Integrating TNM and Traffic Flow Theory to Provide Freeway Noise Impact Analysis Early in Project Development

Peter T. Kleeman

Techniquest
407 Hedge Street
Charlottesville, VA 22902
(804) 296-6208
techniquest@netscape.net

Abstract - Noise Impact analysis for freeway improvement projects is not typically undertaken until highway alignment and many other final design decisions are made. This timing of noise analysis eliminates consideration of relative noise impacts among a broad range of preliminary design alternatives and may ultimately result in unnecessary noise mitigation costs, citizen opposition, and project delays. The research presented here integrates freeway speed-flow relationships from current traffic flow theory and the FHWA Traffic Noise Model (TNM 1.0) to identify a range of anticipated noise impacts under all free flowing traffic conditions for a freeway. The methodology developed here uses only design related parameters including anticipated free-flow speed, distribution of vehicles by type in the traffic stream, number of travel lanes, and widths of median. Anticipated noise levels at various distances from a proposed freeway can be easily generated using the proposed methodology for a wide range of preliminary design alternatives to consider where Federal Noise Abatement Criteria (NAC) may be exceeded and if some alternatives should be eliminated from further consideration due to unacceptable noise impacts. The developed methodology is demonstrated by considering freeway improvement proposals for the Capital Beltway project (I-495) in Fairfax County, Virginia. Results based on use of the methodology presented here indicate the range of flow conditions where NAC would be exceeded at various distances from the freeway for hard and soft ground conditions if no berms, barriers, or other noise protection between the freeway and the receptor is present.

INTRODUCTION

The Metropolitan Planning (23USC134(f)(1)) and Statewide Planning (23USC135(c)(1)) sections of Title 23 of the United States Code as amended by TEA-21 require that the planning process "provide for consideration of projects and strategies that will protect and enhance the environment, promote energy conservation, and improve quality of life." Traffic noise from new or expanded freeways is an issue of major concern in many urbanized areas and can result in major environmental impacts on residences, businesses, institutions, historic properties, parkland, and recreational facilities, and also have a major impact on quality of life in the vicinity of these freeways. Noise impact assessments typically are not undertaken until very late in the project development process and then primarily for purposes of noise mitigation considerations. Assessment of noise impacts early in project development while a wide range of alternatives are under consideration would allow potential noise impacts and quality of life issues to influence ultimate selection among design alternatives for further consideration and aid in the public involvement and project acceptance process.

This paper presents a new methodology developed to provide planning level noise impacts that integrate current traffic flow theory for freeways and traffic noise impact prediction modeling based on FHWA's Traffic Noise Model (TNM) (*1*). All variables, parameters, and equations relating to the traffic flow theory component of this modeling effort are as described in the Highway Capacity Manual chapter on Basic Freeway Sections (*2*). Readers unfamiliar with this theory are referred to that material for detailed definitions and descriptions.

The methodology proposed here is at present implemented for freeway projects only and its use is illustrated for the Capital Beltway expansion project proposed for a 21 kilometer (13 mile) section of I-495 between Springfield, Virginia and the Maryland State Line.

NOISE MODEL CONSIDERATIONS

Noise generated by each vehicle in a traffic stream is modeled in TNM as a function of vehicle type, vehicle speed, and pavement type. Noise level predictions at receptor sites are modeled as a function of the highway noise level anticipated during the peak traffic noise hour, acoustic properties of the ground between the freeway and the receptor, and existence of natural or man made barriers such as earth berms, dense trees, noise walls, or buildings.

For purposes of generating planning level noise impact analysis, location specific topographic features and other forms of shielding are not included in the analysis because sufficient detail on terrain and specific alignments are not generally known at this early stage of project development, but a good representation of several generic cases can be developed and analyzed to provide estimates of likely noise impacts. These generic cases can include hard ground and soft ground cases, different lane configurations of general and special purpose lanes, and different freeway geometries with different anticipated free-flow speeds on the various lane groups comprising the freeway.

FHWA recently published a table of noise impact values for each of five vehicle types at distances from a roadway between 10 m (33 ft) and 300 m (984 ft); for vehicle speeds up to 130 km/h (81 mph); and for soft ground and hard ground conditions using TNM (*3*). The five TNM vehicle types are defined in the FHWA report as follows:

Automobiles: all vehicles with two axles and four tires - primarily designed to carry nine or fewer people (passenger cars, vans) or cargo (vans, light trucks) - generally with gross vehicle weight less than 4,500 kg (9,900 lb);

Medium trucks: all cargo vehicles with two axles and six tires - generally with gross vehicle weight between 4,500 kg (9,900 lb) and 12,000 kg (26,400 lb);

Heavy trucks: all cargo vehicles with three or more axles - generally with gross vehicle weight more than 12,000 kg (26,400 lb);

Buses: all vehicles designed to carry more than nine passengers; and

Motorcycles: all vehicles with two or three tires and an open-air driver/passenger compartment.

An effective flow resistivity of 20,000 cgs rayls was assumed for propagation of traffic noise over acoustically hard ground, and an effective flow resistivity of 300 cgs rayls was assumed for propagation of traffic noise over acoustically soft ground for all of the analytical results presented in the FHWA tables.

