



Quieter Pavements Guidance Document

Addendum for Years 2013 to 2018

Natural Resource Report NPS/NRSS/NSNSD/NRR—2021/2300



ON THE COVER

View of Badwater Road, Death Valley National Park

Source: Volpe Center photographs (November 2016)

Quieter Pavements Guidance Document

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Natural Resource Report NPS/NRSS/NSNSD/NRR—2021/2300

Aaron L. Hastings

U.S. Department of Transportation
Volpe National Transportation Systems Center
Cambridge, MA 02142

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Contents

	Page
Figures.....	iv
Tables.....	iv
Abstract.....	v
Acknowledgments.....	vi
List of Terms.....	vii
Acronyms.....	x
Introduction.....	1
Performance Trends	2
Performance Over Time.....	6
Pavement Maintenance	9
Cost/Benefit Analysis	10
Predicting OBSI.....	13
Summary of Findings in Literature from 2013 to 2018.....	17
Recommended Reading	18
Annotated Bibliography.....	19
Literature Cited	24

Figures

	Page
Figure 1. A-weighted On-board Sound Intensity Levels for California AC Categories – Flexible Pavements.	2
Figure 2. A-weighted On-board Sound Intensity Levels for California PCC Categories – Rigid Pavements.	3
Figure 3. OGAC OBSI Spectra over a Sixteen Year Period for one Site in California.	8
Figure 4. LLCA for HMA Pavement using an ARFC Overlay for Noise Reduction.	10
Figure 5. TNM-Predicted Traffic Noise Levels at 100 Feet.	11
Figure 6. Example of OBSI microphone array mounted on a passenger car.	13
Figure 7. Measured and Predicted Overall OBSI Levels, Leading Edge, RoboTex Data,.	16

Tables

	Page
Table 1. A-weighted On-board Sound Intensity Levels for California AC Categories – Flexible Pavements.	4
Table 2. A-weighted On-board Sound Intensity Levels for California PCC Categories – Rigid Pavements.	5
Table 3. Average monthly OBSI Levels for Two Open-Graded Friction Courses and a Reference Hot Mix Asphalt.	6
Table 4. Summary of Deterministic LCCA Results for the Primary HMA and PCC Alternatives.	12
Table 5. Comparison of Pavement Texture Property Inputs for Tire-Pavement Noise Models.	15
Table 6. Comparison of Other Pavement Property Inputs for Tire-Pavement Noise Models.	15
Table 7. Comparison of Outputs for Tire-Pavement Noise Models.	16

Abstract

Sohaney (2013) published a “Quieter Pavements Guidance Document” for the National Park Service in June of 2013. Since then several reports, articles and presentations have been made public. This document provides updates to the “Quieter Pavements Guidance Document”, both in a summary of recent findings and an annotated bibliography.

Acknowledgments

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List of Terms

The following terms are used in this report.

Pavement Types

Asphalt Rubber – An asphalt pavement with 15 to 20% rubber content (often from recycled tires). The rubber increases flexibility and decreases noise.

Chip Seal – A wearing surface added to an existing pavement consisting of a gravel friction course and an asphalt binder course.

Dense-Graded Asphalt Concrete – a well-graded hot mix asphalt.

Flexible Pavement – Asphalt pavement.

Hot Mix Asphalt – asphalt mixture (aggregate and asphalt cement) poured at temperatures between 300 and 350 degrees Fahrenheit.

Open-Graded Asphalt Concrete – a porous asphalt mix with large voids to allow water drainage.

Open-Graded Friction Course – A friction course (see Pavement Construction below) of open-graded asphalt concrete.

Porous – a pavement with large voids to allow water drainage. Voids are typically 20% or more of the volume.

Portland Cement Concrete – A rigid pavement with Portland cement as the binding agent. Portland cement is the most common binding agent used in structural concrete such as is used for creating building foundations, sidewalks and roadways.

Quieter Pavement – A pavement that is quieter than a reference pavement.

Rigid Pavement – Portland cement concrete pavement.

Rubberized Asphalt Concrete – See Asphalt Rubber.

Stone Mastic Asphalt – An asphalt pavement with a high concentration of coarse aggregate that resists deformation better than dense graded asphalt.

Pavement Construction

Base Course – a 4 to 6 inch layer below the binder and friction courses. It provides a stable foundation for the friction course.

Binder Course – a layer that is sometimes applied on top of the base course before applying the friction course.

Drag Texturing – a method of texturing Portland cement concrete. Typically a material like a burlap bag is dragged over the newly applied pavement.

Friction Course – The top layer of a pavement.

Grinding – a method of correcting surface imperfections in Portland cement concrete. Grinding is done after the pavement has cured and may only be done to rehabilitate worn pavement.

Longitudinal Tining – Grooves applied to Portland cement concrete in the direction of vehicle travel to provide friction and skid resistance. Longitudinal tining tends to be quieter than transverse tining.

Seal Coat – A sealant layer applied to a pavement. Seal coats can be asphalt, tar or petroleum based.

Subgrade – The layer below the base layer in a pavement. This layer is made up of material existing at the site.

Transverse Tining – Grooves applied to Portland cement concrete perpendicular to the direction of vehicle travel to provide friction and skid resistance. Transverse tining tends to be louder than longitudinal tining.

Wearing Surface – See Friction Course.

Pavement Failures

Bleeding – Excess bituminous binder rising to the surface. Produces a shiny but tacky surface.

Clogging – Filling of voids in porous pavement by fine detritus such as dirt or sand.

Corrugations – Transverse undulations due to stop-and-go traffic.

