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Implementation of TNM Calculation Method into a Commercial Software Platform: Technical Aspects and Quality Assurance

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ABSTRACT

The Noise prediction is an extremely important task to assess the noise derived from transit systems that are planned or shall be modified. In most of the cases, calculations with the aim to predict noise levels are undertaken by applying software tools which are usually divided into stand-alone solutions and commercial software platforms, where different calculation methods have been implemented and can be selected by the user. The advantages of using such software platforms are obvious as they include powerful features supporting many actions from data import and modelling up to analysis and presentation of results. On the other hand, the precision and accuracy of the implemented calculation methods into a common software platform must be ensured. With the example of the FHWA's TNM method¹ some important technical aspects and features to support the correct implementation into a software platform are presented and discussed.

1 INTRODUCTION

The calculation of probable noise impacts caused by transit systems such roads or railways, is the only method to check whether the legal requirements can be fulfilled in the vicinity of new developments. Nearly all calculations with the aim to predict noise levels are undertaken by applying software tools which are normally divided into stand-alone solutions and professionally developed software platforms. Compared to the stand-alone software development, where developers usually implement a calculation method and design an interface so users can manage it, professional software development efforts are faced to a common user interface, where the calculation methods are implemented as modules through it. This way, the user can access all the modelling tools and import data formats available from a single work bench, and build one general model where all types of sources will be present. Furthermore they allow many other important jobs and operations like the user interfacing, the tools to inspect and modify the input data and last not least the tools to present and analyze the final results.

In this paper the implementation of the FHWA's TNM method¹ into a software platform² is discussed. The applied noise prediction methodology has been designed to be consistent with the FHWA TNM although the software offers a wide range of calculation settings that may be altered and special objects that can be used. Therefore the software must be carefully configured if a correct comparison of results is needed.

2 IMPLEMENTATION OF TNM MODEL INTO A COMMON SOFTWARE PLATFORM – TECHNICAL ASPECTS

2.1 Emission model

In the TNM calculation method, the emission is based on A-weighted levels (expressed in energy form), while sound level computations use one-third octave-band data, converted to A-weighted levels for display and output. The emission parameter is the A-weighted level $L_{\text{traf, ref}}$ in dB(A) at a distance of 50ft. (15,24m) perpendicular to the axis of a road with infinite length with absorbing flat ground. The model considers a number of different vehicle categories, shown in table 1

Table 1: TNM vehicle categories

TNM – vehicle categories	Definition
<i>Autos</i>	all passenger cars (2 axles, 4 tires), gross mass < 4500 kg (<9900 lb)
<i>Medium Trucks</i>	cargo vehicles (2 axles, 6 tires), 4500 kg < gross mass < 12000 kg (9900 lb < m < 26400 lb)
<i>Heavy trucks</i>	all cargo vehicles with 3 and more axles, gross mass > 12000 kg (> 26400 lb)
<i>Buses</i>	all vehicles (2 or 3 axles) designated for transportation of 9 or more passengers
<i>Motorcycles</i>	all vehicles with 2 or 3 tires with an open-air driver and/or passenger compartment

Depending on the type of vehicle, sub-sources are located at different heights (at 0.1 m for tire, 1.5 m (5 feet) for engine, and 3.66 m (12 feet) for stack, all above ground).

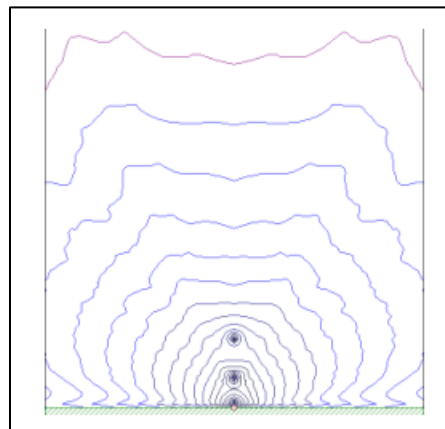


Figure 1: Vertical map showing 3 sub-sources at 0.1/1.5/3.66 m

The way the traffic data is entered in some software platforms², uses – as the majority of road noise standards do – a scheme based on hourly overall traffic and percentage of heavy vehicles, while traffic in TNM³ software is specified in absolute figures for the five TNM-specific vehicle categories shown in Table 1. On the other hand, a scheme using hourly traffic and percentages