To facilitate development of the current methodology and eliminate the need to analyze a large number of TNM model cases, the generic cases of soft and hard ground as used in the FHWA report were adopted for model implementation and the noise data presented in the FHWA tables were used as data in the noise impact analysis component of the model described below.

PLANNING CONSIDERATIONS

To develop anticipated noise impacts for a specific freeway design, it is necessary to estimate speed and volume of vehicles by type that will be using the proposed freeway in the peak noise hour. The peak noise condition for the roadway is a function of vehicle speed, volume, and number of vehicles in each classification. To eliminate errors that can result from inaccurately selecting peak noise conditions, the methodology developed here generates anticipated noise impacts over the full range of theoretical uncongested flow conditions so that peak noise conditions and the peak noise levels can be determined directly for the given facility being analyzed. The methodology includes specification of vehicle type distribution, free-flow speed, peak-hour factor, and driver population factor for each lane group - all of which will impact peak noise condition and level. These data can be generated for freeways using speed-flow relationships of the type included in FIGURE 3-2 of the Highway Capacity Manual (*2*). The 110 km/h (68 mph) freeway free-flow speed relationship from that figure is shown in FIGURE 1. Use of 110 km/h (68 mph) free-flow speed is recommended in the Highway Capacity Manual as the default free-flow speed for planning level freeway analysis and is used in the case example given below. All other free-flow speed cases can be handled using the appropriate theoretical speed-flow relationship. Preliminary results using the developed methodology indicate that peak noise levels increase with increased free-flow speed of the facility as one might expect due to the increased speed and flow possible on facilities of higher free-flow speeds. Detailed results using the model at different assumed free-flow speeds is not presented in this paper due to paper size limitations.

Theoretical speed-flow distributions relate average passenger-car speed to flow rate of passenger car equivalent (PCE) vehicles. Heavy vehicles such as trucks and buses have PCE values greater than 1.0 to reflect their relative impact on traffic flow in comparison to that of a passenger car. All vehicle types can be transformed to PCEs. PCEs for heavy vehicles vary by vehicle type and terrain. For this analysis it is assumed that the freeway being modeled is classifiable as an extended general freeway segment with level terrain. This implies that changes in grade along the freeway are insufficient to affect the overall operation of vehicles on the freeway and that heavy vehicles can maintain the same speeds as passenger cars. In this case all trucks and buses have a PCE of 1.5, recreational vehicles have a PCE of 1.2, and all other vehicles have a PCE of 1.0. These assumptions simplify the model development presented here by reducing the number of cases for analysis, maintaining consistency with current traffic flow theory as presented in the Highway Capacity Manual, and representing typical values for analyzing a wide range of freeway designs. These assumptions are also consistent with the Capital Beltway case example presented below. The model implementation described below can be readily modified to reflect other assumptions through decomposition of the problem into a sufficient number of component analyses that can all be combined to produce total anticipated noise levels at receptor sites in the vicinity of the freeway.

By relating PCE values and volumes of vehicles in the traffic stream by type it is possible to generate traffic noise estimates for all points along the speed-flow curve for the freeway under consideration. EQUATION 1 is taken directly from the Highway Capacity Manual (*2*) and relates 15-minute passenger-car equivalent flow and hourly volumes as follows:

$$V_p = \frac{V}{PHF * N * f_{HV} * f_p} \quad (1)$$

where:

V_p = 15-minute passenger-car equivalent flow rate (pcphpl)
V = hourly volume (vph)
PHF = peak-hour factor,
N = number of lanes,
f_{HV} = heavy vehicle adjustment factor, and
f_p = driver population factor.

The peak-hour factor reflects anticipated variability of 15-minute volumes within a one-hour recording period (typically PHF is specified in the range of about 0.90 to 0.95). The driver population factor reflects impact of driver population on flow where f_p generally ranges from 0.85 for a population of drivers unfamiliar with the facility to 1.0 where drivers are frequent users of the facility.

METHODOLOGICAL DEVELOPMENT

To develop planning level noise impacts at various distances from a proposed freeway, the following steps are required:

Step 1: Problem Specification

Facility Description

1.1 Divide freeway into lane groups with similar vehicle populations as necessary to consider HOV, bus-only lanes, truck-free lanes, etc.

1.2 Estimate free-flow speed of all freeway lane groups.

Traffic Description

1.3 Estimate proportions of total vehicle population by vehicle type in traffic stream.

1.4 Estimate peak-hour factor (PHF) for the facility under anticipated flow conditions.

Driver Description

1.5 Specify driver population adjustment factor f_p.

Step 2: Traffic Flow Analysis

In this step, traffic speed and number of vehicles by type that correspond to a range of flow levels are computed. Each flow rate specified in units of passenger car equivalents per hour per lane (pcphpl or equivalently pc/h/ln) is multiplied by number of lanes in the lane group currently under analysis prior to computing the equivalent vehicle volumes by type. The steps 2.1 through 2.4 below are repeated for each selected flow rate.

