

Modeling Passenger Vehicle Acceleration Profiles from Naturalistic Observations and Driver Testing at Two-way-stop Controlled Intersections

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ABSTRACT

A primary goal of crash reconstruction (or collision avoidance system) is to determine whether a crash is avoidable or not. A prerequisite for the determination of avoidance is knowledge of the time that is available to a driver. In a path intrusion crash scenario, a method to determine the time available for a major road driver is to know the time a minor road driver accelerated before impact. This research is an attempt to model the time based upon acceleration distance.

The current study involved two parts. Part one was a naturalistic study of driver acceleration behavior at two-way-stop controlled intersections. In part two, ten drivers with instrumented vehicles were asked to drive a route that included four acceleration runs at two-way-stop sign control intersections. In the naturalistic study, the accelerations were measured using video recordings and videogrammetry at known distances.

The purpose of the research was to gather acceleration data that was used to develop mathematical models that offers crash reconstructionists (and collision avoidance systems) the time duration of an acceleration given the distance to travel and the location of the accelerating vehicle along the acceleration profile.

The result was that drivers accelerate at a non-linear rate from two-way-stop controlled intersections. Duration of acceleration was best modeled with respect to distance (time *versus* distance) with a power function. Acceleration distance

versus time and speed *versus* time models are also offered. These results were compared to results from prior acceleration research that was conducted at similar and different intersections.

INTRODUCTION

Vehicle acceleration over a known distance offers information regarding the time of acceleration. The time a minor road driver accelerates from a stop sign area to impact offers information regarding the time available for a major road driver to respond. Given the time available to a driver, a crash reconstructionist may then determine if the driver on the major road could avoid the crash or not. As an example, if an intruding driver accelerated 5 m (16 ft) into the major road in 2 seconds and we learn that a typical driver on the major road needs two seconds to respond (perception-response time), then no time would be available for an avoidance maneuver and that crash scenario would be unavoidable for most drivers. Knowledge of the time available to a driver may also be vital information for a collision avoidance system. Another use of average acceleration and the variance of accelerations would be to determine the probability of a driver stopping before entering an intersection.

A driver's acceleration varies throughout the acceleration process. One of our primary goals is to determine the duration of the acceleration. To that purpose, the average or nominal acceleration factor utilized by a crash analyst should account for the portions of the acceleration profile that were part of a driver's pre-impact acceleration. Long [1] reported that "Design accelerations were found to deviate substantially from observed accelerations" (p. 58). Further, normal



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acceleration has been found to be more closely related to driver preference rather than vehicle capability [1]. Therefore driver acceleration behavior models for the purposes of crash reconstruction have yet to be produced.

Of interest are the acceleration curves or the manner in which acceleration changes. Previous research [1, 2, 3] has shown that driver accelerations in traffic involve three phases. Phase one is the initial slow phase in which the foot moves from the brake to the acceleration pedal and the pedal is depressed. Phase two involves a linear (or near linear) acceleration. Phase three involves a decreasing acceleration as the driver reaches his or her desired speed.

The American Association of State Highway and Transportation Officials (AASHTO) [5] assumes a piecewise linear acceleration, meaning that they assume linear accelerations for different phases of the acceleration. Long [1] indicated that the AASHTO Model is based upon research by Harwood [6] which utilized a trap between 61 and 122 m (200 and 400 ft) from the start of the acceleration and noted that most drivers will accelerate to 40 km/h (25 mph) before reaching the start of the trap at 61 m (200 ft).

Some acceleration models are concerned with the acceleration of vehicles to speeds near the speed limit; the research by Long [1], Hong [4], and Wang [7] modeled accelerations up to 60 km/h (37 mph). Bonneson [8], for instance, was concerned with the acceleration of vehicles on highway on-ramps, which involved a much higher desired constant speed than is common at most intersections. Happer [9] studied the trajectory and movement, including acceleration of left-turning vehicles at a signalized intersection. Many of the available models neglect the initial (slow) portion of the acceleration. Fugger [10] and Proctor [11] did address the slow acceleration at the initial phase.

On the basis of the literature, acceleration behaviors change at four-way-stop controlled intersections [7, 9, 10], two-way-stop controlled intersections [12, 13, 14], and at arterial entrances [15]. Further, accelerations change from an initial slower phase, to a more linear acceleration to a gradual tapering off phase. Therefore, the average acceleration will differ at different type intersections and will also differ during various phases of the acceleration. This research will build upon the research of others while specifically dealing with a common crash scenario by addressing acceleration at two-way-stop controlled intersections.

Several papers have reported that drivers exhibited linear decreasing acceleration profiles [1, 3, 7, 8]. A linear decreasing model assumes that drivers start at a peak acceleration and acceleration gradually decreases to zero. The linear decreasing model was based primarily upon research in which drivers were accelerating longer distances, such as along highway on-ramps. The time or distance necessary to

reach peak acceleration was not addressed in the linear decreasing model because it was not a significant factor in a long acceleration and because most research involved data collection at one sample per second. At a sampling rate of one per second, an initial slow acceleration is neglected.

