Recognition (ANPR) cameras at strategic locations along a road section. An image of the number plate is taken at the initial camera location and at any subsequent camera locations. Image processing is used for character recognition, followed by the retrieval of vehicle data from a central database. The known distance between the cameras and the time taken to travel between both cameras is used to calculate the average speed of the vehicle along the section. A fine is issued if the calculated average speed is higher than the enforcement threshold limit of the road. Fixed or mobile cameras may be used for ASOD implementation. Most systems use fixed cameras due to lower subsequent speed violations and crash rates associated with them [2]. Camera visibility is enhanced through roadside notifications. It should be noted that ASOD as a speed enforcement countermeasure is different from instantaneous speed enforcement. While the latter has also been used to control speed [9], unlike the former, it is limited to specific locations.

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A. Problem statement and Research objectives

With road transportation becoming an increasingly integral part of societal activities in Africa, the need for efficient road safety measures is growing. Speeding is often cited as the leading human factor responsible for road fatalities. Studies have shown that there is a direct relationship between vehicle speed, crash risk and crash severity [3]. According to South Africa's 2011 road traffic report, speeding contributed to about 40% of fatal crashes, due to human error [4]. As a result, modern ITS (Intelligent Transport System) safety measures such as ASODs are geared towards regulating human factors. The need to evaluate the impact of ASOD systems on speed profiles is therefore inevitable. Such an investigation needs to transcend macroscopic effects as discussed in [5] to address microscopic effects such as reductions in average speed and speed variability, while considering different modes of transport.

The objective of this paper is to investigate the effects of ASOD systems on speeding, before and during ASOD enforcement: this will be referred to as 'time differentiation' analysis. The paper also compares the effects of ASOD implementation on enforcement sites and control sites: this will be referred to as 'spatial differentiation' analysis. Unlike most previous studies, the specific objective of this paper is to investigate the impact of ASODs on private and public modes of transport. The research focuses on passenger vehicles (mainly used for private transportation) with a legal speed limit of 120 km/h, and minibus taxis (mainly used for public transportation) with a legal speed limit of 100 km/h.

II. Related work

ASE systems have been operating in certain regions for about seventeen years. The first instance was a trial form installed in 1997 in the Netherlands, which ran for five years

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before permanent implementation in 2002. In 2000, England launched its first permanent implementation after running trial versions for a year [7]. Besides South Africa, there is no documented literature on the implementation of average speed enforcement in Sub-Saharan Africa. The majority of Sub-Saharan African nations rely on police patrols, rumble strips and speed humps to control speed [10]. South Africa launched one of its first ASE technologies – known as the ASOD – in October 2011 on the R61: a 71.6 km stretch of road between Beaufort West and Aberdeen [5].

Media reports on ASE systems indicate that they have been effective in improving road safety. This is evidenced by the number of speed fines issued and reduction in road fatalities. The evaluation of the effectiveness of ASE systems is, however, a relatively new research topic. This applies particularly to the African context, where ASOD systems have been operational for less than half a decade. Hence, there is still a general lack of a credible body of research on the extent of its effects on speed management in different regions, and the availability of concrete evidence to substantiate its supposed benefits [6].

A. ASE impact on speed

This section summarizes outcomes based on studies carried out in Europe where the impact of ASE systems has been evaluated in detail. A number of studies have been conducted, which evaluate the impact of ASE on speed and crash rates. However, this paper dwells on the impact of average speed enforcement on speeding patterns. Soole et al. [7] compiled a concise literature survey of ASE evaluation in Europe. The aim of their research was to monitor compliance with posted speed limits on ASE sites. They also investigate the evidence of the effectiveness of ASEs through comparison with other countermeasures, driver perception and cost-benefit analyses. Previous studies in some enforcement sites reveal that average speed enforcement reduced the mean and 85th percentile speeds by upto 33%. In addition, speed variation from the posted speed limit was reduced with speeds typically below or at the posted speed limit [6][7]. Their findings support ASE as a complementary measure to existing speed management measures, which should focus on roads with historically high crash rates. Nevertheless, they conclude that ASE is a more reliable and cost-effective approach to speed enforcement, and is widely accepted by road users.

