DETERMINING THE END LIMITS OF QUIETER PAVEMENT PROJECTS

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ABSTRACT

Ongoing work in the area of tire pavement acoustics has definitively determined that there can be a significant variation of noise levels between the loudest and quietest pavements. Using the On-Board-Sound-Intensity (OBSI) measurement procedure, it has also been determined that tire/pavement noise is highly correlated to the overall traffic noise levels especially when traffic is flowing at freeway speeds. This presents road agencies with a potential new tool for lowering traffic noise levels by using quieter pavements. Changing from a ‘loud’, or old and raveled pavement to a newer, smoother, lower noise pavement can yield acoustic benefits to roadside communities or ‘receivers’. The decrease in noise level depends on the difference between OBSI levels of the existing pavement and the selected quieter pavement and the magnitude of this decrease may also be influenced by vehicle mix. After the decision to use a quieter pavement has been made, the end limits for the pavement must be determined. The problem is somewhat similar to deciding where to terminate a sound wall relative to the location of the roadside receivers. This analysis determined that the quiet pavement end limits are less sensitive to variation in typical roadway cross sections, somewhat sensitive to the distance between the receiver and the roadway and where the quiet pavement terminates, and very sensitive to the absolute differences between the noisier and quieter pavements.

INTRODUCTION

A great deal has been learned about pavement acoustics in the last ten years and the technology to more accurately quantify pavement noise levels is presented in the AASHTO OBSI Standard[1]. In California, a comprehensive OBSI database of flexible and rigid, old and young pavements has become an important environmental tool and has immediate practical application for Caltrans. This acoustic data is used to evaluate and address noise complaints, minimize noise impacts on the public, and enhance pavement rehabilitation projects. Between extremes, the range between the loudest and quietest pavements can be as much as 16dB(A), a 10dB(A) variation is possible on any roadway section, and 6dB(A) is typical for at-grade pavements in California[2]. A highly correlated relationship exists between tire/pavement noise levels and roadside noise levels[3]. For highway speeds of 55 mph and greater, the dominant contribution to traffic noise is due to tire/pavement noise. In these cases, the acoustic benefit of quiet pavement over loud pavement would translate almost directly to a reduction in roadside noise levels. However, this will be diminished somewhat with increasing truck volumes as the noise from truck tires are often not affected as much by quieter pavements than are light vehicle tires[4]. At lower speeds and particularly on grades other noise sources such as exhaust, and mechanical noise may contribute to the overall noise levels, particularly for trucks. These additional noise generators may diminish the quieter pavement benefits.

Current Federal Highway Administration (FHWA) Regulation (23 CFR 772) does not allow federal funds to use quieter pavement to mitigate noise impacts in part because of the unknown acoustic durability or longevity of the ‘quieter’ pavements in providing noise abatement. However, this does not preclude road agencies from inventorying their pavements and making informed pavement design decisions to avoid placing loud pavements next to sensitive receivers. With the OBSI tool, road agencies can take proactive steps toward lowering noise impacts of their transportation infrastructure by inventorying the acoustics of their various pavements and then using this information to avoid placing loud pavements near sensitive receivers. After a significant amount quiet pavement research, Caltrans issued a Quiet Pavement Policy Bulletin[5] in October 2009. The bulletin was intended to be guidance for pavement engineers in the use and implementation of ‘quieter’ pavement strategies and was a proactive attempt to use pavement to lower traffic infrastructure noise impacts. The bulletin outlines selecting quieter pavement strategies, programming for quieter pavement rehabilitation projects, identifies funding methods, and monitoring noise levels. In developing this document, it was desired to set guidance limits for where to terminate quieter pavement projects relative to the roadside receivers. It was further desired to relate these limits to the tire/pavement noise levels that had been documented with OBSI measurements in California. As this could not be accomplished with the FHWA Traffic Noise Model (TNM), an alternate method was developed. It was not intended for this method to be a substitute for rigorous modeling of highway noise impacts, but rather to provide “rule-of-thumb” guidance to pavement engineers. This paper will present how these limits for quieter pavement projects were established based on typical OBSI values for California pavements.

MODEL DEVELOPMENT

Determining where to end the quiet pavement treatment is *somewhat* similar to deciding where to terminate a sound wall, but there are differences. Streaming freeway-speed traffic is a linear noise source. Sound walls block noise in the transmission path while quiet pavement attenuates the noise at the source. To a receiver, high-volume traffic is an unchanging line source, but a pavement switch is a change to the line source noise levels.

