Cover note for the report entitled:
Noise and the Full Cost Investigation in Canada

Dr David Gillen has prepared the attached report. It was requested in relation to the Full Cost Investigation. It followed a literature review completed by a University of British Columbia team and their report was entitled "Towards Estimating the Social and Environmental Costs of Transportation in Canada" (2004). In that review, Dr Gillen proposed a methodology to generate estimates of noise costs, a methodology requiring the availability of some needed information.

The steering committee created in relation to Dr Gillen's research was informed very early in the work of the difficulties tied to it. The work was nevertheless pursued with the ultimate objective of producing the best possible estimates within the limits of available information.

The methodologies proposed by Dr Gillen to assess costs associated with transportation-related noise are based on methodologies designed for project specific noise impact estimates (micro-level costs). The proposed methodologies allow generating aggregate, macro-level, noise-related cost estimates. The report presents the original methodologies that help understanding the theory supporting the models and how they have had to be modified to allow to generate the noise related cost estimates.

All required data were not available at the desired level of details to produce the most precise estimates. For instance, road traffic information at precise location by period of the day broken down by vehicle type and traveling speed is not captured for most road segments. The work of Dr Gillen produces the "best possible estimates given available information" and it provides an order of magnitude of costs of noise from transportation activities. The applicability of the work for the Full Cost Investigation is therefore delimited by these realities. For example, the allocation within a mode among different modal activities is not possible. For instance, allocating the road transportation related noise costs among the different road transportation vehicles is not possible. Provincial allocations are also not possible.

Despite the said limitations, the measure of noise related costs from transportation in Canada made possible by the work of Dr Gillen has its usefulness. These macro-level noise cost estimates allow to note that in the context of the Full Cost Investigation of transportation, noise related costs represent a small share of the full costs, other costs elements being significantly more important. Consequently, not being able to do a precise allocation by vehicle type of noise related costs is not to compromise the findings of the full costs of transportation nor distort modal comparisons. The attached report is made available despite its limitations.

Noise and the Full Cost Investigation in Canada: Final Report

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Estimation of Noise Costs due to Road, Rail and Air Transportation in Canada

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(Prof.) David Gillen, Director
Centre for Transportation Studies
Sauder School of Business
University of British Columbia
Vancouver, BC

Email: david.gillen@cts.ubc.ca

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CHAPTER 1: INTRODUCTION

1.1 Purpose of the Research

This report describes methods of calculating total and marginal costs for noise externality costs associated with air, rail, and road. It reports total annual noise costs calculated for Canada and for each province. There were no calculations for rural areas due to a lack of data. Marine is also not considered, as there has been almost no research undertaken with respect to noise impact of marine. It would therefore not be possible to undertake the fundamental research necessary to measure the cost of noise associated with this mode nor the quantification of noise exposure.

The report provides description of how to calculate measures of total and marginal noise costs for six (6) transportation activities; air, rail, road (automobile, truck, Intercity bus, public transit bus) but provides actual measures for road, rail and air; the road mode could not be segmented due to a lack of data. These costs are aggregated and reported for each province for rail and road noise costs and at the national level for aviation noise costs. These measures are calculated using Transport Canada's FCI base year of 2000, meaning noise costs using data for year 2000.

As a final point we note that the emphasis in this document is to measure and report on the social costs of a noise externality for each mode of transportation. It should not be overlooked that any assessment of the net social value of the different modes or of transportation in general is to include the benefits which transportation provides. There have been numerous benefit cost studies of air, rail, truck, auto and marine transportation that show significant net social benefits (see Boardman et al. 2006). Our purpose here is to examine just one side of this equation.

1.2 Description of Noise Variation across Modes

Many approaches have been undertaken to estimate the costs of externalities. The first class of approaches may be termed "damage" based methods; a second can be called "protection" based methods. The damage-based methods begin with the presumption that there is an externality and it causes X amount of damage that is measured through lower property values, quality of life, and health levels etc.

The protection methods estimate the cost to protect against a certain amount of the externality through abatement, defense, or mitigation. One example of a defense measure is thicker windows in a house to reduce noise from the road. An abatement measure would have the highway authority construct noise walls to reduce noise or require better mufflers on vehicles. A mitigation measure may only be applicable for certain types of externalities; e.g. increased safety measures that reduce accidents on one facility also offset the increased number of accidents on another facility.

Rising marginal costs are expected with protection measures. The first quantity of externality abated /defended/mitigated is cheaper than the second and so on because the most cost-effective measures are undertaken first. This is not to say there are no economies of scale in mitigating externalities within a given mitigation technology. It merely suggests that between technologies, costs will probably rise. A second important feature of protection measures is the assumption that 'we know' the right level of protection; how much sound insulation or how high a noise berm should be. The literature illustrates that if there is uncertainty on the costs of such measures; protection and mitigation yield the same level of the externality. However if there is uncertainty of the benefit measures, the protection and mitigation methodologies lead to very different outcomes.

The mitigation approach can be applied if we consider the externality fungible. Noise pollution from the road may cause as much damage as an equivalent amount of noise pollution from nearby factories or an airport. The most cost effective approach to eliminating the amount of pollution produced by the road may come from additional mitigation measures at the factory. While it may be prohibitively expensive to eliminate 100% of roadway noise pollution from the roadway alone, it may be quite reasonable to eliminate the same amount of pollution from the system. Determining the most effective method of mitigating each system-wide externality requires understanding the nature of its fungibility.

Neither of these two approaches (damages or protection) will necessarily produce a single value for the cost of a facility or mode. It is more likely that each approach will produce a number of different cost estimates based on how it is undertaken and what assumptions are made. This reinforces the need for sensitivity analyses and a well-defined "systems" approach.

1.3 Fundamental Inputs into the Calculation of Noise Costs

Calculating the costs of noise requires basically three pieces of information; how much noise is produced, how much the noise exceeds some defined acceptable threshold level and what is the unit price of the noise. The first two components represent the quantification of noise and the last the monetization of noise. The acceptable threshold is defined for the calculations carried out here as the amount of noise which exceeds 60-65 dB(A) during daylight and 55 dB(A) during nighttime in the year 2000. This would mean the amount of traffic for each mode and for the given physical, social and economic environment defines the level of noise. The amount of noise produced is determined from engineering based models which estimate noise generation as a function of vehicle and terrain characteristics.

Establishing the price or cost can be accomplished in several ways. The techniques of costing can be divided into three main categories: revealed preference, stated preference, and implied preference. Revealed preference is based on observed conditions and how individuals subject to the externality behave; stated preference comes from surveys of individuals in hypothetical situations, while implied preference looks at the cost which is implied based on legislative, executive, or judicial decisions.

1.3.1 Revealed Preference

The revealed preference approach attempts to determine the cost of an externality by determining how much damage reduces the price of a good. Revealed preference can also be used to estimate the price people pay for various protection (defense/ abatement) measures and the effectiveness of those measures. For instance, insulation costs a certain amount of money and provides a certain amount of effectiveness in reducing noise; the extent to which individuals then purchase insulation or double-glazed windows may suggest how much they value quiet. However, individuals may be willing to spend some money (but less than the cost of insulation) if they could ensure quiet by some other means which they do not control - but which may be technically feasible.

<u>Hedonic Models</u>: The most widely used estimates of the cost of noise are derived from hedonic models. These assume that the price of a good (for instance a home) is composed of a number of factors: square footage, accessibility, lot area, age of home, pollution, noise, etc. Using a regression analysis, the parameters for each of these factors are estimated. From this, the decline in the value of housing with the increase in the amount of noise can be estimated. This has been done widely for estimating the social cost of road noise and airport noise on individual homes.

Similarly, when determining some of the costs of noise, one could investigate how much individuals might be willing to pay for vehicles that are quieter. Like a home, a hedonic model of vehicle attributes could be estimated. A vehicle is a bundle of attributes (room, acceleration, MPG, smooth ride, quiet, quality of workmanship, accessories), which influence its price, also an attribute.

<u>Unit/Cost Approach</u>: A simple method, the "unit cost (Rate) approach" is used often for allocating costs in transit. This method assigns each cost element, somewhat arbitrarily, to a single output measure or cost center (for instance, Vehicle Miles Travel, Vehicle Hours Travel, Number of Vehicles, Number of Passengers) based on the highest statistical correlation of the cost with output.

Wage/Risk Study: A means for determining the economic cost of risk to life or health or general discomfort is by analyzing wage/salary differentials based on job characteristics, including risk as a factor.

Time Use Study: This approach measures the time used to reduce some risk by a certain amount. For instance, seatbelts reduce the risk of injury or using pedestrian overpass may reduce the risk of being hit by a car. The time saved has a value, which may inform estimates of risk aversion.

Human Capital: The Human Capital approach is an accounting approach which focuses on the accident victim's productive capacity or potential output, using the discounted present value of future earnings. To this are added costs such as property damage and medical costs. Pain and suffering can be added as well. The Human Capital approach can be used for accidents, environmental health, and possibly congestion costs. It is used in the Australian study Social Cost of Road Accidents (1990). However, Miller (1991) and others discount the method because the only effect of injury that counts is the out-of-pocket cost plus lost work and housework. By extension, it places low value on children and perhaps even a negative value on the elderly. While measuring human capital is a necessary input to the costs of accidents, it cannot be the only input.

1.3.2 Stated Preference

Stated preference involves using hypothetical questions to determine individual preferences regarding the economic costs of a facility. There are two primary classes of stated preference studies: Contingent Valuation and Conjoint Analysis.