In the Netherlands, a study was conducted in 2005 on the A13 in Rotterdam with a posted speed limit of 80 km/h. Average speed in the enforcement site reduced from 100 km/h to 80 km/h. Reduction in speed variance and 85th percentile speed were also observed. Moreover offence rates dropped by 4% [11].

In Italy, an evaluation of all enforcement sites was conducted in 2009. Average speeds reduced by 16 km/h (corresponding to a 15% reduction) during the first year of operation. After the first year, average speeds further reduced by 9.1 km/h [7]. In 2011, a one week pre-installation and one week post-installation comparative study conducted on an 80 km/h road in Naples also showed positive impact. Average speed dropped by 9 km/h and speed variance dropped from 18.1 km/h to 12.1 km/h. In all cases, reductions were greater in free-flow conditions compared with peak periods [12].

In 2010, a series of ASE evaluations was conducted by speed check services on over 13 sites in England. Speed profiles three years before enforcement were compared with speed profiles three years during enforcement. The posted speed limits of the sites were between 30 mph and 50 mph. The 85th percentile speed dropped by an average of 14.4% for 11 sites, but increased for one site. Average speed reduced by an average of 12.5% for 10 sites, increased for two sites and remained unchanged for one site. The proportion of vehicles travelling above the speed limit reduced by an average of 30% [13].

According to the Western Cape government in South Africa, ASOD systems also have a positive effect on speeding patterns [5]. A macroscopic evaluation of the ASOD system on the R61 was conducted in 2012. Prior to ASOD enforcement, a total of 509 crashes were reported, 75 of which were fatal crashes. The specific time frame before ASOD implementation during which these crashes occurred is not mentioned. During ASOD enforcement, between November 2011 and November 2012, no fatal crashes were reported. The proportion of vehicles driving above the speed limit of 120 km/h dropped from 39% to 26%, and the percentage of vehicles driving below the speed limit increased from 61% to 74%. Moreover, the number of speed fines issued decreased from 2558 in January 2012 to 157 in August 2012 [5].

Previous studies focus on enforcement sites with little reference to the impact on control sites just outside enforcement sites. In addition, the impact of ASE systems is generalized for different modes of transport and vehicle types. In this paper, time differentiation (the period before and during ASOD enforcement) on enforcement and control sites is examined. Spatial differentiation (the impact on ASOD enforcement sites versus control sites) is also examined for a specific time frame. The analysis is carried out on passenger vehicles and minibus taxis based on data availability before and during ASOD enforcement.

III. Methods

This section presents data sources, and discusses the methods applied to evaluate the extent to which ASOD systems have affected speeding patterns of passenger vehicles and minibus taxis on the R61.

A. Data sources

In order to conduct the evaluation effectively, commission dates and the precise location of cameras on roads must be known. This data was made available by relevant stakeholders. For this study, data was captured using tracking devices equipped with GPS receivers and cellular connectivity. Two independent data sets were used in this study. The paragraphs that follow discuss the data sources, accuracy and sample sizes.

The first data set was obtained from tracking devices installed in nine minibus taxis by Mix Telematics. Taxi owners were incentivised to have fleet monitoring devices permanently installed in their taxis. These devices provide GPS time, location and speed information at a frequency of 1Hz. This data set contains a total of 402 complete trips through the ASOD system between November 2013 and May 2014. Although the data was gathered from taxis within the same association, each

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taxi owner has a set of contracted drivers who usually work across different minibus taxi associations. As such, the sample is a representative set of drivers who take the long distance route along the R61. Every weekend, minibus taxis from Cape Town travel to the Eastern Cape along this route. On a Friday night, about 300 minibus taxis use this route. The reader is referred to [8] for details on how the minibus taxi industry operates in South Africa.

The second data set was obtained from a database of historical tracking information from all vehicles tracked on TomTom Traffic Stats. Information was obtained from tracking devices, TomTom navigation devices, TomTom fleet management, and other TomTom solutions. The set contained over 2300 samples for the segments analysed before and during ASOD enforcement. This data was collected from a range of high quality data sources such as live PNDs (Personal Navigation Devices), in-dash navigation and business solutions, after which sophisticated data fusion was applied to achieve high accuracy and detailed road coverage.