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has the advantage that the overall traffic figures can be changed without altering the traffic mix. Therefore, the following transformations can be applied to convert absolute figures into hourly traffic data:

<i>Hourly Traffic Input data</i>	<i>Calculation from TNM input data</i>
Number of vehicles / hour	$n_{tot} = n_{autos} + n_{mediumtrucks} + n_{heavytrucks} + n_{buses} + n_{motorcycles}$ (1)
Percentage of Trucks / Buses (%)	$(n_{mediumtrucks} + n_{heavytrucks} + n_{buses}) / n_{tot} \cdot 100\%$ (2)
Percentage of Motorcycles (%)	$n_{motorcycles} / n_{tot} \cdot 100\%$ (3)
Percentage of heavy trucks (%)	$n_{heavytrucks} / (n_{mediumtrucks} + n_{heavytrucks} + n_{buses}) \cdot 100\%$ (4)
Percentage of heavy buses (%)	$n_{buses} / (n_{mediumtrucks} + n_{heavytrucks} + n_{buses}) \cdot 100\%$ (5)

TNM also considers the following pavement types:

Table 2: TNM road surface types

TNM – surface types	Definition
<i>Average</i>	i.e. average of DGAC and PCC
<i>DGAC</i>	dense-graded asphaltic concrete
<i>OGAC</i>	open-graded asphaltic concrete
<i>PCC</i>	Portland cement concrete

Other aspects that must be taken into account are the traffic speed and the operating condition. Traffic speed in the software platform can be specified for "Autos" and - if activated - for "Trucks" separately (in km/h). The speed limit entered for "Autos" will be considered as limit for autos and motorcycles, while the speed limit entered for "Trucks" - if any - will be considered for medium and heavy trucks, and for buses. With the limit entered just for "Autos" (i.e. "Trucks" deactivated) the value applies to all types of vehicles (no intrinsic speed limit for trucks). Finally, TNM has two kinds of operating conditions causing a different emission: "cruise throttle" and "full throttle". This setting can also be specified.

The emission for each category, pavement type and throttle setting, is represented by 17 constants ($2 \cdot 7 + 3 = 17$, resulting in $17 \cdot (5 \cdot 4 \cdot 2) = 680$ constants in total) applying the following equations.

The radiated energy E_A is:

$$E_A(s_i) = (0.6214 \cdot s_i)^{A/10} \cdot 10^{B/10} + 10^{C/10}, \quad (6)$$

Converted to A-weighted levels per third-octave band:

$$L_{emis,i}(s_i, f) = 10 \lg E_A + \sum_{j=1}^7 (X_1 + 0.6214 \cdot X_2 \cdot s_i) \cdot \lg f^{j-1} \quad (7)$$

$$(X_1; X_2) = \{(D_1; D_2), (E_1; E_2), \dots, (J_1; J_2)\}, \quad (8)$$

Where s_i is the speed of vehicle type i (in km/h), $A1 \dots J1$, $A2 \dots J2$ are constants and f is the frequency in Hertz.

Converted back to its energy form:

$$E_{emis}(s_i, f) = 10^{L_{emis,i}/10}, \quad (9)$$

With each TNM calculation run the emitted energy E for each vehicle category and sub-source is determined. The summation of all energy parameters E gives $L_{traf, ref}$ as a result.

The emission comparison between TNM 2.5³ and CadnaA² was achieved by studying different emission cases with different traffic numbers, speeds and vehicle mixes. In all cases the value of $L_{traf, ref}$ (50 ft) matched without any difference.

