A SPEED-FLOW MODEL FOR AUSTRIAN-MOTORWAYS

Dr. Hassan Mahdy
Public Works Dept., Faculty of Engineering
Ain Shams University, Cairo, Egypt.
E-mail: h9840417@hotmail.com

ABSTRACT

Conventional speed-flow models were developed to describe the interaction between both the speed and traffic volume for different types of traffic facilities, but without taking into consideration the variation in both the free flow speed and percentage of trucks from lane to lane among the motorway cross-section. Moreover, national traffic and driver behavior, which may vary from country to country, have significant influences on the interaction between speed and traffic volume.

In light of the recent studies dealing with speed-flow models and taking into consideration the recent understanding of the speed-flow relationship, which indicated that speed-flow relationship has more gradual slope with constant speed for higher levels of flow, this research focuses on a) development of a suitable speed-flow model for Austrian motorways, b) Estimation of passenger car equivalent factor for non-passenger cars traffic on Austrian motorways, c) Establishment of a speed-flow relationship of each specific traffic lane, and d) Estimation of the practical lane capacity of each specific lane.

1 THE EXAMINED AUSTRIAN MOTORWAYS

In the framework of a research project, two Austrian motorways were examined. This research project aimed at investigating the actual speed-flow interaction on Austrian motorways, and was sponsored by the Austrian motorways and tunnels financing corporation “ASFINAG”. The examined motorways are:

- The A2 motorway “Südautobahn”, six lane divided motorway with a speed limit of 130 km/h. The site plane of A2 motorway is shown in Figure 1.
- The A4 motorway “Ostautobahn”, four lane divided motorway with a speed limit of 80 km/h. The site plane of A4 motorway is shown in Figure 2.
2 DATA COLLECTION

Speed-flow data of the A2 motorway were provided by six automatic traffic count stations installed on the motorway at different locations. These data were projected over five minute observation intervals including traffic volumes and speeds of both the passenger and non-passenger cars for each traffic lane. Passenger and non-passenger cars were automatically classified according to each vehicle’s length. Vehicles up to 6 meters in length are passenger cars and those with more than 6 meters are non-passenger cars, including light trucks, trucks, trailers, buses, and similar vehicles. Traffic data of the A2 motorway were for three different days (3, 6, and 9/03/2000). These data were organized in an applicable form to be analyzed with the statistical software SPSS.

For the A4 motorway traffic data were collected using one point measurements with one video camera fixed over a railway bridge “Ostbahnbrücke” crossing the motorway. This traffic data was collected in three different days (18, 21 and 22/05/2000).

3 THE PROPOSED SPEED-FLOW MODEL

Based on the revision of the available speed-flow models, Brilon’s speed-flow model was structurally modified and used to fit the stable portion of speed-flow relationship on Austrian motorways. This model is expressed by:

\[ S = A_1 - A_2 \left[ e^{\alpha Q_{pc}} + e^{\beta Q_{nc}} \right] \]

(1)

To enable simultaneous analyses of different traffic lanes, dummy variables were introduced to the model, and the model is expressed by:
\[ S_l = A_1 - A_2 * \left[ A_3 * 10^{A_4} (Q_{pc,l} + E*Q_{n,l}) \right] \]  

(2)

Where:

\[ A_1 = a_1 + a_{11} * d_1 + a_{12} * d_2 \]
\[ A_2 = a_2 + a_{21} * d_1 + a_{22} * d_2 \]
\[ A_3 = a_3 + a_{31} * d_1 + a_{32} * d_2 \]

\( A_1, A_2, \) and \( A_3 \).....Parameters of the model;

\( d_1 \).......................Lane dummy variable (\( d_1 = 1 \) for 1st lane “right lane”, 0 for middle and left ones);

\( d_2 \).......................Lane dummy variable (\( d_2 = 1 \) for 2nd lane “middle lane”, 0 for right and left ones);

\( a_i, a_{ij} \)..............Coefficients of the lane dummy variables where \( i =1, 2 \) and 3 and \( j =1 \) and 2 (model parameters);

\( S_l \).......................Speed of traffic lane \( l \) where \( l =1, 2 \) and 3 (km/h);

\( Q_{pc,l}, Q_{n,l} \)..........Traffic volumes of passenger and non-passenger cars; respectively, of lane \( l \) where \( l =1, 2 \) and 3 (v/h);

\( E \).......................Weight factor (passenger car equivalent factor) for non-passenger cars.

