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Noise modelling of road intersections

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ABSTRACT

Road traffic noise modelling is usually performed with statistical models (e.g. Calculation of Road Traffic Noise "CORTN" algorithm) and calibrated based on experimental data related to standard conditions and assumptions such as free flow constant-speed traffic with uniformly distributed vehicles. However, as the standard modelling approach does not take into account traffic dynamics, traffic noise emission from intersections are not always modelled correctly. In this paper, analysis of an intersection is presented based on a case study. Noise measurements were conducted to characterize the existing noise environment. The measurement data was compared against the simulated noise model. The study outlines a method to account for traffic dynamics such as deceleration / acceleration / stop / start and low speed of traffic at junctions to improve predictions of traffic noise.

Keywords: Road traffic noise, intersection I-INCE Classification of Subjects Number(s): 76.1.1, 52.3,

1. INTRODUCTION

Road traffic noise in urban zones constitutes an ever-growing issue of environmental pollution for most cities. The consequences of noise pollution in general have been studied and its effects on mental and physical health have also been well documented. Sleep disturbance, hearing loss, cardiovascular problems, anxiety and stress are some of the adverse effects observed from noise pollution.

Traffic noise is among the most extensively studied fields of noise pollution based on the level of influence traffic has on people irrespective of them living in urban, sub urban or rural areas. Various noise prediction models have been developed to assess and predict noise propagation from road networks for free-flowing traffic conditions. However an important aspect of traffic noise study is the assessment of road intersections. Prediction of noise emissions for such scenarios is not adequately considered in standard noise modelling algorithms as they don't accommodate the complexity of sources, traffic dynamics and road specifications near intersections. The standard model includes operating speed on the approach and departure sections equal to the free flow speed irrespective of the traffic volume. All vehicles are assumed to be running at a constant cruising speed. In this paper, the authors present a set of parameters to tune the standard noise model for a situation such as a road intersection where standard noise modelling usually fails.

2. FEATURES OF INTERRUPTED VS. FREE FLOWING TRAFFIC

Frequency spectrum analysis provides explanation to the variation in response to noise, which are associated with variations in the conditions of the noise generation process. Figure 1 shows the frequency spectra of free and interrupted traffic flow of set of 10 cars and were collected under controlled test conditions (15). The figure illustrates the existence of lower frequency energy (below 300 Hz) for interrupted flow of traffic compared with free flow traffic. Hunt et al (15) demonstrated that lower frequency energy is typically produced by vehicle engine while higher frequencies are a result of tyre/ road interaction for all speeds which is the predominant noise source for all speeds in excess of 30km/hr. This points to the fact that free flowing traffic is dominated by road/tyre interaction while interrupted traffic flow noise is controlled by engine noise.

A lot of studies have demonstrated that traffic dynamics have substantial impact on the noise levels of road intersection.

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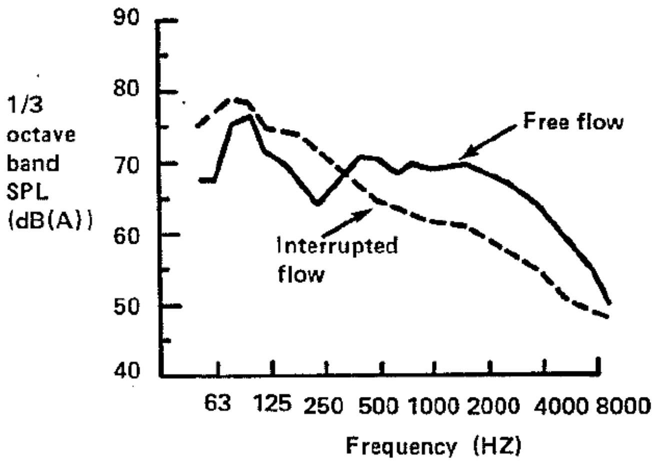

Figure 1 – Spectra for free and interrupted flow, Hunt et al (14)

A lot of studies have demonstrated that traffic dynamics have substantial impact on the noise emissions from road intersections. Two situations are shown in Figure 2 (5), with a similar number of vehicles near the roundabout demonstrating the effect that interactions between vehicles has on noise emissions. The figures display an instantaneous 'snapshot' of noise levels as vehicles approach/depart the roundabout. The left figure shows vehicles freely moving without any hindrance from any other vehicles already present in the roundabout. The right hand figure shows three vehicles queuing at the entrance of the roundabout (top left) because of their requirement to give way to vehicles already present (travelling clockwise) on the roundabout. Lower speeds in the right hand side figure consequently produces lower noise levels although a higher number of vehicles are present inside the roundabout. This example shows the importance of vehicle interactions and dynamics on the noise impact at the surrounding areas.