2.2 Sound Propagation

According to TNM the geometrical attenuation (divergence) is calculated based on the 2D-path length in XY-plane only. This causes the receiver level not depending on height (e.g. the level is not decreasing with receiver height). This can be modified in the calculation settings so the 3D distance for calculation of A_{div} is applied.

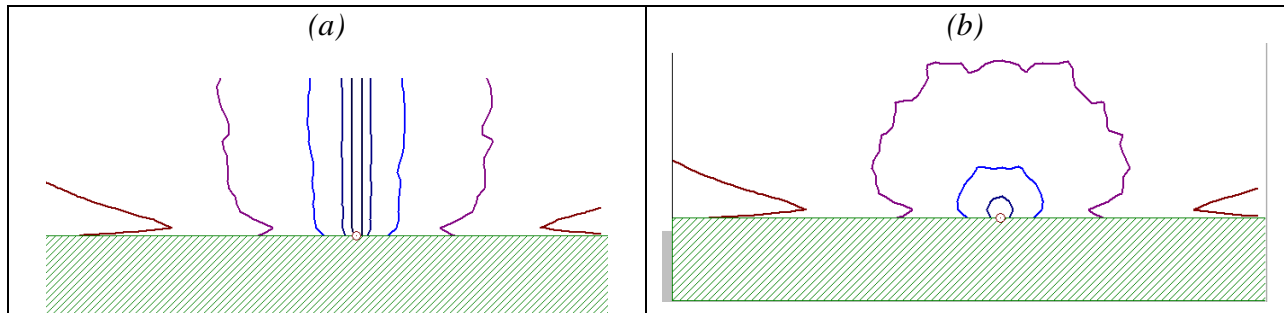


Figure 2: (a) Vertical map of a calculation based on the 3D-Path distance (strictly according to TNM) (b) Calculation by using 3D-distance for A_{div}

The ground attenuation in TNM is handled by the ground impedance (air-flow resistivity). To account for the extension of the reflecting surface element the concept of Fresnel zones is applied.

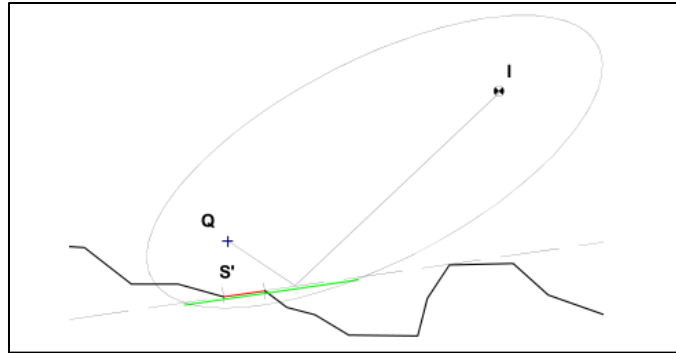


Figure 3: Construction of a Fresnel Zone to determine the contribution of the surface S' to the reflected sound

The implementation also considers a calculation setting in order to avoid sign error in the calculation of Fresnel zones discovered in TNM 2.5-code which can alter the calculation results. With this option activated the Fresnel zone error is corrected. However in case results shall be compared with results obtained by TNM 2.5 software this setting should be deactivated. Figure 2 shows results from a test case consisting of a road over a wavy terrain:

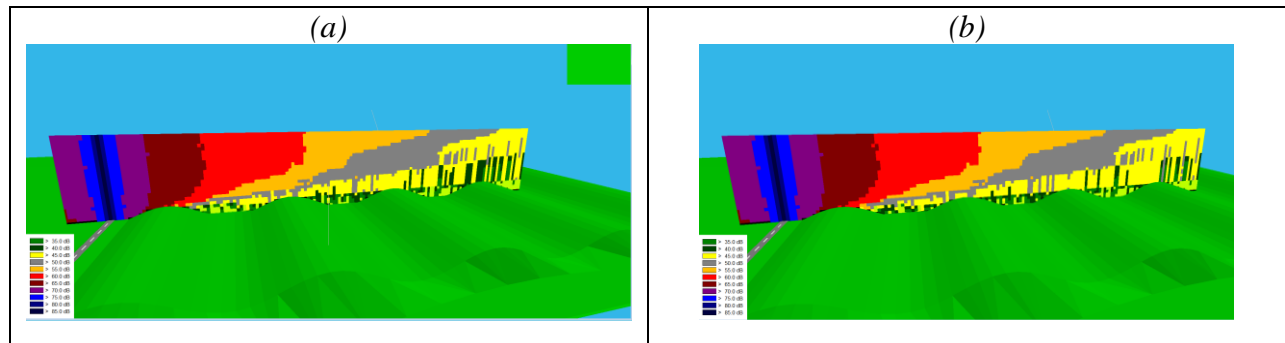


Figure 4: (a) Vertical map of a calculation strictly according to TNM (b) Calculation by activating the correction in the Fresnel Zone Calculation

Regarding the ground absorption the input settings are generally based on the ground absorption factor G of ISO 9613-2⁴. Table 3 shows the correspondence between the airflow resistivity and the Ground Absorption G :

Table 3: Correspondence between Airflow Resistivity, Ground Absorption G and TNM ground types

Airflow Resistivity (in rayls)	Ground Absorption Factor G (ISO 9613-2)	TNM-specific ground type
20000	0 (reflecting)	Pavement
1000	0.33	-
600	0.5	-
400	0.67	-
300	1 (absorbing)	lawn

With regards to the screening many of the objects available in the software platform² can be used with TNM calculation method: buildings, cylinders, barriers, embankments, bridge plates and ground absorption areas. However, floating and cantilevered barriers, built-up and foliage areas and 3D reflectors cannot be used as they are not compatible with TNM numerical diffraction model. On the other hand TNM 2.5 software builds up the digital terrain model by triangulating between existing terrain contours, while other software platforms can include the heights of the objects in the triangulation. Therefore, it may be needed importing all objects additionally as contour lines as otherwise they will not influence the resulting terrain shape.

2.3 Features not implemented

While the implementation of the TNM is consistent and, as it was discussed before, the results are comparable between both programs, there are some restrictions such as the TNM specific barrier analysis, acceleration ramps and flow control devices, which have not been implemented.

3 SPECIAL TECHNIQUES TO IMPROVE CALCULATION RESULTS

In the scope of transit systems noise prediction the use of highly developed software platforms is extremely recommendable because many additional techniques can be combined with a certain calculation method in order to improve the prediction results. Some of these techniques are known as “acceleration techniques” and are used to reduce calculation time while reasonable results are obtained. In other cases some techniques give more precision although the calculation time is incremented. When these techniques shall be applied depends on the acoustical situation within the project. One relevant technique to the road simulation is the projection of line sources. In order to illustrate this special technique a simple test case consisting of a straight road, two buildings and a receiver point is used. Upon a calculation the road is divided into sections by applying a raster factor. Therefore, depending on the distance between the source and the receiver a different number of sections will be created.