In order to evaluate pavement limits, a simple line source model is used in which the point where the transition between the quieter pavement and the louder pavement is a variable. This simplified analysis assumes a flat roadway tangent, with no surface or meteorological effects. Several different versions of line source models are available to represent traffic flows[6,7], however, for the purpose of this application, the basic calculation was re-developed in a form amenable to this specific application. Conceptually, the traffic flow of individual vehicles is considered as a continuous "stream" of sources when averaged over time. One slice of that stream, dl, can be considered as having a sound power per unit length of Π_l. The sound power for that slice along the length of the source is then just $\Pi_l\, dl$. Figure 1 presents the general line model geometry. Considering a very small length of the element dl to correspond to a point noise source in a free field, the sound intensity at point R, the receiver location, is given as:

$$I = W/4\pi d^2$$

where W in the sound power radiated by the element or $\Pi_l\, dl$ and the distance between the element and the Receiver(R) is represented by d. Sound intensity in the far field of a point source is related to the mean square sound pressure by the relationship:

$$p^2 = I\rho c$$

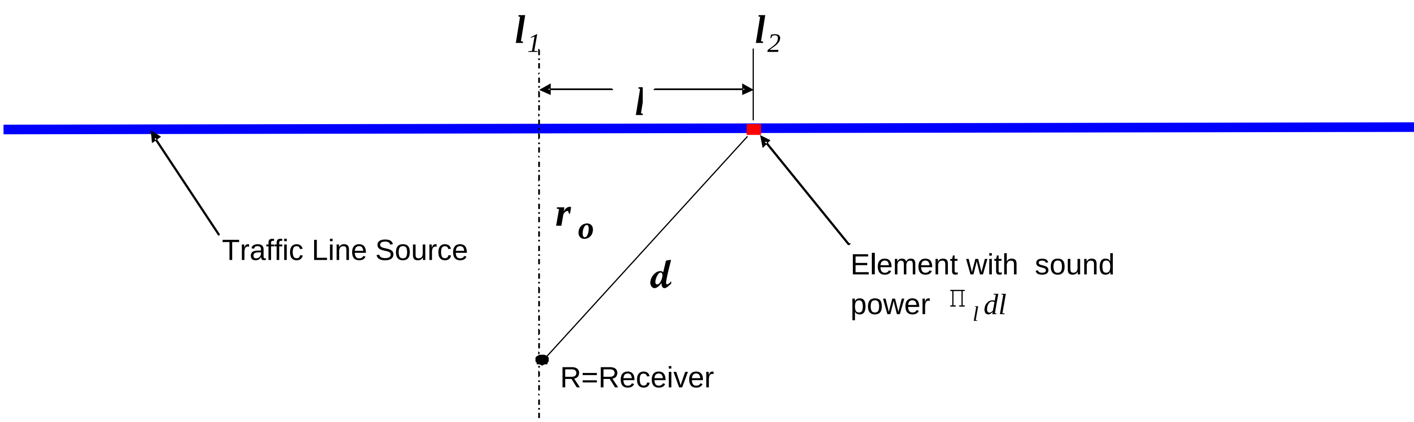

Figure 1 : Quieter Pavement Line Source Geometry

where ρ is the density of air and c is the speed of sound. Substituting these relationships, the mean square sound pressure at R for a segment of the line source is given by:

$$p^2 = \int_{l_1}^{l_2} \frac{\Pi_l \rho c}{4\pi d^2} dl$$

For the purpose of the model, d needs to be expressed in terms of r_o and l or simply d^2 is the sum of r_o^2 and l^2. The beginning of the pavement section to be analyzed is l_1 and the end of the pavement section is l_2. Substituting this expression for d^2 into the above equation and bringing the constant terms out of the integral, the mean square pressure at R becomes:

$$p^2 = \frac{\Pi_l \rho c}{4\pi} \int_{l_1}^{l_2} \frac{dl}{r_o^{\,2} + l^2}$$

which can be solved as:

$$p^2 = \frac{\Pi_l \rho c}{4\pi} \times \frac{1}{r_o} \left[\tan^{-1} \frac{l}{r_o} \right]_{l_1}^{l_2}$$

To implement this equation, the sound power per unit length of Π_l is taken to be defined by the tire/pavement sound intensity level measured for the quieter and louder pavements. Using the geometries defined in Figure 2 for the quieter and louder segments, the level contribution for each segment can be calculated. The objective is then to use the calculations to minimize the sound levels at the Receiver and minimize the extension (d_2) of quieter pavement beyond the Receiver. The variables as defined in Figure 2 are the distance of the receiver to the roadway, r_0,