Contingent Valuation: Perhaps the most straight-forward way of determining the cost of an externality is asking the hypothetical questions, "How much would a person pay to reduce externality by a certain amount" or "How much would a person pay to avoid the imposition of a certain increment of externality". Jones-Lee (1990) has been the foremost investigator into this method for determining the cost of noise. This method can, in theory, be applied to any recipient of noise, although it has generally been asked of the neighbors (or potential neighbors) of a transportation facility. There are several difficulties with this approach. The first difficulty with any stated preference approach is that people give hypothetical answers to hypothetical questions. Therefore, the method should be calibrated to a revealed preference approach (with actual results for similar situations) before being relied upon as a sole source of information. The second regards the question of "property rights". For instance, someone who believes he has the property right to quiet will not answer this question in the same way as someone who doesn't. The third involves individuals who may claim infinite value to some commodity, which imposes difficulties for economic analysis.

Conjoint Analysis: To overcome the problems with contingent valuation, conjoint analysis has been used. Conjoint analysis requires individuals to tradeoffs between one good (e.g. quiet) and another (e.g. accessibility) has been used to better measure the cost of noise, as in Toronto by Gillen (1990).

1.3.3 Implied Preference

There are methods for measuring the costs of externalities, which are neither revealed from individual decisions nor stated by individuals on a survey. These are called implied preference because they are derived from regulatory or court-derived costs.

Regulatory Cost: Through government regulation, costs are imposed on society with the aim of reducing the amount of noise or pollution or hazard is produced. These regulations include vehicle standards (e.g. mufflers) roadway abatement measures such as noise walls, as well as the many environmental regulations. By determining the costs and benefits of these regulations, the implicit cost of each externality can be estimated. This measure assumes that government is behaving consistently and rationally when imposing various standards or undertaking different projects. It also assumes the government has introduced the economically efficient amount of the regulation.

Judicial Opinion and Negotiated Compensation: Similar to the implicit cost measure, one can look at how courts (judges and juries) weigh costs and benefits in cases that come before them. The cost per unit of noise or life from these judgments can be determined. This method is probably more viable in accident cases.

1.4 Measuring the amount of Noise for Road and Highway and Rail

Noise and subsequent noise costs are a composite of the amount of noise exposure or change in noise exposure and how this increased nuisance is valued. Noise exposure not only detracts from quality of life, it may have health affects as well. The FHWA and other US Federal government agencies as well as agencies in the EU have stated the effects of noise on health are both physiological and psychological, though primarily psychological. Physiologically, excessive noise is capable of producing hearing loss, however it seems unlikely that many people have suffered from highway [ground] generated noise in this way. Psychologically, the affects are more widespread and include interference with speech communications, sleep disturbance and relaxation, interference with an individual's ability to perform complicated tasks and noise can be a source of annoyance, it can influence mood, and can otherwise detract from the quality of life.

The traditional areas viewed by engineers and acousticians which highway [ground] noise affects, in economic terms, are a) property values, b) impaired health, and c) lowered working efficiency. To this should be added the loss in consumer surplus associated with the use of the home.

To the human ear, loudness is not only a function of sound intensity, but also of sound frequency. Higher frequency sounds tend to seem louder to people than lower frequency sounds. Therefore, sound level meters are often equipped with weighting networks, which give more weight to higher frequency sounds. There are three different weighting networks, designated as A, B and C, which give varying degrees of weight to high frequency sounds. Highway generated noise is usually measured with the A-weighted network. The readings taken on the meter are recorded in A-weighted decibels (dBA).[1]

In measuring noise that fluctuates, such as traffic noise, it is necessary to consider some average of noise level readings taken over time because sounds and noises we hear are not steady. Apart from variation in tones, the magnitude or the sound pressure level of a sound or noise changes with time. In the case of highway, or generally ground, noise measurement, it is important that this "average" correlates well with human annoyance to noise.[2] In principle there is no reason why these metrics cannot be used to assess noise from other modes of transportation.[3] To obtain a meaningful measure of traffic noise, readings can be taken periodically over a period of several hours, and a selected percentile level can be used.

Three commonly used noise level descriptors are:

L_{10} - The noise level exceeded 10% of the time
L_{50} - The noise level exceeded 50% of the time
L_{90} - The noise level exceeded 90% of the time

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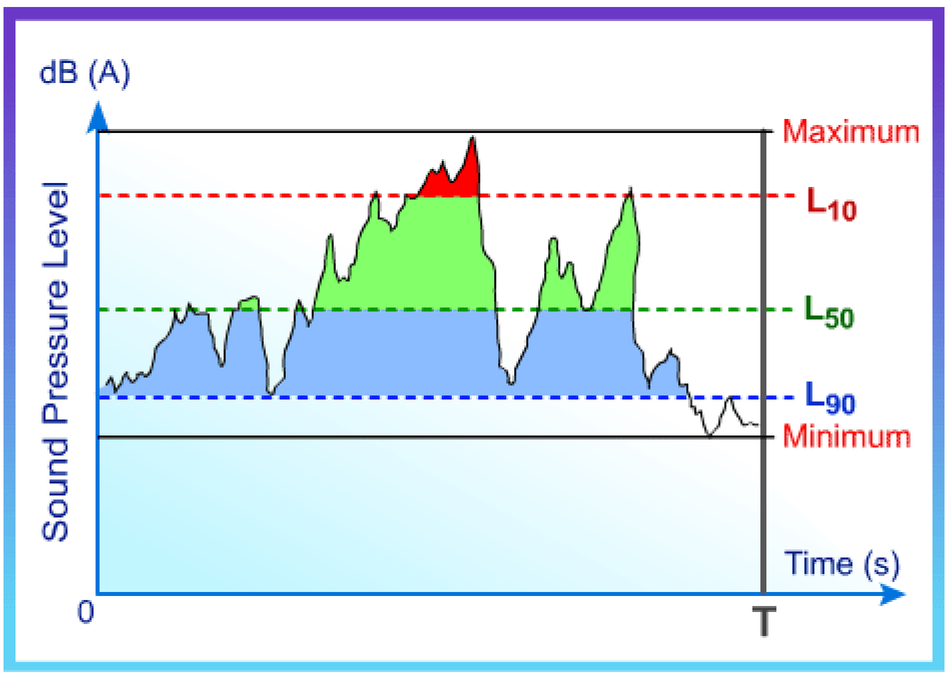
1 See T. Litman, Transportation Costs and Benefits – Noise Costs, Victoria Transport Policy Institute (2005)
2 An official group of noise metrics has been established for measuring and evaluating noise generated by aviation for land use planning and environmental impact assessment. These are discussed in the following section.
3 Surveys and laboratory studies have been conducted aimed at developing descriptors to best correlate community response to various environmental noise sources. This is why different countries have adopted different noise descriptors for assessment of different community noise sources.

The n-percent exceeded level, L_n, is the sound pressure level exceeded for n percent of the time. In other words, for n percent of the time, the fluctuating sound pressure levels are higher than the L_n level. L_{10} is the level exceeded for 10% of the time. For 10% of the time, the sound or noise has a sound pressure level above L_{10}. For the rest of the time, the sound or noise has a sound pressure level at or below L_{10}. These higher sound pressure levels are probably due to sporadic or intermittent events. The L_{10} noise level is an indicator of the noisiest portion of highway traffic, while L_{50} and L_{90} respectively represent the average and quietest portions. Because annoyance seems to be more a function of the loudest of the noisiest vehicles, e.g., trucks, the L_{10} descriptor correlates best with annoyance. According to the EPA the traffic noise planning standard, which is L_{10}(1 hour) of 70 dB(A), means that when this limit is just met, traffic noise will exceed 70 dB(A) for 10% of an hour. For the remaining time, the traffic noise will be less than 70 dB(A). The figure below provides an illustration for L_{10}, L_{50} and L_{90}.

Figure 1



Please note that $L_{10} > L_{50} > L_{90}$ for the same sound or noise.

Source: See footnote 4

While an A-weighted decibel scale is useful for measuring the noise impact of a single occurrence, it does not measure the impact of continuous noise. A frequently used measurement in the US and by the OECD and WHO for continuous noise is the equivalent sound level (Leq), known also as the energy mean sound level. Leq includes both the intensity and length of all sounds occurring during a given period; it indicates "the average acoustic intensity over time and is the equivalent noise energy level of a steady, unvarying tone."

The Environmental Protection Agency has developed a measurement for a community's exposure to noise (the average energy sound level) for a 24-hour period from midnight to midnight. The measure of this day-night sound level, designated DNL or Ldn, is commonly used to evaluate noise impacts on communities and residential areas. [4]

1.5 Measuring Noise Exposure in Aviation

The standard for measuring [aviation] noise at Canadian airports is the Noise Exposure Forecast (NEF). The Noise Exposure Forecast is a hybrid acoustical-behavioural noise measure. It is acoustical because it is a function of sound pressure levels of single noise events and the frequency of events over a "planning" day. It is behavioural because it incorporates a weighting factor to discriminate between day and night flights, on the assumption that noise is more annoying during the night. The number of night flights (between 2200hrs and 0700 hrs) is multiplied by 16.67 in the calculation of NEF.[5] The weighting scheme is based on the assumption that background noise levels are approximately ten decibels lower at night than during the day, making the contrast between quiet and aircraft noise more pronounced.[6]

The sound pressure levels used to calculate the NEF for a location depend on the noise characteristics of the fleet of aircraft that use the airport, normal takeoff and landing practices, and the relationship between the location and the flight tracks of inbound and outbound aircraft following these practices. Flight frequency depends on the capacity of the airport and demand for air transportation to and from its facilities.