B. *Method of evaluation*

The aim of this study is to investigate the impact of ASOD systems on speeding and compliance with speed limits inside and outside the ASOD enforcement site. Since the literature already provides evidence of crash reduction on the R61, the goal of this paper is to complement this evidence with detailed speed profile results. To achieve this, one enforcement site (with ASOD) and one adjacent control site (without ASOD) is evaluated. The control site was chosen such that its geometric characteristics and traffic conditions would be similar to those of the enforcement site. Figure 1 shows camera locations, the ASOD enforcement site and the control site for this study, and Table I is a summary of time frames and road characteristics. The date ranges were chosen while taking the implementation date of November 2011 and data availability into account.

Fig. 1: R61 evaluation section

Source: TomTom and Google earth view

Time differentiation was performed on the enforcement and control sites. This involved a ‘before’ and ‘during’ ASOD enforcement analysis on both the enforcement and control sites. Results from time differentiation on the enforcement site were expected to show reduction in travel speeds during ASOD enforcement. Similar results were also expected of the control site considering its proximity to the enforcement site.

Spatial differentiation was also performed with the aim of finding out the impact of ASODs on the control site relative to the enforcement site. This involved ‘in’ and ‘out’ of ASOD analysis before and during ASOD enforcement. Results from spatial differentiation before ASOD enforcement were expected to be similar while results during enforcement were expected to be slightly different.

TABLE I: Summary of date ranges and road characteristics

		Passenger Vehicle	Minibus Taxi
Enforcement site	Before ASOD	Jan 2008-Jun 2011	-
	With ASOD	Nov 2011-Dec 2013	Nov 2013-May 2014
	Distance (km)	51	71.6
	Speed limit (km/h)	120	100
Control site	Before ASOD	Jan 2008-Jun 2011	-
	With ASOD	Nov 2011-Dec 2013	Nov 2013-May 2014
	Distance (km)	52	54
	Speed limit (km/h)	120	100

A further investigation was conducted for minibus taxis, which used the probe data to detect whether vehicles violated the system. Using camera locations, complete trips along the enforcement site were identified and analysed. Average speed along the enforcement site was calculated using distance travelled and travel time. The integrity of the analysis was ensured by excluding any trips with no probe data within one kilometre from both camera locations.

Eight months of probe data between November 2013 and June 2014 were available for minibus taxis along the R61. This means there was no sample data for minibus taxis before ASOD implementation in November 2011. Due to this data availability constraint, only spatial differentiation during ASOD enforcement has been performed for the taxis.

IV. Results

In total, more than 2300 samples were used in the analysis of passenger vehicles and 402 trips were analysed for minibus taxis. Figure 2 shows the speed percentile plots for passenger vehicles and minibus taxis for each site and time. The figure shows an overall reduction in speed for passenger vehicles in both the enforcement and control sites during ASOD enforcement. There are, however, no significant differences between the speed profiles in enforcement and control sites for minibus taxis. Speed statistics obtained for passenger vehicles are summarized in Table II for time and spatial differentiation, while Table III shows the spatial differentiation results of taxis against those of passenger vehicles.

A. *Passenger vehicles*

As shown in Table II, the ASOD system appears to have had an impact on the speed profiles of passenger vehicles on the enforcement site. ASOD enforcement led to a reduction in mean speed by 5.5 km/h from 110.7 km/h before enforcement. The 85th percentile speed also reduced by 5 km/h, which corresponds to a 4% reduction. In addition, the percentile at the 120 km/h legal speed limit increased from 66% to 75%. This implies that passenger vehicles spent more time driving below the legal speed limit on the enforcement site.

The control site also showed positive results for passenger vehicles. Mean speed reduced by 6.9 km/h from 108.5 km/h before ASOD implementation. A 13 km/h reduction in the 85th

TABLE II: Spatio-temporal comparison for passenger vehicles

		N	Mean	V_{85}	$\%_{120}$	$\%_{100}$	Δ_{mean}	Δ_{85}	Δ_{120}
Enforcement	Before ASOD	306	110.7	129	66	20			
	With ASOD	1389	105.2	124	75	30	-5.5	-5 (4%)	9
Control	Before ASOD	101	108.5	136	64	20			
	With ASOD	528	101.6	123	80	28	-6.9	-13 (10%)	16

Note: N = average sample size; Mean = mean speed; V_{85} = 85th percentile speed; $\%_{120}$ = 120 km/h percentile crossing; Δ = difference between During and Before. All speeds are in km/h.