Cracking – Separation of the mix either in multiple directions (alligator or fatigue cracking), along a line of shear stress, e.g. where excessive wheel load is applied (shear cracking), or long cracks through the full pavement thickness due to, e.g. settlement of fill material (longitudinal cracking).

Raveling – A disintegration of a hot mix asphalt layer from the top down due to loss of aggregate.

Rutting – Formation of depressions or grooves (ruts) in the region of wheel travel.

Shoving – Similar in appearance and cause as corrugations, but displays on a single undulation.

Measurement Methods

Close Proximity Method – A Method of measuring tire-pavement interaction of a moving vehicle by using microphones mounted near the tire. Described in ISO 11819-2.

Continuous-flow traffic time-integrated method – A method of measuring roadway related noise that, rather than focusing on single pass-by events, aggregates all events within a specified time.

On-board Sound Intensity – A method of measuring the sound intensity generated by tire-pavement interaction of a moving vehicle by using intensity probes mounted near the leading and trailing edge of a tire.

REMELs – Reference Energy Mean Emission Levels. A database of noise levels for a variety of vehicle types, over a variety of pavement types, over a range of speeds. The reference distance is 50 feet.

Statistical Pass-by – Wayside measurements of a random sample of vehicles. Described in ISO 11819-1.

This section is also optional for NRR reports. Some reports include a list of terms (or small glossary), commonly used acronyms, or personal contacts. If they will fit on one page, two or more sections of this type may be placed on the same page.

Acronyms

The following acronyms are used in this report.

AC – Asphalt Concrete

AR – Asphalt Rubber

ARFC – Asphalt Rubber Friction Course

dB – Decibel

dB(A) – A-weighted Decibel

CPB – Controlled Pass-by

CPX – Close Proximity Method

CTIM – Continuous-flow traffic time-integrated method

DGAC – Dense-Graded Asphalt Concrete

EFR – Effective Flow Resistivity

FHWA – Federal Highway Administration

HMA – Hot Mix Asphalt

LCCA – Life Cycle Cost Analysis

NGSC – Next Generation Concrete Surface

OBSI – On-board Sound Intensity

OGFC – Open-Graded Friction Course

OGAC – Open-Graded Asphalt Concrete

PCC – Portland Cement Concrete

PFC – Porous Friction Course (AKA OGFC)

PFC – Porous Friction Course

QP – Quieter Pavement

RAC – Rubberized Asphalt Concrete

REMELs – Reference Energy Mean Emission Levels

SMA – Stone Mastic Asphalt

SPB – Statistical Pass-by

TNM – Federal Highway Administration’s Traffic Noise Model

Introduction

Sohaney (2013) published a “Quieter Pavements Guidance Document” for the National Park Service in June of 2013. Since then several reports, articles and presentations have been made public. This document provides updates to the “Quieter Pavements Guidance Document”, both in a summary of recent findings and an annotated bibliography.

Performance Trends

No significantly new quieter pavement materials have been introduced in the last five years and acoustic performance is generally the same. Specific pavement types do continue to be added to the publicly available documentation, but these “fill in the middle” of the performance spectrum. For example, see Lodico (2018). One pavement that now has data available, when before it did not, is Chip Seal. In 2018, Caltrans published some of their own results (Lodico, 2018)—their results show a wide range of performance (see Figure 1). Chip seal pavements are also currently being evaluated in Death Valley (Hastings et al., 2017) in a multi-year study funded by NPS. The data being collected in Death Valley over the next several years will help to understand this variation. Specifically, the Death Valley collection and analysis is looking closely at aggregate size, changes in texture over time, Effective Flow Resistivity (EFR) and pavement age.

