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An Australian case study on the estimation of heavy vehicle noise emission on grade

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ABSTRACT

Heavy vehicles are considered the primary determinant of night-time noise disturbance, particularly along principal freight routes. To capture the dynamic influence of heavy vehicles associated with variation in speed and road grade on noise emission, heavy vehicle kinematic variables need to be incorporated within a road traffic noise emission model. These kinematic variables in turn assist with accurate estimation of engine noise and rolling noise. An existing prediction method that considers the driving speed profiles of articulated trucks is the American FHWA TNM road traffic noise model. However, it can only consider a fixed set of speed profiles based on a single heavy vehicle power-to-weight ratio. As such, the model is limited and does not accurately represent the longer and heavier vehicle combinations that dominate the Australian freight haul fleet. In this work, a road traffic noise prediction model which includes the equation of motion for a typical Australian heavy vehicle operating on grade is presented. A case study based on a principal freight route in New South Wales, Australia, is presented to illustrate the predicted variations in engine noise and rolling noise throughout the heavy vehicle's journey.

Keywords: Heavy vehicle dynamics, traffic noise prediction, acceleration, speed

1. INTRODUCTION

Road traffic noise is one of the most prevalent sources of environmental noise resulting in annoyance as well as health concerns such as hypertension and sleep deprivation (1). Specifically, noise emitted by heavy vehicles has been identified as adversely impacting on those living along or near freight routes (2). The noise problem is further compounded by the use of longer and heavier truck-trailer combinations with a greater number of axles to increase freight productivity (3). The two main sources of noise emission of a heavy vehicle are engine noise which is associated with engine load, and rolling noise generated at the interface between the vehicle tyres and road surface. Variation in road grade and vehicle speed affects the contributions of to the overall noise emission of a heavy vehicle (4,5). Rolling noise is most prominent in high-speed environment while engine noise becomes increasingly dominant as speed reduces. The accurate assessment of road traffic noise requires that the contributions of both heavy vehicle engine noise and rolling noise be calculated for realistic operating scenarios.

Existing research recognises the need for accurate estimation of kinematic variables to capture the variation in the contributions of rolling noise and engine noise (6). The consideration of heavy vehicle dynamics within principal road traffic noise emission models remains insubstantial. European traffic noise models default to maximum legal speed limits (7). The American FHWA-TNM is the only government approved method that considers heavy vehicle dynamics, whereby speed profiles of a standard 5-axle single-trailer truck are incorporated into the model to enable more accurate prediction of heavy vehicle noise levels along a route featuring different road grades and speed profile zones (6). However, the approach is based on curve-fitting of speed profile data and the range of validity is restricted to one particular truck-trailer configuration and power-to-weight ratio. A fixed set of heavy vehicle speed profiles is insufficient in the Australian context because the predominant long-haul freight vehicle has been trending towards longer and heavier vehicle combinations since the 1990s (3,7).

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In this work, the Nordic and American road traffic noise prediction models are combined with a simple analytical model to yield the equation of motion for a heavy vehicle on grade. The Nordic model is used to replace rolling noise emission featured in the American model as it includes the ability to vary heavy vehicle rolling noise emission based on the axle configuration. The proposed analytical model considers rolling resistance, grade resistance, aerodynamic drag force, as well as tractive force delivered by the engine. The equation of motion provides a relationship between the distance travelled by the heavy vehicle as a function of speed and is applied to a 5 km long section of the Princes Motorway in New South Wales, Australia. In this case study, a 6.4 kW/t 9-axle double-trailer truck is used to demonstrate the transition in dominance from rolling noise to engine noise as a heavy vehicle ascends road grades of up to 8.6%.