1.6 Calculating Noise Costs

Measuring the cost of noise regardless of mode requires measures of the amount of noise and the value of noise or quiet. These values are combined in an equation which takes account of the amount of noise exposure relative to some base level and the price or value of this noise. Noise exposure depends on a number of factors including location, distance from the noise source, density of structures, types of terrain, existence of any noise barriers and the amount of noise or level of traffic and time of day.

The measure of noise cost used in this report is based on the model used by Delucchi and Hsu (1996) to measure the aggregate external noise costs in the US for 377 urbanized areas. The model as used by Delucchi and Hsu used six different types of roadways and took into consideration type of terrain and the existence of noise barriers and noise berms. The equation has been modified to reflect our more limited data; there is one road type, no consideration is given to types of terrain and the noise distance function is discrete not continuous.

The equation measures the external damage cost of noise (in their case only from motor vehicles whereas we calculate noise costs for air and rail) and is equal to the $ damage per excess decibel, multiplied by the annualized value of housing units exposed to differing noise sources above some reference level, multiplied by the density of housing units exposed to the differing noise sources above some threshold reference level, multiplied by the amount of traffic (road, rail , air). In the Delucchi and Hsu (1996) model, they also adjust for noise for non-resident areas. This is not included in the calculations developed in this or subsequent reports. The equation is:

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4 http://www.epd.gov.hk/epd/noise_education/web/ENG_EPD_HTML/m2/types_3.html

5 There does not appear to be any solid scientific basis for the number 16.67, it is the number that has been conventionally used. Canada also weights night flights more heavily than does the US, the factor is 16.67 versus 10.

6 Noise Exposure Forecast performs the same role as DNL or CNEL but is developed using EPNL as the intermediate single event dose metric. The NEF metric incorporates a weighting factor which effectively imposes a 12.2 dB penalty on sound occurring between 10 p.m. and 7 a.m. This corresponds to a nighttime event multiplier of 16.7. NEF correlates extremely well with DNL and the equivalency DNL = NEF + 35 is often used, Ldn=NEF+31

$$C_n = \left(\sum_k \left(\sum_u AN_{u,k} \right) M_u P_u \right) \times HV_k$$

where

$$AN_{u,k} = \frac{L_{u,k}}{5280} \cdot \left(\left(\int_{d_e}^{d_{t^*}} L_{dn^k} \left(d_{u,k} \right) \right) - ANB_{u,k} \right)$$

where

C_n is the total noise costs for metropolitan area n across rail, road and air noise

u is for 27 metropolitan urban areas in Canada

k refers to type of noise; air, rail, road(auto, truck, bus, transit)

$AN_{u,k}$ is the noise level of type k in urban area u

$ANB_{u,k}$ is the noise level at or below the reference noise level due to noise type k at distance t* in area u

M_u is the housing density in urban area u

P_u is the average house price in urban area u

HV_k is the depreciation of house value due to noise type k

$L_{u,k}$ is the length of road (or area) exposed to noise type k in urban area u

d_e is the distance from noise source to nearest recipient

d_{t^*} is the distance at which noise exposure is at the reference level.

L_{dn}^k is the noise of type k as a function of distance for the noise source type k in urban area u

This formula will be applied against each urban area for which we have available data. It will (should) be possible to calculate noise costs due to excess noise (noise above a reference level) for each mode in each urban area. Aggregation can also be made across modes and across urban areas (e.g., total noise costs due to transit in Canada), and aggregation within an urban area across all modes.

1.7 Marginal Noise Costs

Marginal cost measures the change in noise costs as the amount of noise changes. Each mode will have different marginal costs and the functional relationship for each mode is described in the following chapters.

There have been a number of previous studies that have measured both the average and marginal costs. The most recent values have been produced by Delucchi and Hsu (1998) and are reproduced below. Note that the marginal costs are reported by type of road surface. The road surface as well as the speed is reflected in these values. Interestingly no values are available for 'local roads' (see last column) and thus there is no direct comparison with the marginal cost values calculated using Canadian data, although principal and minor arterials may serve as a reasonable proxy for the types of road that are considered in the data used here.

Marginal Noise Costs in Urban Areas (1991$/1000 VMT)

	Interstate	Other Freeways	Principle Arterials	Minor Arterials	Collectors	Local Roads
Light Automobiles	2.96	4.25	1.18	0.57	0.07	0.00
Medium trucks	8.50	13.20	7.02	5.37	1.05	0.00
Heavy Trucks	16.69	30.80	20.07	29.93	4.93	0.00
Buses	6.36	9.77	7.18	6.42	1.22	0.00
Motorcycles	17.15	27.03	8.71	4.67	0.56	0.00

Source: Delucchi and Hsu (1998)

1.8 Summary

The quantification of noise is based on engineering models, discussed in more detail in subsequent chapters. The price placed on noise in this report comes from many sources and is based on several methodologies. Air transport noise prices rely on hedonic models while auto, truck and train are a composite of hedonic and stated preference studies (Boardman et al. 2004) and Litman (2005).

CHAPTER 2: MEASUREMENT OF NOISE COSTS FOR ROAD (AUTO, TRUCK, INTERCITY BUS AND PUBLIC TRANSIT)

2.1 Introduction

Two alternative models that could be used to calculate noise costs associated with different types of vehicles using the roadways and highways are described. The choice of model is a function for the most part of what data are available. The first model was developed by Gillen and Levinson (1996) while the second was developed by the USDOT (US Department of Transportation) in 2006.

2.2 Gillen-Levinson Model (1996)

Essential to determining the cost of noise of a specific facility is a calculation of the amount of noise generated by that facility, or the traffic on that facility. Factors that influence this include: traffic flow, percentage of heavy vehicles, traffic speed, road gradient, and the materials of the road surface. In addition, ground cover, obstruction, barriers, and buildings influence the propagation of the noise over distance. For this exercise, it will be assumed that propagation is simple, over an unobstructed plain. The basic noise level measured is L_{10}, the amount of noise exceeded 10% of the time, as explained earlier. The L_{10} equations in this section were developed by the U.K. D.O.T. (1988).[7] The 1 hour basic noise level is given by:

$$L_{10} = 42.2 + 10 \log_{10} \mathbf{q} \text{ dB(A)}$$

where:

q= hourly traffic flow at 75 km/hr,

assumptions: percentage of heavy vehicles = 0, flat grade

For the 18 hour basic noise level, the equation is

$$L_{10} = 29.1 + 10 \log_{10} \mathbf{Q} \text{ dB(A)}$$

where:

Q = thousand vehicles per 18 hour day

The correction (C_{pv}) for mean traffic speed and heavy vehicles is given as

$$C_{pv} = 33 \log_{10}(\mathbf{V} + 40 + 500/\mathbf{V}) + 10 \log_{10} (1 + 5\mathbf{p}/\mathbf{V}) - 68.8 \text{ dB(A)}$$

where:

V = mean traffic speed in km/hr.

p = percentage of heavy vehicles

[7] United Kingdom, Department of Transport

The impact of noise declines with distance from the edge of the roadway. This correction (C_d) is given as follows:

$$C_d = -10 \log_{10} (\mathbf{d}/13.5) \text{ dB(A)}$$

where:

d = shortest slant distance from the effective source (meters)

Given the land use density, the number of houses at each distance from the roadway can be computed for a given square km, the cost of the noise can be computed.

2.3 USDOT Model (2006)

Auto, truck and transit noise arises from idling, running and accelerating vehicles. Given the similarity in motive power and size, large trucks would generate similar noise exposure as would large diesel buses. As with rail, the sources of noise stem from the power unit and the rolling unit. Transit and heavy truck noise will differ between urban and rural areas principally because of speed. Haling and Cohen (1997) have claimed that heavy trucks can have 150 times greater impact on property values than automobiles but this would apply for major arterial roads.[8]

The USDOT (2006) has developed models for measuring noise exposure for buses including three axle commuter buses. This may provide a lower bound approximation to noise from large trucks given the similar size and power characteristics. As with rail, the source reference SEL values have been established as:

Figure 2

Source reference SELs at 50 feet (assuming 50 mph)

Source	Reference SEL dB(A)	Approximate Lmax (dBA)
Automobiles	74	70
Buses (diesel)	2	79
Buses (Electric Trolleybus)	80	77
Buses (Hybrid)	83	80

Source: USDOT (2006)

According to the USDOT (2006) and Delucchi and Hsu (1998) noise emissions from buses do not depend significantly on whether the buses are accelerating or cruising when in traffic. However, on major arterial roads there is a difference. The FHWA has estimated that the following percentage change in operating conditions will produce a 2-decibel increase in noise exposure:

- 40 percent change in the number of vehicles per hour
- 40 percent change in the number of vehicles per day, or per night
- 15 percent change in vehicle speed.

8 Traffic noise can have a significant effect on property value. A home located adjacent to a major highway may sell for 8% to 10% less when compared to one located along a quiet neighborhood street. Heavy truck traffic lowers property value at a rate 150 times greater than cars. This is because at 50 feet heavy trucks emit noise at 90 dBA while car traffic produces noise at a level of 50 dBA (see Haling and Cohen, 1997).

