Traffic Operation and Safety Analyses of Minimum Speed Limits on Florida Rural Interstate Highways

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ABSTRACT

Traffic operation and safety characteristics were analyzed in relation to the posting of the minimum speed limit of 40 mph on Florida rural interstate freeways. The operational analysis results showed that 57% of the recorded vehicles exceeded the maximum speed limit. In addition, while only 0.14% of recorded vehicles had speeds below the 40 mph posted minimum speed limit, safety analysis results revealed that 9% of crash-involved vehicles were estimated to have occurred at speeds below 40 mph. The over-involvement of slow moving vehicles in the crash data suggests that even a small proportion of vehicles traveling under 40 mph can have negative impacts on safety. Thus, regulation of vehicle speeds at the lower end of speed distribution is important. Further, the second-order crash risk model developed to estimate the crash risk of a vehicle on the freeway as the function of the deviation from the mean traffic speed indicated that the minimum risk occurred when the pre-crash driving speed is 8 mph above the mean speed, which is equivalent to the 85th percentile speed observed in the field.

Key words: freeway operation—minimum speed—speed variation
BACKGROUND

The relevance of the 40-mph minimum speed limit posted on the Florida interstate highway system (FIHS) is increasingly being questioned in light of the National Highway System Designation Act of 1995, which repealed the federally sanctioned maximum speed limit of 55 mph. Following this act, Florida had the maximum speed limit raised to 70 mph, the maximum speed limit allowed by Florida state statutes, leaving the 40 mph minimum speed limit unchanged. It seems logical to question the safety and operational effects of the wide existing gap (30 mph) between the two speed limits. This wide gap can affect the operation of these freeways by increasing speed differentials between vehicles, which can lead to an increase in passing maneuvers (and its attendant consequences of improper lane changing), tailgating (driving too close to the slow vehicle in front), frustrations for faster drivers, and the formation of platoons of traffic.

The posting of 40-mph minimum speed limits was motivated by the desire to make the traffic flow as uniform as possible by bringing slower drivers closer to the average speed of traffic on interstate freeways, which are designed for high-speed mobility. This paper reviews the operational and safety aspects relevant to the posting of these limits on the FIHS by analyzing individual vehicle speeds and traffic crashes that occurred on these sections. The theme throughout the analysis is the contribution of slow moving vehicles to the speed distribution and occurrence of traffic crashes.

This paper is organized as follows. The following section reviews previous studies related to the effect of speed variability and the posting of minimum speed limits. The next sections describe the research methodology used to accomplish this study, followed by a data analysis section, and finally a discussion of the research findings.

Literature Review

The posting of minimum speed limits on freeways influences drivers to operate their vehicles at speeds higher than the minimum speed values that authorities consider safe for normal operation, and thus reduce speed variability between fast and slow vehicles. Certainly, this would reduce traffic conflicts and crashes likely to be caused by interactions among the slow moving vehicles and other vehicles on the freeway.

Several studies have documented the effects of speed variability, slow driving, and the risk of crashing. The consistent findings in these studies are that the risk of crashing is smallest in the vicinity of the median speed of the traffic stream and that slow drivers are as hazardous as fast ones in the operation of the freeways. After examining 10,000 drivers on 35 sections of rural highways in 11 states, Solomon (1964) was the first to show an association between speed deviation from the mean speed and frequency of crashes. Solomon found that there was a parabolic relationship between the crash risk of a vehicle and its deviation from the mean traffic speed, where traveling slower or faster than the mean speed had higher crash risks. In this study, the minimum risk of crashing was found to occur when the difference between the vehicle speed and average traffic speed reaches 10 mph above the average speed. Solomon’s results were supported by another multi-state study done by Cirrilo (1964). This study analyzed crashes that occurred on both rural and urban sections of interstate highways in 20 states. Cirrilo found that the crash risk was highest for vehicles traveling 32 mph below the average speed and fell to a minimum for vehicles traveling 12 mph above the average speed, rising again with a further increase of speed. Harkey et al. (1990) recently reproduced these findings, where the minimum risk of crash involvement was found to be at about the 90th percentile speed (90% of the drivers are traveling below this speed), for analyzed crashes that occurred on urban roadways in North Carolina and Colorado.
A study conducted by West and Dunn (1971) found that the presence of a significant number of slow moving vehicles in the traffic stream increases speed variability and the number of crashes. The authors found that vehicles traveling at speeds of about two standard deviations below the average traffic speed were more involved in crashes than vehicles traveling at the average speed. To minimize the crash risks associated with slow driving, the authors suggested using the 15th percentile speed (15% of drivers are traveling below this speed) to set the minimum speed limits. A study by Hauer (1971) supported West and Dunn’s findings after finding that the imposition of minimum speed limits on highways was twice or thrice as effective as an equivalent maximum speed limit in reducing the frequency of overtaking and thus traffic conflicts and crashes. The negative effects of slow moving vehicles in the traffic streams was also pointed out by a Transportation Research Board study, which found that the likelihood of traffic crashes on the highway increases as the speed variance increases, because the latter causes significant lane changing maneuvers, which is a potential source of conflicts on the freeways (TRB 1984). In the fatality models developed in this TRB study, speed variance was found to have a statistically significant effect on the fatality rates on interstate freeways. Other studies have supported the positive association between speed variation in the traffic stream and crashes, including Garber and Gadiraju (1998) and Garber and Ehrhart (2000).