2. ROAD TRAFFIC NOISE EMISSION MODEL

The noise emission of a stream of heavy vehicles is customarily characterised by a line source comprising a series of incoherent point sources (6). In this present work, heavy vehicle noise emission represented at each point source comprises the rolling noise algorithm from Nord2005 and full-throttle engine noise from FHWA-TNM (4,5):

$$L_{WA,rolling} = A_R + B_R \log_{10}\frac{v_{m,i}}{70} + 10\log_{10}\frac{N}{4} \tag{1}$$

$$L_{WA,engine} = 111.6 \tag{2}$$

In Eq. (1), the sound power at the tyre/pavement interface is given as a function of the number of axles N and mean vehicle speed $v_{m,i}$ along each road segment represented by the point source. For rolling noise, the regression coefficients (A_R and B_R) at each one-third octave band centre frequency are taken from Ref. (4) for Swedish, Norwegian and Finnish conditions. Furthermore, in accordance with Ref. (4), rolling noise is increased arithmetically by 3 dB per doubling of axles with reference to a 4-axle truck to account for the increase in road/tyre contact noise for a 9-axle truck. In Eq. (2), engine sound power level under full-throttle is taken as 111.6 dB(A) irrespective of vehicle speed and grade. The expression of engine noise from the FHWA-TNM model ignores the small perturbations in engine rotational speed from the gear-changing sequence. As seen in Figure 1, when the 9-axle truck is operating under full-throttle condition, the contributions of rolling noise and engine noise to the overall noise emission depend solely on vehicle speed. At 70 km/h, rolling noise is equal to engine noise under full-throttle. Engine noise becomes increasingly dominant as vehicle speed reduces. Below 35 km/h, rolling noise becomes inconsequential as engine noise is shown to be 10 dB higher.

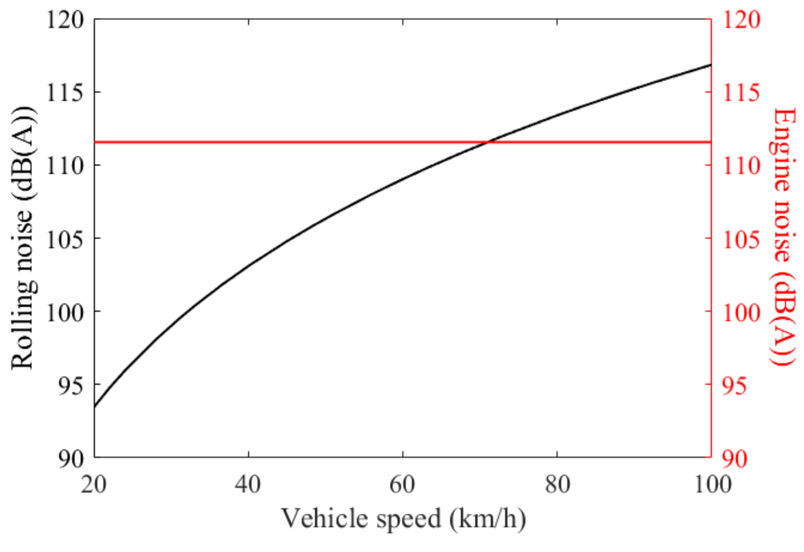

Figure 1 – Rolling noise and full-throttle engine noise as a function of vehicle speed

3. EQUATION OF MOTION FOR A HEAVY VEHICLE ON GRADE

To calculate the vehicle speed as a function of distance travelled, the equation of motion for a heavy vehicle on grade is initially defined as (7):

$$\sum F = m_e a = F_T - F_D - F_R - F_G \tag{3}$$

where a is the acceleration and m_e is the effective mass of the vehicle, corresponding to the sum of the vehicle's static mass and the equivalent dynamic mass to account for the loss of tractive force due to the inertia of the engine and driveline components. The significant forces correspond to the retarding forces associated with aerodynamic drag F_D, rolling resistance F_R and grade resistance F_G, as well as the tractive force F_T delivered by the engine under full-throttle to overcome the retarding forces. According to Eq. (3), the vehicle will accelerate when tractive force is greater than the sum of all resistance forces. Conversely, the vehicle will decelerate when the engine is not able to deliver sufficient power to overcome all the resistances forces, in which case the heavy vehicle would slow down even under full-throttle condition. Furthermore, on any given grade, the maximum sustainable speed (also known as crawl speed) of a vehicle is reached when the tractive force is equal to sum of all resistance forces. Re-arranging Eq. (3) in terms of acceleration, the estimated crawl speed for a specific heavy vehicle combination on any given grade is obtained under full-throttle by setting $a = 0$. Using the simple kinematic relation $adx = vdv$ for translational motion, entrance speed v_i and exit speed v_{i+1} can be computed by numerical integration at the respective ends of a given road segment.

