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A concept on predicting road network scale noise event probability by road function

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ABSTRACT

This paper presents a concept towards the development of a flexible method of predicting noise event probability across a road network using road function categories. The need for a flexible method is derived from the varying levels of data availability and data accuracy for different road authorities. A road authority should not be prevented in assessing noise events due to lack of highly detailed and accurate data. The benefits of a network scale method of predicting noise event probability include the ability to: (1) produce network scale noise event maps, (2) better conduct public health research, and (3) assess changes to the road traffic distribution across a network. These three listed benefits combined will allow application of localised transport-health research. The paper commences with a short review of literature and theoretical concepts, followed by an outline on the data and computational requirements for noise event probability prediction. Analysis of sample road vehicle speed and classification data is conducted across varying road functions. The concepts behind a flexible prediction method are then presented along with a discussion on its potential application, limitations and benefits.

Keywords: road traffic noise, noise events, road function, event probability
I-INCE Classification of Subjects Number(s): 52.3, 76.1.1

1. INTRODUCTION

Recently interest in road traffic noise dynamics has increased [1-5] but it appears cumbersome mathematically and computationally to apply these methods across a whole network. Thus, a method is required to predict noise event magnitude and probability across an entire region. The method should be flexible to various levels of input data accuracy because of varying amounts of data and data accuracy available to different road authorities across different jurisdictions. The benefits of such a method will be to (1) map noise event magnitude and probability across a network (2) to conduct epidemiological spatial research between sleep disturbance or other health, psychological or developmental related data and noise road noise events, (3) to assess planned or unplanned changes to the road traffic distribution across a network.

Today, most Australian States and numerous countries around the world use the Calculation of Road Traffic Noise (CoRTN, [6]) methodology for predicting and assessing road traffic noise. This method can be described as a simple comparative tool, but its simplicity provides a number of advantages for example (i) it is easy to apply consistently, (ii) does not require large data inputs (iii) does not require expert users. As CoRTN remains in common use, it would be an advantage to establish an adjunct method that can indicate the likelihood of noise events and their magnitude without requiring extensive calculations and large data inputs. It would be useful to attempt to relate noise events to Annual Average Daily Traffic (AADT) and percentage commercial vehicles. This may be possible by introducing the road function as a variable with some predefined inputs that are similar to CoRTN. Naturally the author does not promote this concept if real and accurate data and methods are available. However, in the instance where a large scale comparative assessment is required but there is limited input data availability, one should not abandon attempts to assess the impacts of noise events on communities.

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1.1 Aims of the paper

The purpose of this paper is to outline a conceptual method of predicting road noise event probability, but a detailed analysis and validation is left to a future body of work. A future study will assess a regional area and analyse a number of roads within that region with the aim to compare the noise event probability predictions with data related to human responses with the anticipation that a correlation can be observed.

Here, a small sample of roads of different functions within a region will be analysed against simple traffic engineering parameters which are outlined in the sections below. This analysis is provided to support the hypothesis that different roads of different functions may be distinguished through a method of predicting noise event probability.

The paper firstly presents the variables and basic traffic engineering theory needed. It then presents the use of traffic engineering theory in the conceptual method of predicting noise event probability for a traffic stream on a road. It follows this with a brief presentation of traffic flow data analysis for various roads and then concludes with a discussion on potential future work directions.

2. METHODOLOGY

To characterise roads into road functions and their likelihood of producing noise events, one first needs to determine the nature of the traffic flow along a road. This requires an understanding basic traffic theory. In combining the theoretical traffic flow characteristics of a road and the noise characteristics of vehicles likely to travel on a road, a theoretical evaluation of the noise character of a road can be developed. The variables of main interest in this methodology are listed in Table 1.

