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A six-category heavy vehicle noise emission model in free-flowing condition

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ABSTRACT

Annoyance and sleep disturbance caused by transportation noise are frequently associated with heavy vehicles. The ability to accurately predict heavy vehicle noise impact using conventional road traffic noise prediction methods has reduced over the years as the variety of heavy vehicles have increased progressively and the predominant long haul freight vehicle is trending towards larger trucks with a greater number of axles. In this paper, a six-category heavy vehicle source emission model in free-flowing condition has been developed based on the state-wide road setting in New South Wales, Australia. The six-category model allows traffic noise across the road network, carrying a diverse fleet of heavy vehicles, to be predicted with notably higher accuracy and precision in comparison to conventional models that aggregate heavy vehicles into one, or at most, two distinct categories. A comparative analysis is carried out to examine the source emission from various traffic mix scenarios in urban areas and along major freight routes. Current findings also highlight the importance of distinguishing regional characteristics in a harmonised road traffic noise prediction model.

1. Introduction

Road freight is crucial to the economy and delivers many benefits to the community [1]. However, noise emitted by heavy vehicles can adversely impact on those living along or near freight routes. This problem is being compounded by changes to regulations as well as heavy vehicle access improvements which have encouraged strong growth in the use of larger truck and trailer combinations with a greater number of axles to increase freight productivity. This is a global phenomenon where the predominant long-haul road freight vehicle in most countries has been trending towards 5 and 6 axle articulated trucks, and up to 9 axles in Australia, New Zealand, as well as some European countries and American states [2–6].

Noise prediction for the assessment of environmental road traffic noise impact in the United Kingdom (UK), Ireland, Hong Kong, Australia and New Zealand has been made largely using the Calculation of Road Traffic Noise (CoRTN) procedure initially developed by the UK's Department of Environment in 1975 and later refined by their Department of Transport in 1988 [7–9]. The vehicle classification system described in CoRTN identifies only two vehicle groups, namely, light vehicles and heavy vehicles. This assumes that vehicles within each group are acoustically similar. Further, its heavy vehicle category is representative of 4 axle trucks because measurements that underpin the CoRTN prediction model were taken prior to 1973 [8,10]. As such, the ability for CoRTN to accurately predict source emission levels has reduced over the years in line with the changes that have taken place not only in the design of vehicles and motor vehicle noise regulation [11], but also due to the increasing diversity of heavy vehicle axle configurations on the road network [4]. Confidence limits are also broadened by the fact that the predominant axle configuration varies between roads with different functions and time of day, which is not currently reflected by a source emission model that only uses a single heavy vehicle category.

Many researchers have employed regression analysis as well as descriptive and inferential statistics in an attempt to improve the prediction performance of a road traffic noise model [12–15]. This has been achieved by developing corrections based on the correlation between predicted and measured road traffic noise levels. In these studies, the primary cause of prediction uncertainty has been identified to be due to the use of a road traffic noise model in a region with significantly different traffic mix. However, instead of expanding on the source emission model to influence its input, in

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each case the model's output has been modified using statistical correlation.

In an attempt to improve the prediction performance of a source emission model and expand its range of validity, several road traffic noise prediction methods have encompassed a refined heavy vehicle classification system based on common features, such as the number of axles and weight. Heavy vehicles in the Japanese model (ASJ-RTN) [16], American model (FHWA TNM) [17] and two principal European models (Nord2005 and CNOSSOS-EU) [18,19] are subdivided into two categories corresponding to medium (2 axle) and heavy (3 axle or more) trucks. This additional vehicle category approach that separates 2 axle and multi-axle trucks reduces the statistical dispersion and thus more accurately represents the noise emission characteristics of different heavy vehicle configurations [16]. However, a number of other principal road traffic noise models, such as CoRTN [7–9], the Swiss model (SonRoad) [20] and the French model (NMPB2008) [21], that only employ a single heavy vehicle category, are still being commonly used to assess environmental road traffic noise impact. The option to change heavy vehicle noise emission is only included in the Nord2005 model, whereby the number of axles for the multi-axle heavy vehicle category is increased to account for larger trucks under Swedish and Finnish conditions [18,22]. It is further recognised that the same source emission model should not be commonly applied across all Nordic countries [23]. The present work expands on these features to develop a source emission model to assess heavy vehicle noise impact with the versatility to adapt the predominant axle configuration to each traffic mix scenario.