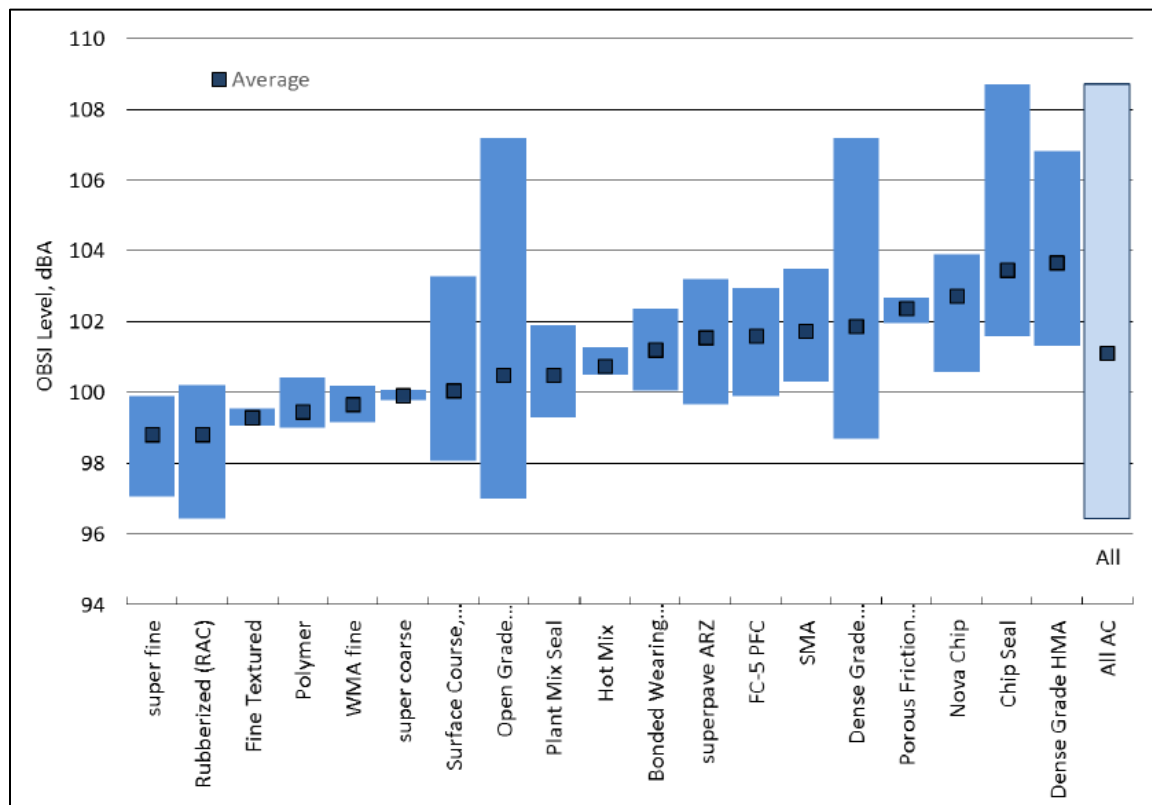


Figure 1. A-weighted On-board Sound Intensity Levels for California AC Categories (from Lodico, 2018, Page 6.2-2) – Flexible Pavements.

Generally the most effective pavements used to reduce noise have smooth textures and/or are porous and are flexible. For flexible (asphalt) pavements, effective types include: Rubberized Asphalt Concrete (RAC), Open-Graded Asphalt Concrete (OGAC) and fine aggregate Asphalt Concretes (ACs). For rigid (concrete) pavements, effective types used to reduce noise include: ground and drag texture Portland Cement Concrete (PCC). Ranges for the overall On-board Sound Intensity (OBSI) for a set of pavements measured in California are shown in Figure 1 for flexible pavements and in

Figure 2 for rigid pavements. These data were manually extracted from the figures and are presented in Table 1 and Table 2. OBSI measurements involve measuring the acoustic intensity of a vehicle near the tire-pavement interface as the vehicle is driving over the pavement at typical travel speeds. The value reported is an A-weighted intensity level (dBA) whose average time depends on the speed and distance of the roadway surface being measured, but is on the order of a few seconds. OBSI measurements generally correlate with wayside measurements but the exact relationship between the two is sufficiently complex that there is currently no direct method of converting from one measure to the other. The usefulness of OBSI measurements is to obtain an indication of the relative loudness or quietness of a pavement using a short, repeatable measurement.

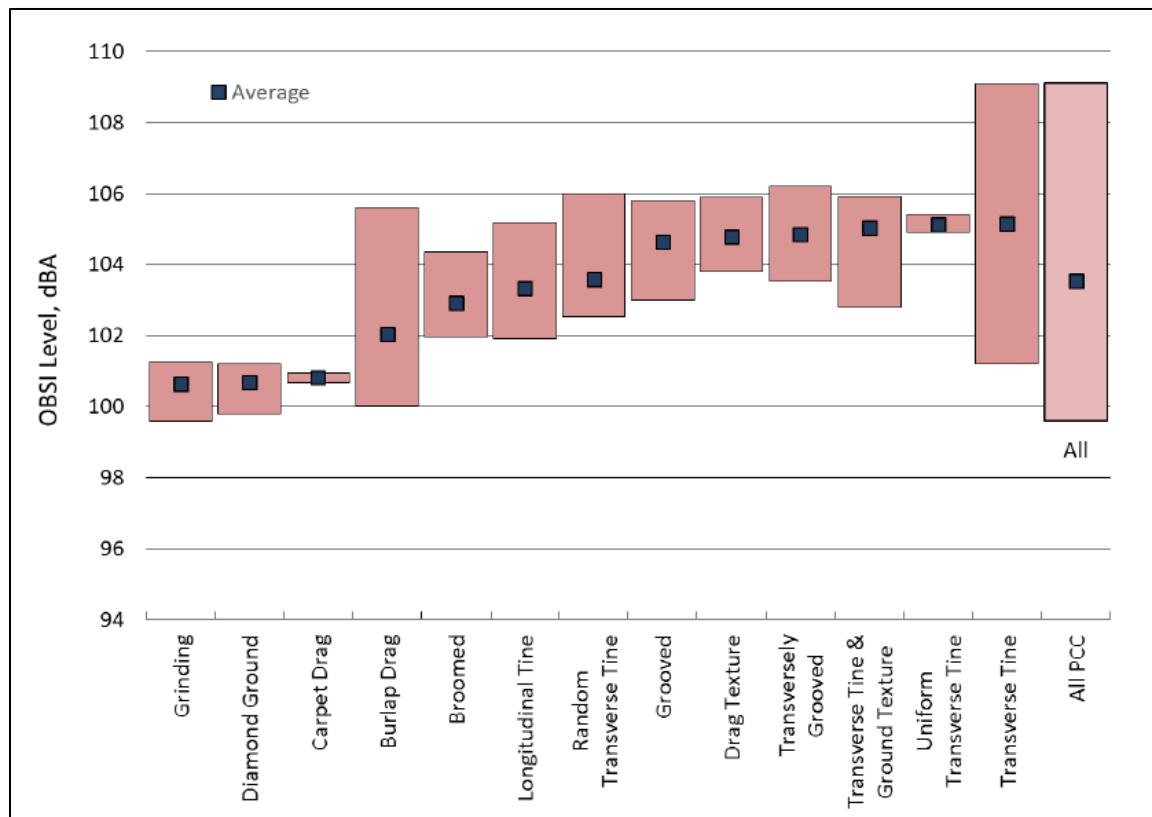


Figure 2. A-weighted On-board Sound Intensity Levels for California PCC Categories (from Lodico, 2018, Page 6.3-2) – Rigid Pavements.

Table 1. A-weighted On-board Sound Intensity Levels for California AC Categories (from Lodico, 2018, Page 6.2-2) – Flexible Pavements.