Table 1: Variables of main interest

Variable Category	**Variable**	**Description**
Traffic Flow	Vehicle number	The number of vehicles on the road, and more specifically in a particular lane.
	Speed	The velocity of individual vehicle.
	Headway	The time between consecutive vehicles in a lane.
Traffic Composition	Vehicle Type %	The classification of vehicles, largely dependent on number of axles. Austroads [7] has 12 classification categories (Class 1 to 12) where for this research a 13th category (Class 0) is created to cater for motorcycles.
Acoustic	Vehicle L_w (Type, Speed)	A comprehensive L_w database in terms of vehicle type, vehicle speed and road geometry and pavement type (For example Brown & Tomerini [8] and Naish [9].
Road	Function	The function of a road is the purpose of the road and are often categorised as Freeway, Motorway, Urban Arterial, Rural Highway, Urban Collector, Local Road.
	Geometry	Includes, for example, horizontal and vertical geometry, longitudinal and lateral grade, number and width of lanes.
	Pavement	The effect of different pavement types of vehicle noise generation.

Of the variables in Table 1, this paper focuses on road function (which includes traffic flow, traffic composition) and acoustic variables and their potential influence on noise event probability. The road variables that include horizontal and vertical geometry and pavement type are not discussed further because their effects on noise event probability would be included in any comprehensive road vehicle sound power database. Road function will tend to define the type of geometry, type cross-section and pavement, therefore geometry and pavement are sub-variables.

The following sections briefly outline the relevant parts of traffic theory and analysis of traffic flow data. This is then followed by the presentation of how road traffic flow information may be used to describe and predict noise event probability.

2.1 Basic traffic theory and its relationship to road traffic noise

Fundamental traffic theory involves and understanding of the relationships between (i) volume ‘q’ and headway ‘h’, (ii) density ‘k’ and average spacing ‘s’, and (iii) speed ‘v’ [10]. Headway ‘h’ is the time interval between two consecutive vehicles in a traffic stream and is the reciprocal of volume. Traditionally road traffic noise has focused on traffic volume, such as the hourly flow or annual average daily traffic (AADT). AADT however does not describe the fluctuations in road traffic noise due to variability in the time interval between consecutive vehicles. In this regard, headway data from a road can describe the probability of the number of vehicles separated by a certain time. The traffic flow volume of a road leads to the concept of whether road traffic noise is continuous or discontinuous; however there is no clear distinguishing point between a continuous versus discontinuous road traffic noise. The higher the traffic volume, the more consistent the sound pressure level at receiver. The lower the traffic volume, the dynamic range of the sound pressure level is greater depending on the distance between the source and receiver.

Figure 1(a) shows a typical theoretical probability distribution for headway; which can be represented by a negative exponential distribution. The figure shows three divisions which figuratively describe positions in headway (time) that could be used to define the probability of traffic along a road being continuous, discontinuous or an isolated vehicle. Not shown in Figure 1(a) is that headway distributions can be different for different classes of vehicle; the effect of this on noise events is worthy of a future investigation.

The other major traffic stream variable affecting road traffic noise is vehicle speed. The speed of individual vehicles along a road can vary significantly and the speed probability will generally follow a normal distribution as shown in Figure 1(b). A key feature in road design speed parameters is the operating speed which is defined as the 85% (percentile) of actual vehicle speeds and most geometrical elements will be designed related to this parameter. This speed parameter is often different to the posted speed which introduces further discord between standard ‘continuous’ road traffic noise prediction methods and noise event probability prediction. Roads of different functions are designed with varying operating speeds, and roads of the same function can have different operating speeds. Therefore it is important to measure or predict the operating speed and determine a speed probability distribution for all vehicle classifications.