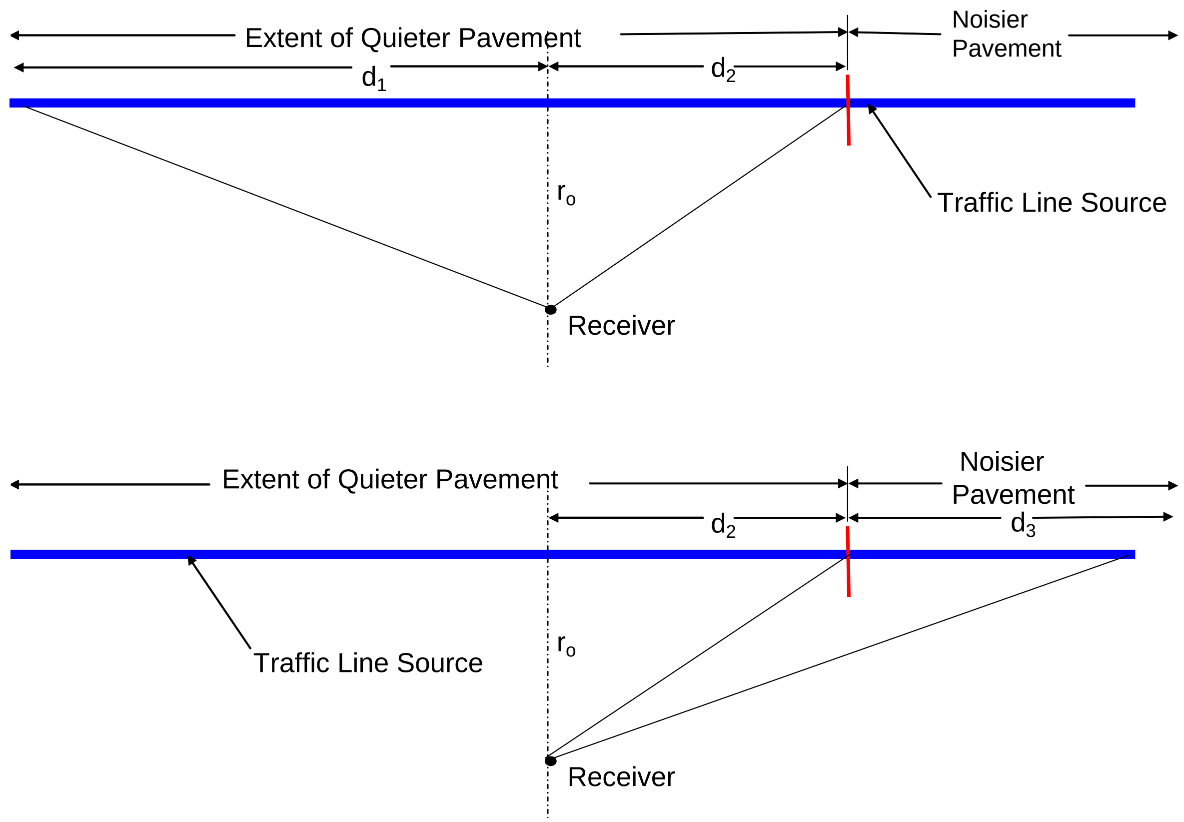

Figure 2: Model Geometry for Quieter/Noisier Pavement Line Source

the OBSI level for the quieter and louder pavements, number of lanes, median width, lane width, and length of three quieter/noisier pavement segments (d_1,d_2,d_3) which extend upstream and downstream of the receiver. For simplicity, the distance to extend the pavement beyond the receiver (d_2) will be a multiple of the perpendicular offset (r_0) between the pavement and Receiver. The calculations to optimize the distance d_2 are done in an Excel spreadsheet that display the input and output field shown in Figure 3. The linear model breaks the line source into two segments, one with the quiet pavement (QP) and one without it (non-QP). By breaking the line source into segments, the acoustic power at the receiver can be calculated by summing the acoustic energy of each pavement segment. In Figure 3, the spreadsheet outputs are the level from the QP segment, the non-QP segment, and then both segments as if they both were QP. From these, the total level with both quiet and loud segments is calculated. This is then compared to the level as if QP were used far upstream and far downstream from the receiver. This idealized condition is also the baseline for the comparisons. The difference between these (QP + non-QP level minus all QP) is also calculated.