Speed-flow data of the A2 motorway covered both the stable and unstable flow conditions. Since the developed speed-flow model was utilized to fit speed-flow data only in stable flow condition, another model was suggested to fit the unstable portion of speed-flow data. This model is expressed by:

\[ S = B_1 + B_2 * \left( Q_{pc} + E* Q_{n} \right)^2 \]  

(3)

To enable simultaneous analyses of different traffic lanes, dummy variables were introduced to the model, and the model is expressed by:

\[ S_l = B_1 + B_2 * \left( Q_{pc,l} + E* Q_{n,l} \right)^2 \]  

(4)

Where:

\( S_l \).......................Speed of traffic lane \( l \) where \( l =1, 2 \) and 3 (km/h);

\( d_1 \).......................Lane dummy variable (\( d_1 = 1 \) for 1st lane “right lane”, 0 for middle and left ones);

\( d_2 \).......................Lane dummy variable (\( d_2 = 1 \) for 2nd lane “middle lane”, 0 for right and left ones);

\( b_i, b_{ij} \)..............Coefficients of the lane dummy variables where \( i =1 \) and 2, \( j =1 \) and 2 (model parameters);

\( B_1 \) and \( B_2 \)...........Parameters of the model;

\( Q_{pc,l}, Q_{n,l} \)..........Traffic volumes of passenger and non-passenger cars of lane \( l \) where \( l =1, 2 \) and 3;

\( E \).......................Passenger car equivalent factor for non-passenger cars.

The above two models were simultaneously calibrated using non-linear regression analysis. To differentiate between stable and unstable flow, speed boundary was used. This boundary
is a shift of the developed model with a speed margin. This margin was determined by iterations in the regression analysis (see the schematic diagram in Figure 3).

Figure 3. Schematic diagram of the used procedure to analysis speed-flow data of the A2 motorway.

4 MODEL ESTIMATION

4.1 The A2 motorway
As shown in Figure 3 both the stable and unstable flow data were simultaneously analyzed. Truck traffic in both stable and unstable segments were converted to passenger car units (as shown in Figure 3) using weight factor \((E)\) which was a parameter in the models and was determined as output of the regression analysis.

The parameters of the models are in Table 1 and the predicted speed-flow relationships of left, middle, and right lanes of the A2 motorway are in Figures 4 through 7. The results of simultaneous analysis of all lanes of the A2 are in Figures 8 and 9.

Table 1. Parameters of speed-flow model of the A2 motorway

<table>
<thead>
<tr>
<th>Traffic lane</th>
<th>Stable flow</th>
<th>Unstable flow</th>
<th>Weight factor</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A₁</td>
<td>A₂</td>
<td>A₃</td>
<td>B₁</td>
</tr>
<tr>
<td>Left</td>
<td>142.74</td>
<td>5.920</td>
<td>0.889</td>
<td>24.11</td>
</tr>
<tr>
<td></td>
<td>4.361</td>
<td>0.891</td>
<td>1.231</td>
<td>2.102</td>
</tr>
<tr>
<td>Middle</td>
<td>126.09</td>
<td>2.968</td>
<td>1.249</td>
<td>23.21</td>
</tr>
<tr>
<td></td>
<td>3.655</td>
<td>0.743</td>
<td>0.976</td>
<td>1.881</td>
</tr>
<tr>
<td>Right</td>
<td>118.04</td>
<td>11.13</td>
<td>0.722</td>
<td>24.62</td>
</tr>
<tr>
<td></td>
<td>4.886</td>
<td>0.465</td>
<td>0.765</td>
<td>1.765</td>
</tr>
<tr>
<td>Simultaneous analysis of all lanes</td>
<td>Model Parameters:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a₁=182.56)</td>
<td>(a₁₁=-43.04)</td>
<td>(a₁₂=-47.30)</td>
<td>(a₃₁=0.093)</td>
</tr>
<tr>
<td>-Stable flow:</td>
<td>(a₂=41.33)</td>
<td>(a₂₁=-10.47)</td>
<td>(a₂₂=-30.63)</td>
<td>(a₃₁=0.308)</td>
</tr>
<tr>
<td>-Unstable flow:</td>
<td>(b₁=23.89, b₁₁=0.051, b₁₂=0.12)</td>
<td>(b₂=0.012, b₂₁=0.0032, b₂₂=-0.00089)</td>
<td>(b₃₁=b₃₁<em>d₁+b₃₂</em>d₂)</td>
<td>(b₃₂=b₃₂*d₃)</td>
</tr>
</tbody>
</table>