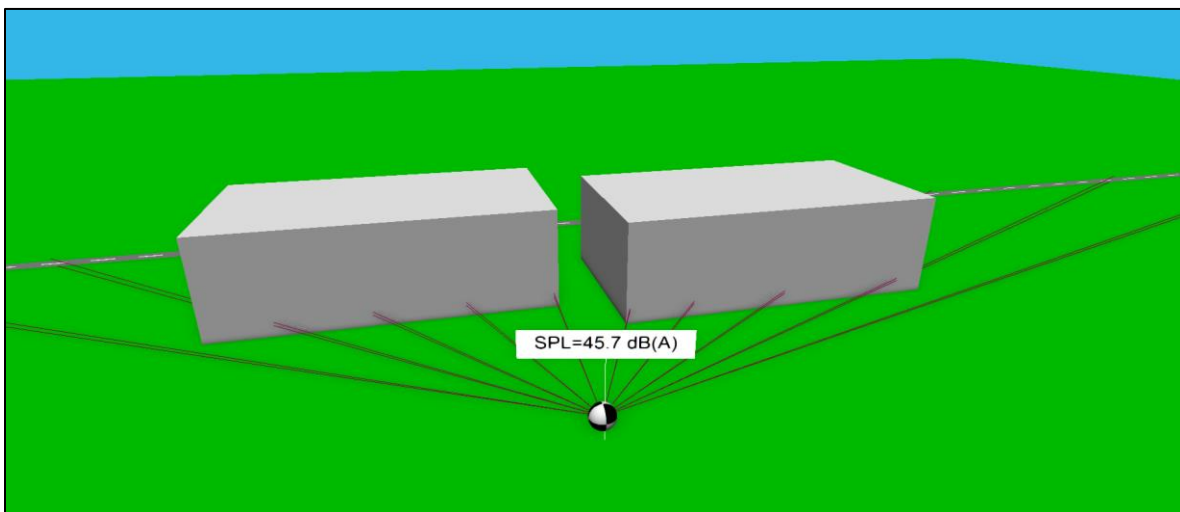


Figure 5: Calculation of the test case at a receiver (without projection technique). The rays are created starting from the center of each road section

But, in fact, not all partial areas, which are included in the calculation with the paths of the two rays, are shielded by the building. Figure 5 shows the ray paths created from the road to the receiver point by following the standard segmentation rules. But, in fact, there is a direct view between the road and the receiver through the gap between the two buildings however that

section is not accounted for the calculation. The resulting Sound Pressure Level (SPL) will be too low in the present example.

With the projection technique, prior to the segmentation of sources, a pre-partitioning for the road occurs subdividing the source into screened and unscreened parts. In a second step both types are segmented separately based on a distance criterion. The resulting Sound Pressure Level is higher and in this case more correct than without projection.

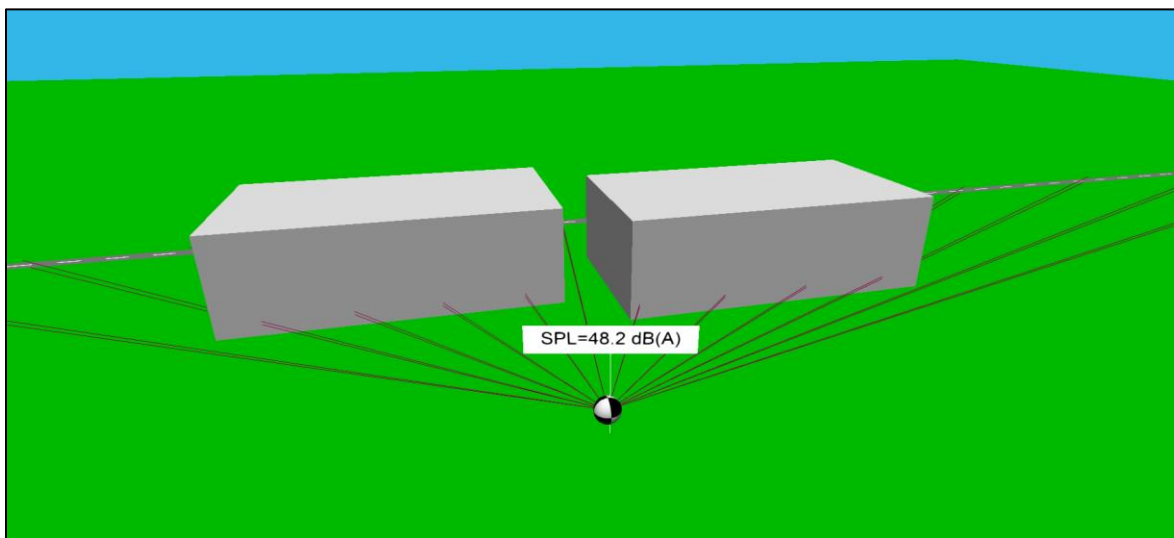


Figure 6: Calculation of the test case at a receiver (with projection technique). The new segmentation now takes into account the direct view between the road and the receiver point

4 SOFTWARE TECHNIQUES AND QUALITY ASSURANCE

As it has been demonstrated before there are a number of techniques oriented to improve results or to accelerate calculations. In addition, some extra calculation settings added to the TNM implementation in the software platform have been discussed. Therefore is important to implement features to support the quality assurance and to help to decide about the right calculation configuration.

