Measuring the Speed Before and After an Electronic Speed Enforcement System Using Bluetooth Technology

S. Yucel[1], H. Tuydes-Yaman[2]

[1]Integrated Systems & Systems Design (ISSD), Ankara, Turkey, sule.yucel@issd.com.tr
[2]Department of Civil Engineering, METU, Ankara, Turkey, htuydes@metu.edu.tr

Abstract

Electronic Control System (ECS) is an increasingly used Intelligent Transportation System (ITS) technology for traffic safety. There are different applications of ECSs aiming to mainly control vehicle speeds or enforce drivers to follow traffic rules and regulations. However, it is important to measure the impact of these ECS tools, which is a rather small literature in traffic safety. This study aims to measure the impact of ECS for speed limit enforcement applications, also known as Electronic Speed Enforcement (ESE) systems. In the determination of speed profiles before and after an ESE application point, Bluetooth Technology is employed, which itself is another innovative method for speed measurement in traffic studies. Though, the proposed methodology does not detect speed for every vehicle, a sample is created by detecting vehicles with active Bluetooth devices. The vehicular trip characteristics were estimated by processing the detection information of the same Bluetooth device over multiple observation points at, before and after an ESE location. Numerical examples were obtained by studying two corridors with ESE applications in the City of Ankara. Results showed that, drivers before the ESE system location obeyed the speed limits, while they increased their speeds immediately after the ESE point. These results support the fact that ESE is a powerful way of forcing speed limit; however, it is not easy to assess their impact on increasing traffic safety. Secondly, use of Bluetooth technology, a cheap and timesaving alternative for speed studies, is capable of providing information to analyze the impact of an ESE application.

Keywords: *Bluetooth Technology, Electronic Control Systems, Electronic Speed Enforcement, Average Travel Speed.*

1 Introduction

Due to high number of traffic accidents, traffic safety is a very critical issue currently in Turkey. Speeding is one of the major reasons of traffic accidents. Especially young drivers are the potential risk group for the personal injury and fatal accidents caused by over speeding (Wasielewski, 1984; Toroyan & Peden, 2007). Therefore, speed management is a crucial component of traffic safety applications. One of the most popular speed management techniques is “Speed Enforcement”, which aims to control vehicle speeds, enforce drivers to drive safe and increase the traffic safety. Besides the traditional manned speed limit enforcement (with radar, etc.), the advancements in technology led to development of ECS applications for Electronic Speed Enforcement (ESE). However, as the definition of “speed” change from application to application, some ESE systems focused on spot speed limit enforcement while others aimed to control corridor speed (average) enforcement.

As the ESE systems are being used increasingly in road traffic management in Turkey, majority of the applications focus on “spot speed limit enforcement” in Turkey, such as all the ESE application in Ankara. Although spot speed limit enforcement is more preferred mostly due to easier and cheaper system requirements, it is equally important to analyze the impact of these systems in terms of travel characteristics, mainly travel speed. This, however, will need speed data collection before and after an ESE application, which can be an expensive and time-consuming procedure. This study aims to measure the impact of an electronic speed limit enforcement application on vehicular travel speed. In the determination of speed profiles before and after an ESE application point, Bluetooth Technology is employed, which itself is another innovative method for speed measurement in traffic studies. Though, the proposed methodology does not detect speed for every vehicle, a sample is created by detecting vehicles with active Bluetooth devices. The vehicular trip characteristics were estimated by processing the detection information of the same Bluetooth device over multiple observation points at, before and after an ESE location. It is important to note that, despite the common use of Bluetooth technology in travel studies, such as corridor speed or Origin-Destination (O-D) estimation, Bluetooth data was capable of providing enough information to analyze the impact of an ESE application. However, low and non-random sampling ratio problems create a limitation on generalization of the findings.