A six-category heavy vehicle noise emission model is developed with reference to a wide variety of traffic mix scenarios in Australia to evaluate the prediction performance of conventional one- and two-category heavy vehicle noise emission models. To take into account variation in road function between metropolitan and rural areas, a variation to the source emission regression formula depending on the percentage of heavy vehicles in the traffic flow is introduced here. The proposed approach to investigate and improve the prediction performance of the one- and two-category models involves a four-step process: (1) analysis of traffic mix; (2) development of a detailed noise emission model with six categories of heavy vehicles classified based on axle-configurations; (3) evaluation of the one- and two-category models against the six-category model; and (4) performance of a sensitivity analysis to understand the impact of varied heavy vehicle axle configurations.

This paper is organised as follows. A review of the heavy vehicle type and traffic flow pattern is described in Section 2. In Section 3, seven principal road traffic noise emission models are compared. A six-category heavy vehicle noise emission model is developed in Section 4. Its performance is assessed with reference to measured road traffic noise levels at 41 locations along four arterial roads, one motorway and three rural freight routes covering a variety of traffic flows. The six-category heavy vehicle noise emission model is subsequently used in Section 5 to examine the extent to which the prediction performance of the one- and two-category models across 391 traffic mix scenarios are affected by changes to the input heavy vehicle sound power level. The findings in this study highlight important factors in a source emission model which can significantly affect its performance in accurately predicting the A-weighted sound pressure level for a stream of traffic in free-flowing condition.

Table 1
Broad vehicle groups (LV denotes light vehicles; HV denotes heavy vehicles).

Vehicle type	Austroads classification	Group
Light vehicles	C1, C2	LV
2 axle rigid trucks	C3	HV1
3, 4 axle rigid trucks	C4, C5	HV2
3, 4, 5 axle articulated trucks	C6, C7, C8	HV3
6 axle articulated trucks	C9	HV4
9 axle B-doubles, heavy truck and trailer	C10	HV5
12 axle B-triples, road trains or equivalent	C11, C12	HV6

2. Heavy vehicle classification and composition

2.1. Vehicle classification system

To address the increasing diversity of heavy vehicles in Australia, Austroads has developed a 12-class vehicle classification system which describes heavy vehicles by axle configuration [24]. This classification system is summarised in Table 1. The most common single trailer articulated truck (6 axles) in Australia has one more axle than its European and American counterparts [4,6,25]. Heavy vehicles up to 19 m in length have unrestricted access to the Australian road system, except where a road or bridge is sign posted otherwise. Following the introduction of B-doubles (comprising a prime mover which pulls two semi-trailers, typically 9 axles) in the early 1990s, and the increase in mass limits in the late 1990s, B-doubles have since overtaken single trailer articulated trucks as the predominant vehicle type for road freight transport in Australia. Larger high productivity vehicles, such as B-triples (12 axles), are less common across the wider road network as their access to some key parts of the network is restricted. This restriction is attributed to insufficient infrastructure to support high productivity vehicle access such as steep grades, pavement types or bridges that cannot support heavier vehicles, roads that are not wide enough to accommodate longer vehicles when turning, or the lack of overtaking lanes and rest areas [26].

2.2. Heavy vehicle composition

The heavy vehicle classification system outlined in Table 1 is used to identify the diverse heavy vehicle compositions occurring in different regions and at different times of day. Fig. 1(a) and (b) present the heavy vehicle composition across 391 sample sites in New South Wales for daytime (between 0700 and 2200 h) and night-time (between 2200 and 0700 h), respectively, covering wide-ranging traffic flow conditions from regional to metropolitan areas. Traffic data was obtained from the New South Wales State Government's permanent roadside traffic classifiers employing a combination of piezo-electric and infrared sensors. The location of each traffic data collection point across the road network can be found in Ref. [27]. Traffic information which was continuously collected from these classifiers each day of the year includes traffic volume counts and vehicle type based on the Austroads 12-class vehicle classification system. In Fig. 1, the sum of sample size, N, is equal to 391 for both daytime and night-time. The percentage of light vehicles (C1 and C2) is implicitly shown in Fig. 1 as the remaining percentage from that indicated by the presence of heavy vehicles. The difference in the percentages between light and heavy vehicles indicates the level of urbanisation (for the same time period) and commuter activities (between day and night). Heavy vehicles are categorised by the Austroads heavy vehicle classes (C3–C12). Their distribution across the road network is represented using side-by-side boxplots comprising median values, inter-quartile ranges, variability outside the upper- and lower-quartiles, and outliers.

Roads in metropolitan areas are characterised by a high proportion of light vehicles. The predominant heavy vehicle movements