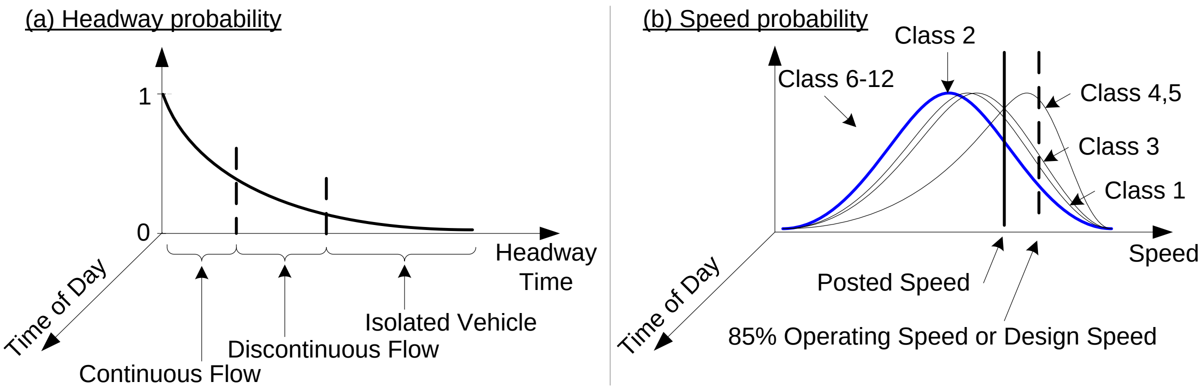

Figure 1: Illustrative probability distributions for (a) headway ‘h’ and (b) speed with example differences in speed probability distribution per vehicle class (Class 1 to 12 as per Austroads [7]). Probability distributions for headway and speed will vary according to time of day.

2.2 Road Function

Road function is an important first step in designing, constructing and managing an element of the road infrastructure network. There are numerous classification systems nationally (for example Austroads [11] and internationally (for example FHWA [12]) however each classification system is similar. For the purpose of this work and considering its focus on noise event probability, the following road functions are proposed in Table 2.

It is expected that the ‘Freeway’ would be subject to the highest number of noise complaints and may in fact demonstrate the highest number of noise events. However, it is hypothesised that through the concept method presented in this paper, it might be revealed that roads of a lower function have a noise event probability that is also significant.

Table 2: Example road function classification system

Function	Location	Speed	Volume	Configuration
Freeway	Urban (sparse access connecting major population districts)	High	High	Multi-lane Divided
Urban Arterial	Urban (sparse access within a population district)	High to Medium	Medium	Multi-lane Divided
Urban Collector	Urban (regular access within a population district)	Medium	Medium	Multi-lane Undivided
Urban Local	Urban (local access within suburb)	Low	Low	Two-lane Undivided
Rural Highway	Rural (high speed access to other population districts)	High	Low	Two-lane Undivided
Rural Local	Rural (local access within rural population district)	Low	Low	Two-lane Undivided

2.3 Traffic Data Analysis

A sample of different roads was selected that included four different road functions, as listed in Table 3. Traffic census and traffic flow survey data was obtained from the Queensland Department of Transport and Main Roads.

Table 3: Roads selected for traffic flow analysis

Function	Designation	Speed km/h	AADT	%C.V.	Number of vehicles in sample data
Freeway	Road A	80	62149	12.4	1048575
Urban Collector	Road B	60	59199	5.5	429102
Rural Highway	Road C	100	9097	10.5	65535
Rural Local	Road D	60	8836	4.7	77437

The survey data was analysed according to vehicle classification and grouped into light and heavy vehicles. The speed data was analysed to find the normal distribution fit for both light and heavy vehicles.

Headway was analysed for each road, where for some roads the large range of headway ensured that for ease of comparison a $\log(x+1)$ transformation of the headway data was suitable. The transformed headway data was rounded to the nearest tenth of a decimal which formed a suitable range to calculate frequencies. Due to the large differences in traffic volume between the four roads, the frequency count distributions were normalised to a standard curve integral area of unity.

2.4 Noise Event Probability

The concept presented below aims to establish a simple method to compare the probability of noise events from two different roads, or from two different traffic flow scenarios. In the latter case, the probability of noise events before and after a road upgrade may be of interest to a road authority. Noise event probability needs to have a 'Reference Conditions' in order for comparisons to be made (Section 2.4.1). Once the reference conditions have been established, the 'Event Conditions' can be determined (Section 2.4.2).