TABLE III: Spatial differentiation for taxis versus passenger vehicles

		N	Mean	V_{85}	$\%_{120}$	$\%_{100}$	Δ_{mean}	Δ_{85}	Δ_{120}	Δ_{100}
With ASOD	Enforcement	1389	105.2	124	75	30				
	Control	528	101.6	123	80	28	-3.6	-1	5	-2
With ASOD (Taxis)	Enforcement	402	110	128	60	14				
	Control	402	112	129	60	15	2.0	1	0	1

Note: N = number of trips for taxis and average sample size for passenger vehicles; Mean = mean speed; V_{85} = 85th percentile speed; $\%_{120}$ = 120 km/h percentile crossing; $\%_{100}$ = 100 km/h percentile crossing; Δ = difference between Control and Enforcement. All speeds are in km/h.

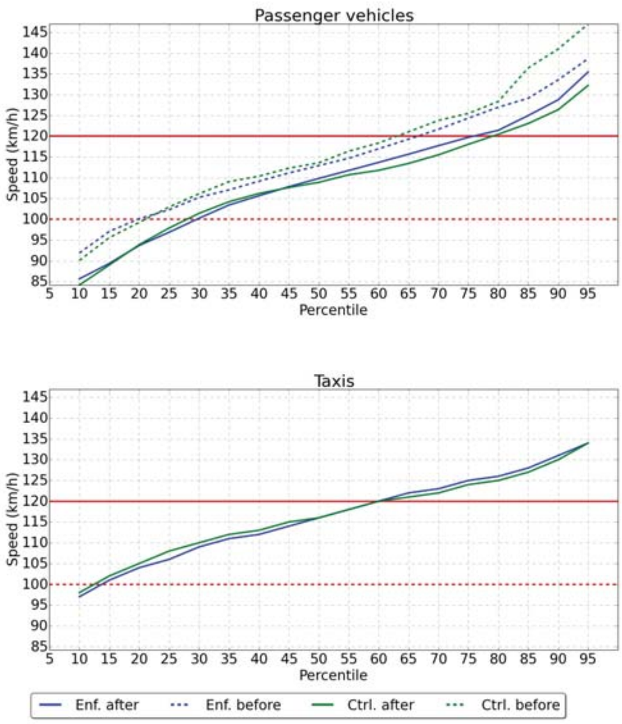

Fig. 2: Speed percentiles for passenger vehicles (top) and taxis (bottom)

percentile speed was also observed, corresponding to a 10% reduction. In addition, the percentile at the 120 km/h legal speed limit increased by 16% indicating that drivers adhered to the legal speed limit more often.

Time differentiation results for passenger vehicles showed that speed profiles on both the enforcement and control sites improved. However, the control site, which is some 20 km from the enforcement site, was characterized by a greater adherence to speed limits than the enforcement site. Given that other factors besides the ASOD system such as prolonged road works may result in speed profile improvements, the time differentiation results need to be validated. This will be accomplished by examining the spatial differentiation results before ASOD enforcement.

Before ASOD enforcement along this road segment, speed profiles on the enforcement and control sites were quite similar. This is evident from the plots in Figure 2 and in Table II where a difference in mean speed of only 2.2 km/h is observed. In addition, percentiles at the 120 km/h speed limit differ by only two percentage points. These observations indicate that before ASOD implementation, driver behaviour in the enforcement and control sites was not only similar, but was also characterized by higher speeds. Hence, the spatial differentiation results before ASOD implementation show that speeding patterns were very similar, which indicates that the speed reduction observed in time differentiation can only be attributed to the ASOD system, in agreement with findings in [5]. In addition, while time differentiation analysis for passenger vehicles shows that the ASOD system had an effect on the enforcement and control sites, spatial differentiation analysis shows that it had a greater impact on the control site with a mean speed 3.6 km/h lower than that of the enforcement site. This suggests that the ASOD system along the R61 also influences drivers to comply with legal speed limits on the control site with no ASOD enforcement.