The estimated weight factor for non-passenger cars = 1.36
It should be noted that only one model was used in the simultaneous analyses of traffic lanes of the A2 motorway, where the parameters of the model are functions of dummy variables of traffic lanes. Figures 4 through 7 show that the expected lane capacities of the left, middle and right lanes of the A2 motorway are 2335, 2152 and 1839 pc/h, respectively. Note that the predicted weight factor for non-passenger cars (passenger car equivalent factor) is lower than 2 (the recommended weight factor by the Austrian guidelines), that could be attributed to the fact that the predicted weight factor does not cover all influences of non-passenger cars such as vehicle dimension, weight to horse power ratio, etc. It should also be noted that the relatively low coefficient of determinations (0.44 to 0.65) could also be attributed to the used method in the determination of the weight factor of non-passenger cars.
Lane density at the expected capacity can be calculated from the predicted lane capacity and the associated speed. The calculated lane densities at capacity of left, middle and right lanes of the A2 motorway are 25, 26 and 24 pc/km, respectively. The HCM 2000 stated that in ideal conditions, the lane density of motorways at capacity is 28 pc/km. It is easy to recognize that the calculated lane densities of the A2 at capacity are close to the value of HCM 2000.

4.2 The A4 motorway

Speeds and volumes of the A4 motorway were calculated with five-minute observation intervals. Unstable flow condition was not observed, therefore only the stable part of speed-flow relationship is presented. The developed speed-flow model was used in fitting speed-flow data of the A4 motorway. The estimated model parameters are displayed in Table 2 and the results are graphically represented in Figures 10 and 11. It should be noted that relatively low coefficient of determinations (0.41 and 0.46) obtained from the model calibration could be attributed to the used method in the determination of the weight factor of non-passenger cars (as an output of the model calibration). This method does not cover all influences of non-passenger cars such as vehicles dimension and weight to horsepower ratio of each vehicle.

Table 2. Parameters of speed-flow model of the A4 motorway

<table>
<thead>
<tr>
<th>Traffic lane</th>
<th>Stable flow</th>
<th>Weight factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1</td>
<td>A2</td>
</tr>
<tr>
<td>Left</td>
<td>85.81</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>2.871</td>
<td>0.672</td>
</tr>
<tr>
<td>Right</td>
<td>84.42</td>
<td>0.049</td>
</tr>
<tr>
<td></td>
<td>3.101</td>
<td>0.756</td>
</tr>
</tbody>
</table>

The analyses of the A4 motorway, as presented in Figures 10 and 11, show the effect of the 80 km/h speed limit on the speed-flow relationships of the left and right lanes. The estimated free flow speeds of the left and right lanes are 85.80 and 84.37 km/h respectively. Unfortunately no unstable flow data were observed and the practical lane capacity cannot be estimated. But it should be noted that with a lane traffic volume of about 2200 pc/h stable flow existed.
5 CONCLUSIONS

Speed-flow models were developed. These models cover the main factors influencing speed-flow interaction and fit the actual speed-flow data.

Passenger car equivalent factor for non-passenger cars traffic was estimated. This “weight factor” is lower than the recommended weight factors in Austrian guidelines, which could be attributed to the fact that estimated weight factor does not reflect vehicle’s dimension, weight to horsepower ratio, etc.

A practical speed-flow relationship for each specific lane of the examined motorways was established.

For the A2 motorway, it is found that the lane capacity are not equal for different lanes, which could be attributed to the differences in free flow speeds, traffic composition, and driver risk readiness factors from lane to lane.

BIBLIOGRAPHY