2.4.1 Reference Conditions

The reference conditions observe a road's average headway, mean speed per vehicle class which results in a mean L_w per vehicle class. Average or Equal Headway, $h_{eq,t}$, is the inverse of traffic flow per time period, t, as in Eq.(1), where q_t is the total number of vehicles in that time period.

$$h_{eq,t} = \frac{1}{q_t} \tag{1}$$

Mean speed per vehicle class, $v_{av,class,t}$, is given by Eq.(2), where v_n is the velocity of vehicles of a certain class over a specified time period, t, and n_{class} is the total number of vehicles of that particular class.

$$v_{av,class,t} = \frac{1}{n_{class}} \sum_{n=1}^{n_{class}} v_n \tag{2}$$

The $v_{av,class,t}$ is used to extract a mean sound power level per vehicle class, $L_{w,avg,class,t}$, from a sound power level database that is representative of the vehicle fleet in the area under investigation. To reduce the large variability between different roads, it is possible to determine a Weighted Mean Sound Power Level ($L_{w,R,t}$) (Eq.(3)). The weighting is based on the proportion of vehicle classes to the total number of vehicles, n_{class}/q_t, which is single number representing the average L_w based on the road function.

$$L_{w,R,t} = 10log_{10}\left[\frac{1}{q_t}\sum_{class=0}^{class=12}\frac{n_{class}}{q_t} \times 10^{0.1\left(L_{w,avg,class,t}\right)}\right] \tag{3}$$

Although $L_{w,R,t}$ can be used to compare roads, it can be further used along with $h_{eq,t}$ to calculate a theoretical L_w dynamic pulse as per the example in Figure 2 below.

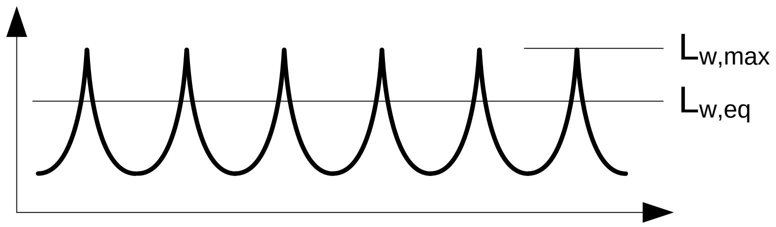

Figure 2: Theoretical L_w dynamic pulse

The theoretical pulse can be used to review the roads dynamic character without needing to specify a distance. Thus the reference conditions for a road in terms of event probability can be reviewed outside of the sound pressure level domain. One can then determine or decide on conditions that will define events, for example through calculating and analysing the relationships between the $L_{w,max}$ and the $L_{w,eq}$ and the number and magnitude of such events over a specified time period.

2.4.2 Event Conditions

Specification of event conditions can take place more easily once the reference conditions are known. Event conditions are here defined in terms of the probability of a noise event occurring over a certain time period. Sound intensity or pressure levels at the receiver will always be the most important parameter for assessment of individual exposure. However, probability of a noise event is proposed to be an easy assessment compared to attempts to predict the actual sound pressure level magnitude and number of events. Prediction of noise event probability can be conducted at a community or regional scale.

The first step in determining the probability of a noise event is to predict the probability of an isolated vehicle. This requires a return to headway analysis used in the calculation of reference conditions (i.e. $h_{eq,t}$). In selecting an appropriate factor, α, it is possible to determine a suitable headway, $h_{C,t}$, that will define an isolated vehicle (Eq.(4)).

$$h_{C,t} = \alpha \times h_{eq,t} \tag{4}$$

If headway can be expressed by a displaced negative exponential distribution, determine the probability, $P_{(h_t > h_{C,t})}$, that the headway h_t, exceeds $h_{C,t}$ through the use of Eq.(5) and Figure 3.

$$P_{(h_t > h_{C,t})} = e^{\frac{-q(h_{C,t}-\beta)}{1-q\beta}} \qquad for\ h_{C,t} > \beta \tag{5}$$

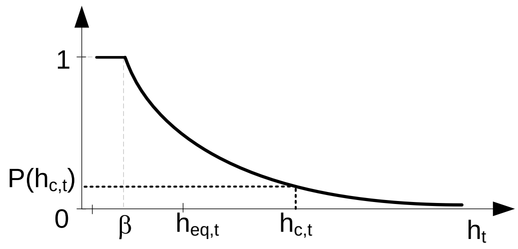

Figure 3: Typical displaced negative exponential distribution for headway probability.