The rest of the paper is organized as follows: A brief literature on speed enforcement and Bluetooth technology is given in Section 2. In Section 3, developed methodology is presented step by step. Section 4 deals with the numerical results of the developed approach and Section 5 concludes the study with the shortcomings sand recommendations.

2. Literature Review

It is important to measure the impact of ESE systems, which constitutes a rather small portion of the literature in traffic safety. Soole et al. (2013) gave a comprehensive literature review about average speed enforcement. They concluded that, all studies indicate the reduction in vehicle speeds and crashes via the use of average speed enforcement systems and it has an advantage of being a network-wide approach regarding spot speed enforcement. The stated studies had mostly used speed check services and consultations as the data source. Retting et al. (2008) provided an evaluation of the automated spot speed enforcement system which belongs fixed speed cameras located among a freeway in Arizona. They measured speeds via photo radar positioned between speed cameras and they concluded that, especially highly visible enforcement systems have a large effect in reducing the speed. Liu et al. (2010) compared the speed limit effects of two automatic enforcement equipment, camera and radar. They measured the speeds before, at and after the enforcement location using a MC5600 vehicle classifier system and they concluded that, the cameras are more durable and effective method than the radars. Zhang et al. (2011) aimed to evaluate effectiveness of automated speed enforcement systems in China. They used radar gun during data collection process, gathered speed data from road segments before and after enforcement point and it was concluded that, the automated enforcement system is still effective up to 1 km away by roadside. Tay (2009) compared the traditional and automated traffic enforcement considering the number of crashes and violations. He obtained the speed and the crash data from Queensland Transportation Department and automated and manned enforcement data separately. Results showed that, manned enforcement is more effective in number of crashes, while automated enforcement has a more general deterrence effect.

Additionally, it is necessary to review Bluetooth technology and its usage in travel studies. Bluetooth is basically a wireless technology using a special radio frequency (2.4 GHz) to transmit data in short distances, mainly because of low power consumption and the security issues. Bluetooth protocol uses unique electronic identifiers, which are named Media Access Control (MAC) addresses. MAC addresses can be easily recorded with their time stamps by a Bluetooth sensor (hereafter will be named as “reader”). Bluetooth technology can be used in a variety of traffic applications, such as travel time and speed measurement, O-D estimation, intersection level of service calculation, etc. Some of the studies focused on travel time and OD estimation using Bluetooth data gathered from Bluetooth readers (Blogg et al., 2010 and Barcelo et al., 2010). They located Bluetooth readers which can capture Bluetooth enabled devices automatically by roadside; they concluded that, travel time analysis provides more reliable results, although OD estimation is more challenging and needs supplementary methods. Haghani et al. (2010) aimed to use Bluetooth data as travel time ground truth, instead of floating car data. They focused on filtering raw data, comparing results with floating car data and defining sampling rate for each Bluetooth reader. As a result of this study, Bluetooth technology was considered as a new alternative which can be used as especially travel time data source. Quayle et al. (2010) introduced a pilot study which aims to do arterial performance analysis using Bluetooth technology. They called Bluetooth sensor as Media Access Control (MAC) reader and emphasized that, MAC address is able to provide offline or real-time performance evaluation of various traffic applications, especially in intelligent transportation systems. Results showed that, larger data sets and more complex filtering algorithms are necessary to eliminate outliers, increase sampling rate and obtain more reliable results. Haseman et al. (2010) collected a comprehensive Bluetooth data and he concentrated on the evaluation of this data for work zones in real time. He tried to find a relation between crash rates and queuing in construction zones via the use of solar-powered Bluetooth readers.