As with rail, separate day and night measures should be made. The requisite input data are source SELs, average speeds, average hourly daily volume of traffic of type k (k= auto, truck, bus type b).

$$\mathrm{L}_{\mathrm{eq}}\ (\text{hourly at 50 feet}) = \mathrm{SEL}_{\mathrm{ref}} + 10\log(V) + C_{type\,k} - 10\log\left(\frac{S}{50}\right) - 35.6$$

Daytime L_{eq} at 50 feet: $L_{eq}(day) = L_{eq}(h)\big|_{v=v_d}$

Nightime L_{eq} at 50 feet: $L_{eq}(night) = L_{eq}(h)\big|_{v=v_n}$

L_{dn} at 50 feet: $L_{dn} = 10\log\left[(15)\times 10^{\left(L_{eq}(day)/10\right)} + (9)\times 10^{\left(L_{eq}(night)+10/10\right)}\right] - 13.8$

$C_{type\,k}$ is defined as: $C_{type\,k} = 25\times\log\left(\frac{S}{50}\right) for\ bus, = 1.6\ for\ accerating\ 3-axle\,bus$ [9]

As before V is defined as the hourly volume of vehicles of type k (where k=auto, or truck, or intercity bus or transit bus), in vehicles per hour, V_d is daytime vehicles (7am to 10pm) and V_n is nighttime vehicles (10pm to 7am) and S is speed.

As an example, consider a transit route with 200 buses passing in daytime and 20 in nighttime hours; therefore, V_d=200/15=13.33 buses per hour and V_n=20/9=2.22 buses per hour. Using the formulas for buses, L_{eq} (day)= 56.2 dB and L_{eq} (night)=48.4 dB. Total day and night traffic results in L_{dn} at 50 feet = 57.2 dB.

2.4 Measures of Marginal Cost using the USDOT Model

Functions for calculating the marginal cost of noise resulting from changes in the amount of noise produced by cars, buses and trucks are presented below. Noise can change due to a change in speed, a change in the proportion of heavy vehicles or redistribution in the proportion of vehicles traveling in daylight hours.

2.4.1 For Automobiles

These functions describe how noise costs can change because of increases in the number of vehicles, and because of a change in the distribution of traffic between night and day.

$$\frac{\partial L_{dn}}{\partial S} = \frac{15*10^{a+1} + 9*10^{b+1})}{S(5*10^{a} + 3*10^{b})}\text{, where }\begin{aligned} a &= 0.1SEL_{ref} + \log(V_d) - 3.56 \\ b &= 0.1SEL_{ref} + \log(V_n) - 2.56 \end{aligned}$$

$$\frac{\partial C}{\partial S} = z\frac{15*10^{a+1} + 9*10^{b+1})}{S(5*10^{a} + 3*10^{b})}$$

9 For automobiles, $C_{type\ k}$ is = 40*log(S/50)

$$\frac{\partial L_{dn}}{\partial V} = \frac{10}{V}$$

$$\frac{\partial C}{\partial V} = \frac{10z}{V}$$

$$\frac{\partial L_{dn}}{\partial V_d} = \frac{10}{V_d + \frac{3}{5} * 10^{b-a} * V_n}$$, where $$\begin{aligned} a &= 0.1SEL_{ref} - 3.56 + 3 * \log(S/50) \\ b &= 0.1SEL_{ref} - 2.56 + 3 * \log(S/50) \end{aligned}$$

$$\frac{\partial C}{\partial V_d} = z \frac{10}{V_d + \frac{3}{5} * 10^{b-a} * V_n}$$

$$\frac{\partial L_{dn}}{\partial V_n} = \frac{10}{\frac{5}{3} * 10^{a-b} * V_d + V_n}$$, where $$\begin{aligned} a &= 0.1SEL_{ref} - 3.56 + 3 * \log(S/50) \\ b &= 0.1SEL_{ref} - 2.56 + 3 * \log(S/50) \end{aligned}$$

$$\frac{\partial C}{\partial V_n} = z \frac{10}{\frac{5}{3} * 10^{a-b} * V_d + V_n}$$

2.4.2 Marginal Cost Functions for Buses/Trucks,

$$\frac{\partial L_{dn}}{\partial S} = \frac{50 * (4.5 * 10^a + 2.7 * 10^b)}{S(15 * 10^a + 9 * 10^b)}$$, where $$\begin{aligned} a &= 0.1SEL_{ref} + \log(V_d) - 3.56 \\ b &= 0.1SEL_{ref} + \log(V_n) - 2.56 \end{aligned}$$

$$\frac{\partial C}{\partial S} = z \frac{50 * (4.5 * 10^a + 2.7 * 10^b)}{S(15 * 10^a + 9 * 10^b)}$$

$$\frac{\partial L_{dn}}{\partial V} = \frac{10}{V}$$

$$\frac{\partial C}{\partial V} = \frac{10z}{V}$$

$$\frac{\partial L_{dn}}{\partial V_d} = \frac{10}{V_d + \frac{3}{5} * 10^{b-a} * V_n}, \text{ where } \begin{array}{l} a = 0.1SEL_{ref} - 3.56 + 1.5 * \log(S/50) \\ b = 0.1SEL_{ref} - 2.56 + 1.5 * \log(S/50) \end{array}$$

$$\frac{\partial C}{\partial V_d} = z \frac{10}{V_d + \frac{3}{5} * 10^{b-a} * V_n}$$

$$\frac{\partial L_{dn}}{\partial V_n} = \frac{10}{\frac{5}{3} * 10^{a-b} * V_d + V_n}, \text{ where } \begin{array}{l} a = 0.1SEL_{ref} - 3.56 + 1.5 * \log(S/50) \\ b = 0.1SEL_{ref} - 2.56 + 1.5 * \log(S/50) \end{array}$$

$$\frac{\partial C}{\partial V_n} = z \frac{10}{\frac{5}{3} * 10^{a-b} * V_d + V_n}$$

2.5 Noise Cost Calculations based on Gillen Levinson Model- Integrated Noise Model

In order to translate noise production rates into economic damage costs the Gillen-Levinson model described in section 2.2 is used. This model estimates noise cost where the price of noise is established by considering total residential property damage costs per linear kilometer of a roadway. The model variables are shown in Table 2 and are grouped into Assumptions (inputs) and Results (outputs) Table 3. The engineering relationships described earlier are used in generating outputs from the assumed parameter value of the inputs. A step by step calculation sequence is described with reference to a copy of the Excel spreadsheet model used in the calculations.

In the model estimates for the differing categories of heavy trucks and buses are not included separately as there is insufficient data to identify the separate contribution of each type of vehicle. Vehicle flow was considered as a composite of cars, buses and heavy trucks with the latter two considered as composing 20 percent of the flow.

The key assumptions used in calculating the road noise costs were:

- Traffic mix assumes 20 % of vehicles include heavy trucks and buses based on USDOT data which finds heavy trucks are 12 percent of urban traffic, this was increased to 20 percent to take account of urban bus traffic.
- Noise depreciation index is a weighted average (using the 20% assumption for heavy trucks and buses) of each vehicle type's noise depreciation index; this is 0.0067 per dB(A)
- Average speed of vehicles is 80 km/hour
- Housing density along roadways is uniform and the average density for the CMA
- Base dB(A) is assumed to be 58; an average of 55 night and 60 day as there were no data separated by day and night.
- Interest cost is assumed at 5% in calculating annual costs
- Amortization is assumed over 30 years in calculating annual costs

Data were available for traffic flows for 4 cities; Toronto, Winnipeg, Victoria and Regina. Flows for these cities were calculated as the average two-way flow for arterial roadways (major and minor). In cases were information was available by category of road, flows were calculated as a weighted average where the weight is the proportion of each type of arterial road in total arterial roadways. Next each CMA was categorized as to which of the 4 cities was most representative of size, the decision was made on the basis of population. The categories are listed below; so for example, it is assumed that data from Toronto are also relevant for Montreal and Vancouver.

Category One: Toronto, Vancouver and Montreal – use Toronto data

Category Two: Calgary, Edmonton, Halifax, Hamilton, London, Ottawa-Hull, Winnipeg – use Winnipeg data

Category Three – Kitchener, Oshawa, Quebec City, Victoria – use Victoria data

Category Four – Abbotsford, Chicoutimi, Sudbury, Kingston, Regina, Saint John, Saskatoon, Sherbrooke, St. Catharines, St. John's, Thunder Bay, Trois-Riviere – use Regina data

Next the data had to be adjusted from 2004 and 2005 values to 2000 values. The growth in vehicle registration was used as the basis for 'deflating' the vehicle flow values. Table 1 shows the vehicle registrations by province for the 4th quarter of 2000 and 2005 respectively.[10] From these figures the growth from 2000 to 2005 was calculated and the average growth rate was calculated. These growth rates were used for each CMA to bring flow rates to 2000 values.

Table 1

Growth in Registered Vehicles by Jurisdiction

Vehicles registered in 4th Quarter	2000	2005	Growth	Average Annual Growth
Newfoundland	253579	266338	0.048	0.010
PEI	77864	80755	0.036	0.007
Nova Scotia	534139	551117	0.031	0.006
New Brunswick	451114	466835	0.034	0.007
Quebec	4024687	4421968	0.090	0.018
Ontario	6648227	7078835	0.061	0.012
Manitoba	611752	653123	0.063	0.013
Saskatchewan	699857	730201	0.042	0.008
Alberta	2144389	2453704	0.126	0.025
BC	2304490	2322081	0.008	0.002
	Page 20 Statistics Canada Catalogue no. 53F0004XIE	Table 1 in TP 13627E, Catalogue no. 53F0004XIE		

[10] Data are provided by quarter; see Statistics Canada Cat. 53F0004X1E. Vehicle registration were chosen as this is a number which is relatively stable over time and would provide consistent proportions.