Similarly, the method requires determination of a suitable sound power level criterion that will define a noisy vehicle. By multiplying $L_{w,R,t}$ from the reference conditions with a factor, φ (where $\varphi > 1$), a sound power criterion (c or criteria can be established (Eq.(6)).

$$L_{w,C,t} = \varphi \times L_{w,R,t} \tag{6}$$

Distribution of sound power levels across the vehicle fleet or within a vehicle class per time period, $L_{w,class,t}$, is assumed to follow the normal probability distribution. The probability of exceeding the sound power level criterion for either the entire vehicle fleet or for each class of vehicle can be calculated using $L_{w,C,t}$ and the normal probability distribution, $P_{(L_w > L_{w,C,t})}$. In regard to Eq.(6), the factor φ could take a number of values to define different categories of $L_{w,C,t}$, such as Minor, Moderate or Extreme as shown in Figure 4. This option would allow flexibility in further studies that attempt to correlate road traffic noise events and human responses. The setting of criteria levels through the use of Minor, Moderate and Extreme could also be manipulated to provide the best fit correlation between varying severities of human response, for example, with lowly annoyed, annoyed and highly annoyed categories.

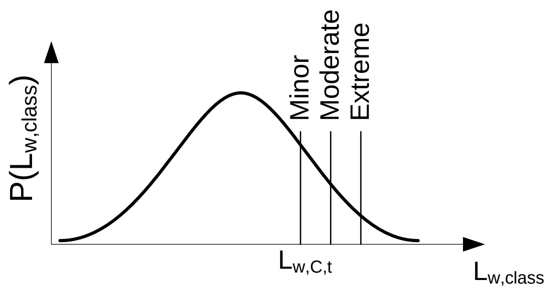

Figure 4: Example of normal distribution for vehicle class $L_{w,class}$ and exceedance levels

In addition to the prediction of a vehicle's sound power level, the introduction of the vehicle speed probability could provide further exploration. In this case, comparison to the reference condition $v_{av,class,t}$ might provide a useful benchmark to determine event conditions related to vehicle speed.

Once the probability of exceeding a nominated sound power level criterion is known, the predicted number of 'noisy' vehicles per vehicle class per time period, $q_{noisy,class,t}$, is calculated with Eq.(7), where $n_{class,t}$ is the total count of vehicles per class in the specified time period.

$$q_{noisy,class,t} = n_{class,t} \times P_{(L_w > L_{w,C,t})} \tag{7}$$

Thus the total number of noisy vehicles from all classifications is the sum of $q_{noisy,class,t}$, as per Eq.(8).

$$q_{noisy,t} = \sum_{class=0}^{class=13} q_{noisy,class,t} \tag{8}$$

The quantity $q_{noisy,t}$ can be used as an indicator to compare roads. However a further useful indicator is the predicted number of isolated noisy vehicles, $q_{isolated,noisy,t}$, which is the multiplication of the probability of an isolated vehicle ($P_{(h_t > h_{C,t})}$) by the predicted number of noise vehicles ($q_{noisy,t}$) as shown in Eq.(9).

$$q_{isolated,noisy,t} = P_{(h_t > h_{C,t})} \times q_{noisy,t} \tag{9}$$

Note that here the equations do not show a prediction of an isolated vehicle of a specific classification e.g. articulated truck, but a minor extension of the method would be possible to conduct that analysis.