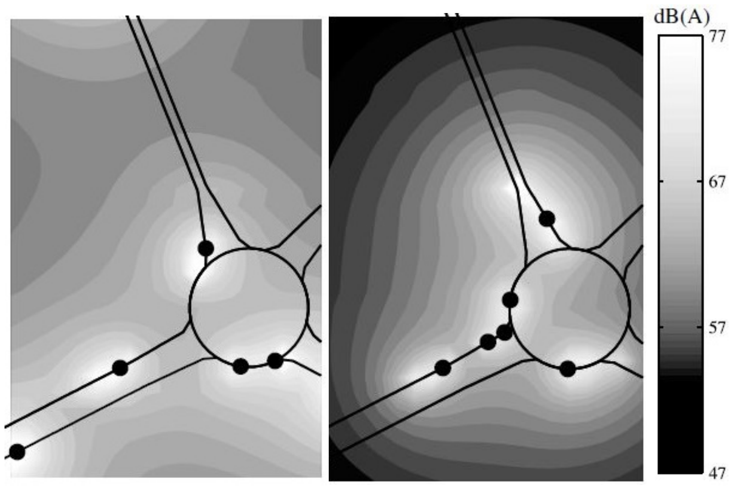

Figure 2 – Dynamic noise contour maps of events occurring in the evening peak (5)

Another example is shown in Figure 3 (21) demonstrating the influence of traffic lights installed at an existing roundabout on the noise impact. No significant (<2dBA) noise level difference was noticed for two situations before and after installation of traffic lights at an existing roundabout in Rohr (Germany). The compared results showed higher noise levels for situation with traffic lights. The increase in noise level was due to the constant K that German noise prevention guideline for roads (reference to RLS-90 algorithm) introduces for intersections regulated by traffic lights.

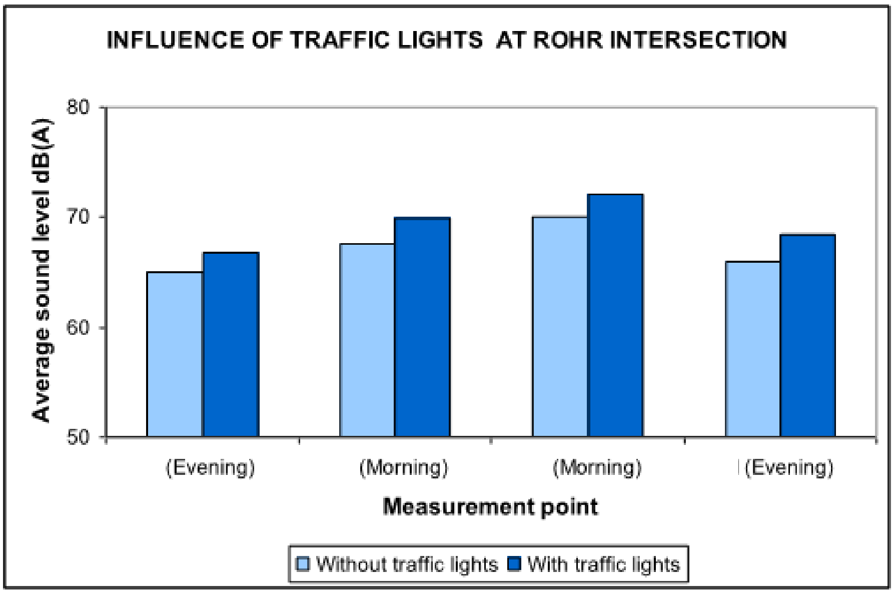

Figure 3 – Comparison of roundabout and traffic lights noise levels at Rohr, Germany, Ressel I.W (21)

Replacing a roundabout by traffic lights can induce higher noise levels based on the 2 dBA increase shown in Figure 3. In low traffic, the noise increase concentrates in the vicinity of the intersection because of:

- Non-stopping vehicles going straight at high velocity during green light.
- Stop & go vehicles trapped into queues.

