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This Technical Manual is for the Federal Highway Administration’s Traffic Noise Model (FHWA TNM®), Version 1.0 -- the FHWA’s computer program for highway traffic noise prediction and analysis. Two companion reports, a User’s Guide and a data report, respectively, describe the use of TNM and its vehicle noise-emissions data base. The Technical Manual documents the fundamental equations, the acoustical algorithms, and the interactive logic for all computations within TNM.

Section 1 overviews the basic elements of TNM’s prediction model. It describes the basic concepts of the model, from vehicle noise emissions to predicted sound levels. Section 2 describes TNM’s prediction model in more detail, with references to the manual appendixes for detail on algorithms and mathematics. In particular, this section describes the following: (1) vehicle noise emissions for TNM’s built-in vehicle types, (2) computation of vehicle speeds, when they are affected by upgrades and traffic-control devices, (3) geometrical complexity in the XY plane, plus computation of free-field sound levels from a roadway segment, (4) geometrical complexity in the vertical plane, along any line between roadway and receiver, plus the computation of attenuation relative to free field along any such line, (5) computation of parallel-barrier degradation for barriers or retaining walls that flank the roadway, and (6) computation of sound-level contours, insertion-loss contours, and level-difference contours. In addition, this manual contains detailed appendixes for each of these subjects.
2. MODEL DESCRIPTION

The following section of the manual describes the basic formulation, capabilities and logic flow of the FHWA TNM*. As appropriate, references are given to the literature and the detailed appendices. This section limits mathematical description to a minimum; some equations are used where necessary for clarity. The detailed mathematical description is given in the appendixes.

The organization of this section roughly parallels that of the preceding Section 1. First, vehicle noise emission levels are discussed (Section 2.1), followed by discussions of vehicle speed computation (Section 2.2), and free-field noise levels (Section 2.3). A large section is then devoted to the "vertical geometry" and acoustics (Section 2.4), including the basis of the acoustical model, the combining of two cross sections to represent an "elemental triangle," elements in the propagation path, and the logic flow and the geometry modeling of path elements. A section is devoted to the two-dimensional parallel-barrier calculation module (Section 2.5), and lastly, a section on noise contours is included (Section 2.6).

2.1 Vehicle Noise Emission Levels
In 1994 and 1995, the Volpe National Transportation Systems Center Acoustics Facility organized and collected vehicle pass-by noise emission data as the basis for a new emissions data base for the TNM [Fleming 1995]. Approximately 6000 vehicles were measured in 9 states. As described in Section 1, data were collected for many vehicles under various operating conditions. The data base includes automobiles (2 axles and 4 tires), medium trucks (2 axles and 6 tires), heavy trucks (3 or more axles and 6 or more tires), buses (2 or 3 axles and 6 or more tires) and motorcycles (2 or 3 tires). Data were collected for vehicles cruising, accelerating, idling, and for vehicles on grades. In addition, data were obtained for vehicles traveling different pavement types, including DGAC, OGAC, and PCC. Both 1/3-octave band data and A-weighted sound level data were collected.

Figure 2 shows the A-weighted noise emission levels as a function of speed for autos, medium trucks, heavy trucks and buses under cruise conditions and traveling over average pavement (DGAC and PCC combined). The complete set of emission level curves for all vehicle types under all conditions is given in Appendix A. The appendix also shows the generalized vehicle spectra at various speeds. The 1/3-octave band emission level spectra are used by the TNM for all sound level calculations.
Figure 2. A-Weighted Vehicle Noise Emission Levels under Cruise Conditions

Noise data acquisition methods, data analysis procedures, and the complete set of emission levels for vehicles under all conditions are documented in Development of National Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model [Fleming 1995]. Additional detail pertaining to accelerating vehicles are documented by Bowlby [Bowlby 1997].

TNM uses the full-throttle emission levels where there is an upgrade roadway (heavy trucks only on grades equal to 1.5 percent or more) or where user-entered traffic control devices indicate an acceleration condition. (The next section discusses speed computations associated with these conditions.)

An additional field study was undertaken to determine the effective source heights of various vehicles [Coulson 1996]. This study assigned two "sub-source" heights to each vehicle type. They are 0 meters (0 feet) and 1.5 meters (5 feet) above the pavement for all vehicles except heavy trucks, where the upper source is 3.66 meters (12 feet) above the pavement. The study also determined the ratio of sound energy distributed at the lower and upper heights as a function of frequency, vehicle type, and throttle condition (cruising or full throttle). Table 1 shows the percentage of total emission sound energy distributed to the upper source height at
the low frequencies and at the high frequencies. In the middle frequency range, between 500 and 2000 Hz, the sound energy distribution transitions gradually between the two values. Further detail about the energy distribution is presented in Appendix A, including curves showing the sound energy split by frequency for each vehicle type.

Table 1. Sound Energy Distribution Between Sub-source Heights

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Operating Condition</th>
<th>At Low Frequencies (500 Hz and below)</th>
<th>At High Frequencies (2000 Hz and above)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autos</td>
<td>Cruise or Full Throttle</td>
<td>37%</td>
<td>2%</td>
</tr>
<tr>
<td>Medium Trucks &amp; Buses</td>
<td>Cruise</td>
<td>57</td>
<td>7</td>
</tr>
<tr>
<td>Medium Trucks &amp; Buses</td>
<td>Full Throttle</td>
<td>58</td>
<td>13</td>
</tr>
<tr>
<td>Heavy Trucks</td>
<td>Cruise</td>
<td>37</td>
<td>26</td>
</tr>
<tr>
<td>Heavy Trucks</td>
<td>Full Throttle</td>
<td>37</td>
<td>28</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>Cruise or Full Throttle</td>
<td>58</td>
<td>13</td>
</tr>
</tbody>
</table>

Further detail about the energy distribution is presented in Appendix A, Section A.4.

2.2 Vehicle Speed Computation
The TNM computes adjusted speeds based on the user input speeds, roadway grade, and traffic control devices. For level or down-grade roadways, TNM uses the speeds assigned to the roadway by the user (the "input speed"). For heavy trucks (only) on upgrades equal to 1.5 percent or more, TNM reduces the input speeds. The speeds are reduced depending on the steepness and length of the upgrade in accordance with speed-distance curves similar to those published for geometric design by the American Association of State Highway and Transportation Officials [AASHTO 1990 and TRB 1985]. The TNM speed-distance curves were calibrated to the speeds measured during the emission level noise measurement program. Appendix B describes the details of these computations and gives examples.

The TNM allows the user to enter the following traffic-control devices: traffic signals, stop signs, toll booths, and on-ramp start points. The reason for these devices is to allow a more precise modeling of vehicle speeds and emission levels under these interrupted-flow conditions. TNM will compute speeds all along any roadways with traffic control devices. These devices abruptly reduce speeds to the device's "speed constraint," for the device's "percentage of vehicles affected." Stop signs, toll booths, and on-ramp start points affect 100 percent of the vehicles. However, traffic signals affect only the portion of the traffic stopped at the red signal phase, so the TNM allows the user to define the percentage of vehicles