2.1 Determine associated speed from the appropriated speed-flow distribution for the current flow rate.

2.2 Determine the heavy vehicle adjustment factor for the assumed distribution of vehicles using EQUATION 2.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad (2)$$

where:

f_{HV} = heavy-vehicle adjustment factor,
P_T = proportion of trucks or buses in the traffic stream,
E_T = passenger-car equivalent for trucks or buses in the traffic stream,
P_R = proportion of recreational vehicles in the traffic stream, and
E_R = passenger-car equivalent for recreational vehicles in the traffic stream.

2.3 Determine the hourly volume (V) of vehicles that has the same passenger-car equivalent flow using EQUATION 1.

2.4 Decompose the total volume of vehicles into volumes of each of the five vehicle types used in TNM using proportions of each vehicle type anticipated in the traffic stream. Note that a recreational vehicle is defined as a heavy vehicle engaged in the transportation of recreational equipment (e.g. mobile homes, vehicles towing boats) in the Highway Capacity Manual (*2*). Thus, once volumes and speeds have been determined, all recreational vehicles are included with heavy trucks in the noise analysis to conform with the vehicle types specified for analysis using TNM.

Step 3: Noise Impact Analysis

In this step, noise levels at all selected flow levels anticipated on the freeway at each selected distance from the freeway are determined. Steps 3.1 and 3.2 are repeated for each lane group considered in describing the facility.

3.1 Determine noise contribution of each vehicle type at various distances from the freeway using the FHWA Look-Up Table values.

3.2 Combine the noise contributions for each vehicle type at each distance considered using the methodology presented in the FHWA Look-Up Tables document (*3*).

Step 4: Determine Final Noise Levels

4.1 Combine the contributions for each lane group into a total noise level at each of the selected receptor distances from the freeway.

4.2 Display noise impact results for each lane group, and for all lane groups comprising the freeway in combination. In the current implementation of the methodology no provision is made to generate automatically the combined impact of multiple lane groups but this step can be done as a simple side computation by the analyst once all component lane group results are generated.

MODEL IMPLEMENTATION

Data specification and all analytical components of this model have been implemented in spreadsheet form to allow preliminary noise analyses to be generated easily. Four separate spreadsheets were developed to correspond to freeways at four different free-flow speeds of 90, 100, 110, and 120 km/h (56, 62, 68, and 75 mph). Passenger-car equivalent flows for 100 pcphpl through capacity of the freeway in increments of 100 pcphpl were analyzed to enable generation of noise impact distributions covering the entire range of uncongested flow (Levels of Service A-E). Lane groups consisting of 1 through 6 lanes are specified in the spreadsheets. Noise levels are computed at distances of 50, 100, 150, 200, 250, and 300 meters (164, 328, 492, 656, 820, and 984 feet) from the centerline of the lane group. This range of data specification is anticipated to cover all freeway development cases of interest at a level of detail sufficient to evaluate differences in anticipated noise impacts among candidate freeway designs.

The spreadsheets are developed to provide both tabular and graphical output. The tabular output is useful in combining multiple lane group impacts. The graphical output in the current implementation provides noise impact level as a function of flow rate at each of the six distances from the freeway and also provides peak noise level as a function of distance from the freeway for each lane group. Examples of the tabular and graphical output are illustrated in the Capital Beltway case example below.

AN ILLUSTRATIVE EXAMPLE: THE CAPITAL BELTWAY

The Virginia Department of Transportation is currently considering expansion of a 21 kilometer (13 mile) section of the Capital Beltway (I-495) between Springfield, Virginia and the Maryland State Line. This freeway is currently an 8-lane freeway (four lanes in each direction). Two of the alternative build considerations are expansion to a 10-lane facility and expansion to a 12-lane facility. Traffic projections for the project suggest that peak-hour demands will produce congested flow during peak commuting hours even for the 12-lane facility. Thus, the facility is anticipated to operate over a full range of service levels (Level-of-Service A through F) over the course of a typical day. This project is selected to demonstrate the input requirements and output results of the current implementation of the described model and indicate preliminary noise estimates at various distances from the centerline of the nearest lane group to receptor sites. Data necessary to utilize this model are generally available early in project development and use of this data in generating relative impacts among proposed alternative designs could greatly enhance public participation and understanding of likely impacts of the project.

The data used in developing these noise estimates are described below. The example given here describes only one of the 10-lane alternatives proposed (five general traffic lanes in each direction), but other 10-lane and 12-lane alternatives could be described in a very similar manner. Additional lane groups would be necessary to analyze designs using HOV lanes or where through traffic and local traffic lanes are separated.

Problem Specification (Capital Beltway)

In this step, all of the case specific information is entered into spreadsheet cells from which all of the desired noise levels are computed, tabulated, and represented graphically.

Facility Description (Capital Beltway)

Divide freeway into lane groups with similar vehicle populations as necessary to consider HOV, Bus Only lanes, truck free lanes, etc.

- Select 5-lane northbound direction as lane group ‘Inner Loop’.
- Select 5-lane southbound direction as lane group ‘Outer Loop’.

Estimate free-flow speed all freeway lane groups.