3. STANDARD NOISE ASSESSMENT PROCESS

The standard process implemented for the assessment for road traffic noise usually involves computational traffic modelling to predict noise emissions and also to assess the feasibility of noise mitigation measures. Noise emissions are simulated along with site measurements when the complexity in noise sources and topographical features are demanding. As per the New South Wales Road Noise Policy (NSW RNP) (11) the assessment process is shown in Figure 4 as follows:

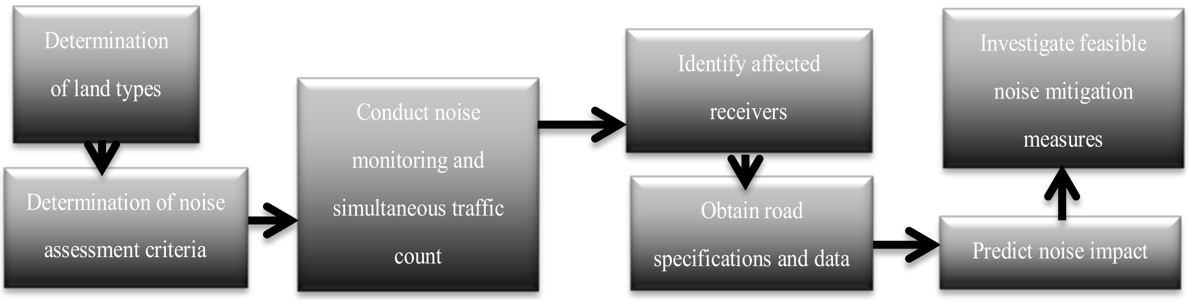

Figure 4 –Traffic noise prediction process as per NSW RNP (10)

The prediction of traffic noise may be based on one or the other modelling methods, each of which has its share of advantages and disadvantages. In general the equivalent levels evaluated with a statistical noise model are moderately reliable for standard traffic flow conditions such as constant speeds, no abrupt changes and an absence of any intersections, etc. The prediction of traffic noise impact for a standard situation can be successfully performed with many statistical noise models such as Calculation of Road Traffic Noise - CORTN, Federal Highway Administration Model - FHWA (STAMINA 2.0), Federal Highway Administration Model - FHWA (TNM 2.5), Nord2000, RLS 90, etc.

The UK CORTN, Swiss (SonRoad road traffic noise model) and French prediction model (NMPB-96 & Guide du Bruit) are unable to include noise impacts from an intersection. Nordic model include correction for deceleration and acceleration for vehicles approaching and leaving an intersection but it recommends using cruising vehicle emission values. The Dutch model (RMW2002) includes a maximum of 2.4 dBA correction at the centre of intersection depending on the intersection type and diurnal traffic intensity up to a distance of 150 m. The German model (RL90) also includes a correction factor for signalised intersection up to a distance of 100 m. Correction factor for transient driving condition near an intersection is introduced for US (FHWA) and Japanese (ASJ RTN-Model 2003) traffic prediction model.

The earliest studies in the UK on interrupted traffic flows used L_{10} descriptor to understand the noise impact from intersection and roundabouts. In general it was apparent that noise was within 1dBA from the accelerating traffic compared to free flow traffic.

4. Issues related to statistical noise models for intersections

Many traffic noise models have been developed in the past which usually use an empirical approach referencing model parameters on set of data and discarding many useful parameters such as road features, traffic flow, etc. An example showing FHWA Traffic Noise Model (TNM) equation and its corresponding attributes is provided below. The TNM is dependent on vehicle classification such as light, heavy vehicles and other additive corrections but lack any reference to traffic flow changes with respect to time. TNM (14) can be written as:

$$Leq = ALogQ[1+P/100(n-1)]+bLog(d)+C \tag{1}$$

Q – Traffic volume in vehicles per hour

P – Percentage of heavy vehicles

n – acoustical equivalent (number of light vehicle that generate the same acoustic energy of heavy one)

d – Distance from the observation point to centre to the traffic lane

Coefficients A, b, C may be derived for a fixed investigation area by linear regression method.

Traffic flow representation near an intersection is less accurately depicted for urban traffic noise estimation where traffic conditions vary a lot. Modifications have been incorporated in some classical models to account for interrupted traffic flow characteristic in urban environment. Adjustments for interrupted traffic flow have been introduced and deduced from queue lengths determination at the entrance of the intersection. Noise estimation closer to an intersection can also be refined by considering the mean kinematic patterns of the approaching vehicles (15). However the limitation of those models is their estimation of energetic descriptors, like L_{den} or L_{Aeq}. Those descriptors are not always sufficient to precisely describe urban traffic noise, which is characterized by strong dynamic linked to traffic intersection including different vehicles, speed and conditions, the road maintenance status, etc.