Table 2

Assumptions (Inputs):

Variable	Definition
Interest	Discount Rate to convert total home depreciation into a annual value
Years	Number of Years over which depreciation occurs
Flow (Qh)	# of Vehicles per Hour
Speed	Speed in km/hr
heavy	% trucks, heavy vehicles (highway)
Cost/dB(A)	noise depreciation index
HouseValue	Weighted average Home Price
Density	houses/square kilometer

Table 3

Results (Outputs)

Variable	Definition
Total Cost	Total Home Depreciation Value
Annual Cost	Annual $ Value of Total Cost
Cost per dwelling	Total and Annual cost divided by number of dwellings in CMA

Road costs are calculated in the following way; I describe each calculation in the road noise spreadsheet model which is based on the equations displayed in section 2.2. A copy of the Excel spreadsheet is illustrated in Figure 4. This figure is a copy of the spreadsheet model, the cell which is titled Distances (m) and heads the column for distances has values stop at 70 in the figure but in the spreadsheet model distance goes to 200; meaning noise costs are measured up to 200 meters from the road.

Step 1: Inputs into the model include house value, housing density which is assumed uniform as one moves away from the road and the density is equal to the average for the city, the number of vehicles per hour and the km of arterial road in the CMA.

Step 2: Note formulas are based on the description of the Gillen-Levinson model at the beginning of the chapter. The model calculated dB(A) for each 10 meter interval according to the formula =42.2+10*LOG10(flow)+33*LOG10(speed+40+500/speed)+10*LOG10(1+5*heavy/speed)-68.8-10*LOG10(D)/13.5); D is defined as Distance, speed is assumed to be 80 kph.

Note: these equations in step 2 provide a measure of the total amount of noise produced exceeding the level 58 dB(A)

Step 3: I assume housing is uniform density and houses per band, where a band is 10 meters and noise is calculated in 10 meter increments since sound decreases with distance. As we move away from the roadway density is assumed to equal the average density in the city and is assumed uniform.

Step 4: Cost per band is established as density of housing in each band times the value of the house times the change in noise from the base times the noise depreciation factor. Total noise costs are calculated as the sum of noise costs in each band. Note: this is the same as the formula displayed in section 1.6

Step 5: The total cost is the total depreciation value of a stock of capital. To annualize this value we use the following equation-where recall the discount rate is 5% and the time period is assumed 30 years.:

$$Annual\ \ Cost = \left(\left(total\cos t\right) * \left(i * \left(1+i\right)^{t}\right)\right) / \left(\left(1+i\right)^{t-1}\right)$$

All steps are carried out for each CMA and recorded.

Figure 3

Road Noise Model Spreadsheet Layout

The Cost of Road Noise: Model and Calculations

Interest rate	0.05			Total Cost	$39,574,389
Years	30				
Flow (hourly)	123				
Speed (km/hr)	80	Mean House Value	$149,688		
% Heavy Vehicles	20	Density (hh/sqkm)	92.77		
height	0	Base dB(A)	58		
Km of arterial road	758.00				
		ANNUAL COST	$2,077,655		

Distance (m)	Noise dB(A)	Houses/Band	Cost/Band	Cost/Band/House	Relevant Costs/Band	Marginal Cost per Hourly Flow	MC per 1000 Vehicles per Hour
10	68.46	1.8554	19473	10495	$19,473	$20.00	$0.16
20	65.45	1.8554	13871	7476	$13,871		
30	63.69	1.8554	10595	5710	$10,595		
40	62.44	1.8554	8270	4457	$8,270		
50	61.48	1.8554	6467	3485	$6,467		
60	60.68	1.8554	4993	2691	$4,993		
70	60.01	1.8554	3747	2020	$3,747		

The values for noise costs for Canada and provincial totals are presented in Table 4. The average noise cost per dwelling is $805.38 and the annual noise cost per dwelling is $42.28. If one considers the average dwelling has 1.5 or so cars and annual distance driven is about 15,000 km, annual noise cost per km is $0.0022 in 2000.

2.6 Marginal Noise Costs using Gillen-Levinson Model

The cost of noise will change with the level of traffic (flow) and also mix of traffic (proportion of cars, trucks and buses). One possible method which can be used to calculate the marginal cost of noise is to estimate a regression. Since we have 27 CMAs, the noise, traffic mix and flow data can, in principle, be used in to empirically measure the marginal cost of noise. Note that because noise changes with respect to amount of vehicles and unless one has separate measures of automobile, truck and bus traffic, this marginal cost measure is equivalent to a ray average (marginal) cost function since traffic proportions are held constant, calculating marginal costs across traffic mix is akin to a scope measure (trans-ray convexity).[11] Since our traffic flow data is limited, a cost regression was not estimated.

[11] One could also use a hedonic cost function approach to control for traffic mix.

Table 4

Road Noise Costs for 2000

	Total Noise Cost	Annual Cost	Cost per dwelling	Annual Cost per Dwelling
Canada	**$4,249,156,470**	**$223,080,715**	$805.38	$42.28
BC	$1,006,615,521	$52,847,315		
Alberta	$80,255,199	$4,213,398		
Saskachewan	$4,245,400	$222,883		
Manitoba	$23,888,190	$1,254,130		
Ontario	$1,940,228,306	$101,861,986		
Quebec	$1,168,617,468	$61,352,417		
New Brunswick	$3,145,107	$165,118		
Nova Scotia	$12,127,430	$636,690		
Newfoundland	$10,033,850	$526,777		

An alternative method for calculating marginal noise cost for roadway is to use the equation developed by Gillen and Levinson (1998). Based on this work the marginal cost (MC) of noise for roadways is calculated as:

$$MC_{\text{Road Noise}} = \partial TC/\partial Q_R = fD * fH * fC \ (-0.018 + 0.0028 * (1 + \ln(Q_R)))$$

where:

TC=total noise costs
Q_R is the traffic flow measured in vehicles per hour
fD = housing density
fH = House Value
fC = noise depreciation cost per dB(A) (assumed to be 0.0062)

Using this approach a marginal noise cost can be calculated, these are reported in Table 5.

Table 5

Marginal Road Noise Cost by Province and Canada – for 2000

	Marginal Cost per Hourly Vehicle Flow	Marginal Cost per 1000 Vehicle-km
Canada-average	$ 193.97	$ 0.50
BC	$ 2,432.24	$ 5.71
Alberta	$ 39.68	$ 0.29
Saskatchewan	$ 1.25	$ 0.01
Manitoba	$ 14.04	$ 0.10
Ontario	$ 1,661.40	$ 4.93
Quebec	$ 1,067.87	$ 2.35
New Brunswick	$ 0.94	$ 0.01
Nova Scotia	$ 11.00	$ 0.08
Newfoundland	$ 6.04	$ 0.05

CHAPTER 3: MEASURING NOISE COSTS FOR RAIL

As with roadway noise there are two alternative models that can be used to calculate the cost of noise generated by rail traffic in Canada; the Gillen-Levinson (1998) model or the USDOT (2006) model. Both models are described below and the choice of which to use is based on data availability.

3.1 Gillen-Levinson Model

Noise levels for rail depend on the technology chosen. Rail noise differs from highway noise in one key respect. Highway noise is a relatively continuous drone, while rail noise is a punctuated event, which occurs for the few moments when a train passes.

In conventional diesel powered train, rail noise is made up of two primary sources: the locomotive engine and wheel-rail interaction (Wayson and Bowlby 1989). For diesel, the maximum A-weighted sound level has been measured and an equation developed:

$$L_A = 11.09 \log 0.6\mathbf{V} + 70.8$$

where:

L_A = maximum A weighted sound level, dB(A)

V = speed in kph

For General Electric E-60CP engines, and ASEA RC4 engines, passby noise results (measured at 15 meters) have been estimated for the two sources: Drift, and Power. These are given below:

Drift

$$L_A = 30 \log 0.6\mathbf{V} + 32$$

$$L_A = 27 \log 0.6\mathbf{V} + 37$$

Power

$$L_A = 27.5 \log 0.6\mathbf{V} + 35.4$$

$$L_A = 34.5 \log 0.6\mathbf{V} + 23$$

Rail noise emanates from two principal sources: wheel-rail noise, which is proportional to 30 log Speed; and aerodynamic noise, which is proportional to 60, log Speed (Hanson 1990). Measurements have been made for noise levels of different high speed train technologies.-, reported in Table 6.

Hanson (1990) has calculated that in order to maintain 55 dB(A) background Ldn at 180 mph (288 kph), one needs about a 480 ft (146 m) corridor. In order to provide a comparison between highways and rail, L_{10} was taken to be a function of speed. A simple model from the data in the above Table was estimated, giving the following equation

$$L_A = 19.94 + 29.72 \log 0.6\mathbf{V}$$

[R-squared = 0.81]

Table 6

Train Noise Levels (dB(A)) for Various Technologies

Train	60 MPH 96 KPH	100 MPH 160 KPH	120 MPH 192 KPH	200 MPH 320 KPH
Maglev		72	75	85
ICE	72	75	78	92
Shinkansen	79	80	82	
Amtrak	79	82	89	
TGV*				97
Turbotrain		~100		

Source: Hanson (1990), except * from Wayson and Bowlby 1989; note: at 25 m.

Wayson and Bowlby (1989) report that the noise level does not decrease linearly for each doubling of distance as would be expected (probably due to ground impedance) and that geometric spreading has much more effect on the noise levels at higher speeds than does changes in speed (noise levels are more influenced by distance than changes in speed). He also stated that the noise level measurements are correlated with the logarithm of speed.