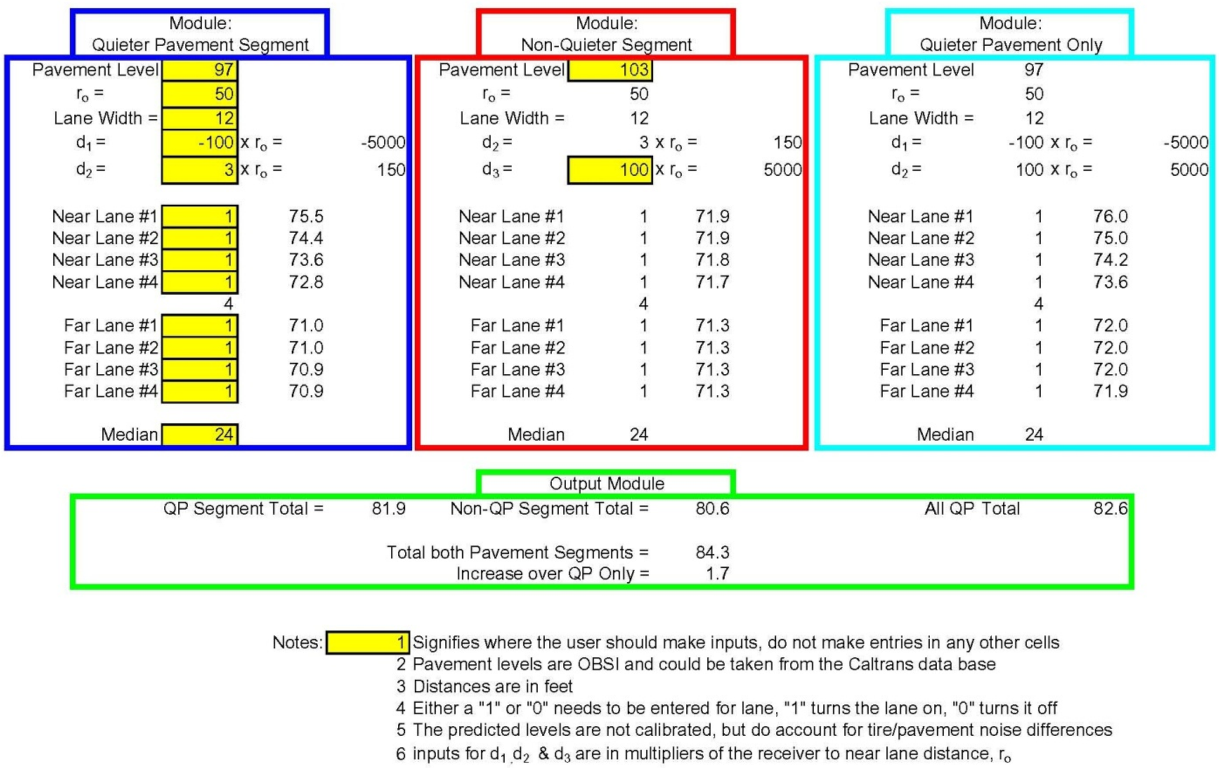

Figure 3: Example Spreadsheet Calculation Modules of Pavement Segments with Input Variables

The intent of this model is to strictly provide guidance for the extension of quieter pavement in a totally generic manner and to not include site specific parameters. Consistent with this purpose, the model does not consider the influence of terrain features, sound walls, ground effects, roadway curvature, safety barriers, meteorological effects, etc. If site specific calculations were deemed necessary, these could be done using a modified version of the FHWA Traffic Noise Model[7].

MODEL SENSITIVITY ANALYSIS

Looking at Figure 4, the abscissa represents the distance the quiet pavement is carried beyond the receiver in multiples of the offset between the receiver and roadway (r_0). The ordinate represents the difference between having an infinite length of quieter pavement (in both directions) and quieter pavement that switches to loud pavement at some multiple of the offset (r_0). The results match expectations; noise levels decrease as the quieter pavement is extended beyond the receiver and approaches the idealized 'all quieter pavement' condition. Also, given the assumed roadway cross section, as the offset distance, r_0, increases from 30 to 400 feet and the receiver gets further away from the pavement, the noise levels only decrease by about 0.5 dB(A). The extension distance (d_2) beyond the receiver from one to five offsets only decreases the acoustic benefit by about 1.8 dB(A) over the length of the colored curves. These curves are based on a 6 dB(A) OBSI difference between the quieter (97 dB(A)) and noisier (103 dB(A)) pavements.

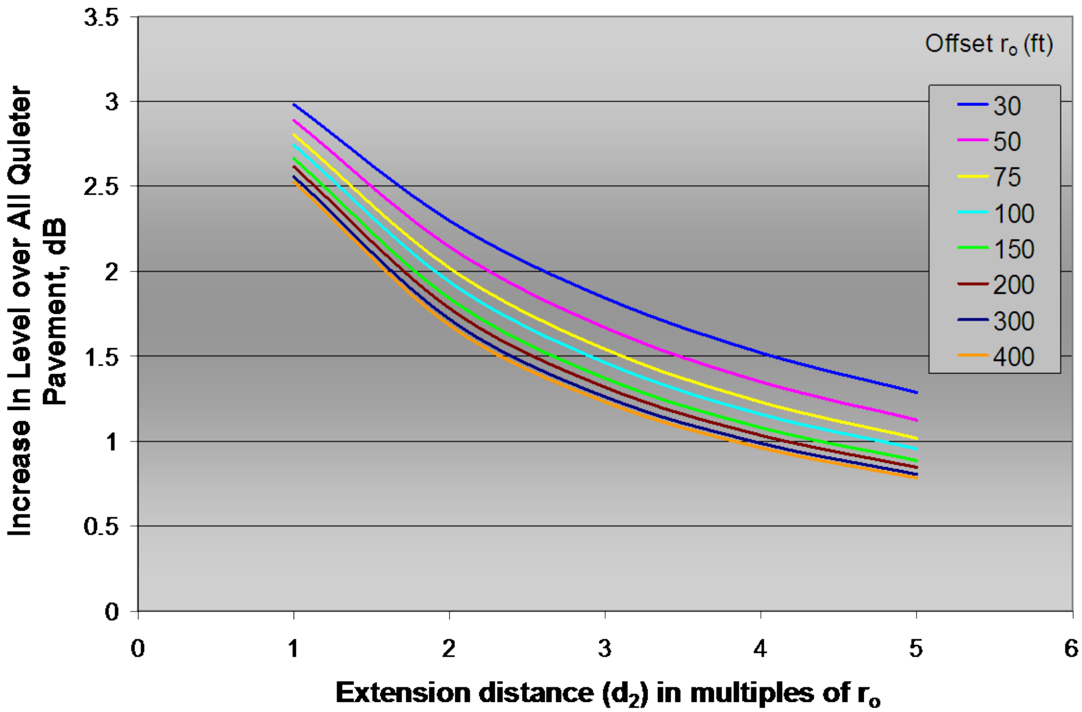

Figure 4: Eight Lanes Twenty Four Foot Median, 97 and 103 OBSI Levels

The sensitivity analysis started with a wider cross section of eight lanes, because the request to use quiet pavement is more likely to be in a multilane urbanized area with sensitive receivers nearby. Similar results with narrower roadway cross sections can be seen in Figures 5 through 7. Even though the number of lanes is progressively halved, from eight, to four, to two lanes, there is little significant change seen in the beginning and ending of the nested curves. The sound power is halving, but there is little overall change between eight, four, and two lanes. It appears that the spacing between the lanes as well as the wider medians and spherical spreading drop-off of acoustical energy compensated for the increased number of noise generators. A