4. VARIATION IN ROLLING NOISE AND ENGINE NOISE

Figure 2 shows the computed speed profile as a function of road grade and distance travelled, for a 6.4 kW/t 9-axle double-trailer truck traversing the Great Dividing Range at Mount Ousley in New South Wales, Australia with an approach speed of 100 km/h. As shown in Figure 2, there are six distinct changes in the road grade along this section of the Princes Motorway, ranging from 0% to 8.6%. The speed profile shows that the 6.4 kW/t double-trailer truck operating under full-throttle is barely maintaining its initial speed of 100 km/h on a relatively flat section of the road and begins to decelerate rapidly as road grade reaches 3.3%. Figure 3 presents the variation in the contributions of rolling noise and engine noise at each point source location. As seen in Figure 3, rolling noise is only observed to be dominant during the first 1200 metres of the vehicle's journey as it travels from the south. For the remainder of the vehicle's journey through the adjacent residential suburb, engine noise is found to exceed rolling noise as the 9-axle double-trailer truck is unable to maintain its speed above 70 km/h. On 8% grade, the crawl speed of double-trailer truck is 22.5 km/h, in which the full-throttle engine noise is shown to be more than 15 dB above rolling noise. Immediately after the 8% grade, vehicle speed (see Figure 2) and the contribution of rolling noise (see Figure 3) increases momentarily as the significantly lesser grade resistance on the 1.5% grade allows the double-trailer truck to accelerate before another steeper section is encountered. Based on the above case study, it is concluded that a road traffic noise prediction model that defaults to maximum legal speed limit would overestimate the contribution of rolling noise. Furthermore, a road traffic noise prediction model that does not consider vehicle dynamics would be unable to identify localised areas impacted by high levels of engine noise when designing appropriate noise mitigation measures such as barriers.

5. CONCLUSIONS

In this work, a road traffic noise prediction model that considers heavy vehicle dynamics has been applied to a 5 km section of the Princes Motorway in New South Wales, Australia, with road grades varying from 0% to 8.6%. Results show that a 6.4 kW/t 9-axle double-trailer truck is unable to maintain its initial approach speed, with speed reducing from 100 km/h (along a relatively flat section of road) down to just over 20 km/h (when negotiating the steepest part of the ascent). Engine noise was found to dominate heavy vehicle noise emission over the majority of the heavy vehicle's journey on uphill grade, with the contribution of rolling noise reducing rapidly as speed decreases on grade. The significance of this finding is the identification of appropriate noise mitigation measures depending on the dominance of engine noise and rolling noise. Further work will consider more case studies to investigate heavy vehicle noise emission and the duration of the sound exposure at receiver locations associated with heavy vehicle dynamics using the model proposed in this paper.

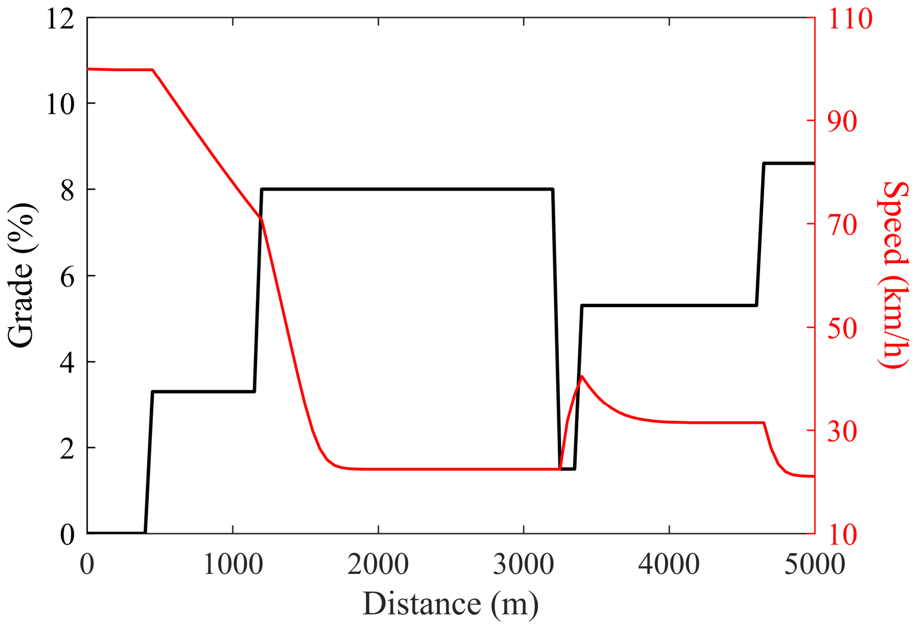

Figure 2 – Variation in grade and speed as a function of distance travelled for a 9-axle heavy vehicle