4.1 Traffic dynamics

Relevant road and traffic data is required for the road under investigation and also for any nearby arterial road that may contribute to the total noise level exposure at the receptor location. The data may be acquired either by direct measurements and observations and/or by obtaining current data from the relevant authority. The data required includes information such as traffic volumes (hourly and daily), traffic compositions (usually expressed as the percentage of heavy vehicles in the traffic), traffic speeds, speed limits, traffic growth and/or traffic modelling forecasts and road pavement surface type together with accurate representations of the road alignment.

The flow of traffic near an intersection or roundabout may not always be smooth. The characteristics of traffic flow may have variability between peak and non-peak traffic hours as shown in Figure 5.

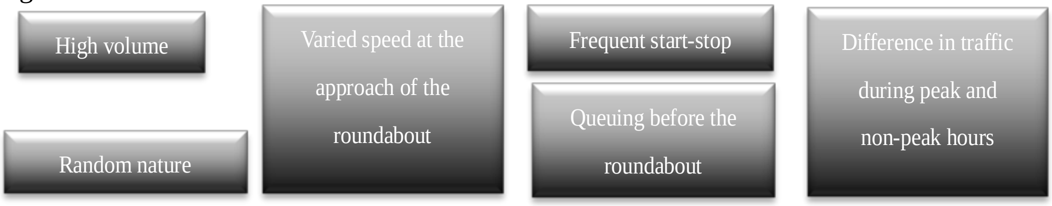

Figure 5 –Traffic variability during peak and non-peak hours

Free flowing traffic is typically relatively evenly distributed along the road length allowing assumptions to be made regarding noise distribution over time. Interrupted traffic flow yields a noise level distribution over time that is less normal. Interrupted flows have the potential to produce noise level distribution that is close to random, under certain conditions. The conditions that control the distribution of noise levels related to the traffic conditions are specific to each site and intersection. It is seen that free flowing traffic conditions produces temporal variations that are constant with time depending upon speed variations, vehicle speed, total flow and road surface. While interrupted traffic flow produces wide range of temporal variations, which are purely random. The random nature of temporal variation in noise level is more evident in roundabouts while less in signalized intersections (9).

5. ALTERNATIVE ALGORITHM AND TECHNIQUES

Below are few alternative algorithms to develop transient models from the prediction of noise emissions from intersections, which has some advantages over statistical model typically used for interrupted traffic flow conditions.

5.1 Regression based models

Many attempts to create an interrupted flow parameter suitable for traffic noise prediction have been made in the past. Gilbert et al (13) tried to produce a regression model for intermittent traffic flow but fell short in developing an algorithm that was suitable for interrupted traffic conditions. They produced a regression equation based on the measurement program as follows:

$$L10(1hr) = 43.5 + 11.2Log(L + 9M + 13H) + 0.42Y + 10LogA + 4.6LogB \quad (2)$$

Where L = Light vehicle flow (v/h)

M = Medium vehicle flow (v/h)

H = Heavy vehicle flow (v/h)

Y = Carriage width (m)

A, B = Mathematical terms incorporating propagation and reflection parameters.

The equation had a coefficient of determination of 0.88 and a validation study revealed that mean and standard deviations of the prediction difference (Predicted value – Measured value) associated with the equation were -0.6 dBA and 1.3 dBA respectively. The major shortcoming of this regression equation was it does not include any input on interrupted traffic flow.

Noise at roundabouts was regressed against traffic flow and the percentage of heavy vehicles by Lewis and James (12) for $L_{10\,(1hr)}$ and L_{eq}. Their regression equation for both approach and departure road to roundabouts was given as:

$$L10(1hr) = A + BLogQ + CP \quad (3)$$

Where A,B,C = Regression coefficients

Q = Total vehicle flow (v/h)

P = Proportion of heavy vehicles (%)

The equation gave a 1.5 dBA standard error of the $L_{10(1hr)}$ compared to the measured results. The major disadvantage of using this methodology was that it was valid for a specific site and therefore had limited application.