B. *Minibus taxis*

Currently, the posted speed limit for minibus taxis on the enforcement and control sites is 100 km/h. But looking at the speed percentiles in Figure 2, only about 15% of all recorded taxi speeds are within this legal speed limit. Further more, besides a lower variation in speed for the minibus taxis, the speed profiles of minibus taxis are very similar to, or higher than those of passenger vehicles. This finding conforms with studies in [8], which presents similar results for three other road sections. Also, Table III shows that the average speed of minibus taxis during ASOD enforcement in both sites is at least 110 km/h, which is very similar to the average speeds of passenger vehicles before ASOD implementation. Furthermore, it can be observed from the spatial differentiation

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results that for minibus taxis, there appear to be no significant differences in driving behaviour at the enforcement and control sites due to very low percentile and mean speed changes. From these results, it is therefore evident that unlike passenger vehicles, minibus taxis are not influenced by the presence of the ASOD system along the R61. Also, the similarity between minibus taxi speeds during ASOD enforcement and passenger vehicle speeds before ASOD enforcement is an indication that performing time differentiation analysis on minibus taxis will show little or no significant changes

C. Further investigation on minibus taxis

An investigation on individual trips and speed distributions for minibus taxis shows that most drivers did not conform to the 100 km/h legal speed limit, which contradicts findings in [5]. Table IV shows a summary of system violations detected from probe data, for each tracked taxi. Results are expressed as a percentage of trips with an average speed beyond a certain threshold. The thresholds start at the 100 km/h speed limit and end at 120 km/h, with 5 km/h increments.

TABLE IV: Trip-based violations summary for taxis

Taxi	*N*	*SL (%)*	*SL+5 (%)*	*SL+10 (%)*	*SL+15 (%)*	*SL+20 (%)*
6000	74	81.1	71.6	62.2	52.7	32.4
6001	49	77.5	67.3	53	34.7	16.3
7000	32	75.0	56.2	31.2	15.6	0.0
7001	53	90.5	75.5	56.6	30.2	13.2
3001	56	80.3	76.8	64.3	50.0	21.4
1000	60	83.3	75.0	58.3	35.0	16.6
5000	30	83.3	76.6	56.6	46.6	33.3
4000	28	85.7	78.6	67.8	35.7	10.7
1001	20	70.0	60.0	35.0	20.0	15.0

Note: *N* = number of complete trips through ASOD system. *SL* = Speed limit of 100 km/h. *SL+10* = 110 km/h. *SL+10 (%)* is the percentage of trips with average speed greater than 110 km/h.

The results show that at least 70% of trips taken by each taxi violate their 100 km/h legal speed limit, and for some taxis, close to 34% of their trips violate the 120 km/h speed limit for passenger vehicles. While these results show that ASOD enforcement has little or no impact on minibus taxis, they also support findings in [14] on the impracticality and enforcement difficulties associated with differentiated speed limits. Furthermore, interviews with some of the drivers revealed that although they know the 100 km/h speed limit, they nevertheless consider 120 km/h as the limit which governs their choice of speed.

V. Conclusion

Even in the South African context, the effectiveness of ASOD systems in speed reduction and compliance with speed limits is unquestionable, especially for passenger vehicles. Although the average speed of passenger vehicles along the R61 was lower than their 120 km/h speed limit before ASOD implementation, a significant reduction in speed was still observed during ASOD enforcement. In addition, results for passenger vehicles show that the ASOD system also improved speed on the control site without ASOD. On the other hand, speeds of minibus taxis were not similarly reduced. Speed profiles of minibus taxis during ASOD enforcement on the enforcement and control sites were very similar, indicating that the system does not affect the taxis. Since many taxis have been identified for speed-related violations by this ASOD system in previous months, this discrepancy is peculiar. In addition, average speeds measured from probe data also show that most trips violate the system. The reason for such persistent violation by minibus taxis could either be due to discriminatory law enforcement which lets taxis drive above their legal speed limit, or due to failure of the ANPR cameras in detecting the taxis altogether. Investigation on these reasons were beyond the scope of this paper, and as a result, reserved for future work. Further research will also investigate the impact of ASOD systems on other South Africa roads for the same vehicle types considered in this study. This will also include survey responses from the drivers, examining their knowledge on how the ASOD system operates.

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