ACCELERATION CHARACTERISTICS OF VEHICLES IN RURAL PENNSYLVANIA

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ABSTRACT
The objective of the paper is to determine the acceleration characteristics of vehicles in rural Pennsylvania. The floating car method was used to observe the acceleration characteristics during overtaking maneuvers. The acceleration characteristics from rest were observed manually. Various acceleration values for different vehicles were determined. The maximum value of acceleration observed was that of SUVs and the minimum value of acceleration observed was that of buses.

A comparison of observed passing sight distances on a two lane highway in rural Pennsylvania with that of AASHTO was made. The observed passing sight distances were shorter by 18% and 8% at 35 km/h and 85 km/h design speeds. This is because at lower design speeds, the observed acceleration was higher.

Keywords: Acceleration Characteristics, Transport Planning, Traffic modeling

1. INTRODUCTION
For a safe and efficient overtaking maneuver, the driver should have a clear minimum sight distance. Successful overtaking maneuver becomes even more critical when the roads and streets are two lane highways on which overtaking of the slower vehicles stakes place. The minimum sight distance should be void of traffic and the overtaking maneuver should not cut off the vehicle that gets passed [1]. The minimum sight distance is mandatory to overtake on the roads. The vehicle acceleration data is needed not only for calculating the minimum sight distance but also for finding the required lengths of the intersection sight triangles for the vehicles to accelerate. The acceleration rates of vehicles are useful in the areas of economy of gas/fuel, travel time values, prediction of flow of traffic etc. When the acceleration rate is more, then the minimum sight distance needed would be reduced [2,3]. Modeling using acceleration characteristics is required for cost analysis, pollution control calculations, consumer fuel consumption estimations and for calculating the different components of overall delay. The objectives of this paper are:
1. Determination of acceleration characteristics of various starting vehicles.
2. Determination of acceleration characteristics of vehicles during overtaking
3. Performance of passing sight distances on a two-lane rural Pennsylvanian highway and compare the results with that of AASHTO’s recommended values.
4. INITIAL ACCELERATION CHARACTERISTICS OF VEHICLES FROM REST
Initial acceleration characteristics of vehicles are useful for the design of highways, traffic signals, rail road crossings, transportation systems analysis and simulations. Various factors that affect acceleration characteristics of vehicles are the type of the vehicle, the engine power of the vehicle and the vehicle’s dimensions. Hence for this study, the average acceleration values were considered. The vehicle will accelerate more when it starts from its rest position. The maximum acceleration of both vehicles can be explained with the following model
\[ a = A + BV \] (1)
‘A’ is the maximum acceleration corresponding to the velocity of the vehicle (zero) when it starts where, ‘B’ is the rate of decrease in acceleration as the speed increases. In design however, the usage of acceleration characteristics is restricted to boundary conditions. People usually accelerate more when the vehicle is at rest and tend to decrease when they want to bring the vehicle to their desired level of speed. In that case, there will be no acceleration as the passenger is comfortable in their desired level of velocity and does not want to change it. Studying the model of acceleration on a linear basis provides the best description of the behavior of the driver. Glauz [4] estimated the values of the functions A and B to be 2.85 and -0.0853 respectively, establishing a linear relationship. The notion that acceleration decreased with speed when both are a linear function was supported by John and Kobett [5].

3. METHODOLOGY AND DATA COLLECTION
The experiments were performed on 2 stretches of 150m length each, on a two-lane road near Philadelphia. The stretch was equally separated into 5 sections of 30 m each (Table 1). The study started from a traffic signal
intersection, so that the vehicles’ acceleration characteristics from rest would be noted. On an average, studies were conducted for 5 hours on a regular weekday. Studies were conducted with stop watches which had an accuracy of 0.01 s. An observer was employed at each station.

Table 1. Sample Calculation Sheet

<table>
<thead>
<tr>
<th>Speed of Experiment Vehicle (kph)</th>
<th>Steps</th>
<th>Time (s)</th>
<th>Distance (m)</th>
<th>Acceleration, (km/h/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1 - 2</td>
<td>1.11</td>
<td>22</td>
<td>3.90</td>
</tr>
<tr>
<td></td>
<td>1 - 3</td>
<td>3.10</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 - 4</td>
<td>4.17</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 - 5</td>
<td>4.78</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>1 - 2</td>
<td>1.19</td>
<td>23</td>
<td>3.10</td>
</tr>
<tr>
<td></td>
<td>1 - 3</td>
<td>3.28</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 - 4</td>
<td>4.59</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 - 5</td>
<td>5.22</td>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>

4. ANALYSIS OF DATA

The study performed included 187 recordings. Data from 98 cars, 36 SUVs, 22 motorcycles, 13 trucks and 18 buses were considered in the recordings as shown in Table 2. Figure 1 shows the variation between the time and cumulative distance for a car.

