Overview and application of the Continuous-Flow Traffic Time-Integrated Method (CTIM) for determining the influence of road surfaces on traffic noise

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The U.S. Department of Transportation Federal Highway Administration is sponsoring a Technical Working Group (TWG) to develop guidance for measuring the influence of road surfaces on tire-pavement noise, vehicle noise, and traffic noise in the U.S. This paper reviews provisional specification AASHTO TP 99-11, "Determining the Influence of Road Surfaces on Traffic Noise Using the Continuous-Flow Traffic Time-Integrated Method (CTIM)" and example applications. CTIM is a wayside measurement method which is applied to roadways where measuring single vehicle pass-by events would be difficult due

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to continuously flowing, relatively dense traffic. At a specified distance from the nearest travel lane, measurements capture sound from existing traffic for all vehicles on all roadway lanes (equivalent sound levels with a maximum sampling period of 15 minutes). A traffic noise prediction model is used to normalize sound levels in terms of traffic variation in order to compare data taken at different times. The method currently allows for comparison of varying or aging pavement surfaces on a single roadway; extension of the normalization process to include site variations to allow for site-to-site comparisons is being examined.

1 INTRODUCTION

The U.S. Federal Highway Administration (FHWA) conducted two tire-pavement noise strategic planning workshops in 2004 and 2006 in order to address issues related to tire-pavement noise in the U.S. One of the entities that spawned from the workshops is the Technical Working Group (TWG) on tire-pavement noise, sponsored by FHWA. The group was tasked with developing tire-pavement noise measurement guidance material or standards for use in the U.S., either by embracing or adapting existing national or international standards or by developing new material. The main purpose of the guidance is to allow practitioners to obtain comparable results among U.S. states for highway conditions prevalent in the U.S. Members of the TWG include noise and pavement consultants; federal and state policy makers and researchers; academics; and industry representatives.

The TWG is currently working on three measurement methodologies: 1) on-board sound intensity methodology to measure tire-pavement noise at the source[1]; 2) statistical isolated vehicle pass-by methodology to determine the influence of road surfaces on vehicle noise, measured wayside[2]; and 3) continuous-flow traffic time-integrated methodology to determine the influence of road surfaces on traffic noise, measured wayside.[3] All three methods are currently American Association of State Highway and Transportation Officials (AASHTO) provisional specifications. The remainder of this paper describes the third method in the list and reviews example applications.

2 SCOPE OF MEASUREMENT METHODOLOGY

The title for AASHTO TP-99-11 is, "Determining the Influence of Road Surfaces on Traffic Noise Using the Continuous-Flow Traffic Time-Integrated Method (CTIM).[3]" This method can be applied to roadways where measuring single vehicle pass-by events would be difficult due to continuously flowing, relatively dense traffic. Measurements capture sound from existing traffic for all vehicles on all roadway lanes. The method currently allows for comparison of varying or aging pavement surfaces on a single roadway by using a traffic noise prediction model to normalize in terms of traffic variation.

AASHTO TP-99-11 is a provisional specification, where modifications are being made on a yearly basis. AASHTO TP-99-12 should be available mid-2012, and AASHTO TP-99-13 is currently under review.

3   DATA COLLECTION

3.1 Measurement Site Considerations

The roadway test section should be essentially level and straight, extending four times the microphone distance in each direction. The pavement should be representative of the roadway under study, having the same nominal material and surfacing. The site next to the roadway should be relatively flat with no nearby reflecting objects or known intrusive noise sources. Ideally, there should be the availability of a nearby overpass for traffic data collection. There should be minimal expected changes to the site and roadway over time (note: the current working version, TP-99-13, includes an appendix regarding how to address unexpected site changes).

3.2 Acoustical Data

The preferred microphone position is 15 m (50 ft) from the center of the near travel lane, at a height of 3.7 m (12 ft) above the center of the near travel lane, with the height being at least 1.5 m (5 ft) above the elevation of the ground surface. For the current method that is intended for a single site over time, an alternate position can be chosen out to 30 m (100 ft) from the center of the near travel lane. Also, additional microphone locations are encouraged beyond 15 m (50 ft) since it is known that propagation effects change the influence of pavements, especially at higher frequencies (1000 to 5000 Hz).