5.2 Microscopic traffic simulation

The accuracy of any traffic noise model near an intersection is dependent on correctly depicting temporal and spatial evolutions of vehicle speeds and accelerations. Microsimulation model can incorporate these variable parameters and coupled with noise emission models can produce reliable representation of an intersection. Microscopic traffic simulation provides progression of individual vehicles (as point sources) or based on fluid dynamics through a road intersection or a road network (5). The overall simulation period is broken down into a number of discrete time-steps. Specific algorithm updates positions of all vehicles at each time step. Speed and acceleration can then be deduced from positions at successive time-steps. Sound power level can then be used in a traffic-modelling algorithm to understand the noise impact at the nearest sensitive properties.

The major drawbacks associated with microsimulation models are the large amount of detailed traffic data required to build the model, various parameters such as aggression, awareness, reaction time distribution of the vehicle drivers, the queue gap distance, signposting distance, etc. and the time required to construct and calibrate the model, make it feasible for small to medium scale projects.

6. CASE STUDY OF ROAD INTERSECTION PROJECT, NSW

The intersection highlighted in this paper is a four-leg dual lane intersection. The proposal included replacement of the existing intersection with a signalized intersection. The existing intersection had inherent issues in terms of high traffic flow during peak hours, which led to frequent queuing.

Figure 6: Image of an arbitrary signalised intersection and roundabout (24).

6.1 Noise logging

A noise survey of existing traffic conditions was conducted during two separate surveys to characterize the existing noise environment and to calibrate the traffic noise model. Unattended long term noise monitoring was undertaken at four representative locations overlooking the intersection. Traffic monitoring was simultaneously conducted to determine vehicle numbers, speed and percentage heavy vehicles on a 15 minute basis. In addition to the unattended logging, short term attended noise measurements were also carried out at all the representative locations.

Noise measurement data was filtered in accordance with the NSW Road Noise Policy (19), which was critical in ensuring that the noise monitoring data affected by extraneous noise sources such as rain, high wind speeds, extraneous noise, and the like did not affect the measurements of the existing traffic noise levels.

Detailed review of the noise logging data brought to our notice time periods during the daytime period where a relatively constant noise was indicated by one of the loggers. As the measured noise descriptors do not align with the expected results, further investigation was undertaken using the noise recording technology of the Ngara noise logger and attended measurement. Upon further inspection it was revealed that the source of the noise was continuous chirping of a cicada sitting near the microphone windshield, which was subsequently excluded from the logging analysis.

Simultaneous traffic survey (i.e. vehicle type, speed and volume) was undertaken at all the four arterial roads using tube method. Location of few traffic monitoring locations were strategically chosen away from noise monitoring locations to eliminate any extraneous noise contribution from vehicles running over the tube and affecting the noise logging results. Results of the traffic data (approximated to the nearest 100 for the purpose of this paper) are summarized in Table 1.

Table 1 – Traffic count for four arterial road

	Period	Total Vehicle	% Heavy vehicle
Northbound	Day (V/18hr)	10000	10
	Night (V/6hr)	2000	10
Southbound	Day (V/18hr)	20000	15
	Night (V/6hr)	5500	15
Eastbound	Day (V/18hr)	18000	15
	Night (V/6hr)	5000	15
Westbound	Day (V/18hr)	12000	12
	Night (V/6hr)	2200	12

6.2 Noise model features

Noise modelling was carried out using the UK Department of Transport, CORTN algorithm which is considered most suitable free flowing for Australian conditions. The modelling allows for effects of traffic volume and mix, type of road surface, vehicle speed, road gradient, reflections off building surfaces, ground absorption and shielding from ground topography and physical noise barriers to be included in the prediction.

A computer model was used to predict noise levels likely to be experienced by the surrounding residential properties. The environmental noise model was developed using SoundPLAN v7.2 software.

In the original version of the CORTN Model, all traffic noise “sources” are located 0.5 m above the pavement. This approach is appropriate as a “standard” calculation method and yields reasonable consistency from project to project. The predicted noise levels are considered reasonably accurate for free flowing roadway conditions having a clear line of sight from receivers to the traffic.