Koleva M. and Mladenov K. (2000) state that the acoustic environment, as well as the length and speed of the train, determine noise and vibration levels. The average intensity of the noise (assessing by SEL) varies from 83.9 to 104.1 dB/A: the highest intensity accompanies the passing of express (average 95.32 dB/A); the lowest intensity is measured during the passing of EMU (average 89.24 dB/A). Vibrations of the highest intensity are measured during the passing through free fields (0.750 $mm.sec^{-1}$). Regardless of the bridge type, the level of vibrations varies between 0.032 - 0.067 $mm.sec^{-1}$.

To account for that, a distance decay relationship was estimated as:

$$Noise_{@Dist(D)} = Noise_{@25m} - 6.01 \ln(D)$$

where: D = Distance in meters

[R-squared = 0.98]

The noise production and distance decay models are applied using the same adjustments as used for autos in the Gillen-Levinson model.

3.2 Calculating Rail Noise Exposure using the USDOT Model

The key input data for calculating noise exposure and production are:[12]

- N_{cars}, the number of rail cars in the train.
- N_{locos}, the number of locomotives in the train, if any.
- S, the train speed, in miles per hour.
- V_d, the average hourly train volume during daytime hours (equals the total number of train passbys between 7 am and 10 pm, divided by 15).
- V_n, the average hourly train volume during nighttime hours (equals the total number of train passbys between 10 pm and 7 am, divided by 9).

The noise calculation for locomotives is:

$$L_{eqL} = SEL_{ref} + 10\log(N_{eng}) + K\log\left(\frac{S}{50}\right) + 10\log(V) - 35.6$$

where

SEL_{ref} is the reference noise level

N_{eng} is the number of engines per train

K = -10 for diesel, and +10 for electric engine

V is average hourly train traffic in trains per hour

and the noise due to rolling cars is:

$$L_{eqC} = SEL_{ref} + 10\log(N_{cars} + 20\log\left(\frac{S}{50}\right) + 10\log(V) - 35.6$$

where

N_{cars} is the number of cars per train

Therefore the hourly L_{eq} at 50 feet is measured as:

$$L_{eq}(h) = 10\log\left[10^{\left(L_{eqL}/10\right)} + 10^{\left(L_{eqC}/10\right)}\right]$$

However differences between daytime and nighttime L_{eq} must be considered, these are:

$L_{eq}(day) = L_{eq}(h)\big|_{v=v_d}$ and $L_{eq}(night) = L_{eq}(h)\big|_{v=v_n}$

12 With sufficient data one would also want to distinguish the track type (continuously welded or jointed) and profile (at-grade or elevated). As well take account of the location and frequency of train whistles and horns.

where v_d is the average hourly daytime volume of traffic, in trains per hour between 7am and 10pm, divided by 15 and v_n is the average hourly nighttime volume of traffic, in trains per hour between 10pm and 7am, divided by 9.

Thus the L_{dn} at 50 feet would be calculated as:

$$L_{dn} = 10\log\left[(15)\cdot 10^{\left(L_{eq}(day)/10\right)} + (9)\cdot 10^{\left(L_{eq}(night)+10/10\right)}\right] - 13.8$$

The noise distance relationship, for rail car passbys is calculated as:

$$L_{dn} = \left(L_{dn}\big|_{at\,50\ feet}\right) - 10\log\left(\frac{D}{50}\right) - 10G\log\left(\frac{D}{42}\right)$$

where D is distance and G is a ground factor (for hard ground G=0)

A simple example can be developed using these formula. Consider an urban area which has 42 trains per day – 40 during the day and 2 at night-with each train having 3 engines, 82 cars traveling at 30 MPH through the urban area. The L_{dn} at 50 feet from a fixed track would be 75.04. The calculations are indicated below. The reference SELs are:

Source	Reference SEL (dBA)	Approximate L_{max} (dBA)
Rail Cars	82	80
Locomotives – Diesel	92	88
Locomotives – Electric	90	86
Diesel Multiple Unit (DMU)	85	81

Source: USDOT (2006)

Calculation for Example of 3 engine train with 82 cars traveling at 30 mph

SEL-engines	92		
SEL-cars	82		
No.-cars	80		
No.-engines	3		
V-day-Trains/hr	40/15	2.667	
V-night Trains/hr	2/9	0.222	
Speed-mph	30		
		Day	Night
LeqL (locomotives)		73.64993	62.85323
LeqC (cars)		70.361394	59.56469
Total Leq		75.320064	64.52336
Ldn Calculation		510619759	
		255022692	
		8.884026	
Ldn		75.04026	

3.3 Calculation of Marginal Noise Cost for Rail using USDOT Model

The noise costs of rail can change for a number of reasons. These include changes in the number of trains per unit time, the speed of the trains, the length (number of cars) of the train, the number of locomotives and a change in the distribution between day and night operations. Below the marginal cost equations are provided for changes in each of these particular sources of change.

$$\frac{\partial L_{dn}}{\partial S} = \frac{(aK/50^{K/10})S^{(k/10)-1} + (b/125)S}{a(S/50)^{k/10} + b(S/50)^2}$$, where $$a = (10^{0.1SEL_{refe}-3.56})(N_{eng})(15v_d + 90v_n)$$ $$b = (10^{0.1SELrefc-3.56})(N_{cars})(15v_d + 90v_n)$$

$$\frac{\partial C}{\partial S} = z\frac{(aK/50^{K/10})S^{(k/10)-1} + (b/125)S}{a(S/50)^{k/10} + b(S/50)^2}$$, where $$z = \frac{\partial C}{\partial L_{dn}} = (M_u P_u)(HV_k)$$

$$\frac{\partial L_{dn}}{\partial V} = \frac{10}{V}$$

$$\frac{\partial C}{\partial V} = \frac{10z}{V}$$

$$\frac{\partial L_{dn}}{\partial V_d} = \frac{10}{V_d + \frac{b}{a}V_n}$$, where

$$a = 15 * [10^{0.1SEL_{refe}-3.56} * N_{eng} * (S/50)^{K/10} + 10^{0.1SEL_{refc}-3.56} * N_{cars} * (S/50)^2]$$

$$b = 90 * [10^{0.1SEL_{refe}-3.56} * N_{eng} * (S/50)^{K/10} + 10^{0.1SEL_{refc}-3.56} * N_{cars} * (S/50)^2]$$

$$\frac{\partial C}{\partial V_d} = \frac{10z}{V_d + \frac{b}{a}V_n}$$

$$\frac{\partial L_{dn}}{\partial V_n} = \frac{10}{\frac{a}{b}V_d + V_n}$$, where

$$a = 15 * [10^{0.1SEL_{refe}-3.56} * N_{eng} * (S/50)^{K/10} + 10^{0.1SEL_{refe}-3.56} * N_{cars} * (S/50)^2]$$

$$b = 90 * [10^{0.1SEL_{refe}-3.56} * N_{eng} * (S/50)^{K/10} + 10^{0.1SEL_{refe}-3.56} * N_{cars} * (S/50)^2]$$

$$\frac{\partial C}{\partial V_n} = \frac{10z}{\frac{a}{b}V_d + V_n}$$

$$\frac{\partial L_{dn}}{\partial N} = \frac{10}{N}$$

$$\frac{\partial C}{\partial N} = \frac{10z}{N}$$

3.4 Calculating Noise Costs Using the Gillen-Levinson Model

Due to a lack of information it was not possible to calculate the noise costs of rail using the USDOT model. Therefore the model developed by Gillen and Levinson (1998) described earlier in the chapter was used. The model is similar in framework to that used in calculating road noise. The framework of inputs and outputs are listed in the tables below.

Variable	Definition
Interest	Discount Rate to convert total home depreciation into a annual value, assumed to be 5%
Years	Number of Years over which depreciation occurs =30
Trains (Qt)	# Trains per hour; calculated from information on number of locomotives in a CMA and assuming average number of locomotives per train; 2
Speed	Speed in km/hr ; assumed to be 100
Cost/dB(A)	noise depreciation index, assumed for rail to be .0062 per dB
House Value	Average Home Price; calculated as weighted average in CMA, data provided by Transport Canada
Density	houses/square kilometer; assumed constant across CMA, data provided by Transport Canada
Base NEF	Background or threshold noise level assumed to be 58; an average of 55 night and 60 day as there were no data separated by day and night.
Km of track in CMA	Provided by Transport Canada

Variable	Definition
Total Cost	Total Home Depreciation Value
Annual Cost	Annualized $ Value of Total Cost
Total $/dwelling	Total Home Depreciation Value divided by number of affected dwellings
Annual $/dwelling	Annual $ Value of Total Cost divided by number of affected dwellings

Rail costs are calculated in the following way; I will describe each calculation in the rail noise spreadsheet model. This is illustrated in Figure 4. This figure is a copy of the spreadsheet rail noise cost model, as with the road noise model the distances in the illustration stop at 70 m but in the spreadsheet model distances are calculated up to 200 meters; meaning noise costs are measured up to 200 meters from the track.

Step 1: Inputs into the model include house value, housing density which is assumed uniform as one moves away from the track and equal to the average for the city, the number of trains per hour and the km of track in the CMA.