A-weighted sound pressure levels are measured continuously using sound level meters or spectrum analyzers. Broadband levels are required, and one-third octave band frequency spectra are recommended. Equivalent sound levels of either 5 or 15 minutes are used during the data analysis process, either collected directly in the field or constructed post-measurement.

During highway traffic noise data collection, a log is kept by a listener/observer noting any noise that could potentially contaminate the targeted highway noise data.

3.2 Traffic Data

Traffic counts, vehicle types, and speed data are collected in such a way as to obtain the proper data for input in a highway noise prediction model. In addition to traffic composition, the percentage of heavy trucks is noted. Traffic should be continuous and free-flowing at a constant speed.

3.3 Meteorological Data

Meteorological data are measured in the vicinity of the microphone position. It is required to collect air temperature data at least once for each analysis time block (5 or 15 minutes). It is also required to measure wind speed, and acoustical data that are captured when the peak wind speed exceeds 5 m/s (11 mph) are eliminated. Noting the wind direction and sky condition are optional.

4   DATA ANALYSIS

The CTIM data analysis process results in a representative sound level for each data set (single pavement type at one age). The sound levels are then compared between data sets (e.g., a data set for a new pavement is compared to a data set where the pavement is aged 1 year, 2 years, etc.). The analysis process involves minimizing the effect of traffic variation through a traffic normalization process involving a highway noise prediction model, which allows for comparable highway traffic noise levels.

4.1 Organizing Data

The acoustical, traffic, and meteorological data are combined into analysis time blocks as necessary. For example, if acoustical data were collected as 1-minute equivalent sound levels (L_{Aeq}), traffic data were collected in 5-minutes blocks, and meteorological data were collected as 1-minute averages, each data type could be combined into 5-minute analysis time blocks, where, for each 5 minutes, a minimum of the following data are listed: 5-minute L_{Aeq}; 5-minute traffic counts, categorizations, and speeds; and 5-minute average air temperature (other meteorological data are optional, although it is useful to have wind speed listed at this point in order to determine exceedance of 5 m/s to eliminate the analysis time block). Analysis data blocks are eliminated at this point for either exceeding the maximum allowable wind speed (if this wasn't already done prior to data organization) or for incident noise contributing to the measured sound level (note: the current working version, TP-99-13, includes an appendix with examples of the elimination process regarding contaminating noise).

4.2 Normalizing Data for Traffic Variation

Using a highway traffic noise model, traffic data are input to determine the predicted sound level for each analysis time block. For each measurement site (where there will multiple data sets collected over time), a control data block is calculated as the average of all predicted L_{Aeq} for the first data set. All analysis time blocks for all data sets are normalized to this control data block by calculating the differences in sound levels, or normalization values, between the control data block and each analysis time block, and the normalization values are applied to the measured sound levels. This normalization process minimizes differences in sound levels due to variations in traffic from one analysis time block to the next and one data set to the next.

During the modeling step of the normalization process, data outliers are eliminated based on tolerances of differences in measured and modeled sound levels.

4.3 Organizing Data for Reporting

Data are reported in 15-minute time blocks. If the analysis time block is less than 15 minutes, 15-minute data blocks are constructed from the analysis time blocks. For example, if analysis time blocks are 5-minutes, acoustical, traffic, and meteorological data will be combined into 15-minute reporting time blocks, where, for each 15 minutes, a minimum of the following data are listed: 15-minute sound levels, which includes measured, modeled, delta between measured and modeled, and normalized measured L_{Aeq}s; 15-minute traffic counts,

categorizations, and speeds; and 15-minute average air temperature (other meteorological data are optional).