If a minor road driver accelerates from a stop for five seconds or less, an initial slow phase of acceleration may not be ignored, even if it occurs for less than a second. This research will attempt to develop models for driver acceleration that reflects the behavior of drivers at two-way-stop-controlled intersections. Two primary studies were conducted:

1. A naturalistic study, where 244 unaware drivers were observed and videorecorded.
2. Driver testing, where 10 drivers were tested in instrumented vehicles along a route that included two-way-stop sign control.

The distance from the minor road stop line to the major road centerline was measured at several intersections. Based on our observations, the most common acceleration distances were 7.5 m (24.6 ft) for crossing one lane and up to 15 m (49.2 ft) when crossing two lanes. Since the latter acceleration distance data will capture the former, our goal was to capture at least 7.5 m of acceleration distance and preferably 15 m in the naturalistic study.

For the purposes of this research, acceleration will be reported in terms of g (gravitation units; acceleration m/s^2 divided by gravity). The acceleration duration discussed is from the first moment the vehicle starts moving to acceleration durations of 3 s in the naturalistic study and up to acceleration durations of 5 s in the driver testing study. Therefore, this research will focus upon the first two phases of the acceleration. The models presented (for acceleration durations of 1 to 5 seconds) were based on the data from the driver testing which was consistent with the data from the naturalistic study. Previously mentioned studies are in agreement that the final phase of the acceleration can be modeled with a linearly decreasing function.

METHODS

PART 1: NATURALISTIC STUDY

Experimental Set-Up

For this study, eleven two-way-stop sign-controlled intersections in the greater Toronto, Canada area (within about 100 kilometers) were selected. The intersections selected for the study were located in primarily rural environments, flat; without significant curves or elevations. The major roadways had an 80 km/h speed limit and the intersecting secondary roadway had 60 to 80 km/h (37 to 49 mph) speed limits. These intersections appeared to have relatively high traffic volumes. A total of 244 minor road

vehicles were observed, videotaped and analyzed for speed and accelerations. Video recording was conducted for a period of 10 to 20 minutes at each of the eleven intersections. Between 12 and 20 drivers were analyzed for each of the intersections. Only vehicles travelling straight through the intersection were included in our analysis. All vehicles that turned left or right at the intersections were ignored.

The vehicles were observed as they approached the stop sign/stop line area until they moved well into the intersections (up to 15 m) and/or out of camera range. We captured the initial few seconds from the moment the vehicles started moving to the point that the vehicle moved about 3 seconds into the intersection. Please note that many vehicles continued accelerating more than 3 seconds into the intersection, however in several instances, their view was obstructed by traffic travelling in the opposite direction; hence we reported on the initial 3 seconds of acceleration in this study.

A camera with digital video recording capabilities of 30 frames per second was utilized. The camera was set on a tripod and was placed near each intersection, perpendicular to the motion of the vehicles. The observations were made during favorable lighting and environmental conditions, with the exception of one intersection, which was observed during the day and at night. The experimenter was visible to drivers when collecting data; however, this did not appear to affect driver behavior.

Evaluation of Measurement Technique

Before collecting data, pilot tests were conducted to determine the accuracy of the videogrammetry method utilized in the analysis. Video data of an instrumented test vehicle was captured and analyzed. The instrumentation included two accelerometers, which were both placed near the center of gravity of the vehicle. The sampling frequency of the accelerometers was 100 Hz. The vehicle speed was calculated by integrating the acceleration of the accelerometer data and the accelerometer-specific software reported speeds. The instrumentation utilized were a Race Technology DL1 which contains a 100 Hz accelerometer and 5 Hz gps data logging unit, and a Gtech Pro which is a 100 Hz accelerometer and data logger.

Slow, gradual and abrupt acceleration tests were conducted with an instrumented test vehicle, videotaped and analyzed via the methodology presented in this paper. The video analysis software, Vernier Logger Pro, was utilized to create a two dimensional graphical representations of the motion seen in the video to mathematically analyze the events. A comparison of the vehicle wheelbase with the same distance on the video was performed as a way to verify scale. Points were traced manually and directly on selected targets on the videos (such as the center of the wheel). The software automatically entered the position coordinates into a

spreadsheet. The results were graphed as can be seen in [Figure 1](#). Analysis was conducted on each data set to determine the distances and speeds traveled over each time period.

At speeds greater than 1 to 2 m/s, the difference between the speed assessed using videogrammetry and that from the instrumented vehicle was between 5 and 10% overall. During the first second of acceleration, there was greater variance, but that variance reduced to less than five percent at acceleration durations of 3 s or more. These results suggest that videogrammetry is an effective method for measuring vehicle movements for the duration of acceleration in this research, similar to other research [[9](#), [10](#), [12](#)].

<[figure 1](#) here>

Observations and Results

During the study, traffic approaching the stop sign frequently did not stop or did not stop near the stop line. Generally, the traffic was observed to stop ahead of the stop sign or stop line, such that the front of the vehicle was set back from the intersecting roadway by a few meters as seen in [Figure 2](#) below.