Asphalt Concrete Category	Average	Max	Min
Super Fine	98.8	99.9	97.0
Rubberized (RAC)	98.8	100.2	96.4
Fine Textured	99.3	99.6	99.1
Polymer	99.4	100.4	99.0
WMA fine	99.7	100.2	99.2
super coarse	99.9	100.1	99.8
Surface coarse	100.0	103.3	98.0
Open Grade	100.5	107.2	97.0
Plant Mix Seal	100.5	101.9	99.3
Hot Mix	100.7	101.3	100.5
Bonded Wearing	101.2	102.4	100.0
Superpave ARZ	101.5	103.2	99.7
FC-5 PFC	101.6	103.0	99.9
SMA	101.7	103.5	100.3
Dense Grade	102.4	107.2	98.7
Porous Friction	102.7	102.7	101.9
Nova Chip	103.5	103.9	100.6
Chip Seal	103.7	108.7	101.6
Dense Grade HMA	101.1	106.8	101.3
All AC	101.9	108.8	96.4

Table 2. A-weighted On-board Sound Intensity Levels for California PCC Categories (from Lodico, 2018, Page 6.3-2) – Rigid Pavements.

PCC Category	Average	Max	Min
Grinding	100.66	101.25	99.58
Diamond Ground	100.71	101.25	99.78
Carpet Drag	100.84	100.93	100.73
Burlap Drag	102.03	105.64	100.03
Broomed	102.93	104.40	101.97
Longitudinal Tine	103.34	105.16	101.92
Random Transverse Tine	103.59	106.02	102.53
Grooved	104.62	105.77	102.98
Drag Texture	104.78	105.91	103.83
Transversely Grooved	104.87	106.27	103.56
Transverse Tine & Ground Texture	105.03	105.93	102.82
Uniform Transverse Tine	105.12	105.46	104.89
Transverse Tine & Ground Texture	105.14	109.13	101.20
All PCC	103.56	109.15	99.58

Performance Over Time

Consistent with previous literature, recent sources also indicate that the noise reduction performance of quieter pavements typically declines over time, but the time for a quieter pavement to become comparable to a standard pavement depends on pavement types and climate. For example, OGAC applied in Washington State had levels that started with a noise advantage of 4.1 dB relative to Hot Mix Asphalt (HMA), but declined to only about 1 dB within four years (Table 3). In this case the decline was due largely to harsh weather conditions and the associated wear and tear due to studded and chained tires¹.

Table 3. Average monthly OBSI Levels for Two Open-Graded Friction Courses and a Reference Hot Mix Asphalt (from Anderson, 2013A, Page 16).

Age (months)	Date	OGFC-AR	OGFC-SBS	HMA
0	September 2009	96.8	96.8	100.9
1	October 2009	99.7	99.0	100.1
3	December 2009	99.0	101.0	103.0
4	January 2010	99.8	100.2	101.9
5	February 2010	101.6	102.0	102.7
6	March 2010	99.9	100.2	102.0
7	April 2010	101.0	100.8	102.4
9	June 2010	100.5	100.5	102.3
10	July 2010	99.0	100.1	102.4
11	August 2010	99.0	99.0	100.5
12	September 2010	100.1	100.3	102.3
14	November 2010	101.2	101.3	103.0
15	December 2010	100.7	100.8	102.8
17	February 2011	103.5	103.4	104.1
18	March 2011	103.3	102.6	104.1
19	April 2011	103.8	103.2	104.7
20	May 2011	103.5	102.6	103.8
22	July 2011	103.3	102.4	104.8
23	August 2011	103.6	102.8	105.2
25	October 2011	104.6	103.4	105.3
27	December 2011	105.8	104.6	106.2
29	February 2012	105.6	104.7	106.3
31	April 2012	104.7	103.9	105.7

¹ It should also be noted that for this application, the quieter pavement offered little improvement in the winter season.

Table 3 (continued). Average monthly OBSI Levels for Two Open-Graded Friction Courses and a Reference Hot Mix Asphalt (from Anderson, 2013A, Page 16).

Age (months)	Date	OGFC-AR	OGFC-SBS	HMA
32	May 2012	104.9	104.4	105.6
34	July 2012	104.2	103.5	104.9
35	August 2012	104.4	103.9	105.2
36	September 2012	104.4	103.5	105.2
39	December 2012	105.1	104.5	105.3
41	February 2013	105.0	105.0	105.8
43	April 2013	104.5	104.0	105.1
44	May 2013	104.6	104.0	105.3

On the other hand, Lodico et al (2018, 6.2-3) indicated that California had an OGAC that was still approximately 5 dB quieter than its Dense-Graded Asphalt Concrete (DGAC) reference after 10 years and had only increased by about 1.5 dB (it was originally about 6 to 7 dB quieter). The performance of this pavement is shown in Figure 3 over a sixteen year period. Looking at the spectra in this figure, one caveat is apparent. Because the noise of quieter pavements peaks at a slightly lower frequency, it is reasonable to expect that the performance difference between the two pavements may be less at far distances where the low frequencies begin to dominate. This transition can be modeled using a modified version of Federal Highway Administration's (FHWA's) Traffic Noise Model (TNM) 2.5 that can account for differences in measured OBSI (Donavan, 2013a; INCE, 2014); however, this modified tool is not publicly available and is currently only used in a research context. It should also be noted that, at the time of its development, TNM 2.5 was the best version available, but at the time of this writing, TNM 3.0 offers better acoustics. Therefore, if additional analysis of the quieter pavement's transition were to be evaluated, it would be better to first modify TNM 3.0 acoustics to handle the OBSI offsets.