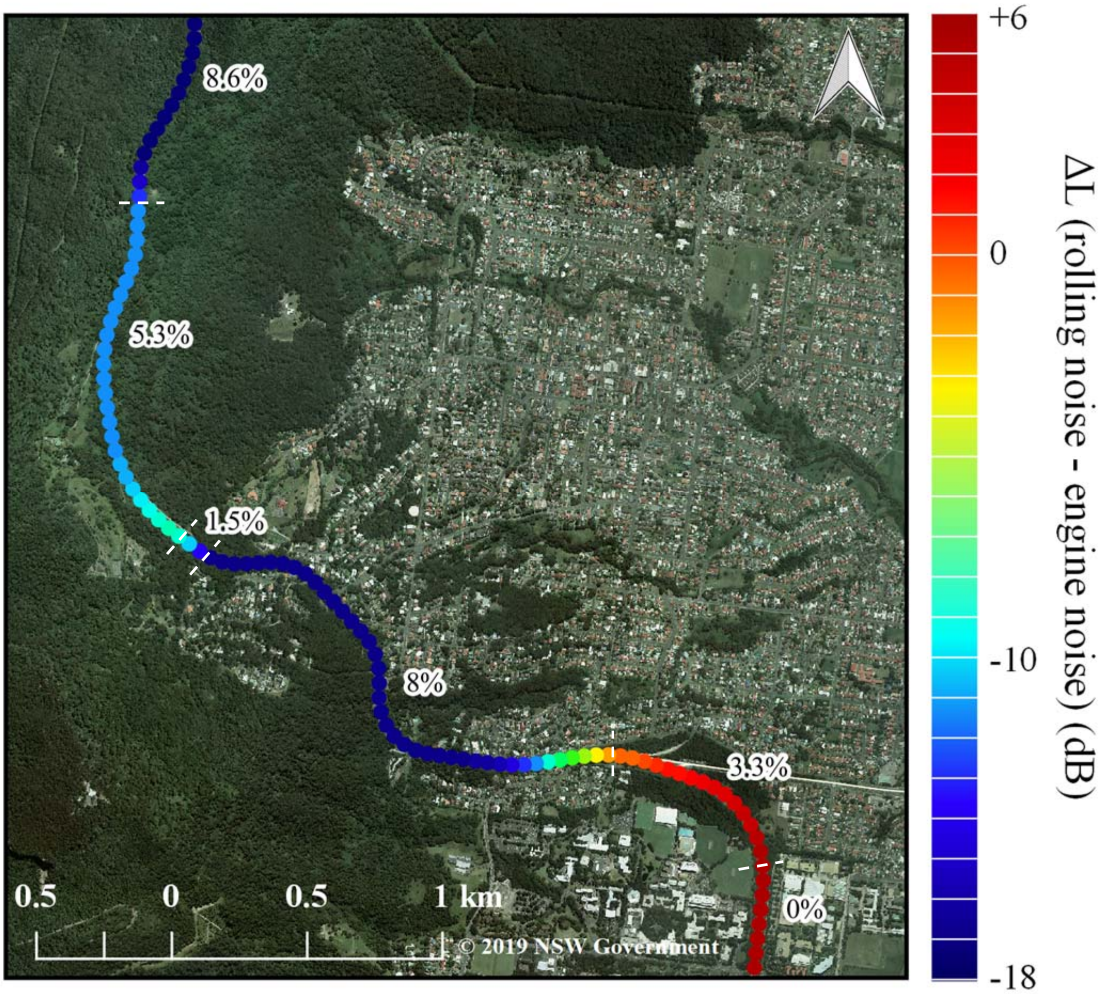

Figure 3 – Variation in the contributions of rolling noise and engine noise (vehicle heading north) (aerial photography of Mount Ousley was sourced from the NSW Government)

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