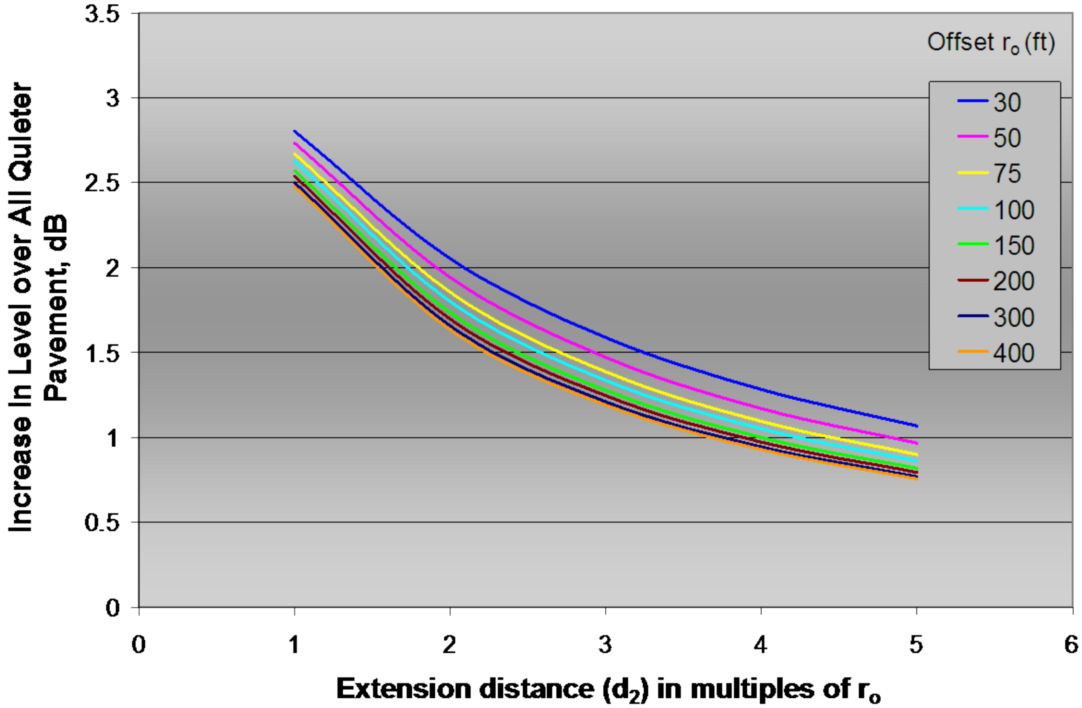

Figure 5: Four Lanes Twenty Four Foot Median, 97 and 103 OBSI Levels

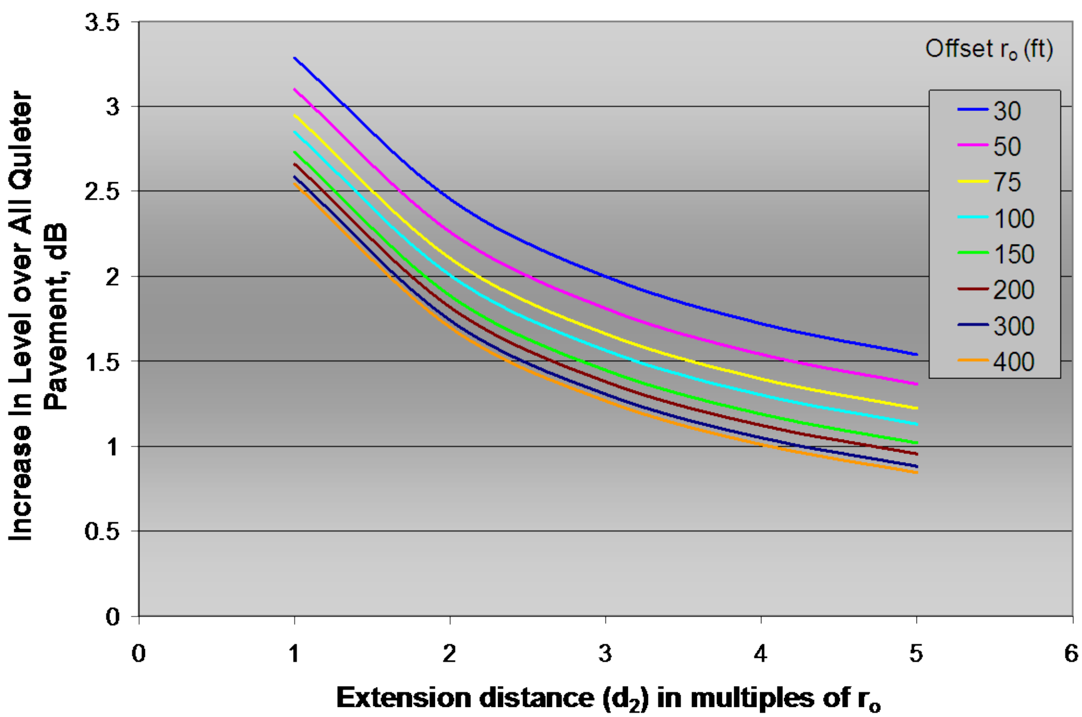

Figure 6: Two Lanes Twenty Four Foot Median, 97 and 103 OBSI Levels

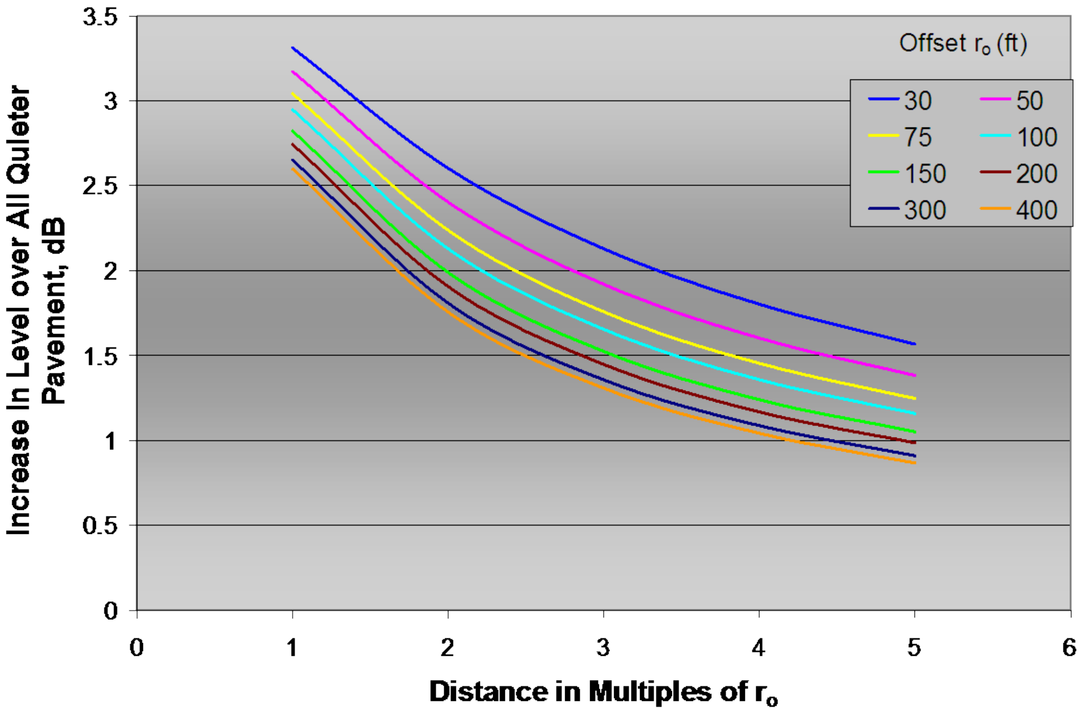

Figure 7: Eight Lanes Two Foot Median, 97 and 103 OBSI Levels

smaller, narrower median does move the noise closer to the receiver and this can be seen in the upward shift of curves as seen between Figures 4 and 7, but there is still little change in noise levels calculated at the receiver. Also, as the receiver distance gets greater than 75 feet, the curves draw closer, indicating that the extension has less impact on the more distant receiver levels.

A significant change in this analysis occurs when the difference between the noisier and quieter pavement increases by 12 dB(A) as shown in Figure 8. This graph shows that as the differences between quieter and noisier pavement increase, the quieter pavement must be extended further from the receiver.

Although there are far too many permutations of pavement and roadway geometry to present in this paper, it is instructive to examine the effect of the difference in level between the quieter and noisier pavement for a specific, but typical roadway geometry. This is presented in Figure 9 for a six-lane highway with a 24 ft wide median for differences in OBSI level from 2 to 12 dB. Figure 9 shows that as the OBSI difference between ‘quiet’ and ‘loud’ pavement levels increases from 2 to 12 dB(A), the extension distance (d2) must increase to achieve lower noise levels at the Receiver

MODEL APPLICATION

Based on a similar analysis, Caltrans set limits for quieter pavement projects in their Quiet Pavement Policy Bulletin. The bulletin suggests, ". . . the limits of the pavement treatment in each direction should extend for at least three times the offset distance from the end noise

