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Driving behavior at a roundabout: A hierarchical Bayesian regression analysis

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ABSTRACT

The paper models and compares driving behavior and vehicular emissions at a roundabout. Four drivers drove a vehicle instrumented with a GPS data logger over a study route. Second-by-second vehicle positions were recorded for various runs. Speed profiles of drivers were modeled using a Bayesian inference methodology. Circulating speed and maximum accelerations were simulated from the speed profile models and were compared across drivers. In addition, vehicular emissions were estimated using past experimental data. It is found that speed profiles differ significantly across drivers, as do the mean speeds at the circulating path of the roundabout. Acceleration events correspond to significantly higher emissions since during acceleration more than required fuel is injected into the combustion chamber of the engine. An emissions hotspot was defined as group of consecutive locations on the route where the sum of absolute values of acceleration was more than 95 percentile. Emissions at these hotspots were more than 25% of the emissions for a given speed profile.

1. Introduction

The transportation sector generates about 30% of the greenhouse gas (GHG) emissions in US. A number of solutions have been proposed to address this problem. Apart from decreasing number of trips or using alternative fuels and vehicle systems, eco-driving (environmentally friendly driving behavior) has gained importance as a part of the solution for the increasing pollution. Driving behavior may be defined as any parameter or group of parameters, their combinations, derivatives or transformations that characterize a driver's choice of speed, acceleration and gear to accomplish the driving task (Ericsson et al., 2006). Driving behavior manifests in terms of controlling speed, acceleration, lane position and headway during driving.

The way we drive has a significant effect on fuel consumption and emissions. Aggressive driving may contribute to 40% higher fuel consumption as compared to normal driving, and emissions may be still higher (Brundell-Freij and Ericsson, 2005) and a single hard acceleration event may cause as much pollution as the rest of the trip (Guensler, 1993). Aggressive driving can lower fuel mileage by about 33% on a highway and 5% on an urban road, and each 5 mph above 60 mph can reduce fuel economy by 7% (EPA, 2011). Nam et al. (2003) found that aggressive driving produced significantly higher carbon monoxide, hydrocarbon, nitric oxide, and carbon dioxide. Holmén and Niemeier (1998) found that the variability associated with driving behavior produced significantly different tailpipe emissions.

A good understanding of driving behavior is likely to help control vehicular emissions and optimize fuel economy. It is important to consider the instantaneous variation in individual speeds and driving behavior to estimate emissions better

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(Laureshyn et al., 2009). Here we model instantaneous driving behavior that goes beyond aggregate comparisons of vehicular emissions.

2. Data collection and extraction

Driving behavior and vehicular emissions are highly depend on the traffic conditions (Ahn et al., 2002), the vehicle (Wenzel and Singer, 2000), the driver (Yu and Qiao, 2004) and the traffic control devices present at a traffic intersection (Ahn et al., 2009). An appropriately chosen test period, test route, test vehicle and subject drivers are needed to control for variables other than individual driving behavior. To this end, a corridor on Douglas Parkway (Urbandale, IA) was chosen as the study route. Douglas Parkway is a minor arterial and is a paved four-lane road (median separated) that passes over interstate I-35 at Urbandale, IA. The study corridor was located west of interstate I-35. It consisted of several traffic intersections with the following traffic control devices: a traffic signal, a roundabout (average radius ≈76.47 ft.), and an all-way-stop.

Four graduate students at Iowa State University, including two male and two female drivers, were chosen as subjects for the study. They were 20–25 years old and had a minimum of 3 years of driving experience and were familiar with US road and traffic conditions and regulations. The test vehicle was a 2005 Ford Taurus, a mid-size gasoline passenger car with automatic transmission system. Second-by-second speed data was recorded for all trips using a GPS attached to the car. Four days of data were collected during April 2010. This included morning and afternoon peak hours from 7 to 9 am and from 5 to 7 pm and morning and afternoon off-peak hours from 9 to 11 am and from 3 to 5 pm. On a typical day of data collection, two drivers and a data collector would visit the site. Both drivers would take turns and drive during the specified peak and off-peak hours. This was done so that everyone drives in similar traffic conditions. On an average, each driver made 25 trips. Drivers would drive back and forth between the two extremes of the study corridor. A typical trip consisted of driving from one end of the corridor to another (either east bound or west bound). One hundred and nine trips and 16 h of data were collected. The data collector was responsible for recording queue position and getting a qualitative assessment of the traffic condition in real-time. On an average, the drivers started to decelerate about 500 ft. upstream of the roundabout and got back to the free flow speed at about 500 ft. downstream of it. Speed profiles (time series) starting 500 ft. upstream and 500 ft. downstream of the roundabout were extracted from both the east bound and west bound trips using a GIS package. Statistical language R (R core Team, 2011) was used for data preparation and analysis and ggplot2 was used for data visualization (Wickham, 2009).

3. Data analysis and speed profile modeling

Various driving behavior parameters have appeared in the literature both in the form of aggregate and instantaneous measurements. The most common aggregate driving behavior parameters used in research are mean speed, mean positive speed, mean acceleration, mean deceleration, mean driving duration, number of acceleration and deceleration events, idling time, positive kinetic energy, and relative positive speed (André, 1996). Some of the instantaneous measures of driving behavior are inertial power (Fomunung et al., 1999), drag power (National Research Council, 2000) and vehicle specific power or VSP (Jimenez, 1999). If speed is known with reasonable accuracy, then acceleration can be derived by taking the first difference.[1] Therefore, if speed is appropriated, most of the other driving behavior parameters can be derived and used for characterizing driving behavior.

Jimenez (1999) derived the expression for VSP (Eq. (1)) by summing up kinetic energy, potential energy, and work done in overcoming the frictional and drag forces, and dividing by the vehicle mass. Jimenez (1999) showed that VSP is highly correlated to vehicular emissions and is therefore an important driving behavior parameter. Eq. (1) applies to specific case of light-duty vehicles. VSP is later used in this paper for comparing driving behavior and emissions.

$$VSP = v(1.1a + 9.81grade + 0.132) + 3.02 \times 10^{-4} v^3 \quad (1)$$

where *VSP* is the vehicle specific power (m^2/s^3), v is the vehicle speed (m/s), a is acceleration (m/s^2), and grade is the road grade (%).

The route was chosen so as to have all different type of traffic control devices (traffic signal, all-way-stop, tangential section, curved section and roundabout) on it. This was done so that it represents a typical road corridor not restricted to roundabout alone. The traffic conditions were comparable during peak and off-peak hours and therefore all trips were combined for modeling.

For each trip, speed profile was defined by taking the consecutive second-by second observations confined within 500 ft. upstream to 500 ft. downstream of the roundabout. The road geometries at the two approaches (east bound and west bound) of the roundabout were different. To maintain consistency, speed profiles from east bound trips alone were used in the model. This reduced the dataset to 58 trips through the roundabout. The spatial locations for the speed profiles differed from one trip to another since vehicle positions were recorded at one second interval and the test vehicle was moving at different speeds on different trips. . Consequently, the speed profiles were also of unequal length. To address this problem, we converted each speed profile from temporal to spatial dimension by snapping each speed profiles to a defined trajectory. This trajectory consisted of 44 points separated by 10 ft. based on, 44 points covering the area of influence of the roundabout (500 ft. upstream to 500 ft. downstream), and that on an average, the vehicle traversed more than 40 ft. every second. This

[1] Almost all of the parameters can be obtained from speed and acceleration (Ericsson, 2000).