3 Methodology

The methodology presented here mainly relies on detecting vehicles at multiple locations before and after an ESE application. To capture the potential change in vehicular speed around an ESE application, it is necessary to focus on the following steps: Bluetooth data collection plan and processing, segment speed profile estimation and overall evaluation of ESE impact. The details of these steps are discussed below:

Step 1 Bluetooth Data Collection Plan: As the initial step, Bluetooth Data Collection Plan must be developed. This plan should include the number and location of Bluetooth readers, including the optimum distance between readers. At least two segments before and after ESE application location should be studied to detect the vehicular movements and speed changes along the study corridor. In this study, enforced speed limits are 70 km/h for private cars and 50km/h for others. Therefore, 5 observation points (ESE application, 500 m and 1000 m before and after the ESE) were chosen as the reader locations. Because of the availability of only 4 Bluetooth readers, a more dynamic plan was developed to get data for these 5-reader measurement plan; for a 2-hour observation period, three of them were located on ESE location, 500 m before and after permanently; the remaining one was located 1000 m before the ESE location for an hour and 1000 m after the ESE location for the next hour. Bluetooth readers recorded reader ID, MAC address, time stamp and signal strength information of the captured device together for the duration of the observation.

Step 2 Bluetooth Data Processing: To determine the vehicular speed before and after an ESE application, Bluetooth data from multiple observation locations has to go through a series of processing as follows:

• ***MAC Matching:*** To estimate speed of a vehicle with an active Bluetooth device over a segment or multiple segments, it is necessary to observe the MAC address at two or more readers; however, the active device can be observed multiple times by a reader. Thus, it is important to i) the unique MAC addresses at a reader and then ii) match these recorded addresses across readers.

• ***Vehicular Speed Estimation:*** Detection time of the matched MAC addresses can be used to estimate travel times of each vehicle which is equipped with a Bluetooth-enabled device. Travel time estimation using Bluetooth data was discussed in Yucel et al (2013). Dividing the segment distance by travel time, it is possible to get "average travel speed" of a vehicle over the segment. Since, it is important to track speed of vehicles before and after an ESE, the methodology does not use the "space mean speed" concept which averages the vehicular speeds harmonically. As it is possible to determine direction of the vehicle movements by comparing the detection time of the same Bluetooth device, vehicle speeds for both directions can be calculated separately. Since Bluetooth data may include outliers of very low value that may belong to pedestrians, bikes, parked vehicles or detours, it is necessary to eliminate them to get more reliable results. At first, calculated average travel speed values were filtered statistically by eliminating those 2-standard deviations lower and higher than the segment mean. Secondly, values lower than 20 km/h (minimum) and more than 150 km/h (maximum) were eliminated intuitively.

Step 3 Segment Speed Profile Estimation: To analyze the impact of ESE system**,** detected vehicular average speeds at each corridor before and after ESE application should be evaluated together. For this purpose, segment speed distributions could be plotted. To create the filters discussed above, it is also necessary to calculate segment mean values. Using the latter and the calculated standard deviations, it is also possible to estimate "expected distribution segment profiles" which can be fit to the real distribution for comparison. For this analysis, a normal distribution is assumed for the expectation. It may be also informative to track a vehicle speed change along the study corridor, which is kept out of the scope of this study.

Step 4 ESE Impact Overall Evaluation: Plotting the segment-wise speed distributions, it is possible to see the change in the mean and standard deviation values over the segment. This may reveal if there are drastic changes before or after ESE application. Looking at the segments before the ESE, it may be possible to comment on the "slowing down" behavior of drivers; similarly, speed change over the segments after the ESE may reveal insights on the "beyond enforcement" behavior. These patterns may be compared to those that would be obtained from a "corridor enforcement", if available. However, the real effect of ESE systems should be certainly interpreted by traffic safety experts. Randomness and sampling ratio issues should be also considered during the impact evaluation process, since non-random data or low sampling ratio directly effects the reliability of the results.

4 Numerical Results

Numerical examples were obtained by studying two ESE application points in the City of Ankara; Eskişehir Road and Mevlana Road (see Figure 1) and the speed limits were 70 km/h for private cars, 50 km/h for the others at the time of the study. The technology that they use is fixed traffic cameras located on the top of the roads. Bluetooth readers were employed during two-hour off-peak noon and afternoon (11:00-13:00 and 16:00-18:00 on Tuesday; 12:00-14:00 and 17:00-19:00 on Wednesday) periods to eliminate the peak-hour factors. Data collection process was repeated on the next day to handle with the missing data. Total number of 4338 unique MAC addresses were captured in the first day, while 5520 unique MAC addresses were captured in the next day.