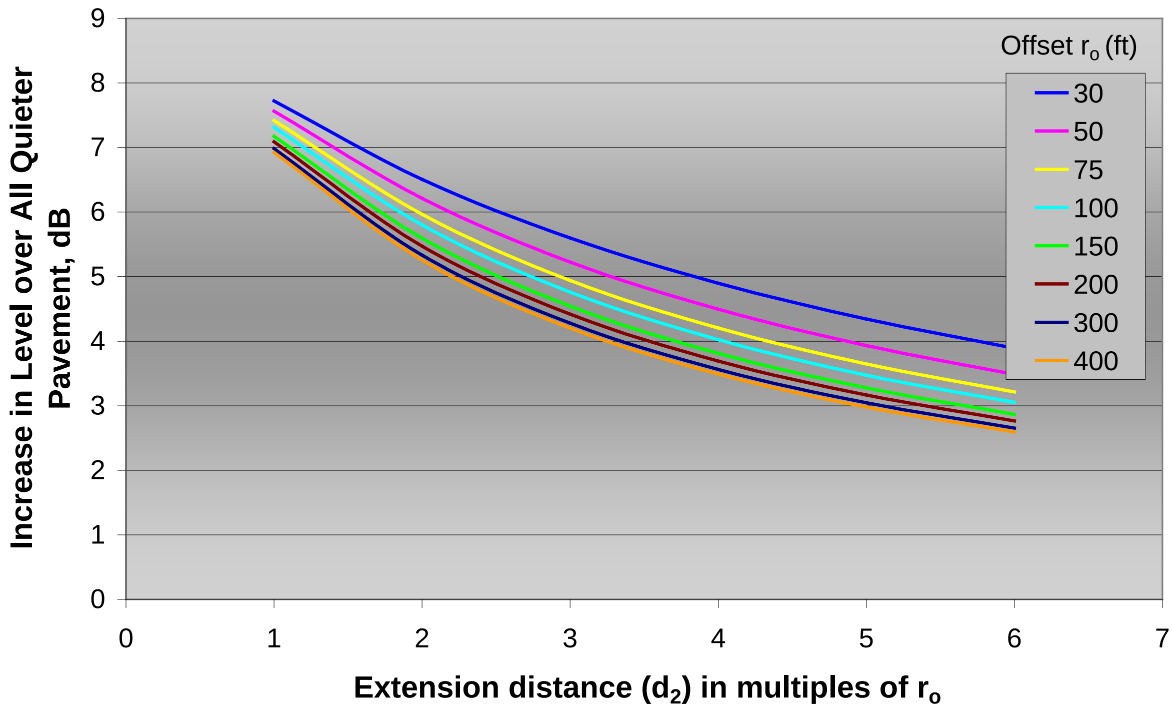

Figure 8: Eight Lanes Twenty Four Foot Median, 97 and 109 dB(A) OBSI Levels

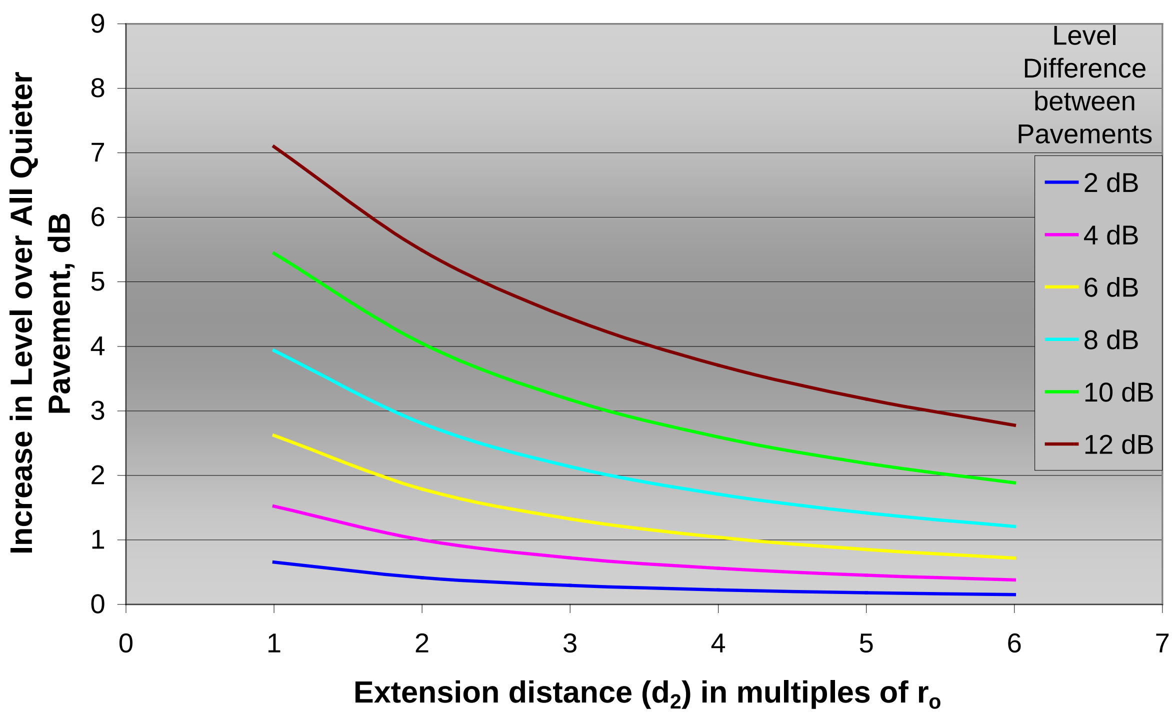

Figure 9: Six Lanes Twenty Four Foot Median Receiver at One Hundred Fifty Feet for Different Level Differences between Quieter and Noisier Pavement

receiver(s) to the center of the nearest traffic lane but not exceed 500 feet beyond the end noise receiver(s) . . ." (see Figure 10). This recommendation was based on a comprehensive California OBSI database and a thorough understanding of the acoustic variability between typical at-grade California pavements. The limits set forth by the Caltrans Quiet Pavement Policy Bulletin may not be appropriate for other road agencies because the variation between their quiet and noisy pavements may be larger. This may be particularly true if a roadway agency uses large aggregates or aggressively textured pavement in their pavement inventory.