The number of trains per hour for each CMA was determined in the following way. Transport Canada provided information of the total number of cars and total locomotives in each CMA annually for CN and CP. I assumed that the trains were evenly distributed over the days in the year and over each day and was therefore able to establish the number of locomotives per hour. For example Calgary CMA had 322,218 locomotives, dividing this by 365 gives 883 locomotives per day, and dividing by 24 gives 37 locomotives per hour. I assumed two locomotives per train and hence used this as the trains per hour input variable, in the case of the Calgary example this is 18.[13]

Step 2: Note formulas are based on the description of the Gillen-Levinson model at the beginning of the chapter. The model calculated L_{10} for each 10 meter interval according to the formula [noise-(6.01*LN(MAXA(1,$A16-25)))] where noise is equal to [19.94+29.72*LOG(0.6*speed)], speed is assumed to be 100 kph.

Leq is calculated as [L_{10}- B16-5+((10)^2)/56].

NEF is calculated as [10*LOG(10^(B16/10))+10*LOG(trains*peak)-88]

Note: these equations in step 2 provide a measure of the total amount of noise produced exceeding the level 58 dB(A)

Step 3: I assume housing is uniform density and Houses per band, where a band is10 meters and noise is calculated in 10 meter increments since sound decreases with distance. As we move away from the track density is assumed to equal the average density in the city and is assumed uniform.

Step 4: Cost per band is established as density of housing in each band times the value of the house times the change in noise from the base times the noise depreciation factor. Total noise costs are calculated as the sum of noise costs in each band. Note: this is the same as the formula displayed in section 1.6

Step 5: The total cost is the total depreciation value of a stock of capital. To annualize this value we use the following equation-where recall the discount rate is 5% and the time period is assumed 30 years.

$$Annual\ Cost = \left((total\cos t)*\left(i*(1+i)^t\right)\right)/\left((1+i)^{t-1}\right)$$

All steps are carried out for each CMA and recorded.

Figure 4

Rail Noise Model Spreadsheet Layout

The Cost of Rail Noise: Model and Calculations

Scenario 1: Within CMA Rail (Train, 92 db(A) at 25 meters)

Interest	0.05					Total Cost $	937,934
Years	30					Total Annual Cost $	61,014
Trains/Hour	18						
Speed (km/hr)	100			Mean House Value	$191,642		
% Heavy Vehicles	100	cars	295411	Density (hh/sqkm)	42.89		
height	0	tons	0	Base NEF dB(A)	4		
u	0.00						
peak	7	capacity	0				
tons/train	0.00	load factor	1				
Noise@25m	72.7866552						
Km of track	257						

Distance (m)	L10	Leq	NEF	Houses/Band	Cost/Band	Cost/Band/House
10	72.7866552	69.572369	5.79036	0.8578	1825	2127
20	72.7866552	69.572369	5.79036	0.8578	1825	2127
30	63.1139333	59.899648	-3.88236	0.8578	0	0
40	56.5112735	53.296988	-10.485	0.8578	0	0
50	53.4412115	50.226926	-13.5551	0.8578	0	0
60	51.4190133	48.204728	-15.5773	0.8578	0	0
70	49.9086136	46.694328	-17.0877	0.8578	0	0

[13] Please note, because of the level of detail a table which shows the calculations for all CMAs cannot be presented in this report.

The rail noise cost calculation model results are reported by province. In some cases there were no significant noise costs, at least as measured using this noise model. This comes about for three reasons; first, the base noise level is assumed to be 60 dB as specified by Transport Canada; it should be noted that an 80 car train with two engines traveling at 15 mph emits 61 dB.[14] Second, train speeds are assumed to be 100 km per hour and third, the numbers of trains per hour are very low. Details of total and annual costs are provided. It is not possible due to data limitations to express costs in terms of per dwelling or per tonne-km.

Due to a lack of data it was not possible to calculate marginal costs of rail noise. From previous work, (Gillen and Levinson, 1998) at levels of greater than 9 trains per hour, marginal and average costs are quite similar; 60 percent of CMAs have number of trains per hour exceeding 9.

Table 7

Total Noise Costs due to Rail (2000)

	Total Noise Cost-Rail	Annual Noise Cost-Rail
Canada	$ 45,706,567	$ 2,399,595
BC	$ -	$ -
Alberta	$ 350,228	$ 18,387
Saskatchewan	$ -	$ -
Manitoba	$ 197,845	$ 10,387
Ontario	$ 41,860,563	$ 2,197,680
Quebec	$ 3,297,931	$ 173,141
New Brunswick	$ -	$ -
Nova Scotia	$ -	$ -
Newfoundland	$ -	$ -

[14] USDOT Noise Model (2006)

CHAPTER 4: MEASURING NOISE COSTS IN AVIATION

Measuring the cost of aviation noise has been more thoroughly researched than for other modes of transportation. The approach suggested here is following Morrison, Winston and Watson (1999).[15] They argue that it is reasonable to assume each flight adds about 0.02 dBA to the daily day-night noise level and about 0.000055 dBA to the annual day-night noise level.[16] Each flight has an arrival and departure, despite difference in the noise levels of each respective event (takeoffs generate more noise than landings), we assume an average and therefore each flight adds 0.00011 dB to the annual noise levels at the houses surrounding airports. The consensus from the literature is a measured willingness to pay of 0.5 to 0.7 percent per each decibel reduction.

Morrison and Winston (1999) argue, I believe correctly, that willingness to pay measures derived from hedonic studies do not account for noise impacts on recreational properties, institutions and businesses. Therefore they suggest increasing the noise depreciation to *1 percent per decibel*; this means a 1 dB reduction in noise increases the present value of affected homes by 1 percent. On the other hand, most noise impact studies have been carried out in more moderate climates than what many cities in Canada face. These studies would also not have considered the quality of insulation generally of homes in Canada and certainly not the [noise] insulating properties of windows and doors. Therefore, the adjustment from .5 to 1 seems unwarranted. Gillen and Levesque (1990) in quantitative research surrounding Pearson Airport in Toronto found noise depreciation varied by type of dwelling; owner occupied homes depreciated twice as much as rental accommodation or condominiums and the depreciation of owner occupied homes was .4. The median depreciation value from a number of studies is .5. It therefore seems reasonable to use the Morrison et al. methodology but adjust their figures to reflect the depreciation of .5 rather than 1 percent per dBA.

Therefore, to measure the total noise cost for each of the 26 NAS airports in Canada, assume each added flight, in perpetuity, depreciates the net present value of affected homes surrounding these airports by 0.000005 percent for a flight.

4.1 Measuring Noise Costs due to Aviation Noise

Using the equation described in section 1.6, as the basis for our calculation we can re-write it for the aviation noise calculation as:

$$C_n = \left[(M_{n,2000} P_{n,2000} \times HV_n \times f_{n,2000}) \right]$$

Total annual noise costs in Canada across all 27 CMAs would be measured as:

$$C = \left(\sum_{n=1}^{27} C_n \right)$$

where

[15] See *Journal of Law and Economics*, Vol. VII, No. 2 (October) 723-745

[16] Based on FAA information for measuring noise characteristics of aircraft and classifying Stage 3 and 3+ aircraft.

C_n is the total noise costs for metropolitan area n for aviation-generated noise, where n goes from 1 to 27 metropolitan urban areas in Canada[17]

$M_{n,t}$ is the housing density in NEF contour 31 in urban area n at time t[18]

$P_{n,t}$ is the average house price in urban area n at time t

HV_A is the depreciation of house value due to noise type A (aviation); an NPV depreciation of 0.00000027 per flight – note this is the depreciation in the stock value of a home not the annual cost.

$f_{n,t}$ is the number of flights in area n at time t

Information requirements for each airport include: the number of homes on the NEF 31, median values for these homes and the number of annual operations at each airport in year 2000.[19]

4.1.1 Number of Homes Exposed to 30 NEF at each Airport

Number of homes exposed to noise of a particular level at each airport is calculated by selecting all DAs that have the majority of their area within the 30 NEF contour. The selected DAs are then summed by dwelling count.

Seven of the 26 airports in the NAS provided information on their NEF contour maps. The total number of homes within the 30 NEF contour for these seven airports have been calculated to be 34,953.[20]

4.2 Calculation of Aggregate Noise Costs

The aggregate noise costs are calculated for year 2000 for each airport, this is considered the base year. Steps in calculating noise costs:

1. House prices were provided for year 2001 (taken from census data as median value in the enumeration area in which the house is situated). These values were deflated to year 2000 using the seasonally adjusted consumer price index, Bank of Canada.
2. Multiply value of homes times number of affected homes times the number of operations in 2000 times the depreciation rate per operation.

Only 6 airports had complete data to undertake the calculation, total noise costs measured as the long run depreciation in the stock of homes exposed to noise in the NEF 30 is $666,488,601. This represents a [depreciation] cost of $19,950 per home.[21] However, this is the depreciation in the stock. The annualized cost of noise is calculated as:

$$Cost_{Annual} = (\$666{,}488{,}601) * \left[i \cdot (1+i)^t\right] / (1+i)^{t-1}$$

---

[17] There are 27 CMAs considered in the analysis but only 7 had complete data on house values, homes exposed to 65 Ldn and airport operations data.

[18] It has been pointed out that NEF=Ldn-31 so the 65 Ldn is closer to 34 NEF not 30 NEF since 30 NEF is being used in the calculations rather than the value of 34NEF that would be more technically correct.

[19] For some airports however information exists for only the 30 NEF contour, thus <u>overestimating</u> the costs since more homes would be included as affected by noise than should be the case.

[20] Only six airports were used in the calculation of noise costs with total homes of 33,408.

[21] We note that this number is consistent with what has been measured in the literature. Nelson (2004) finds noise depreciation in Canada of about 9% and the annual depreciation calculated here is very close to this value.

where i, the rate of interest or discount, is assumed to be 5 percent and t, the life of a home to be 30 years. The total annual noise cost in 2000 is $34,990,652 for Canada; on a per operation bases, the [average] cost is $30.47.