Once data for a data set are represented in the 15-minute reporting time blocks, the following are calculated for the data set: average sound levels (measured, modeled, delta between measured and modeled, and normalized measured L_{Aeq}s); average traffic data (average speed and percentage heavy trucks); and average air temperature. Note that the average normalized L_{Aeq} is the sound level representing the data set.

4.4 Comparing Data Sets

In order to determine the effects of the pavement age or type on wayside sound levels, data sets are compared by calculating the difference in average normalized measured L_{Aeq}. The average vehicle speed and percentage heavy trucks are also compared and noted.

5   ADDITIONAL CONSIDERATIONS

5.1 Collection of other Data to Complement CTIM Results

It is recommended that On-Board Sound Intensity (OBSI) measurements[1] be conducted to help determine potential CTIM locations to represent a roadway section; the best locations would be those with OBSI levels most prevalent in the roadway section of interest.

To benefit pavement design and choices, particularly in terms of experimental pavements and longevity, it can be useful to track pavement properties over time in addition to CTIM results. Such testing could include pavement sound absorption, air-void content, friction, and texture depth.

5.2 Potential Future Modifications

For future versions of CTIM, appendices may be added to help with noise modeling, the use of field forms, and a procedure for spectral analysis of the data. In addition, applying CTIM to site-to-site comparisons (rather than just a single site over time) is being explored; this could be accomplished by extending the normalization process to site differences (rather than just differences in traffic).

6   EXAMPLE APPLICATIONS OF CTIM

6.1 Arizona Quiet Pavement Pilot Program

The Arizona Department of Transportation (ADOT) initiated the Arizona Quiet Pavement Pilot Program (QPPP)[4] in April of 2003 with approval from FHWA. The QPPP consists of two components: construction and research. The construction component consists of overlaying approximately 185 kilometers (115 miles) of existing transversely tined Portland cement concrete (PCC) on urban freeways with asphalt rubber friction course (ARFC). The research component evaluates the potential for using ARFC as a noise reduction or mitigation measure. In regard to noise, the program documents the initial and continuing acoustic performance of the pavement over at least a ten-year period and assesses the difference in measured sound levels

and those predicted with the FHWA Traffic Noise Model® (TNM®)[5,6] using Average pavement (for purposes of potentially receiving credit for quieter pavement in future noise predictions). The acoustic performance has been monitored with three different measurement types: tire-pavement noise reduction at the source; noise reduction in residential neighborhoods near the freeways; and noise reduction using direct measures of traffic noise adjacent to the freeways. For the QPPP, CTIM is applied to measure the noise reduction of traffic noise adjacent to freeways. In addition to the primary microphone position, sound levels at distances out to 75 m (~250 ft) were monitored. As part of the QPPP, pavement properties, including a measure of sound absorption are also being monitored over time, where results will be available through the QPPP.

Figure 1 shows the highway for one of the CTIM measurement sites for the QPPP, with continuously flowing traffic. Figure 2 shows instrumentation deployed at the QPPP CTIM measurement sites. CTIM example results for one site from the QPPP are shown in Figure 3. Each data point represents the average normalized L_{Aeq} (the representative sound level) for a single data set. Results show that the sound level at 15 m (50 ft) for transversely tined PCC was 83.2 dBA and the sound level for ARFC ranged from 74.4 to 76.7 dBA over a 6 year period. So the sound level was initially reduced by 8.8 dB with the ARFC overlay and increased 2.3 dB over 6 years (~0.4 dB/year). In addition to comparisons among measured sound levels, comparisons of measured data to TNM-predicted data for Average pavement showed that the transversely tined PCC was about 3 dB higher than sound levels for TNM Average pavement and ARFC was about 4-6 dB lower than sound levels for TNM Average pavement, value dependent on ARFC pavement age. Note that the study is on-going and data will continue to be collected as the ARFC ages.