3. TRAFFIC ANALYSIS RESULTS

The results of the speed normal distribution results for both light and heavy vehicles are presented in Figure 5. It is observed that truck speeds on Road 1 (Freeway) have a smaller variance than light vehicles, which may mean that prediction of L_w for heavy vehicles would be more reliable from a speed perspective. However, Road 1 (Freeway) exhibited the largest variance of all roads, which may indicate numerous disruptions to the traffic flow, for example, disruption due to accidents thus limiting the ability to reliably predict L_w from vehicle speed. Road 2 (Urban Collector) also exhibited a relatively large variance but there was little difference in the speed distribution between light and heavy vehicles. This may be due to traffic signal disruptions and higher prevalence of congested vehicle platoons. Road 3 (Rural Highway) showed relatively little variance compared to Road 1 (Freeway) and Road 2 (Urban Collector) which suggests an increased ability to predict L_w in relation to traffic speed. Likewise for Road 4 (Rural Local), however there was a notable difference in heavy vehicle speeds being higher than light vehicle speeds.

The results in Figure 5 show the importance of understanding the nature of the traffic flow on a particular road before attempting to predict noise events and their probability. It also demonstrates the large range of speeds that can be encountered along a road which is not considered in standard road traffic noise assessments.

The results from the analysis on headway are presented in Figure 6. The initial observation that can be made is the considerable difference between Road 1 (Freeway) and the other roads. Road 1 (Freeway) provides relatively little opportunity for an isolated vehicle with the smallest headway measured being just over 1 minute. This is due to its high traffic volume. Road 2 (Urban Collector) exhibits a wider frequency distribution that Road 1 which is likely to the due to the interrupted flow situation being in a urban location. Road 3 (Rural Highway) and Road 4 (Rural Local) exhibit the widest range of headways with almost an even distribution of headway up to around 30s. After this time, headway frequencies on both roads drop quickly. It is observed that the likelihood of very isolated vehicles exist for the rural roads, with headways up to 10 minutes in some cases.

The headway results in Figure 6 show that very careful consideration is required to define the event conditions that would lead to the prediction of noise event probability.