For this project, the SoundPLAN traffic noise source “strings” were developed and modified to incorporate three effective noise sources (and heights) in each carriageway. The road source was modelled using source heights of 0.5 m, 1.5 m and 3.6 m above ground level. The source height of 0.5 m corresponds to the noise sources from light vehicles. The heavy vehicle noise source is split into 1.5 m and 3.6 m source heights. The 3.6 m source represents heavy vehicle exhaust noise sources, is 8 dBA lower than the 1.5 m source (i.e. heavy vehicle tyre and engine noise). The truck sources have relative sound power emission levels (compared to total truck sound power) of -0.8 dBA and -8.0 dBA for tyres/engines and exhausts, respectively (22). These modifications ensure that the noise predictions (particularly in the presence of noise barriers) address the significance of the elevated heights of noise emission from truck engines and exhausts.

The predicted levels were for receiver points 1.5 m above the external ground level. The predicted levels were façade corrected, i.e. the predicted noise levels have been adjusted upwards to include a notional +2.5dB due to reflected noise from façade. The height of buildings in the computational model was based on surveyed from site visit photos and site inspection.

Road traffic volume, speed and mix (heavy/light vehicles) information was obtained from traffic counts taken concurrently over the same period as the unattended noise logging. Terrain was modelled as “soft” ground, with 100% absorption, which avoids ground plane reflections contributing to noise levels at receivers. Given the receivers are within 300 m of the road corridor, meteorological effects were minimal. Effects of vehicle acceleration and deceleration are most significant for the intersection configuration and less so for signalized intersections given free-flowing traffic will occur for at least 50% of the time, with the 10^{th} percentile therefore was unaffected.

For continuous traffic flows, in past project experience and baseline measurements conducted as part of this acoustic assessment, L_{A10} has been found to be approximately 3 dBA higher than L_{Aeq} , and therefore the predicted L_{A10} values have been corrected to L_{Aeq} values using this correlation.

6.2.1 Splitting the line source approach

Many scenarios were modelled while only three relevant to this paper are shown, where single line sources were fragmented into many portions. The methodology included splitting the line sources into many fragments and allocating specific average speeds (after adding the speed corrections as per CORTN) for each fragment closely resembling the real traffic scenario at the entry to the intersection. Figure 8 demonstrates the three scenarios modelled for the purpose of this paper. As the vehicle approaches the intersection, the vehicular speeds drops to 10 km/hr from 60 km/hr evident in scenario 3. Speed correction for mean traffic speed corresponding to the percentage of heavy vehicles referenced from CORTN (1) has been applied. The correction equation is as follows:

$$Correction = 33Log(V + 40 + 500 / V) + 10Log(1 + 5p / V) - 68.8dB(A) \quad (4)$$

V = Mean traffic speed km/hr
P = percentage of heavy vehicles

6.3 Noise modelling results

SoundPLAN noise contour graphs along with the schematic diagrams for the three Scenarios for a standard working day with no reported heavy congestion near the intersection are shown in Figure 7. Comparison of predicted results for three Scenarios is summarised in Table 2.

Table 2 – Noise modelling results

Location detail	Scenario 1 $L_{A10\ 18\ hours}$	Scenario 2 $L_{A10\ 18hours}$	Scenario 3 $L_{A10\ 18\ hours}$
Location 1(NE)	71.5	71.0	73.0
Location 2(NW)	68.5	68.0	70.0
Location 3(SE)	71.5	70.5	73.5
Location 4(SW)	72.5	72.0	74.0

Noise emission prediction for Scenario 3 was compared to some previous measurement results for a similar project and in general a good agreement was found. The predicted result for Scenario 3 had additional smaller fragmented line sources and realistically representing the speed variations in the vicinity of the intersection. The entire process was highly time consuming which included breaking the line source into multiple smaller sources and allocating specific speed in CORTN. The speed variation near the intersection was also influenced by the site specific features such as road puddles, speed breakers, natural light conditions, etc.