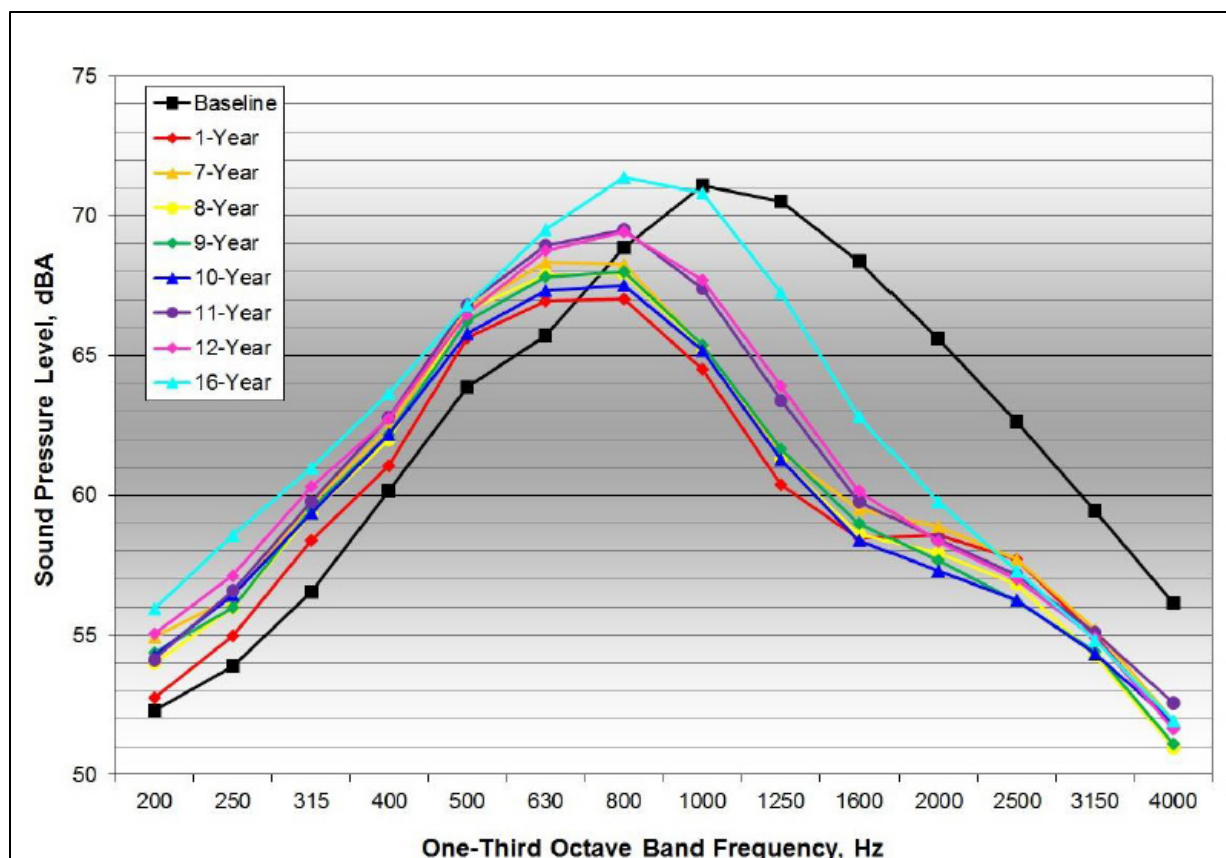


Figure 3. OGAC OBSI Spectra over a Sixteen Year Period for one Site in California (from Lodico, 2018, Page 6.2-5).

Pavement Maintenance

Various physical degradations can affect quieter pavement performance. These include rutting, raveling, cracking, etc. Most of these degradations also have noticeable effect on drive quality and require adding patches, wearing courses or replacing the pavement altogether. Clogging is a degradation that affects the performance of porous quieter pavements and can be fixed without having to add new asphalt. This maintenance helps to restore both water drainage and noise performance. In a report to San Diego Count Facilities, Cahill (2013, Page 6) provided the following recommendations for maintaining porous pavement to maximize the duration of noise benefits of porous pavements:

- Prevent Clogging of Pavement Surface with Sediment
 - Vacuum pavement twice per year
 - Maintain planted areas adjacent to pavement
 - Immediately clean any soil deposited on pavement
 - Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface
 - Clean inlets draining to the subsurface bed twice per year
- Snow/Ice Removal
 - Porous pavement systems generally perform better and require less treatment than standard pavements
 - Do not apply abrasives such as sand or cinders on or adjacent to porous pavement
 - Snow plowing is fine but should be done carefully (i.e. set the blade slightly higher than usual)
 - Salt application is acceptable, although more environmentally-benign deicers are more environmentally preferable
- Repairs
 - Surface should never be seal-coated
 - Inspect for pavement rutting/raveling on an annual basis (some minor ruts may occur in the porous pavement from stationary wheel rotation)
 - Damaged areas less than 50 square feet can be patched with porous or standard asphalt
 - Larger areas should be patched with an approved porous asphalt

Cost/Benefit Analysis

NCHRP report 738 (Donavan, 2013A) developed a methodology for accounting for the financial costs and noise benefits of quieter pavements and comparing those to the financial costs and noise benefits of using barriers to reduce noise at prescribed locations. The methodology considered the lifetime cost of pavement for various options including quieter pavements, barrier costs and user costs (e.g. time lost due to construction). These are combined with estimated noise levels and number of impacts. The tabulated data can then be compared and the best options weighing total cost and total benefit can be made. For example the cost of using a quieter pavement, which would include the lifetime cost of the pavement and the cost associated with time lost due to construction could be compared with the number of people who received a 6 dB reduction in noise. This would provide the cost/benefit ratio for a quieter pavement alternative. A second cost could be computed accounting for the lifetime cost of a standard pavement and the lifetime cost of a barrier plus the cost associated with time lost due to construction. This could then be compared with the number of people who received a 6 dB reduction in noise. This would provide the cost/benefit ratio for a standard pavement and barrier alternative. By comparing these to ratios, the better option based on cost and people benefited could be determined.