6.2 Caltrans I-80 Pavement Noise Study

During June and July 1998, an open graded asphalt concrete (OGAC) pavement overlay was applied to a 9-kilometer (5.6-mile) stretch of aged dense graded asphalt concrete (DGAC) along Interstate 80, a six-lane divided highway, to the east of Davis, California. Noise conditions have been monitored since 1998 as part of a broader quieter pavement research program conducted by the California Department of Transportation (Caltrans) to evaluate the long-term effects of quieter highway pavement types on traffic noise.[7] Both the CTIM and OBSI methods have been applied to the I-80 Davis OGAC Pavement Noise Study. The report for the study (reference 7) describes results for 1) a comparison of the acoustical performance of OGAC pavement to baseline DGAC and other pavement types; 2) a discussion of the acoustical attributes of the OGAC pavement; 3) a description of the effects of aging of the pavement on acoustical performance; 4) a description of seasonal trends in noise levels based on the data set; and 5) a description of the effect of wind conditions on distant CTIM locations (sound levels out to ~143 m or ~470 ft were monitored). Example results of the acoustical performance over time and comparisons to TNM-predicted sound levels will be presented here.

Figure 4 shows a map of the CTIM (and OBSI) locations. CTIM example results are shown in Figure 5. Each measured data point represents the average normalized L_{Aeq} for a single data set. Results show that the sound level at 20 m (65 ft), the primary microphone location, was 78.6 dBA for the aged DGAC and the sound level for the OGAC ranged from 71.9 to 75.1 dBA over a 12 year period. So the sound level was initially reduced by 6.7 dB with the OGAC overlay and increased 3.2 dB over 12 years (~0.3 dB/year). In addition to comparisons among measured

sound levels, comparisons of measured data to TNM-predicted data for Average pavement showed that the DGAC was about 1 dB higher than the sound levels for TNM Average pavement and OGAC was about 3-6 dB lower than sound levels for TNM Average pavement, value dependent on OGAC pavement age. Note that the study is on-going and data will continue to be collected as the OGAC ages.

7   CONCLUSIONS

CTIM was developed to help evaluate the effects of pavement on wayside sound levels for highways with continuously flowing traffic. The method is currently an AASHTO provisional standard, which is being refined and expanded over time before reaching full specification status. Examples of the use of CTIM are provided in this paper, where the method has proven to be quite useful in helping state highway agencies to evaluate the effects of quieter pavements. The method is currently restricted to comparisons of sound levels at a single site over time using a traffic normalization process, however, work has started to expand the normalization process to include traffic and site differences, allowing for site-to-site comparisons.

8   ACKNOWLEDGEMENTS

The authors wish to thank the FHWA for supporting the technical working group members in development of the CTIM standard.

9   REFERENCES

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Fig. 1 - AZ QPPP highway traffic at CTIM measurement site.

