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The application of continuous speed data for setting rational speed limits and improving roadway safety

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ABSTRACT

Speed is a primary contributor to crash frequencies and increased severity with over 30% of traffic fatalities attributed to speed. Research on rational speed limits suggests that simply lowering speed limits does not necessarily result in safer roadways; thus, there is a need to revisit the process by which speed limits, which are the front lines of any speed management program, are established. Traditionally, speed studies are conducted by taking spot speed observations at varying intervals along a roadway, however it would be ideal to have speed values continuously along a roadway. The specific objective of this research effort was to compare a continuous data collection method with existing methods and develop a methodology for integrating them to improve roadway safety. In this study, a group of drivers were equipped with a smartphone application which continuously captured video, vehicle speeds, and location data. The continuous speeds were then compared to speeds captured at eight fixed points. The results identified similarities in the 85th percentile speeds observed using the various data collection methods and a case study was conducted using FHWA's expert system, USLimits2. The results provide evidence for a successful proof of concept for mapping continuous speed data to traditional speed data collection points that may help in the speed limit setting process as well as the establishment of appropriate advisory speed zones. This research endeavor outlined a methodology which may be utilized to improve the process by which engineers determine speed limits and advisory speed zones.

1. Introduction

1.1. The impact of speed limits and methods of setting speed limits

Speed is one of the main factors that influences crash risk and severity. Each year, approximately 30% of traffic fatalities are speeding-related with an economic cost to society of $40 billion (NHTSA, 2012). Engineers use an assortment of traffic control devices to communicate simple messages to vehicle drivers, with speed limit signage being the primary mechanism for conveying appropriate roadway speeds to the motoring public. More specifically, speed limits are the front lines of speed management and serve as a valuable tool in promoting roadway safety. Speed limits that are too low lead to high non-compliance rates (Parker, 1997). By comparison, speed limits violate driver expectancy if they are set above safe operating speeds. Speed limits should reflect the roadway environment and driver expectation. In 1998, the American Association of State Highway and Transportation Officials (AASHTO) published its Strategic Highway Safety Plan which set a target of halving fatalities within two subsequent decades. Within the AASHTO plan, "Setting Appropriate Speed Limits" was identified as an objective to reduce speed-related crashes (AASHTO, 1998).

To set appropriate speed limits it is important to understand the differences in the designated design speed, inferred design speed, and operating speeds. The designated design speed is defined by AASHTO as "a selected speed used to determine the various geometric design features of the roadway" (AASHTO, 2011). The inferred design speed differs from the designated design speed in segments of roadway where all design elements exceed criterion-limiting values (Donnell et al., 2009). For example, if the designated design speed on a roadway sets a minimum sight distance

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requirement, the inferred design speed would exceed the designated design speed when longer sight distance is present. The inferred design speed could, in theory, be less than the design speed if the road was improperly designed. Often times, speed limits are set to the critical inferred design speed, or the segment of roadway where the inferred design speed is at a minimum and most near the designated design speed. This results in operating speeds on the adjacent segments that greatly exceed the posted speed limit, leading to challenges for law enforcement as to how to set a threshold for enforcement.

Over the course of the past decade the concept of rational speed limits has evolved while being promoted on a national level. Rational speed limits are based upon speed data analysis to establish a speed limit that is clear to motorists, provides logical enforcement, and creates a safe roadway environment (Forbes et al., 2012). By this logic, the speed limits on some roadways may be increased or decreased in the effort to improve safety. Various studies have shown that an increased speed limit, combined with enforcement, can lead to fewer speeders, a decrease in standard deviation of speeds, and decreases in crash frequency (Freedman et al., 2007). Education is also critical to implementation, as rational speed limits are more effective when motorists are aware of the increased enforcement (Knodler et al., 2008; Son et al., 2009).

NCHRP Report 500 which provides guidance on the AASHTO Strategic Highway Safety Plan states that a speed limit should depend on four factors: design speed, crash frequencies and outcomes, speed tolerance and enforcement threshold, and finally vehicle operating speed measured as "a range of 85th percentile speeds taken from spot speed surveys of free-flowing vehicles at representative locations along the highway" (Neuman et al., 2009). Free-flowing conditions exist when drivers are able to choose their desired speed without constraints from other vehicles on the road.