METHODOLOGY

The posting of higher speed limits on interstate freeways and the existence of high operating speeds necessitated the evaluation of the minimum speed limit posted on these highways. The effect of the wide existing gap between maximum and minimum speed limits can be assessed by a cross-sectional study examining driver characteristics and the resulting operating speeds for similar sites with and without posted minimum speed limits. However, all interstates highways in Florida have minimum speed limits posted; therefore, creating such a study was not possible at the time of this research. Thus, this study was limited to reviewing the operational and safety characteristics of the Florida rural interstate freeways in relation to the posting of minimum speed limits and the prevailing vehicle operating speeds. Of interest in the review was the operating speeds at the lower end of the speed distribution and the speed variances resulting therefrom. The safety review was focused on analyzing crashes in terms of speed and crash type, occurrences that might be associated with the speed differences among the involved vehicles. The research efforts were also directed at conducting a regression analysis to determine the relationship between speed and crash frequency.

DATA COLLECTION

Identification of Study Sites

At the beginning of the research, the entire freeway system was reviewed by driving through it and observing geometric and traffic operating conditions. During this field review, some few samples of the vehicle speeds were taken using a radar gun. In addition, all telemetered traffic monitoring stations (TTMS) found on Florida interstate freeways were evaluated to determine the suitability of their location in relation to this research. TTMS sites collect individual vehicle records on the roadway on a 24-hour basis through the year. These sites are maintained by the Florida DOT (FDOT). Site selection criteria were then devised based on the FDOT speed zoning manual (FDOT 1997). Site selection was targeted to choosing sites that are representative samples of the FHIS and that will produce the highest free-flow speed possible, i.e., the sites devoid of curves, sustained grades, and any other geometric constraints. Seven sites where then selected, two on six-lane freeways and five on four-lane freeways.
Collection of Speed Data

After the study sites were identified, individual vehicle data were collected for 24 hours from the TTMS sites on a typical weekday under good weather and dry pavement conditions. A computer program was designed to extract volume and speed data from the files downloaded from the TTMS site. This program was capable of checking the integrity of the data by checking for any recording errors and later removing all erroneous data and other anomalies. However, when the erroneous data were too extensive (greater than 5%), all data were discarded and another day’s data was downloaded from the site. Data from over 350,000 vehicles were verified to be good and used to analyze traffic operations in the freeway sections.

Traffic Crash Data

Four years (1998–2001) of crash data were acquired for a two-mile section in each study site. The source of this data was the safety office of the FDOT, which maintains all police-reported crashes that occurred on the state-maintained highway system. It is worth noting that police officers in Florida are required by law to report any crash that has resulted in fatality, injury, or property damage over $500. A total of 169 crashes were reported on these freeway sections during this time and were used for further analysis. It should be noted that any crash that occurred under inclement weather or jammed traffic conditions was not counted in this study.

ANALYSIS OF TRAFFIC OPERATIONS

Analysis of traffic operations was done by evaluating several statistics involving traffic volume, headways, and speeds. In the traffic volume analysis, the researchers were interested in hourly variations and the resulting level of service. Level of service is the stratification of the quality of operation of the roadway from A through F, with A representing the most favorable driving conditions and F the worst, measured at the peak-hour period of the day. In headway analysis, focus was given to vehicle platooning and vehicle speeds in these sections. Statistics useful for speed distribution analysis were the mean speeds, standard deviation of traffic speeds, and 85th and 15th percentile speeds, which traffic engineers normally consider as measures of fast and slow moving vehicles, respectively. In addition, pace speed and coefficient of variation of traffic speeds were analyzed. The coefficient of variation of speeds, which measure the relative dispersion of vehicle speeds, is calculated as the ratio of the standard deviation to the mean speed. The 10-mph pace is the 10-mph speed range with the highest number of vehicles in the speed distribution. Table 1 presents a summary of traffic operation characteristics.