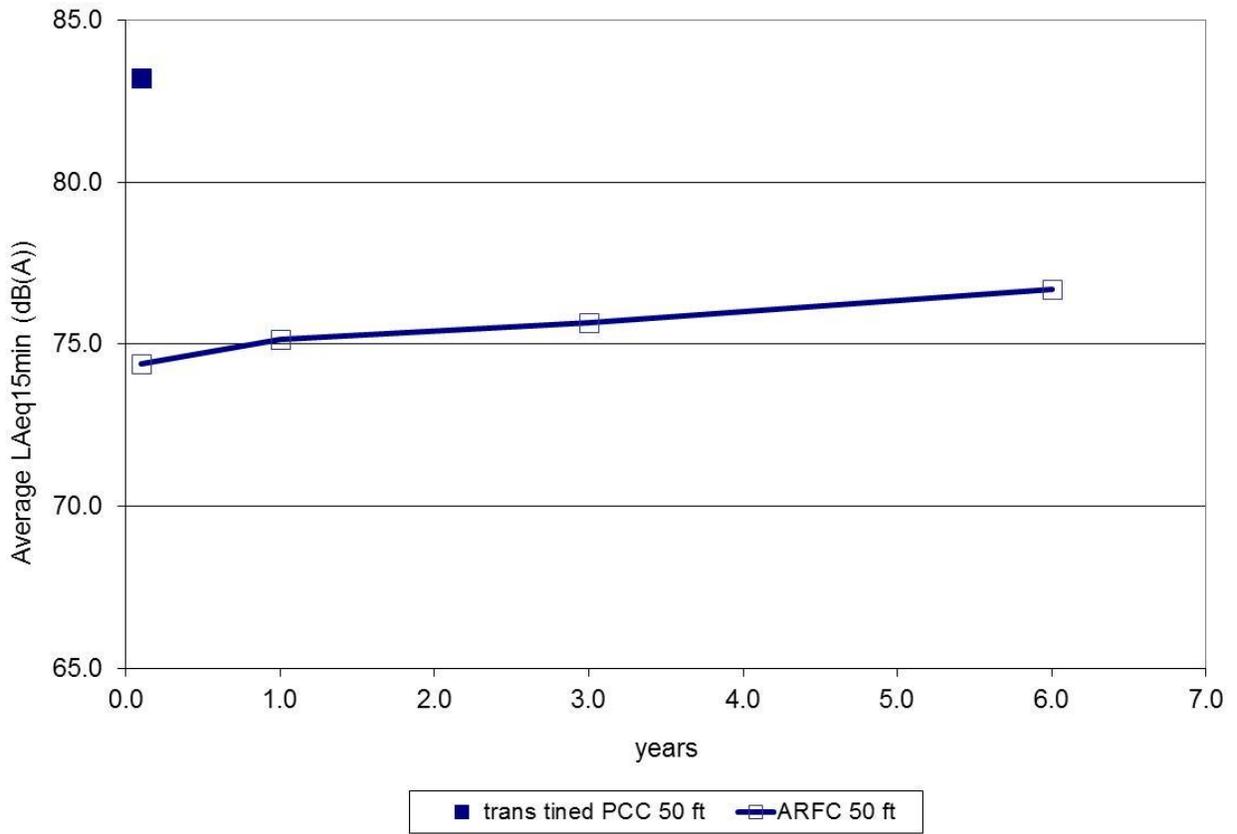

Fig. 2 - AZ QPPP CTIM measurement instrumentation.

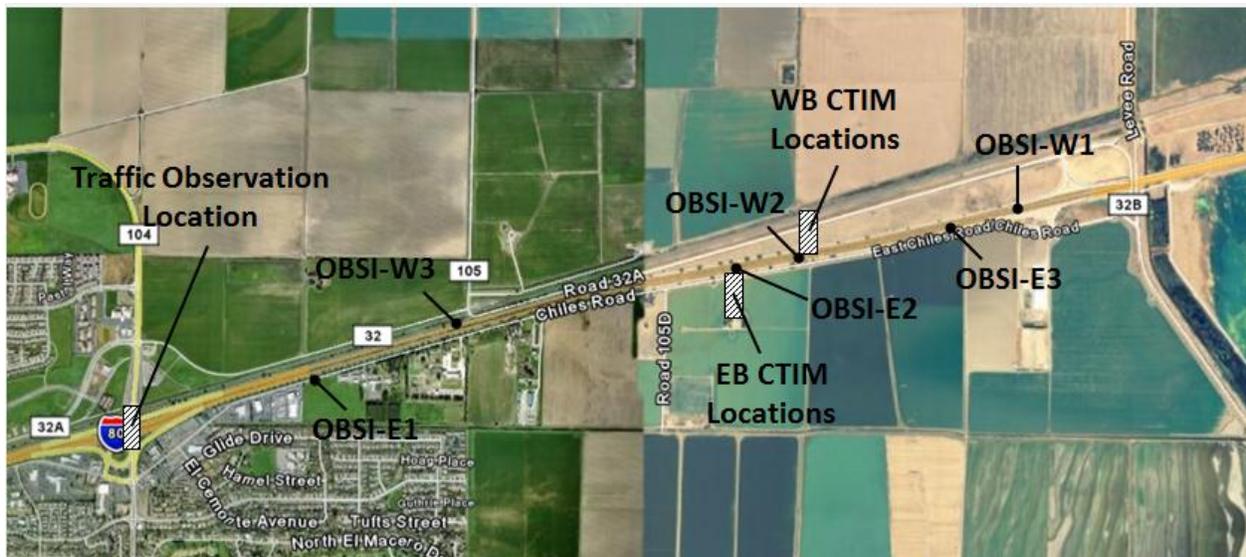*Fig. 3 - AZ QPPP CTIM results at one site over time.*