One of the most relevant of these features is the determination of the uncertainty of noise maps caused by acceleration settings - like reduced search radii or the neglect of lower level contributions-. The German Standard DIN 45687⁵ describes the technique: if the calculation area is defined, a selected number of receiver points is distributed statistically inside this area taking into account some requirements about minimum distance to sources and reflecting objects, the levels are calculated once with a reference setting (no acceleration technique) and once with these settings intended for the calculation of the noise map, the so called project related or alternative setting. Then the level differences are analyzed and the 0.1 and 0.9 percentiles define the interval of deviations caused by this setting. It is extremely helpful if the procedure is done before the time consuming calculation of the noise map is started.

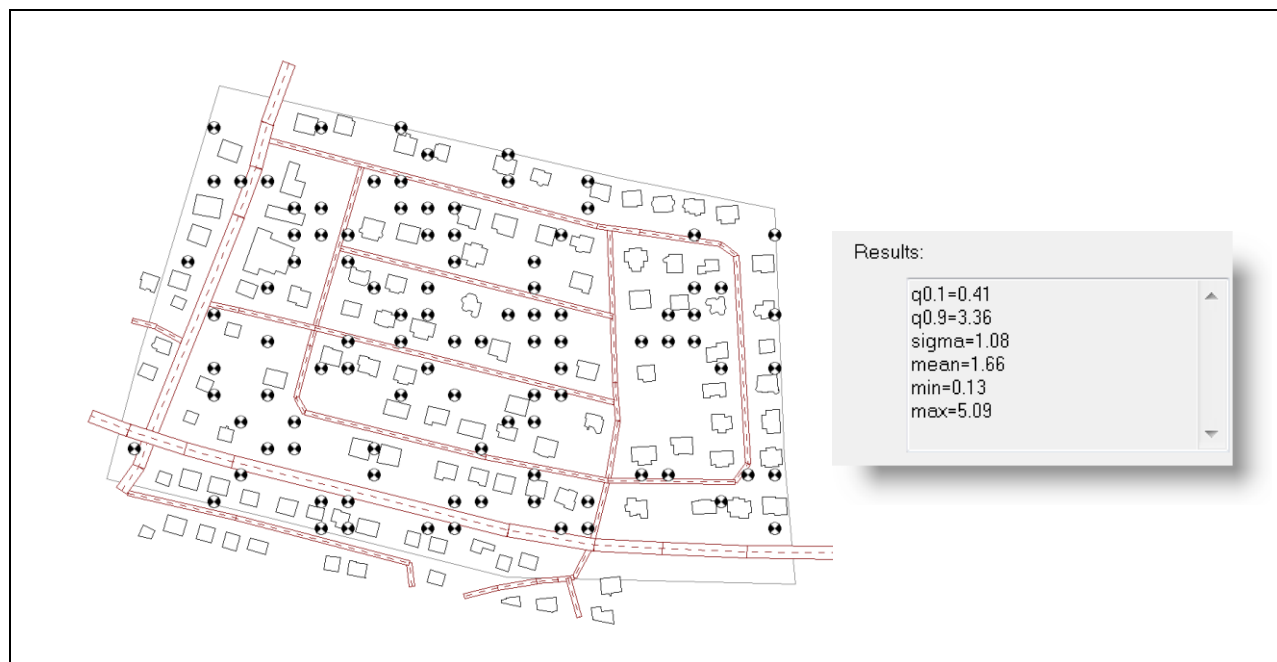


Figure 7: Receiver points distributed automatically according to standardized requirements and results of the statistical analysis

The result of such an analysis comprising generally about 100 or more receivers is presented as an interval specifying the uncertainty of results due to the deviation of the software configuration from reference settings.

8 REFERENCES

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