Table 1. Summary of traffic operating characteristics

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Four-lane sections</th>
<th>Six-lane sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of service</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Percent traveling above 70 mph</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>Percent traveling below 40 mph</td>
<td>0.18</td>
<td>0.10</td>
</tr>
<tr>
<td>15th percentile speed (mph)</td>
<td>67</td>
<td>65</td>
</tr>
<tr>
<td>Average speed (mph)</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>85th percentile speed (mph)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Pace speed (mph)</td>
<td>69-79</td>
<td>69-79</td>
</tr>
<tr>
<td>Percent traveling in pace</td>
<td>65</td>
<td>66</td>
</tr>
<tr>
<td>Standard deviation of speed(mph)</td>
<td>6.2</td>
<td>5.4</td>
</tr>
<tr>
<td>Coefficient of variation of speed</td>
<td>8.5</td>
<td>6.8</td>
</tr>
</tbody>
</table>
The results presented in Table 1 shows that the level of service in these freeway sections is B or better, which indicates good operating conditions most of the time. Analysis of vehicle headways compared the mean speeds of platooned vehicles and non-platooned (or free flowing) vehicles. The results show that the differences between the speeds of platooned and non-platooned vehicles were insignificant for both four-lane and six-lane freeway sections.

The speed analysis results depicted in Table 1 show that, on average, the mean speed of all vehicles on these sections was 73 mph, which is 3 mph above the posted maximum speed limit. Specifically, the percentages of vehicles exceeding the maximum speed limit were 56% and 57% on four-lane and six-lane sections, respectively. Table 1 further shows that only 0.18% and 0.10% of the vehicles had speeds below the posted minimum speed limit (40 mph) on the four-lane and six-lane sections, respectively. The average speeds on the four-lane sections ranged from 66 mph to 74 mph, and 67 mph to 85 mph on the shoulder (outermost) and median lanes (innermost), respectively. On the six-lane sections, the average speeds of the vehicles on the shoulder, middle, and median lanes ranged from 67 mph to 70 mph, 72 mph to 75 mph, and 75 mph to 81 mph, respectively. The results further show that the 15th percentile speed by lane ranged between 61 mph to 77 mph and was averaged to be 65 mph across all sites.

Examination of the standard deviation of vehicle speeds showed low standard deviation of speeds, ranging between 4 mph and 10 mph. The averages of these standard deviations of speeds were 6.2 mph and 5.4 mph on four-lane and six-lane sections, respectively. The results further show low values for the coefficient of variation, ranging between 5% and 14%. These results suggest that the dispersion of the vehicle speeds from the mean speed is relatively small; thus, traffic flow in these sections is sufficiently uniform. Further examination of speed characteristics indicated that traffic in these highway sections flows at higher paced speeds. About two-thirds of recorded vehicles were traveling in this speed range in both the four-lane and six-lane sections.

ANALYSIS OF TRAFFIC CRASHES

Distribution of Crashes by Type

Analysis of crash severity indicated that of the 169 crashes that occurred on these sections in the four-year period, eight (4.7%) were fatal crashes, 99 (58.6%) were injury crashes, and 62 (36.7%) were property damage-only crashes. Analysis of the crashes further indicated that there were four major types of crashes that were frequently reported in the crash report forms: collision with a roadside object and run-off-road, rear-end crashes, angle/sideswipe crashes, and overturned vehicles. Stratification of crash by type indicated that about 41% of the total crashes involved a vehicle hitting a roadside object or a vehicle running off the road. The rear-end and sideswipe crashes were the second and third most occurring crashes, and accounted for 18% and 15%, respectively. All other crash types accounted for 12% of the crashes and are categorized as other.