- Free-flow speed for the Expanded Capital Beltway is assumed to be = 110 km/h (68 mph) for both lane groups.

Traffic Description

Estimate distribution of vehicles by type in traffic stream.

This specification would be done for each lane group. For simplicity, only two vehicle types are assumed in this illustrative example and both lane groups are assumed to have the same vehicle distribution by type as follows:

- Proportion of total volume classified as passenger cars or light trucks = 0.9.
- Proportion of total volume classified as heavy trucks = 0.1.

Estimate peak-hour factor values.

- Peak-hour factor (PHF) is assumed to be 0.9 for both lane groups at all flow rates consistent with typical variability in vehicle flows for freeway facilities.

Driver Description

Specify driver population adjustment factor f_p

- The driver population adjustment factor, f_p is assumed to be 1.0 for both lane groups which indicates that drivers are assumed to be familiar with the facility.

Traffic Flow and Noise Impact Analysis (Capital Beltway)

All of the traffic flow analyses are carried out through use of a spreadsheet to allow easy sensitivity analysis such as varying the proportion of heavy vehicles in the traffic stream, driver population adjustment factor, etc. to see how influential these assumptions would be on noise levels anticipated at receptor sites. The user input values are represented by the plain text numerical entries in TABLE 1. Entries in bold text in TABLE 1 are intermediate values that provide equivalent numbers of vehicles by type for each level of flow on the freeway for use in the noise level determination elements of the spreadsheet. TABLE 2 illustrates the predicted noise levels for a single lane group of five lanes assuming soft ground.

PCE flow rates are specified in increments of 100 passenger-car equivalents per hour per lane (pcphpl or pc/h/ln) from 100 pcphpl to capacity (which varies with assumed free-flow speed). The associated speeds are taken directly from the speed-flow relationship given in FIGURE 1. These data are represented in the spreadsheet as the second and third columns in TABLE 1. From these data and implementation of EQUATIONS 1 and 2 into the spreadsheet, the distribution of volumes by vehicle type is determined at each flow level. These volumes are given in vehicles per hour per lane (veh/h/ln) as the fourth column of the spreadsheet in TABLE 1. The total vehicle volume is decomposed into volumes by vehicle type using the user supplied vehicle classification data. The computed volumes of vehicles in each of the five TNM vehicle types at each flow level are computed in the fifth through ninth columns of the spreadsheet in TABLE 1.

The noise analysis component of the spreadsheet implements the methodology suggested in the FHWA Noise Look-Up Tables (*3*) which combines the impacts of each vehicle type into a total noise level at selected distances from the lane group centerline. Soft ground and hard ground cases are done separately in the spreadsheet and provide estimates of upper and lower bounds on noise levels anticipated in the absence of natural or man-made noise barriers or other screening. A subset of the FHWA Look-Up Table entries - those in the range of speeds encountered for freely flowing freeway traffic (80-120 km/h (50 - 75 mph)) at distance of 50, 100, 150, 200, 250, and 300 meters (164, 328, 492, 656, 820, and 984 feet) from the centerline of the lane group - are included in the spreadsheet. This allows the spreadsheet to handle all of these selected distances simultaneously and provides sufficient information to allow estimates at intermediate distances to be determined through interpolation.

Noise Impact Results (Capital Beltway)

Results for each lane group are displayed in both tabular and graphical form. TABLE 2 presents the tabular output of the nearest 5-lane group at the selected distances of between 50 and 300 meters (164 and 984 feet) under soft ground assumption. These results indicate that the FHWA Noise Abatement Criterion for residential properties of 67 dBA will be exceeded by the contribution of just the nearest lane group at distances up to about 125 meters (410 feet). By combining the second lane group, which for this example is about 25 meters (82 feet) further than the near lane group from the receptors, the resulting noise levels are approximately 2.0 decibels higher than the values reported in TABLE 2. Thus, this analysis indicates that a 10-lane Capital Beltway would result in the FHWA Noise Abatement Criterion (NAC) of 67 dBA being exceeded at distances up to about 150 meters (492 feet) from the center line of the near lane group. Under the hard ground assumption, the NAC of 67 dBA is exceeded at all distances through 300 meters (984 feet) - the greatest receptor distance considered in the Look-Up Table data set.

FIGURE 2 displays predicted noise level as a function of vehicle flow in passenger car equivalents per hour per lane at each of the six receptor distances from the centerline of the nearest lane group consisting of five general purpose lanes. It should be noted that the peak noise flow condition varies with distance from the freeway. The peak noise flow condition at 50 meters (164 feet) from the freeway occurs at about 1800 pcphpl while the peak noise flow condition at 300 meters (984 feet) from the freeway occurs at about 2100 pcphpl.