In order to do this cost/benefit analysis, the lifetime cost of pavement was determined by using Life Cycle Cost Analysis (LCCA), which included the initial construction cost, maintenance (e.g. milling, patching, adding new friction courses, seal coats, etc.) and the final salvage value at the end of the pavement's life. A sample analysis is shown in Figure 4 from Donovan (2013A, page 18). The cost of barriers was estimated by the initial cost and the cost for graffiti removal and repair of damaged barriers. The user cost was computed by considering the time for the initial construction, applying friction courses and other maintenance.

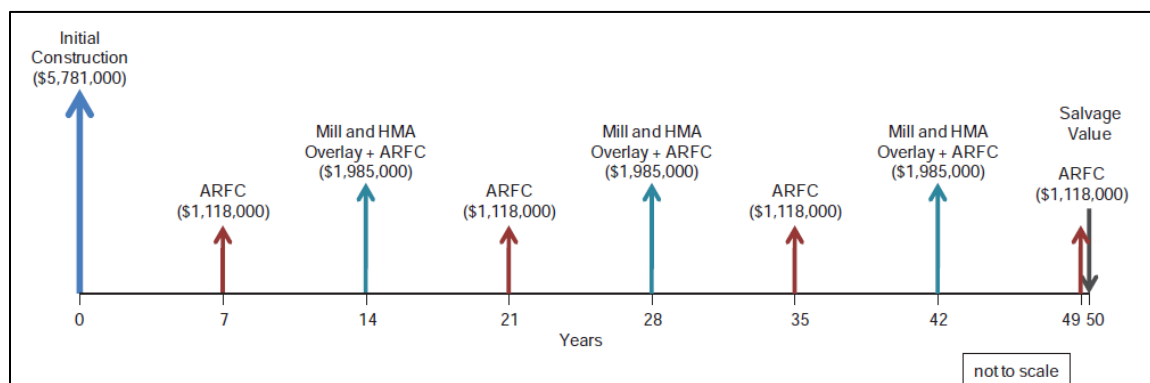


Figure 4. LLCA for HMA Pavement using an ARFC Overlay for Noise Reduction (from Donovan, 2013A, Page 18).

The noise benefits were determined by computing noise levels at various receptor locations for representative years in the lifecycle. This was done using the modified version of TNM mentioned previously to adjust TNM results to account for differences in measured OBSI values for the pavements considered. By obtaining OBSI values for each year of a pavement's life (up to the point

where a new friction course was applied), the yearly levels could be computed and compared to policy to determine impacts.

NCHRP report 738 provides an example of the analysis associated with this cost/benefit analysis approach. Figure 5 provides an example noise analysis that can be used to determine the expected noise benefits of two different pavements, Longitudinally Tined PCC (with a Barrier) and Asphalt Rubberized Friction Course (ARFC). Note that, for this case, while both candidate pavements were quieter than “TNM – Average pavement,” the PCC with Barrier had better levels and longer time between maintenance cycles; however, the ARFC was approximately 20% cheaper over the entire life-span of the pavement as shown by Table 4.

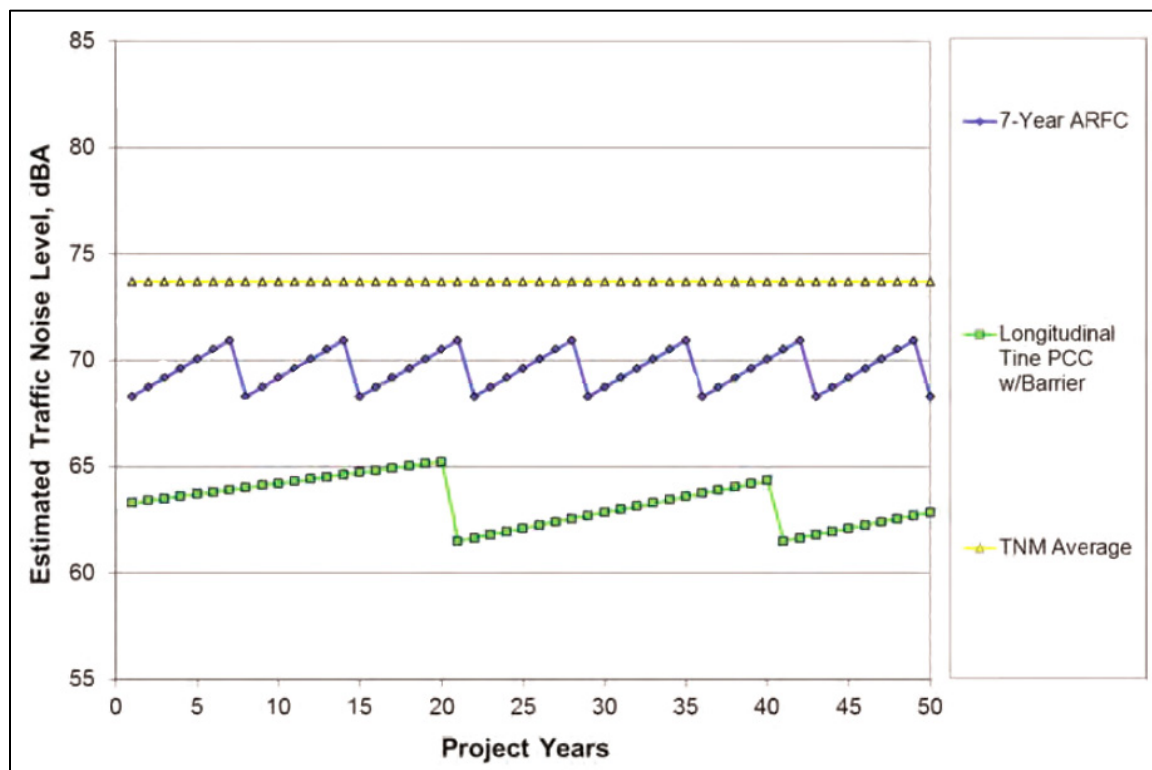


Figure 5. TNM-Predicted Traffic Noise Levels at 100 Feet (from Donovan, 2013A, Page 19).