Table 2. Acceleration rates of vehicles

<table>
<thead>
<tr>
<th>Overtaking vehicles</th>
<th>Minimum (kph/s)</th>
<th>Maximum (kph/s)</th>
<th>Average (kph/s)</th>
<th>S.D</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>1.1</td>
<td>8.3</td>
<td>3.9</td>
<td>4.23</td>
<td>98</td>
</tr>
<tr>
<td>SUV</td>
<td>1.5</td>
<td>8.7</td>
<td>4.5</td>
<td>4.02</td>
<td>36</td>
</tr>
<tr>
<td>Bus</td>
<td>0.90</td>
<td>4.9</td>
<td>2.6</td>
<td>2.91</td>
<td>18</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>0.68</td>
<td>6.7</td>
<td>3.7</td>
<td>3.66</td>
<td>22</td>
</tr>
<tr>
<td>Trucks</td>
<td>1.5</td>
<td>5.2</td>
<td>2.8</td>
<td>2.98</td>
<td>13</td>
</tr>
</tbody>
</table>

\[ y = 0.2343x^2 + 1.5652x + 8.8721 \]

\[ R^2 = 0.9997 \]

Figure 1. Influence of Time on Distance

The time-distance relationship is expressed by the formula:

\[ d = -X t^3 + Y t^2 + Z t \]  

(2)

where \( d \) is defined as the distance covered. The coefficients within the polynomial are constants. The time taken by the vehicles is represented by \( t \). The procedure was repeated several times. The average, minimum and maximum time taken by a vehicle to travel the 150m distance was calculated. Upon the differentiation of the time-distance equations, speed time relationship and the acceleration-time relationships are obtained.
5. ACCELERATION DURING OVERTAKING

The overtaking vehicles increase its acceleration more than that of the vehicle it overtakes, till the process of overtaking takes place. Under the circumstances of no vehicle approaching from the opposite direction, the overtaking vehicle can stop its acceleration increase and return to its normal acceleration in the lane it continued. The variation of acceleration with velocity is given in Figure 2. Figure 3 shows variation of velocity with time for cars.

![Figure 2. Influence of Velocity on Acceleration](image)

![Figure 3. Influence of Time on Velocity](image)

The performances of passenger cars under different circumstances were studied by Samuel and Jarvis [6]. John and Kobett [5] stated that under no acceleration limits, the drivers opted for an acceleration that was a linear function between the difference in the speeds. According to Kumar and Rao [7], the acceleration rate and the overtaking time were found to have good correlation with results of this study.

Field observations were taken on the same stretches. The method used for the field observations was floating car method. One vehicle was chosen to be kept at a constant speed and this acted as the experiment vehicle. The reason the vehicle was kept at constant speed was to allow the overtaking by vehicles and for the data recording purposes. The highway did not have any curves and was a single stretch of a plain level terrain, with a good surface condition.
The overtaking process was split into 5 steps. A safety distance between the front bumpers of the experiment vehicle and the overtaking vehicle was maintained at Step 1. This is given by the equation,
\[ P = m_1 + m_2 V, \]  
where \( V \) is the speed of the test vehicle.

Step 1: The overtaking vehicle begins the overtaking procedure by moving to the adjacent lane.
The distance covered during Step 1 could be given by the equation,
\[ L_1 = m_1 + m_2 V + V_e t_1 - L_e \]  
\[ (4) \]

Step 2: The rear bumper of the experiment vehicle and the front bumper of the overtaking vehicle are at same level.
The distance covered here is given by the equation,
\[ L_2 = V_e t_2 + L_e \]  
\[ (5) \]

Step 3: The front bumpers of both vehicles are at same level. The distance travelled is given by the equation,
\[ L_3 = V_e t_3 + L_o \]  
\[ (6) \]

Step 4: The front bumper of the experiment vehicle and the rear bumper of the overtaking vehicle are at same level.
The distance is,
\[ L_4 = V_e t_4 - L_o + 0.7V_o \]  
\[ (7) \]

Step 5: The vehicle finishes the overtaking procedure and goes to its original lane.

\( t_1 \) through \( t_4 \) are the times taken to complete the respective steps. \( L_e \) and \( V_e \) are length (4.52m) and velocity of experimental vehicles respectively. \( L_o \) and \( V_o \) are length and velocity of overtaking vehicles respectively. 2 observers were present in the experiment vehicle. Observation was carried out when a vehicle came up to the experiment vehicle trying to overtake it. As the different steps involved in the overtaking procedure took place, the observations were made. The time taken for each step was observed. The experiment vehicle was overtaken by different vehicles like cars, SUVs, buses, trucks and motorcycles.