A reasonable approximation to the distribution of noise levels as a function of distance from the freeway for this case example is presented using 1800 pcphpl as an approximation of the peak noise flow condition at all distances. FIGURE 3 displays the relative impacts associated with single lane groups consisting of four lanes, five lanes, and six lanes which correspond to the current Capital Beltway configuration, a 10-lane proposal, and a 12-lane proposal, respectively. The hard ground cases provide an estimate of the upper bound while the soft ground cases provide an estimate of the lower bound of anticipated noise levels at unshielded receptor sites. A flow rate of 1800 pcphpl was selected as the approximate peak noise flow rate for all of the cases presented in FIGURE 2. This corresponds to a Level-of-Service D on this facility. Near peak noise levels (within 1.0 dBA of the peak level) occur over the range of Level-of-Service C through E indicating that noise levels in excess of the NAC may occur over a large portion of the day and have a potentially significant impact on quality of life near the facility.

CONCLUSION

The methodology presented here integrates traffic flow theory for freeways with use of FHWA Traffic Noise Model predictions to provide a basis for preliminary estimation of noise impacts associated with planned freeway improvements. Noise impact predictions generated using this methodology are sensitive to anticipated free-flow speed of the freeway, distribution of vehicle types in the traffic stream, variability of flow anticipated on the freeway, and driver familiarity with the facility. The data necessary to develop noise impact estimates using the described methodology are typically available early in the project development process. Thus, use of this methodology allows potential noise impact to be considered in evaluating a wide range of preliminary design alternatives for further study. The methodology presented here is currently implemented in spreadsheet form to allow sensitivity analysis to be performed on any of the input parameters with great ease. Although the methodology has only been implemented for consideration of freeways to date, implementation of these methods for other types of facilities such as multilane highways and principal arterials would be a desirable extension.

VII. REFERENCES

1. Menge, Christopher W., C. Rossano, G. Anderson, C. Bajdek, *FHWA Traffic Noise Model, Version 1.0 Technical Manual*, Report No. FHWA-PD-96-010 and DOT-VNTSC-FHWA-98-2, Cambridge MA, U.S. Department of Transportation, Research and Special Programs Administration, John A. Volpe National Transportation Systems Center, Acoustics Facility, February 1998.

2. Lee, Cynthia S. Y., G. Fleming, J. Burstein, *FHWA Traffic Noise Model Look-Up Tables*, Report No. FHWA-PD-98-047 and DOT-VNTSC-FHWA-98-5, Cambridge MA, U.S. Department of Transportation, Research and Special Programs Administration, John A. Volpe National Transportation Systems Center, Acoustics Facility, July 1998.

3. Transportation Research Board,. *Highway Capacity Manual*, Special Report 209, Third Edition, National Research Council, Washington D. C., 1998, Chapter 3.

LEGENDS TO TABLES AND FIGURES

TABLE 1: Problem Description Components of the Noise Analysis Spreadsheet.

TABLE 2: Noise Levels (dBA) at distances of 50, 100, 150, 200, 250, and 300 meters from a 5-lane Freeway Lane Group assuming Soft Ground.

FIGURE 1: Speed-Flow Relationship for a Freeway with Free-Flow Speed = 110 km/h

FIGURE 2: Noise Levels at Various Distances from 5-Lane Freeway [Soft Ground Case - Free-Flow Speed = 110 km/h - 10% Heavy Trucks].

FIGURE 3: Noise Profile at a Flow Rate of 1800 pcphpl for 4-lane, 5-lane, and 6-lane Freeway Lane Groups for Soft Ground and Hard Ground Cases [Free-Flow Speed = 110 km/h - 10% Heavy Trucks].

TABLE 1: Problem Description Components of the Noise Analysis Spreadsheet.

General Freeway Section Noise Analysis: **Free-Flow Speed = 110 km/h**

Vehicle Type	**proportion**	**PCE's**
Autos	0.90	**1.0**
Medium Trucks (MT)	0.00	**1.5**
Heavy Trucks (HT)		
Rec. Vehicles	0.00	**1.2**
All other 3+ axle veh.	0.10	**1.5**
Buses	0.00	**1.5**
Motorcycles (Mcycles)	0.00	**1.0**
Total	**1.00**	

PHF = 0.90

f_p = 1.00

f_{HV} = **0.952**

Level of Service	Passenger Car Equivalent (pc/h/ln)	Average Pass.-Car Speed (km/h)	Number of Vehicles (veh/h/ln)	Number of Autos (veh/h/ln)	Number of MT (veh/h/ln)	Number of HT (veh/h/ln)	Number of Buses (veh/h/ln)	Number of Mcycles (veh/h/ln)
A	100	110.0	**86**	**77**	**0**	**9**	**0**	**0**
A	200	110.0	**171**	**154**	**0**	**17**	**0**	**0**
A	300	110.0	**257**	**231**	**0**	**26**	**0**	**0**
A	400	110.0	**343**	**309**	**0**	**34**	**0**	**0**
A	500	110.0	**429**	**386**	**0**	**43**	**0**	**0**
A	600	110.0	**514**	**463**	**0**	**51**	**0**	**0**
B	700	110.0	**600**	**540**	**0**	**60**	**0**	**0**
B	800	110.0	**686**	**617**	**0**	**69**	**0**	**0**
B	900	110.0	**771**	**694**	**0**	**77**	**0**	**0**
B	1000	110.0	**857**	**771**	**0**	**86**	**0**	**0**
B	1100	110.0	**943**	**849**	**0**	**94**	**0**	**0**
C	1200	110.0	**1029**	**926**	**0**	**103**	**0**	**0**
C	1300	110.0	**1114**	**1003**	**0**	**111**	**0**	**0**
C	1400	110.0	**1200**	**1080**	**0**	**120**	**0**	**0**
C	1500	110.0	**1286**	**1157**	**0**	**129**	**0**	**0**
C	1600	109.2	**1371**	**1234**	**0**	**137**	**0**	**0**
D	1700	108.5	**1457**	**1311**	**0**	**146**	**0**	**0**
D	1800	106.9	**1543**	**1389**	**0**	**154**	**0**	**0**
D	1900	104.2	**1629**	**1466**	**0**	**163**	**0**	**0**
D	2000	101.5	**1714**	**1543**	**0**	**171**	**0**	**0**
E	2100	97.7	**1800**	**1620**	**0**	**180**	**0**	**0**
E	2200	93.1	**1886**	**1697**	**0**	**189**	**0**	**0**
E	2300	88.5	**1971**	**1774**	**0**	**197**	**0**	**0**
E	2350	84.0	**2014**	**1813**	**0**	**201**	**0**	**0**