4.3 Measures of Marginal Cost

The marginal noise cost of aviation could be measured using a regression model. I regressed total annual noise cost on number of operations and found the marginal noise cost of an operation was $64.04 albeit there were only six observations.[22] However, one would expect marginal cost to exceed average cost and this is what we find here. The regression results are displayed in Table 8. This result is to be considered illustrative as the F-statistic; a measure of the explanatory power of the equation is not statistically significant at the 5 or 1 percent levels. Higher noise costs can result from increase in traffic, which has a very small impact, increase in homes exposed to greater than NEF30, a highly unlikely outcome given zoning and land use around airports or a change in home values.

Table 8

Regression Results for Calculating the Marginal Cost of Aviation Noise

SUMMARY OUTPUT		
Regression Statistics		
Multiple R	0.97	
R Square	0.93	
Adjusted R Square	0.92	
Observations	6	
	df	*F*
Regression	1	56.95
Residual	4	
Total	5	
	Coefficients	*t Stat*
Intercept	-6425513	-3.34
# of Operations	64.0416	8.28

[22] Recall any regression is made around the mean of the data so the marginal cost coefficient is evaluated at the mean of total costs and of operations; the mean was 191,396 which exceeds annual operations at all airports except Toronto and Vancouver.

CHAPTER 5: SUMMARY OF NOISE COSTS BY PROVINCE AND BY MODE

The noise costs calculated in this report provide measures of total annual costs by mode, province and aggregates for Canada. They are calculated based on data supplied by Transport Canada. These are described in *Final Report, Data Collection: Noise and the Full Cost Investigation in Canada,* Paolo Mazza, School of Planning, University of Waterloo, ON, October 13, 2006.

Table 9

Annual Noise Costs Aggregated for Each Mode for Canada (2000)

Mode	**Road**	**Rail**	**Air**	**Canada**
Total Annual Cost	$223,080,715	$ 2,399,595	$34,990,652	$260,470,962

The numbers are based on assumptions described in each chapter. The numbers reported here are below real costs for rail, may be high or low for road as there was insufficient information on traffic flow, but certainly for air due to a lack of data total noise costs are underestimated. However, the airports included in the data sample represent approximately 60 percent of total flight operations in Canada. Marginal cost calculations were provided for road, were calculated for air using a regression model but the limited numbers of observations make the estimated value suspect and marginal cost could not be calculated for rail. Based on previous work by Gillen and Levinson (1998) marginal and average costs of rail noise are relatively close for trains per hour > 9.

Table 10 provides a summary of total and annual noise costs by mode, by province (except for air) and total for Canada.

Table 10

Noise Cost by Province, Mode and for Canada (2000)

Area	Total Noise Cost-Road	Annual Noise Cost - Road	Total Noise Cost Air	Annual Noise Cost Air	Total Noise Cost-Rail	Annual Noise Cost-Rail	Canada Total Noise Cost*	Canada Annual Noise Cost*
Canada	$ 4,249,156,470	$ 223,080,715	$ 666,488,601	$ 34,990,652	$ 45,706,567	$ 2,399,595	$ 4,961,351,638	$ 260,470,962
BC	$ 1,006,615,521	$ 52,847,315			$ -	$ -	$ 1,006,615,521	$ 52,847,315
Alberta	$ 80,255,199	$ 4,213,398			$ 350,228	$ 18,387	$ 80,605,427	$ 4,231,785
Saskachewan	$ 4,245,400	$ 222,883			$ -	$ -	$ 4,245,400	$ 222,883
Manitoba	$ 23,888,190	$ 1,254,130			$ 197,845	$ 10,387	$ 24,086,035	$ 1,264,517
Ontario	$ 1,940,228,306	$ 101,861,986			$ 41,860,563	$ 2,197,680	$ 1,982,088,869	$ 104,059,666
Quebec	$ 1,168,617,468	$ 61,352,417			$ 3,297,931	$ 173,141	$ 1,171,915,399	$ 61,525,558
New Brunswick	$ 3,145,107	$ 165,118			$ -	$ -	$ 3,145,107	$ 165,118
Nova Scotia	$ 12,127,430	$ 636,690			$ -	$ -	$ 12,127,430	$ 636,690
Newfoundland	$ 10,033,850	$ 526,777			$ -	$ -	$ 10,033,850	$ 526,777

* Provincial figures exclude air sector

REFERENCES

Australian Bureau of Transport and Communications. 1992. *Social Cost of Road Accidents in Australia*, Economics Report 79. Australian Government Publishing, Service: Canberra.

Berlin Digital Environmental Atlas (2005), Traffic and Railway Noise-Statistical Base and Methodology - http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/eia702.htm

Boardman, T., Greenburg, David, Vining, Aidan and David Weimer (2006), *Cost Benefit Analysis: Concepts and Practice*, Prentice Hall New Jersey 3rd Edition

Boardman, T., David Gillen, William Waters and Anming Zhang (2004), *The Full Social Costs of Transportation in Canada* (Research Report, Strategic Analysis Branch, Transport Canada)

Brainard, Julii, S., Andrew P. Jones, Ian J. Bateman and Andrew A. Lovett (2004), Exposure to Environmental Urban Noise Pollution in Birmingham, UK, *Urban Studies, Vol. 41, No. 13, 2581–2600, December*

Delucchi, Mark (2000) "Environmental Externalities of Motor-Vehicle Use in the US," *Journal of Transportation Economics and Policy*, Vol. 34, No. 2, May 2000, pp. 135-168.

Delucchi, Mark and Shi-Ling Hsu (1998) "External Damage Cost of Noise Emitted from Motor Vehicles," *Journal of Transportation and Statistics*, Vol. 1, No. 3, October 1998, pp. 1-24

Delucchi, Mark and Shi-Ling Hsu (1996), *The External Damage Cost of direct Noise from Motor Vehicles*, UCD-ITS-RR-96-3 (14), department of Agricultural Economics, UC-Davis

European Commission, Working Group Railway Noise of the European Commission (1994), *Position Paper on the European strategies and priorities for railway noise abatement*

Federal Transit Administration (1997), *Wheel Rain Noise Control Manual*, Transit Cooperative Research Program Report 23

Gillen, David W. 1990. *The Management of Airport Noise*, DWG Research Associates for Transport Development Centre, Transport Canada, July 1990

Gillen, D., D. Levinson, and A. Kanafani, "The Social Costs of Intercity Transportation: A Review and Comparison of Air and Highway," *Transport Reviews,* Vol. 18, pp. 215-240, 1998

Gillen, David, and David Levinson (1998) The Full Cost of Air Travel in the California Corridor. *Transportation Research Record: Journal of the Transportation Research Board* 1662: 1-9

Gillen, D., D. Levinson, "The Full Cost of Intercity Highway Transportation," *Transport Research D,* 1998.

Gillen, D., D. Levinson, M. Mathieu, and A. Kanafani, "The Full Costs of High Speed Rail: An Engineering Appraoch," *Annals of Regional Science,* 1997.

Hanson C (1990) High-speed Rail System Noise Assessment *Transportation Research Record 1255* p 119–121, W. Harris Miller Miller and Hanson, 429 Marrett Rd. Lexington, Mass 02173

Haling, Daniel and Harry Cohen (1997), "Residential Noise Damage Costs Caused by Motor Vehicles," *Transportation Research Record 1559*, 1997, pp. 84-93.

Jones-Lee, Michael. 1990. *The Value of Transport Safety* Oxford Review of Economic Policy, 6,2:39-60 (Summer 1990)

Koleva M. and Mladenov K.(2000), Measurement and analysis of railway noise and vibration, *Noise & Vibration Worldwide*, Volume 31, Number 5, 1 May 2000, pp. 8-12(5)

Levinson, David, Adib Kanafani, and David Gillen. 1999. Air, High Speed Rail or Highway: A Cost Comparison in the California Corridor. *Transportation Quarterly* 53: 1 123-132

Litman, Todd, Victoria Transport Policy Institute (VTPI), *Transportation Cost-Benefit Analysis – Noise Costs* (2005)

Nelson, Jon (2004) Meta-Analysis of Airport Noise and Property Values: Problems and Prospects, *Journal of Transport Economics and Policy*, Vol. 38, No 1 pp.1-27

Quinet, Emile (1997) "Full Social Cost of Transportation in Europe," *The Full Costs and Benefits of Transportation*, Springer (Berlin), 1997, pp. 69-111

To, W.M., Rodney C. W. Ip, Gabriel C. K. Lam and Chris T. H. Yau (2002), A multiple regression model for urban traffic noise in Hong Kong, *J. Acoustical. Soc. Am.* **112** (2), August, 551-556

TRB, Transportation Research News (2005), *Transportation Noise; Measures and Countermeasures*, September-October 2005, No. 240

United Kingdom Department of Transport *Calculation of Road Traffic Noise*, Department of Transport, Welsh Office, HMSO, 1988.

USDOT (2006), *Transit Noise and Vibration Impact Assessment*, FTA-VA-90-1003-06, Office of Planning and Environment Federal Transit Administration

USDOT (1997) *Federal Highway Cost Allocation Study*, (www.fhwa.dot.gov/policy/hcas/summary/index.htm)

Wayson RL, Bowlby W (1989) Noise and Air Pollution of High Speed Rail Systems. ASCE *Journal of Transportation Engineering* 115(1):20–36