Speed of Crash Involvement

The speed of crash involvement is the vehicle speed estimated by the investigating officer when the crash occurred, also referred to as pre-crash speed. The estimated vehicle speeds of the 244 vehicles involved in crashes were extracted from the crash report forms for the 169 crashes that were analyzed in this study. The distributions of the estimated vehicle speeds before crashes and the actual speed of the vehicles recorded from the TTMS are presented in Figure 1. Examination of the two distributions shows that the estimated pre-crash speeds are skewed to the left of the actual vehicle speeds collected at the site. Figure 1 further shows that the majority of the vehicles involved in crashes were traveling with estimated speeds.
between 60 and 70 mph. This range contains 66% of the vehicles involved in the crashes. However, the curve representing actual vehicle speeds shows that the majority of the vehicles, as defined by the pace speed, were traveling between 69 mph and 79 mph.

At the lower end of speed distribution in Figure 1, the results show an over-involvement of slow moving vehicles in crashes. For example, while the field data show that only 0.14% of the observed vehicles were traveling with speeds below 40 mph (the minimum speed limit) averaged across all sites, crash data analysis revealed that about 9% of vehicles involved in crashes had estimated speeds below 40 mph. Furthermore, the percent of vehicles involved in crashes with estimated speeds below 55 mph were significantly higher than the overall percentage of vehicles observed traveling below 55 mph in the field. This analysis suggests that slow driving is dangerous and poses a large risk of crashing, though the proportion of slow moving vehicles in the traffic stream on these freeway sections is low.

Crash Involvement Rates

Crash involvement rates in these sections were calculated as the ratio of the number of vehicles involved in a crash within a speed range to the total number of vehicle miles of travel within that speed range. This statistic implies the effect of vehicle miles of travel (a product of volume and distance traveled) on the occurrence of crashes. Vehicle miles of travel is also known as a traffic exposure variable. The speeds of the vehicles were expressed as deviations from the average speed of, and then correlated to, the crash involvement rates. It is worth noting that the analysis of actual speed data collected across these sites revealed that the average speed of traffic on these highways was 73 mph. Crash involvement rates are presented in Table 2. Examination of the crash involvement rates and the speed deviations necessitated the use of a logarithmic transformation of the vehicle involvement rates, as shown in the third column of Table 2.
Table 2. Crash involvement rates versus deviation of speed from the mean speed

<table>
<thead>
<tr>
<th>Speed deviation (mph)</th>
<th>Crash involvement rate (CIR) (crashes/million vehicle miles)</th>
<th>logCIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30</td>
<td>30000</td>
<td>10.31</td>
</tr>
<tr>
<td>-25</td>
<td>6494</td>
<td>8.78</td>
</tr>
<tr>
<td>-20</td>
<td>2885</td>
<td>7.97</td>
</tr>
<tr>
<td>-15</td>
<td>1215</td>
<td>7.10</td>
</tr>
<tr>
<td>-10</td>
<td>769</td>
<td>6.64</td>
</tr>
<tr>
<td>-5</td>
<td>497</td>
<td>6.21</td>
</tr>
<tr>
<td>0</td>
<td>914</td>
<td>6.82</td>
</tr>
<tr>
<td>5</td>
<td>134</td>
<td>4.90</td>
</tr>
<tr>
<td>10</td>
<td>123</td>
<td>4.81</td>
</tr>
<tr>
<td>15</td>
<td>413</td>
<td>6.02</td>
</tr>
<tr>
<td>20</td>
<td>580</td>
<td>6.36</td>
</tr>
</tbody>
</table>

A second-order polynomial regression model was later used to model the crash involvement rate as a function of the deviation of the vehicle speeds from the mean speed to produce a crash risk model. The dependent variable measuring the risk that a vehicle will be involved in a crash takes the following form:

\[
\log CIR = \beta_0 + \beta_1 SD + \beta_2 SD^2 + \epsilon
\]  

(1)

Where \( \beta \) are the regression coefficients determined by the model, \( SD \) is the deviation from average speed, and \( \epsilon \) is the error term for uncorrelated variables with a mean of zero and a constant variance. The regression results are presented in Table 2. The fitted curve is also presented in Figure 2.