TABLE 2: Noise Levels (dBA) at distances of 50, 100, 150, 200, 250, and 300 meters from a 5-lane Freeway Lane Group assuming Soft Ground.

Passenger-Car Equivalents (pcphpl)	TOTAL Noise Level [L(Aeq1h)]					
	at 50 m (dBA)	at 100 m (dBA)	at 150 m (dBA)	at 200 m (dBA)	at 250 m (dBA)	at 300 m (dBA)
100	61.9	56.5	52.8	49.9	47.7	46.0
200	64.9	59.5	55.8	52.9	50.7	49.1
300	66.7	61.3	57.5	54.7	52.5	50.8
400	67.9	62.5	58.8	55.9	53.8	52.1
500	68.9	63.5	59.8	56.9	54.7	53.0
600	69.7	64.3	60.5	57.7	55.5	53.8
700	70.4	64.9	61.2	58.4	56.2	54.5
800	70.9	65.5	61.8	58.9	56.8	55.1
900	71.4	66.0	62.3	59.4	57.3	55.6
1000	71.9	66.5	62.8	59.9	57.7	56.0
1100	72.3	66.9	63.2	60.3	58.1	56.5
1200	72.7	67.3	63.6	60.7	58.5	56.8
1300	73.0	67.6	63.9	61.0	58.9	57.2
1400	73.4	67.9	64.2	61.4	59.2	57.5
1500	73.7	68.2	64.5	61.7	59.5	57.8
1600	73.9	68.4	64.7	61.9	59.7	58.1
1700	74.1	68.6	65.0	62.1	60.0	58.3
1800	74.1	68.7	65.1	62.3	60.1	58.5
1900	74.1	68.7	65.1	62.3	60.2	58.6
2000	74.0	68.7	65.1	62.4	60.3	58.7
2100	73.8	68.6	65.1	62.4	60.3	58.7
2200	73.5	68.3	64.9	62.3	60.2	58.7
2300	73.3	68.1	64.7	62.2	60.2	58.7
2350	72.8	67.8	64.5	62.0	60.0	58.6