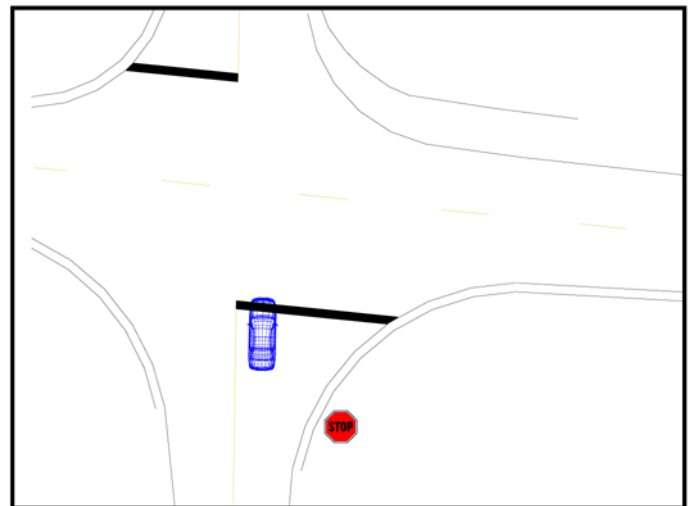


Figure 2. Top view of typical driver stopping position at intersection 9.

Screen captures of typical stopping position and acceleration for a vehicle at intersection #3 is depicted in [Figure 3](#) and [Figure 44](#). In [Figure 3](#), the stopping location of the vehicle is approximately 2.0 to 2.5 m from the edge of the road which is consistent with prior research [[6](#), [12](#)] who found that the typical stopping location of vehicles is with the front of their vehicle 1.7 to 2 m (5.7 to 6.5 feet) from the near edge of traveled lane.

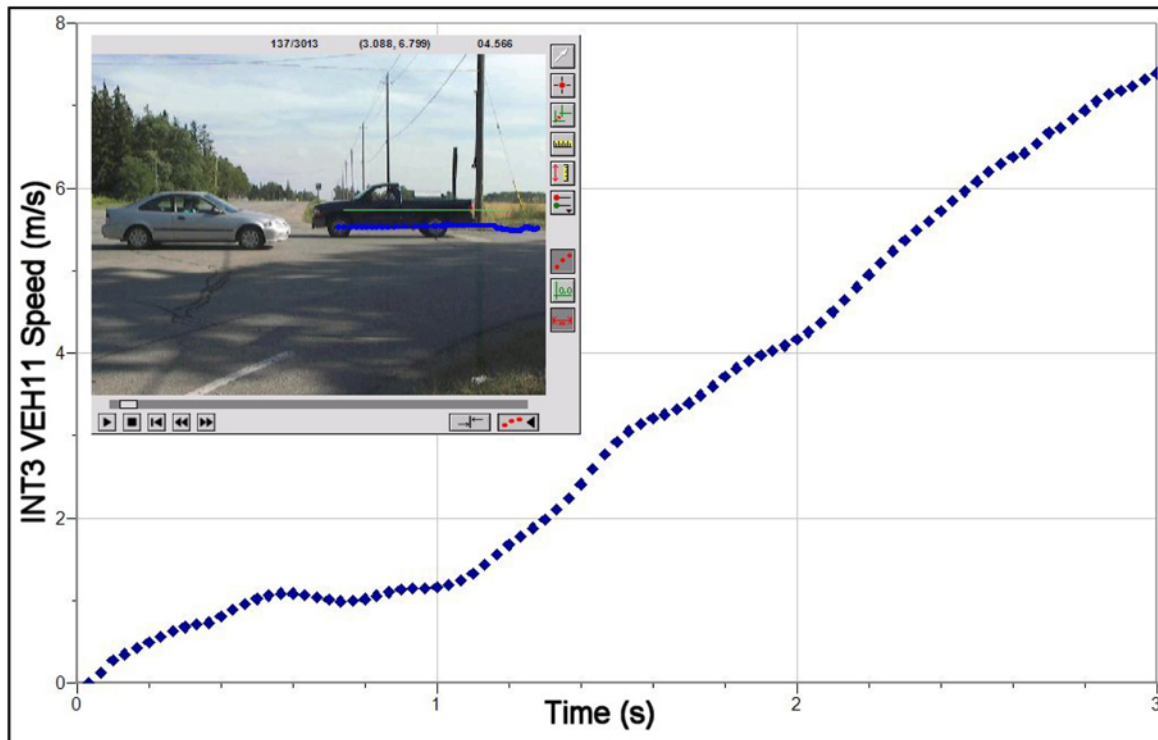


Figure 1. A screen capture of the speed graph for a trial at intersection #3. Note that the vehicle accelerated from a stop.



Figure 3. Typical stopping position for vehicles at intersection number 3.



Figure 4. View of the position of the vehicle seen in Figure 3 at approximately 2 seconds after the vehicle starts moving.

Vehicles were observed to either stop completely before entering the intersection, or they came to a “rolling stop” before entering the intersection. A “rolling stop” was one where the drivers rolled through the stop sign (or stopping) area at a relatively low speed (about 1 to 2 m/s) prior to accelerating across the intersection. The drivers appeared to check for traffic in the proximity of the intersection and then accelerated. There were several instances of queuing of