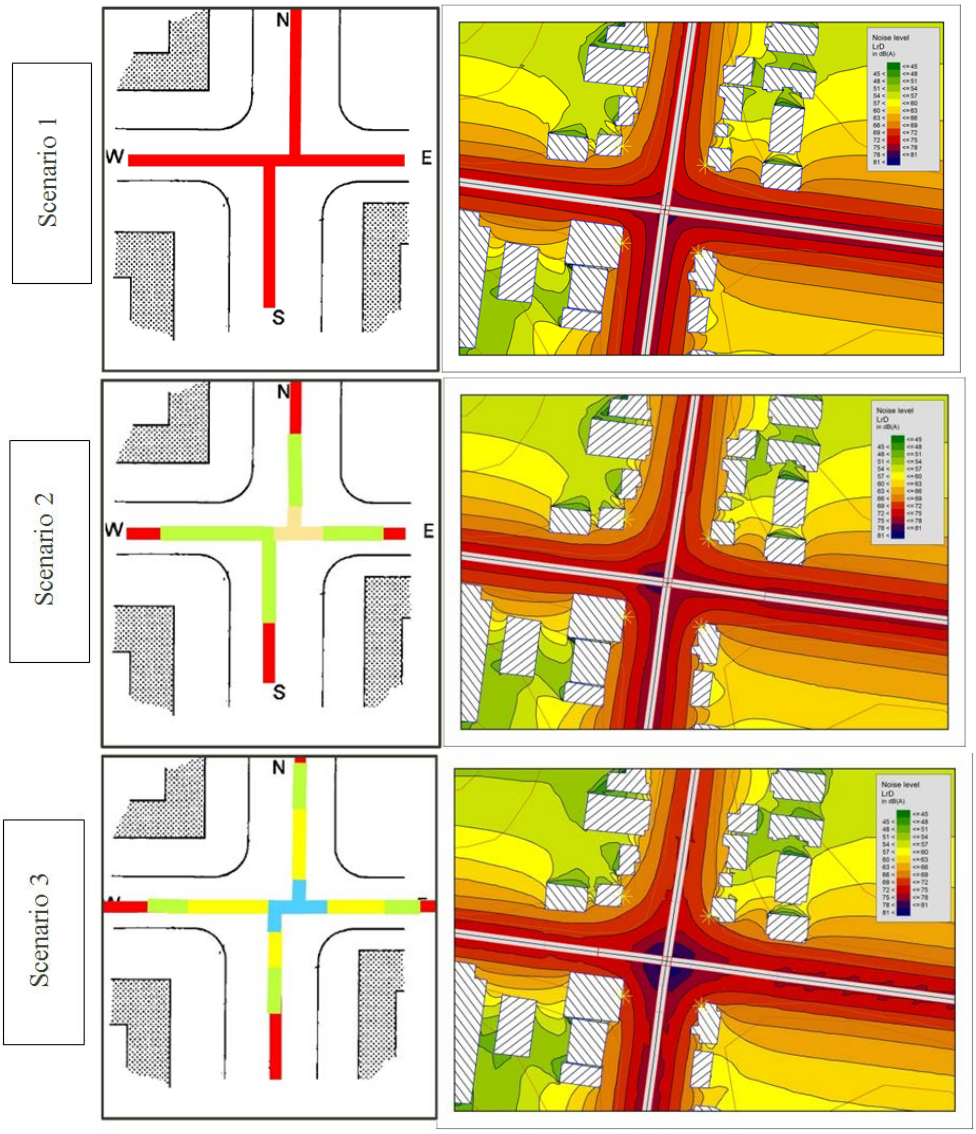

Figure 7: SoundPLAN contour map results for the three Scenarios

7. DISCUSSION

Modelling spatial and temporal noise variations at roundabouts is a tedious task. Indeed, noise levels are strongly influenced by the complex vehicle interactions taking place at the entries. An accurate modelling of the merging process and its impact on vehicle kinematics, waiting time at the yield signs and queue length dynamics is therefore required. Standard noise prediction models disregard those impacts since they are based on average flow demand patterns and pre-defined kinematic profiles. The only way to capture all traffic dynamics impacts on noise levels is to combine a traffic simulation tool with noise emission laws for each scenario and creating a sound propagation model for each specific project.

This paper attempts to define and model a single real traffic scenario, which was based on extensive traffic study of the intersection and traffic dynamics specific to that site collaborated with a standard noise modelling software like CORTN. CORTN is the preferred noise modelling software recommended for Australian road conditions however it provides no guidance in modelling of an intersection. Splitting the line source into multiple fragment approach produced predicted results within reasonable modelling error with the previous measurement results for a similar project. Although, the dynamic noise prediction model result was within typical modelling error for the single scenario modelled, it fell short in representing vehicle interactions when the roundabout was heavily congested and was difficult to calibrate due to its numerous variable parameters. A dynamic approach which integrates the variations in traffic flow for various scenarios and noise emission laws provides better results when compared to the measured results for an intersection. Further research to define the various traffic parameters and scenarios near an intersection is required to honestly represent noise impact from an intersection.

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