The Federal Highway Administration (FHWA) has taken this a step further with the development of USLimits2, a "web-based expert advisor system designed to assist practitioners in determining appropriate speed limits in speed zones" (Srinivasan et al., 2006, 2008). The inputs include: type of surrounding development, access frequency, road function, crash history, pedestrian activity, and existing vehicle operating speeds. The system takes 85th and 50th percentile speeds from segments that do not have adverse alignments. System guidance suggests that speed data should be taken from a 24-h weekday period, which differs from many states' guidelines which require a spot speed study of 100–200 free-flow vehicles (Minnesota Department of Transportation, 2012). With either method, the location(s) of data collection is subject to engineering judgement as time, equipment, and cost restraints limit the amount of data collection points.

1.2. Methods of speed data collection

There are many different ways to conduct a speed study, each with its own strengths and weaknesses. An objective of this research is to compare a new data collection technique with some existing methods. Existing methods of speed data collection include:

- Pneumatic Tubes with Automated Traffic Recorders (ATRs).
- RADAR/LiDAR Speed Guns.
- Probe Vehicles.
- Inductive Loops.
- Side-fire RADAR Units.
- On Board Diagnostic (OBD) Black Boxes.
- GPS Smartphone Apps.

ATRs capture volume, vehicle class, gap and speed data over long time periods. ATRs are commonly used to capture speed data over one week and to measure average annual daily traffic (AADT). ATRs can accurately capture vehicle speeds (Gates et al., 2004) and do not influence driver behavior (Jasrotia, 2011), but cannot easily distinguish whether or not a vehicle is traveling in free-flow conditions. As mentioned above, an ATR is installed in a single location. If multiple data collection locations are desired, then multiple ATR installations are required, which can be costly.

RADAR and LiDAR speed sensors are the preferred method of speed detection by law enforcement as they have the ability to provide the speed of a selected vehicle. They differ in that a RADAR gun can be easily used while moving, while a LiDAR gun functions more effectively while stationary (Bagdade et al., 2012). However, LiDAR guns are more effective at longer ranges and can be more accurate as a laser sight allows the user to know exactly which vehicle is being captured. While other states stipulate larger samples, in Massachusetts a spot speed study using a RADAR or LiDAR gun involves an inconspicuous observer capturing a sample set of 100 vehicle speeds in free-flow conditions (MassDOT, 2012). On rural roads with low volumes this can often take several hours to collect. If more locations are needed, speed studies using a RADAR or LiDAR gun can be costly in terms of person-hours. Additionally, the LiDAR gun itself costs $2000–$3000.

Inductive loops installed consecutively in a roadway provide a more permanent method to capture vehicle speeds. Loops use magnetic fields to detect the presence of passing vehicles and typically cost $1000 per installation before traffic control expenses (Middleton and Parker, 2002). A single inductive loop can be used to calculate vehicle speeds but require algorithms to be installed on the traffic signal controller (Lu et al., 2012).

Side-fire RADAR units are portable devices which can be installed on utility poles and can capture multiple lanes of bidirectional traffic speeds. The units are easy to install and capture speeds accurately, but require a clear line of sight and measuring the geometry of the roadway prior to installation. Additionally, the high cost of the unit, $4000–$5000, may make this form of data collection prohibitive for smaller agencies (Marti et al., 2014).

Trial runs, or probe drives, are usually conducted in addition to one of the methods described above. MassDOT's guidelines for probe drives stipulate that three drivers are to drive the portion of roadway being studied with an observer seated directly behind them recording their speed every 1/10th of a mile (MassDOT, 2012). Probe drives are conducted in order to provide a more complete speed profile than the spot speed observations. However, the effect of the passenger observer is significant on the driver's performance as they feel like they are being studied. This effect is lessened when the probe drive is monitored via vehicle instrumentation. The 100-Car Naturalistic Driving Study found that participants had a lower incident rate in the first hour of the study, but quickly forgot they were being monitored and resumed normal driving behavior (Dingus et al., 2006). Probe drives provide more granular data than the previous methods but are not as granular as the following two methods.

There are various devices which plug into a vehicle's OBD port and function similar to an airplane's black box. An OBD black box can capture the vehicle's GPS position, speed, steering wheel position and RPM one to three times per second (Intelligence to Drive, 2015). The data is a large step up from trial runs in terms of accuracy and OBD devices have less of an impact on driver behavior. However, these devices are similar in cost to LiDAR guns and require after-market installation in vehicles. Additionally, these devices cannot distinguish when the vehicle is traveling in free-flow conditions.

Smartphone apps can have similar functionality to an OBD black box by recording a user's GPS position and speed using the phone's