Table 4. Summary of Deterministic LCCA Results for the Primary HMA and PCC Alternatives (Donavan, 2013A – Table 4).

Total Cost	Alternative 1: HMA overlay cycle (7- year overlay cycle) Agency Cost (\$000)	Alternative 1: HMA overlay cycle (7- year overlay cycle) User Cost (\$000)	Alternative 2: PCC (with barriers) Agency Cost (\$000)	2: PCC barriers) User Cost (\$000)
Undiscounted sum	\$15,249.71	\$66.34	\$14,334.00	\$31.47
Salvage value	\$958.29	\$9.53	\$0.00	\$0.00
Present value	\$9,623.79	\$24.81	\$11,846.04	\$9.88
Equivalent uniform annual cost	\$447.99	\$1.15	\$551.44	\$0.46

Considering several example cases, the NCHRP report 738 concluded the following with regards to costs and benefits of quieter pavements and noise barriers for road noise mitigation (Donavan, 2013A – Page 58):

- *A design goal criterion of 7 dB is generally not achievable with current quieter pavements alone except in extreme cases where a much quieter pavement is compared to a noisier pavement [e.g., an RAC(O) or ground PCC surface is compared to a transversely tined PCC surface].*
- *Quieter pavement alternatives can be both feasible and cost reasonable in some situations (even under current state agency criteria).*
- *Maintaining the acoustic performance of quieter pavements can result in a significant increase in life-cycle cost.*
- *In some situations where a barrier alone would not meet criteria, feasible and reasonable noise abatement alternatives can be obtained by combining quieter pavement with a barrier.*
- *Feasible and reasonable alternatives can be developed using pavements and barriers in combination, in some cases achieving comparable effectiveness.*
- *In some situations, a more effective and lower cost alternative can be obtained by combining quieter pavement with shorter barrier heights.*
- *In some instances, barriers do not meet criteria because of low receptor density or geometric factors, but the quieter pavement would provide noise-level reduction of 3 to 4 dB to impacted receptors at low enough cost.*
- *In cases where there are impacted receptors on both sides of a highway, it may be appropriate to evaluate them together when quieter pavement or combinations of barriers and pavement are considered.*

The most relevant conclusions from this report can be paraphrased as, quieter pavements can provide noise benefits, but levels greater than 7 dB are generally not achievable without combining mitigation strategies. For example obtaining a 10 dB reduction may be achievable by combining quieter pavements with a small berm.

Predicting OBSI

On-board sound intensity (OBSI) is a measure of the tire/pavement noise generated at the source. The standard test method is described in AASHTO TP76-10. In this method two intensity probes are placed three-inches from the tire/pavement interface. Each intensity probe consists of a phase-matched pair of microphones. These probes are positioned at the leading or trailing edges of the tire/pavement interface (see Figure 6). In this way the tire/pavement generated noise is measured as sound intensity at the two locations. The OBSI measurement method is not significantly affected by sounds outside the vicinity of the pavement/tire interface. Therefore, measurement accuracy is unaffected by the presence of other vehicles and natural or other anthropogenic sounds. In addition, a standard reference test tire is used to minimize any differences in the tire ‘source’ from location to location and year to year. Because this measurement technique focuses on the tire/pavement interface, it is very effective at identifying differences in noise level due to pavement differences, but does not account for engine noise or the effects of sound propagation from the source to the receiver.



Figure 6. Example of OBSI microphone array mounted on a passenger car (VOLPE CENTER).

OBSI data are almost always measured; however, efforts are being made to develop methods to **predict** OBSI data (and other direct measures of noise related to tire-pavement interaction). Although promising, the correlation between predicted and measured OBSI data are not yet at a point where it would be reasonable to replace measurements with predictions.

Here we describe how researchers are trying to improve predictions of OBSI. A report to the Minnesota Department of Transportation by McDaniel (2014) reviewed a number of these models. In general, these models are statistically based and take as input pavement and sometimes tire

properties. A listing of models, input properties and output properties are given in Table 5, Table 6, and Table 7 respectively. Note, only one of these models, Reyes and Harvey, produces one-third octave data, which is essential for meaningful predictions of noise at locations other than at the source.

Table 5. Comparison of Pavement Texture Property Inputs for Tire-Pavement Noise Models (from McDaniel, 2014, Page 24).

Tire-pavement Noise Model (Name or Authors)	Mean Profile Depth (MPD)	Asperity height unevenness	International roughness index (IRI)	2-D texture profile	3-D texture profile	Surface rating (SR)	Raveling	Transverse cracking
Khazanovich and Izevbekhai	–	–	X	–	–	X	–	–
Ongel, Kohler, and Harvey	X	–	X	–	–	–	X	X
Rasmussen	–	–	–	–	X	–	–	–
Reyes and Harvey	X	–	–	–	–	–	–	–
Brinkmeier	–	–	–	–	X	–	–	–
Fujikawa	X	X	–	–	–	–	–	–
SPERoN	–	–	–	–	X	–	–	–
HyRoNE	–	–	–	X	–	–	–	–

Table 6. Comparison of Other Pavement Property Inputs for Tire-Pavement Noise Models (from McDaniel, 2014, Page 24).