C++ was used to make observations of the time between the different steps during overtaking. Vehicles that came behind the experiment vehicle were treated as sample vehicles. When the sample vehicle tried to pass the experiment vehicle, the time observations for different steps during the overtaking were noted. At each event the Enter key of the lap top was pressed. This activated the software to calculate the time observations between the events. Various sample vehicles were used during the experiment.

6. DISCUSSION OF RESULTS
The acceleration of the vehicle was calculated by differentiating the time-distance equation two times. With every overtaking maneuver, a time-distance equation resulted. Sample data set for a car overtaking the test vehicle at 2 different speeds is given in Table 1. Acceleration rates for different vehicles were determined by the same method. The values of acceleration for the different vehicles are given in Table 2. Similar results were found by Dey et al [8].

All the relationships developed have excellent coefficient of correlations. The mathematical relationship between time (x) and distance (y), shown in Figure 1 is given below.
\[ Y = 0.234 X^2 + 1.565 X + 8.72 \]  
\[ (8) \]

The mathematical relationship between velocity (x) and acceleration (y), shown in Figure 2 is given below.
\[ Y = -0.0215 X + 0.786 \]  
\[ (9) \]

The mathematical relationship between time (x) and velocity (y), shown in Figure 3 is given below.
\[ Y = 0.585 X + 1.890 \]  
\[ (10) \]

Following AASHTO standard observations were made for passenger cars at 35, 45, 65, and 85 km/h design speeds with 28, 35, 22, and 15 samples respectively. Passing sight distances were calculated for these speeds as shown in Table 3.

Based on the observed passing sight distance at 35 km/h design speed, 195 m is recommended, while AASHTO recommends 230 m. This is a 18% deviation. Based on the observed passing sight distance at 85 km/h design speed, 530 m is recommended, while AASHTO recommends 570 m. This recommendation reduced AASHTO’s value by 8%. This is because at lower design speeds, the observed acceleration was higher.

Some drivers accelerate at the beginning of a passing maneuver to an appreciably higher speed and then continue at a uniform speed until the maneuver is completed. Many drivers accelerate at a fairly high rate until just beyond the vehicle being passed and then complete the maneuver without further acceleration. For simplicity, such maneuvers are ignored by AASHTO. This study accounts for all the driver behaviors in the study area, thus explaining the differences between the two studies.
Table 3. Sample Calculation Sheet

<table>
<thead>
<tr>
<th>Avg. Speed of Passing Vehicle, (km/h)</th>
<th>Acceleration (km/h/s)</th>
<th>Total Passing Sight Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AASHTO</td>
<td>Observed</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>85 Percentile</td>
</tr>
<tr>
<td>35</td>
<td>2.19</td>
<td>3.52</td>
</tr>
<tr>
<td>45</td>
<td>2.22</td>
<td>3.45</td>
</tr>
<tr>
<td>65</td>
<td>2.27</td>
<td>3.33</td>
</tr>
<tr>
<td>85</td>
<td>2.36</td>
<td>3.24</td>
</tr>
</tbody>
</table>

7. RECOMMENDATION FOR FUTURE RESEARCH

Minimum sight distance requirements for passing on two lane roads should be updated in rural Pennsylvania using the acceleration characteristics determined in this study. The test data used for developing AASHTO standards are outdated and the results are conservative. This recommendation is limited to the area studied in this investigation. More tests should be conducted to come up with updated acceleration characteristics of vehicles for determining the passing sight distances on two lane roads. Similar studies may be conducted for determining updated sight distances for other regions in the country.

8. CONCLUSIONS

1. Vehicles travelling at constant speed had negligible changes in acceleration. The acceleration is inversely proportional to the speed.
2. Vehicles needing moderate overtaking times had negligible changes in acceleration.
3. The maximum acceleration during overtaking was observed for SUVs while the minimum acceleration was observed for motorcycles.
4. Based on the observed passing sight distance at 30 km/h design speed, 195 m is recommended, while AASHTO recommends 230 m.
5. Based on the observed passing sight distance at 80 km/h design speed, 570 m is recommended, while AASHTO recommends 530 m.
6. The observed sight distances deviated more from AASHTO’s recommended distances at lower design speeds than at higher design speeds. This is because at lower design speeds, the observed acceleration was higher.

9. ACKNOWLEDGMENT

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10. REFERENCES