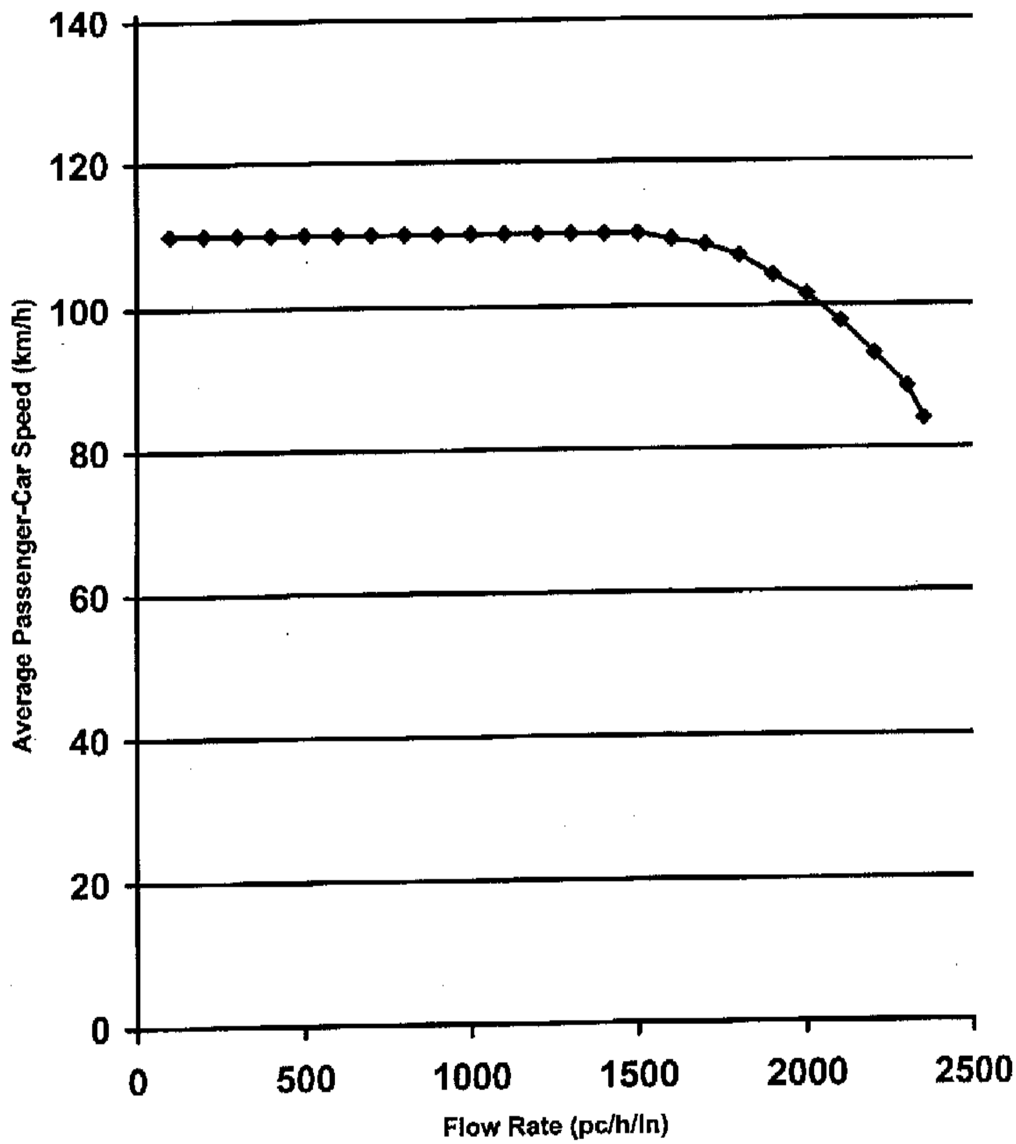

FIGURE 1: Speed-Flow Relationship for a Freeway with Free-Flow Speed = 110 km/h.