![Figure 2. Crash involvement rate versus deviation from the mean speed of traffic stream](image)

The quality of the fitted model was evaluated by its coefficient of determination \( R^2 \) and F-statistic. From the model results presented in Table 3, an \( R^2 \) of 90% suggests that the second order polynomial model adequately fits the data and the relation has a significant curvature. In addition, the small p value (0.0001) of the overall model obtained from the model F-statistic indicates that the model is plausible and statistically significant. The partial t-tests for the individual coefficients in the model also show that all
coefficients are statistically significant. Therefore, the risk of crash involvements can be estimated using the following parabolic equation:

\[
\text{Crash Involvement Rate} = \exp(0.0033SD^2 - 0.048SD + 5.754)
\]  

(2)

After equating the first derivative of Equation 2 to zero, the minimum crash risk was found to be about 8 mph above the mean speed, or 81 mph, as the actual vehicle speeds showed an average speed of 73 mph. This finding mirrors the results that were obtained by Solomon (1964) and Cirrilo (1968), who showed that the driving speed at the minimum risk of crashing on rural interstate freeways is about 10 mph and 12 mph above the average speed, respectively. Furthermore, the data show that the risk is higher when traveling at the average speed than when traveling at 8 mph above and below the average speed.

Further analysis of the regression model developed shows that the minimum risk of crashing is equivalent to the 85th percentile speed of the vehicle speeds observed in the field. These findings mirror the recommendation made by an FHWA study (Parker 1985) that the minimum and maximum speed limits should be set at 10 mph below and above the average speed, respectively. Parker’s study suggested that a speed 10 mph below the average represented the 10th percentile, while a speed 10 mph above the average represented the 90th percentile.

**Table 3. Regression Results of the Polynomial Model**

<table>
<thead>
<tr>
<th>Coefficient, β</th>
<th>Standard error</th>
<th>t</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD</td>
<td>-0.0478</td>
<td>-3.65</td>
<td>0.007</td>
</tr>
<tr>
<td>SD²</td>
<td>0.0033</td>
<td>4.33</td>
<td>0.003</td>
</tr>
<tr>
<td>Constant</td>
<td>5.7542</td>
<td>23.35</td>
<td>0.000</td>
</tr>
</tbody>
</table>

F = 38.15, Prob > F = 0.0001, R² = 0.9051

**CONCLUSIONS**

This paper has presented the results of operational and safety analyses of the Florida interstate freeway system in relation to the posting of minimum speed limits. The research approach was to compare operating speed characteristics with crashes that were reported in the sampled sections. The major theme throughout the analyses was to quantify the level of importance that various speed characteristics had for safety of operations on the selected rural freeway sections.

The operational analysis results show that 57% of the recorded vehicles exceeded the maximum speed limit of 70 mph, while only 0.14% of the vehicles had speeds below the minimum speed limit of 40 mph. The 85th and 15th percentile speeds were 80 mph and 65 mph, respectively. It should be noted that these statistics are used as a guide in setting maximum and minimum speed limits, respectively, in conjunction with other safety aspects of the particular roadway. Comparison of actual vehicle speeds recorded at the site and estimated pre-crash vehicle speeds revealed overrepresentation of slow moving vehicles in the crash data (a slow vehicle was defined as one traveling below the minimum speed limit). While only 0.14% of the vehicles had field-recorded speeds below 40 mph, 9% of the crash-involved vehicles were estimated to have speeds below 40 mph. The overrepresentation of slow moving vehicles in the crashes shows that slow moving vehicle can cause problem for the safety of operation of highways, even when their proportion in the traffic stream is very small. This finding may perhaps underscore the need to raise the minimum speed limits.

The safety modeling results indicate that the presence of a significant amount of vehicles traveling slowly with respect to the driving population increases the risk that the vehicles will be involved in a crash. The
relationship between crash risk and the deviation of the speed from the mean traffic speed explained by a crash risk model was found to be parabolic, with a minimum risk occurring when the vehicles were travelling at 81 mph (or 8 mph above the mean speed). The 81-mph speed was equivalent to the 85th percentile speed of vehicles observed in the field. These results replicate findings from previous research.

Should the minimum speed be raised to 65 mph, equivalent to the 15th percentile of operating speeds observed in the field? Although the results of the polynomial modeling indicate a safe driving speed, this research could not accurately answer this most fundamental question. Therefore, further research is needed to answer this question by probing the effect of the minimum speed limit sign on driver behavior, as simulation analysis would not be able to depict driver behavior appropriately on roadways with and without posted minimum speed limit signs. In the meantime, it can be presumed that higher minimum speed limits might increase incidents of driver error, particularly for vulnerable drivers, e.g., older drivers, recreational vehicle drivers, and drivers of vehicles towing trailers, who are probably comfortable with speeds below 65 mph but above 40 mph. Additional work is also needed to increase confidence in the results reported herein by attempting to determine the actual pre-crash speed, because the use of police-reported pre-crash speeds as the representative operating speed prior to crashing could skew the results.
REFERENCES