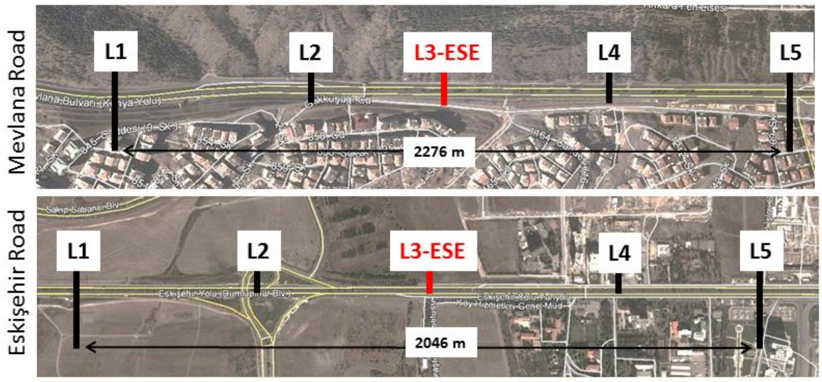

Figure 1. Study corridors: Mevlana Road (above) and Eskisehir Road (below)

Segment speed profiles and mean values were obtained as discussed in Step 3 and displayed in Figure 2. The second half of the figure shows the change of segment mean values over the ESE study corridors. The numbers supported the common expectation of sudden slow-downs (almost in the first 500 m before the ESE) to obey the speed limits, which are mostly increased suddenly after the ESE. Similar behavior is observed on both Eskişehir and Mevlana corridors. To give more insights, speed distribution at the two segments right before and after the ESE location (L3) on Eskişehir Road are provided in the first part of the Figure 2. This graph suggests that vehicles flow at almost similar speeds with small variations before an ESE but display a more dispersed pattern right after it. This may be due to the fact that some aggressive drivers temporarily slow down right before an ESE but speed up right after as opposed to those which follow a more uniform speed through an ESE point.

5 Conclusions

The study showed the potential of a Bluetooth-based methodology to evaluate the impact of electronic speed enforcement. Although the Bluetooth data is a sample of the total flows on the corridor, it was possible to observe main trends in the traffic behavior via Bluetooth based data. Also, since the vehicles are not directly identified, this methodology does not violate privacy rights, and Bluetooth Technology is a cheap and timesaving alternative for traffic related studies. Such monitoring systems should be implemented to evaluate ESE impacts at low costs. However, it is important to create further level data processing to understand the Bluetooth activation (whether multiple active Bluetooth device in the vehicle, etc.) to shed light on the randomness of the Bluetooth-based sampling. It is also more informative if the MAC-to-volume ratios (which means unique MAC number to traffic volume) are calculated to have an idea of the sampling ratio. Considering the increasingly use of this technology, this method may provide more significant results. The Bluetooth data collection plan is important in the reliability of the assessments; if the segments are taken too long, calculated average travel speeds may not reflect the slowing down or speeding up segments properly. Missing Bluetooth data, unexpected mean speed values, limited number of Bluetooth readers may be considered as the major shortcomings of the study. To deal with these shortcomings and limitations, more complicated filtering techniques, verification with supportive data collection techniques like probe vehicle and GPS should be applied. As a more comprehensive method, vehicles should be tracked along the corridor and speed distribution graphs of the whole corridor should be defined. Moreover, the use of Bluetooth technology in speed estimation should be studied in detail and the ways of getting more reliable speed results should be discussed.