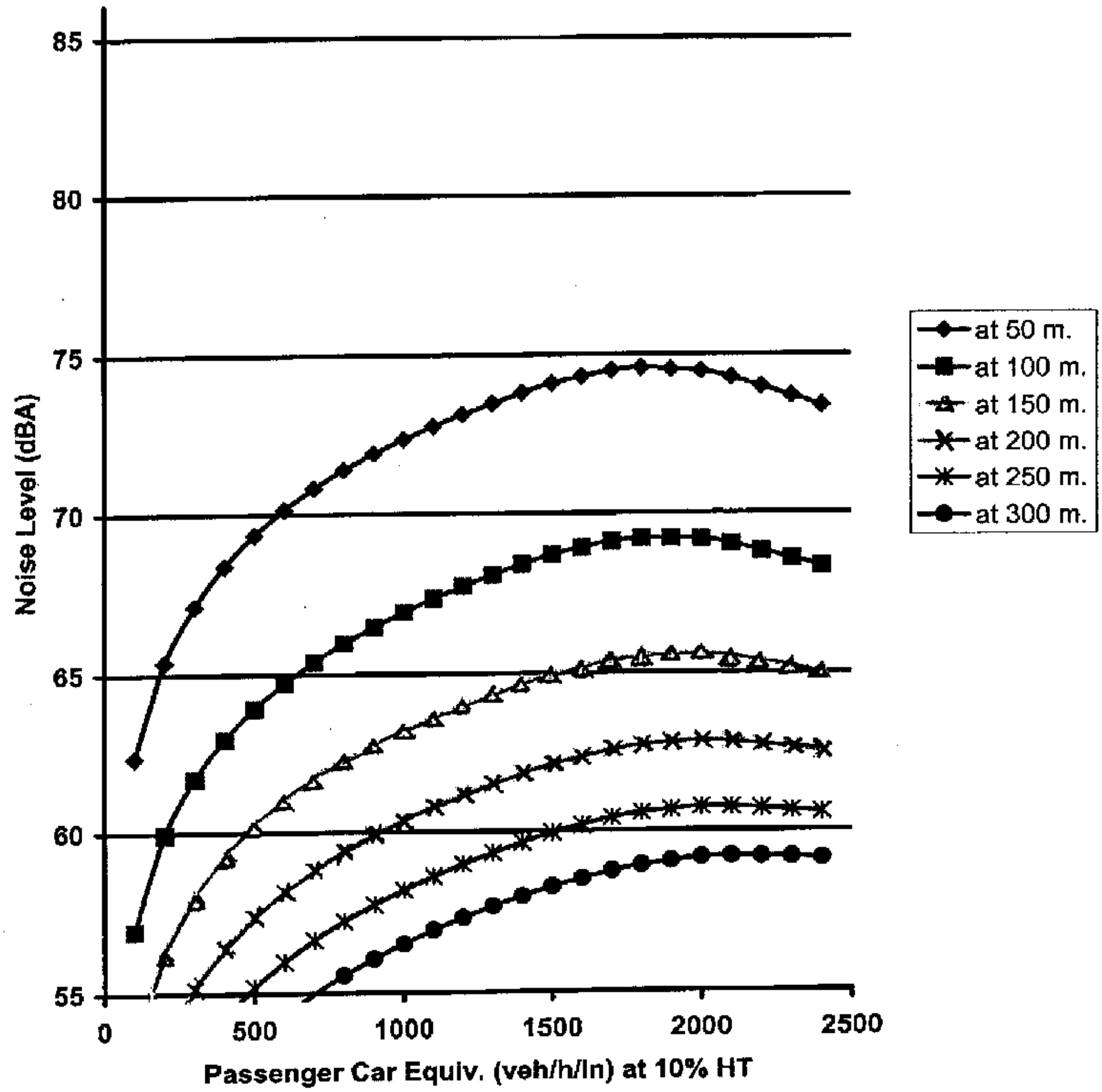

FIGURE 2: Noise Levels at Various Distances from 5-Lane Freeway [Soft Ground Case - Free-Flow Speed = 110 km/h - 10% Heavy Trucks].

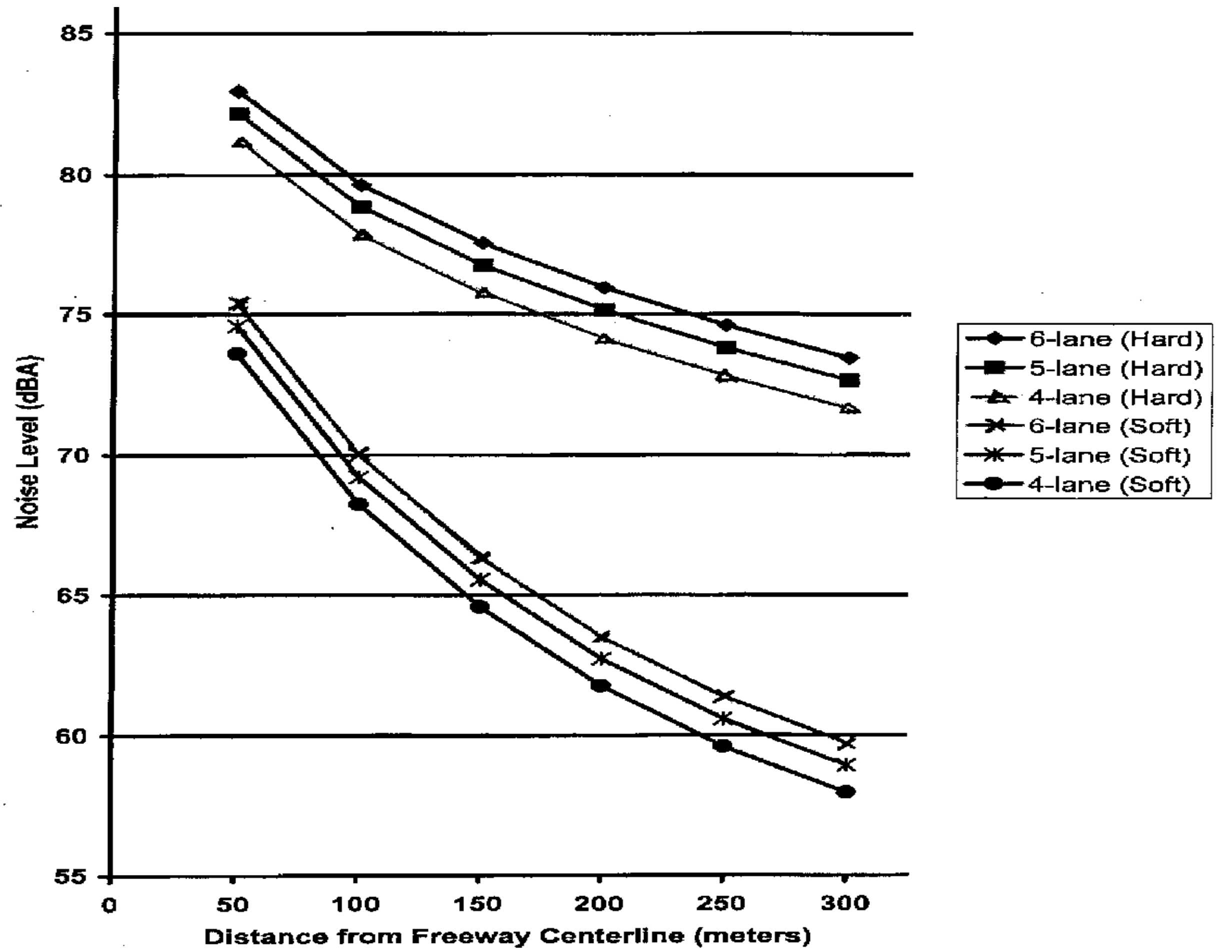

FIGURE 3: Noise Profile at a Flow Rate of 1800 pcphpl for 4-lane, 5-lane, and 6-lane Freeway Lane Groups for Soft Ground and Hard Ground Cases [Free-Flow Speed = 110 km/h - 10% Heavy Trucks].