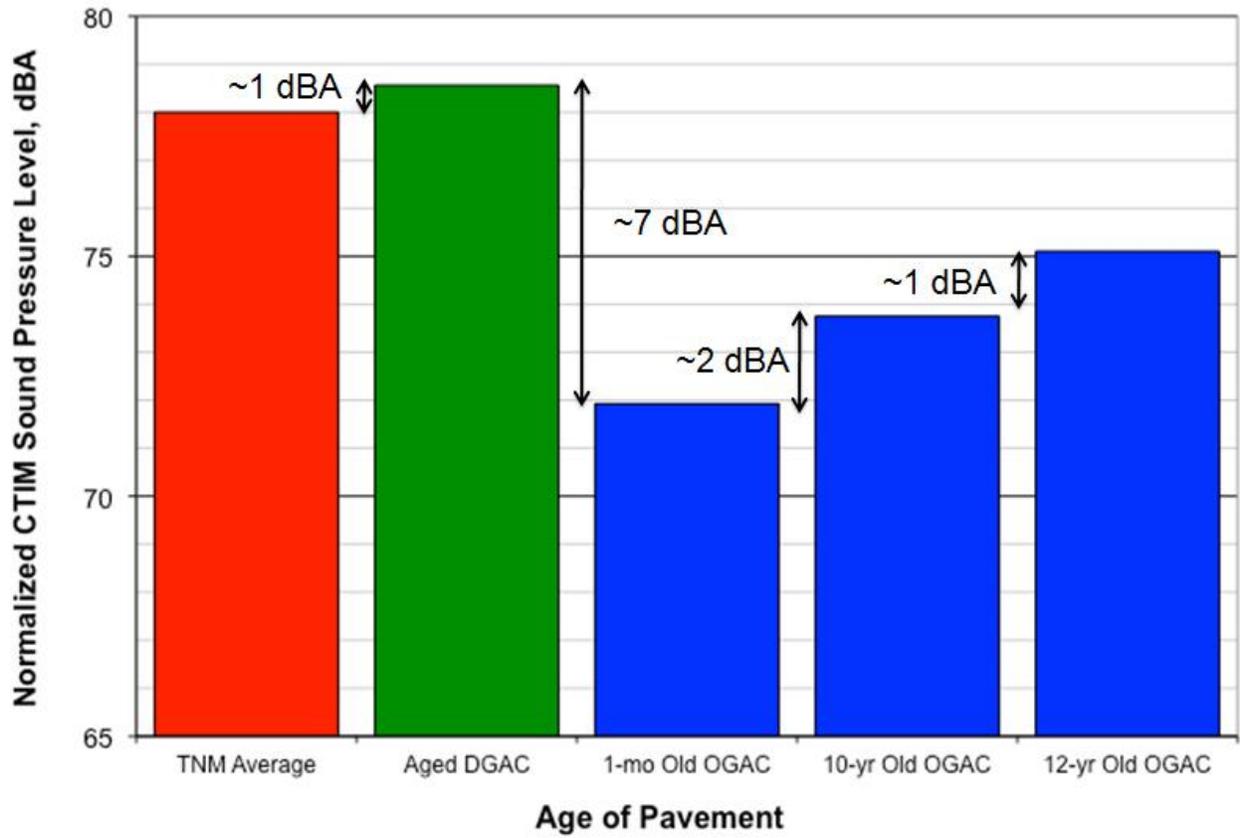*Fig. 4 – I-80 Davis OGAC Pavement Noise Study noise measurement locations.*

Fig. 5 - I-80 Davis OGAC Pavement Noise Study results over time and compared to TNM Average pavement predictions.