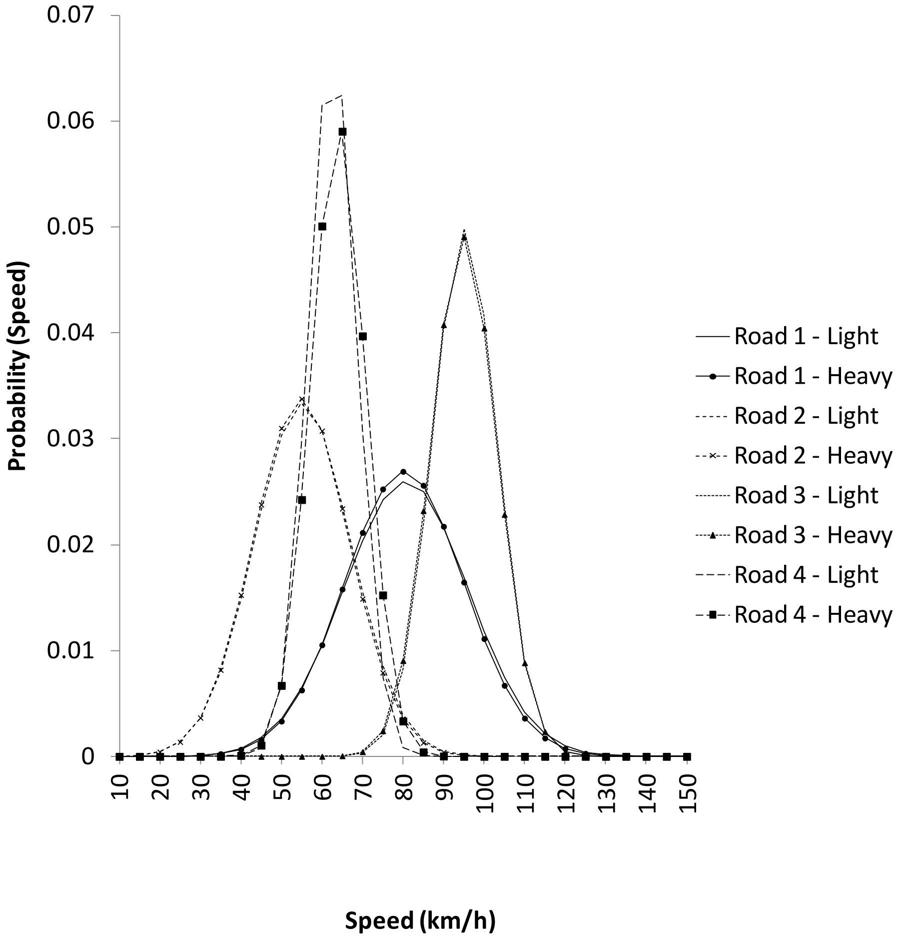

Figure 5: Example Normal distributions of speed for Road 1 to 4, light and heavy vehicles

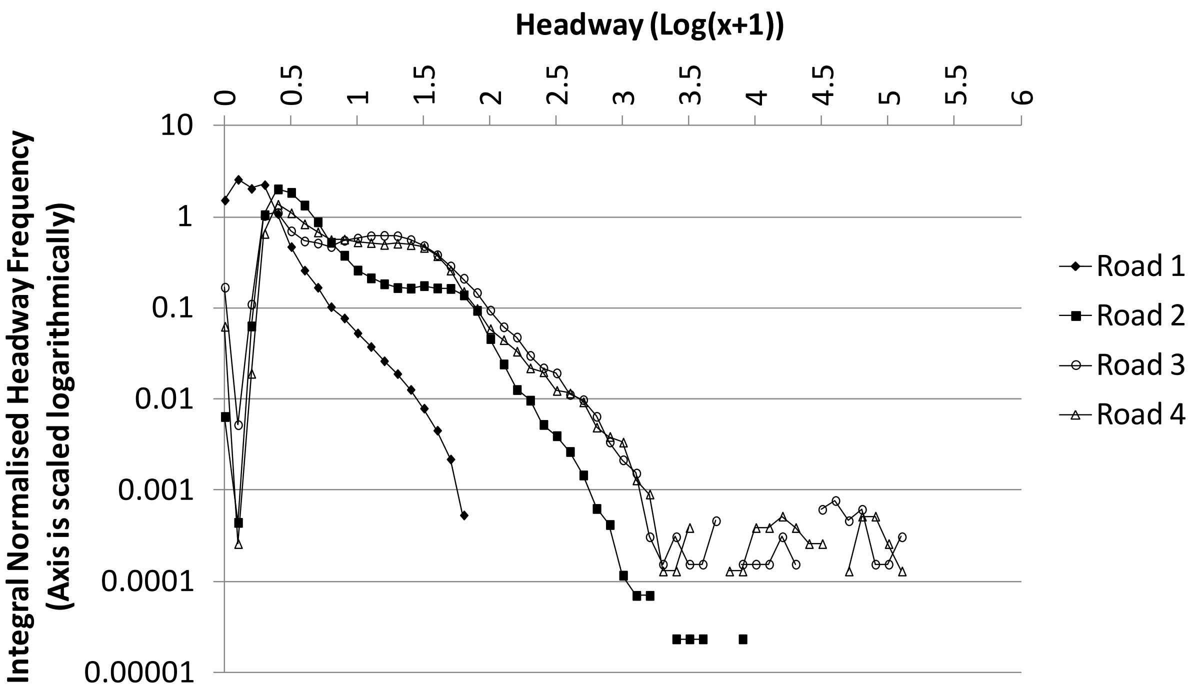

Figure 6: Headway frequency distributions for Road 1 to 4, all vehicles

4. DISCUSSION AND CONLUSIONS

The results in the previous section begin to demonstrate that road functions could be used to generate expected speed and headway distribution profiles. The road function profiles could consequently be used to develop a noise event probability prediction across a road network region. Identifying a change in a road's profile due to changes or upgrades in the road network could feasibly be used to assess the changes in noise event probabilities which may affect the community.

Clearly further work and research needs to be done to judge the worthiness of this noise event probability prediction concept, however the early signs are encouraging and thus more research into this topic is intended.

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