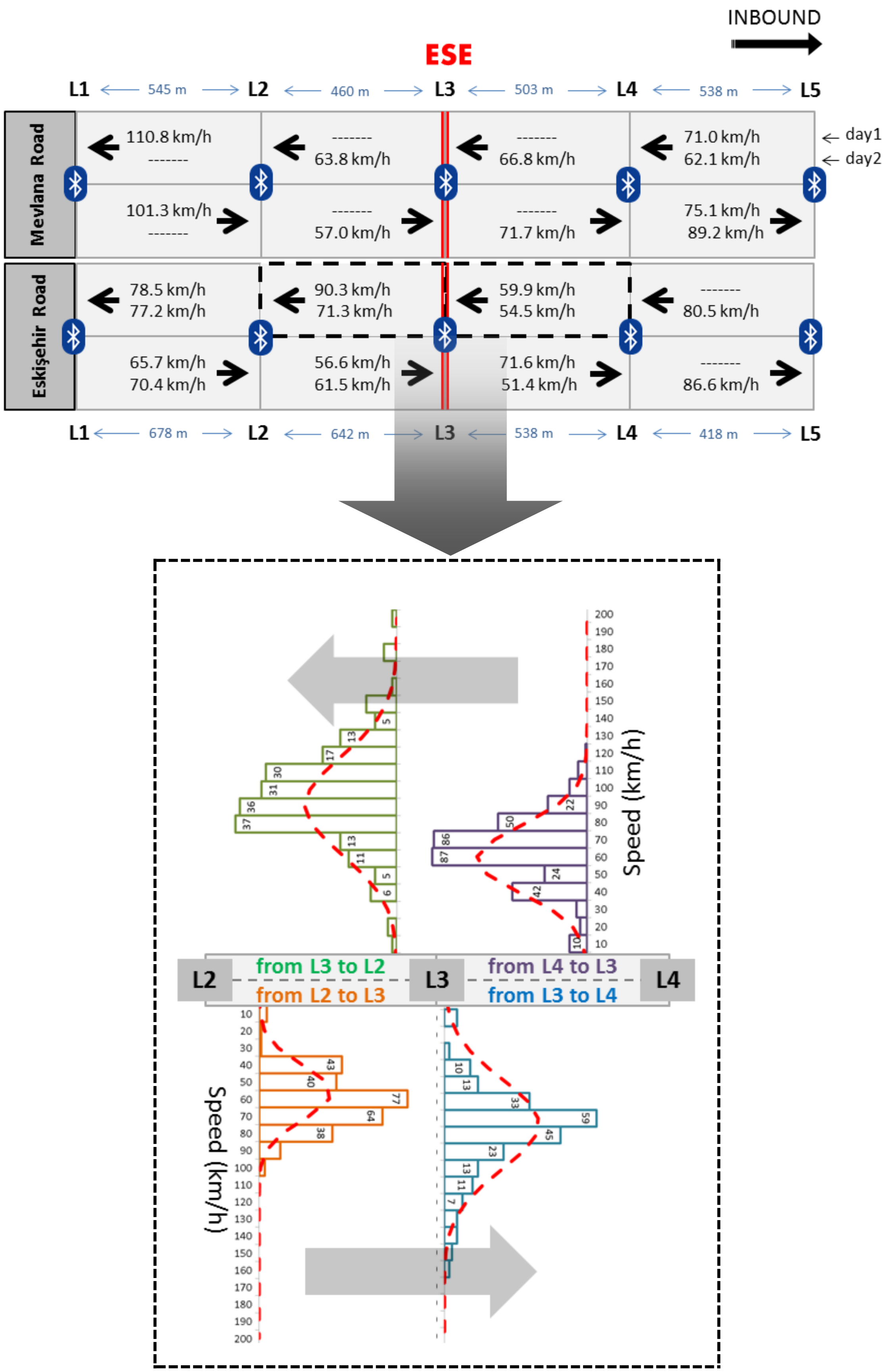

Figure 2. Average travel speeds (above) and Eskisehir Road segment profile (below)

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