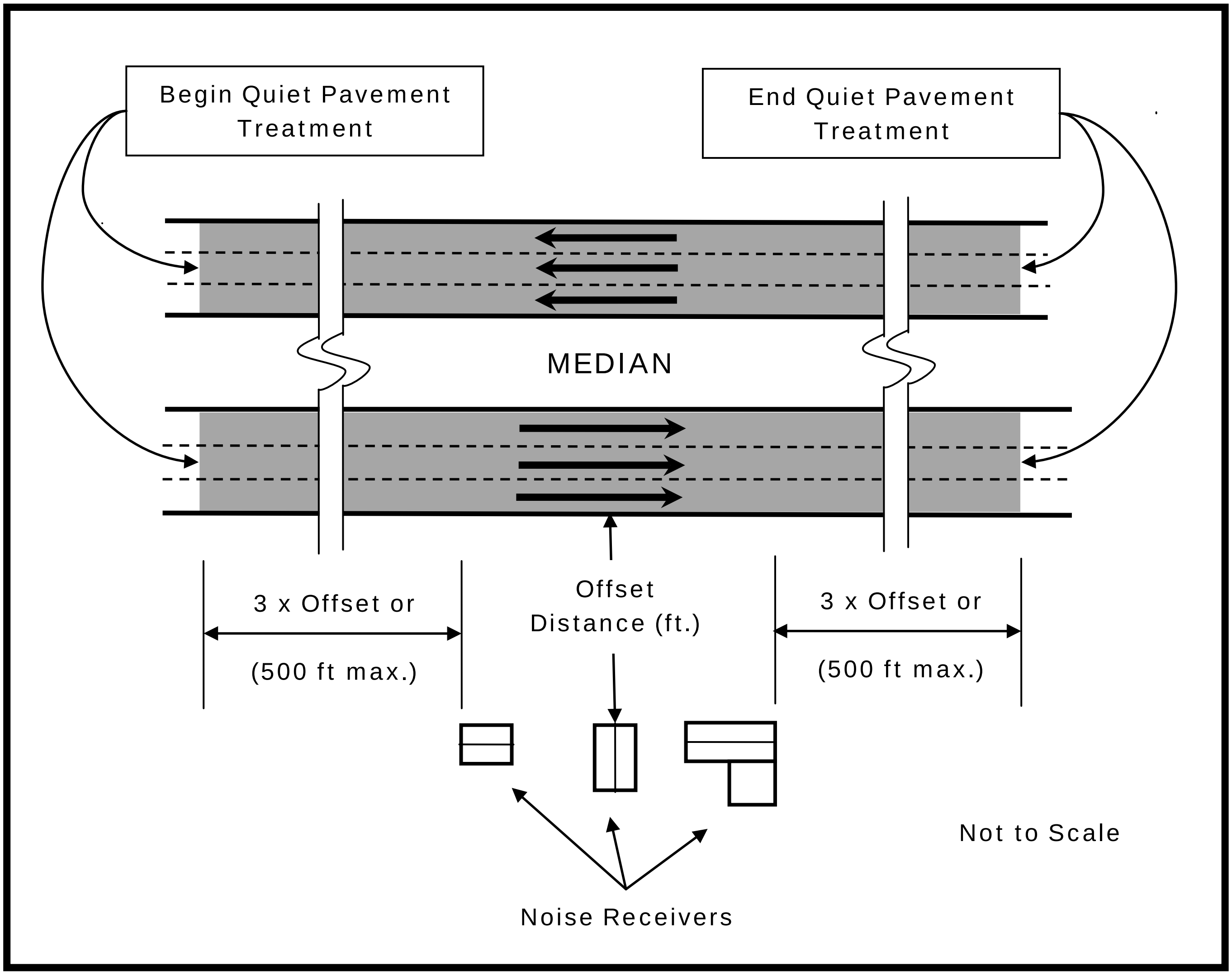

Figure 10: Diagram from Caltrans Quiet Pavement Policy Bulletin Defining Limits of Quieter Pavement Projects

SUMMARY

A line source model approach to evaluating the effect of quieter pavement limits on tire/pavement noise dominated traffic noise has been developed. This approach directly incorporates OBSI data of quieter and noisier pavements to estimate the increase in noise level due to the transition to the noisier pavement as a function of distance from the nearest receiver. Examining a number of different geometries, it was found that the functions of noise level change with increased distance were not very sensitive to the number of lanes or median width of the roadway cross section. The effect of the quieter pavement termination position was, however, very sensitive to the absolute OBSI difference between quieter and noisier pavement. For application in California, a 6 dB difference in level between the quieter and noisier pavements was examined as being typical of the changes in level experienced in the State between the two pavement categories. Using the results of the model for this difference and considering a number of different geometries, it was decided to use a distance of three times the offset distance between the end noise receiver and the center of the nearest lane of traffic. For application by other agencies, it should be realized that this guidance was adopted for Caltrans based on the expected differences in pavement in the State. For wider application, each jurisdiction should determine the expected difference in OBSI level between their quieter pavement and noisier pavements and repeat the analysis tailored to their specific case.

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