Tire-pavement Noise Model (Name or Authors)	Equivalent single axle loads (ESALs)	Age	Mix type	Surface layer thickness	Air void content (V_A)	Fineness modulus	Uniformity	Flow resistivity
Khazanovich and Izevbekhai	X	X	–	–	–	–	–	–
Ongel, Kohler, and Harvey	–	X	X	X	X	X	X	–
Reyes and Harvey	–	–	–	–	–	–	–	X
SPERoN	–	–	–	–	–	–	–	X
HyRoNE	–	–	X	–	–	–	–	–

Table 7. Comparison of Outputs for Tire-Pavement Noise Models (from McDaniel, 2014, Page 24).

Tire-pavement Noise Model (Name or Authors)	Overall OBSI Level	1/3 rd octave band OBSI level	Overall nearfield pressure	1/3 rd octave band coast- by levels	1/3 rd octave band CPB levels
Khazanovich and Izevbekhai	X	–	–	–	–
Ongel, Kohler, and Harvey	X	–	–	–	–
Rasmussen	X	–	–	–	–
Reyes and Harvey	X	X	–	–	–
Brinkmeier	–	–	X	–	–
Fujikawa	–	–	X	–	–
SPERoN	–	–	–	X	–
HyRoNE	–	–	–	–	X

Although promising, the correlation between predicted and measured OBSI data are not yet at a point where it would be reasonable to replace measurements with predictions (see for example Figure 7). However, the approach does provide insight into how various parameters affect tire-pavement noise and could one day serve as a surrogate for OBSI measurements.

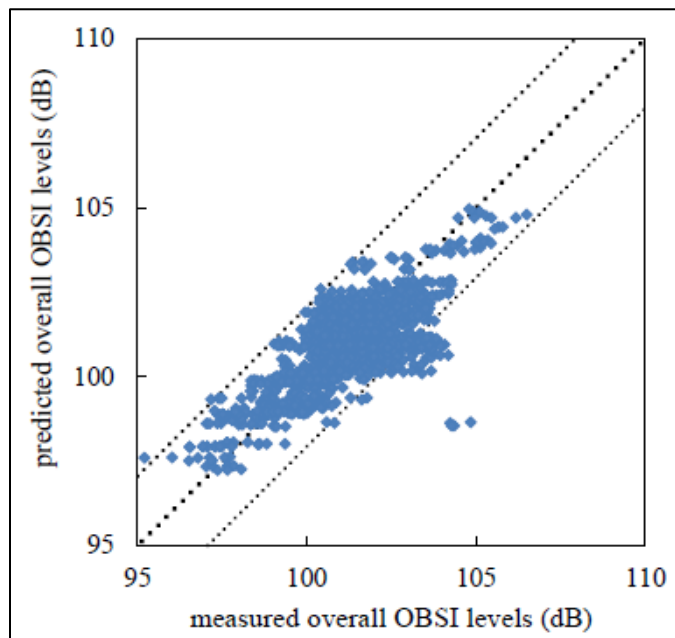


Figure 7. Measured and Predicted Overall OBSI Levels, Leading Edge, RoboTex Data, (from McDaniel, 2014, Page 63).

Summary of Findings in Literature from 2013 to 2018

- No significantly new quieter pavement materials have been introduced in the last five years.
- Acoustic performance of existing quieter pavement materials has not significantly improved.
- Different pavement types and their acoustic performance continue to be added to the publicly available documentation, but these fall within the existing acoustic performance range.
- In the next several years, we will know more about acoustic performance of chip seal pavements with the results that are published from the NSNSD Quieter Pavement Project in Death Valley National Park (Hastings et al, 2017, 2020A and 2020B).
- The “most effective” quieter pavement types typically reduce noise by 3–5 dB when compared to traditional DGAC types.
- The pavement types that are most effective at reducing noise are:
 - Flexible (asphalt) pavements:
 - Rubberized Asphalt Concrete (RAC)
 - Open-Graded Asphalt Concrete (OGAC)
 - Fine aggregate Asphalt Concretes (ACs)
 - Rigid (concrete) pavements:
 - Ground and drag texture Portland Cement Concrete (PCC)
- See Table 1 and 2 for specific noise measurements of reported pavement type data.
- Pavement Performance: The noise reduction performance of quieter pavements typically declines over time, but the time for a quieter pavement to become comparable to a standard pavement depends on pavement types and climate. See section “Performance Over Time” for specifics.
- Pavement Maintenance: Various physical degradations can affect quieter pavement performance including rutting, raveling, and cracking.
- Cost/Benefit: quieter pavements alone can provide noise benefits, but levels greater than 7 dB are generally not achievable without combining mitigation strategies. For example obtaining a 10 dB reduction may be achievable by combining quieter pavements with a small berm.
- Modeled vs. Measured OBSI: The correlation between predicted and measured OBSI data are not yet at a point where it would be reasonable to replace measurements with predictions.
- Quieter pavements can be more beneficial than adding absorption to parallel barriers.

Recommended Reading

While all references (except possibly Shirke, 2013) in the annotated bibliography provide useful references to the state of the practice of quieter pavements, the following list highlights those with information that is well organized within the context of quieter pavements.

- (Donavan, 2013A) – NCHRP Report 738, Chapter 2: Describes a methodology for cost/benefit analysis.
- (Lodico, 2018) – Quieter Pavement – Acoustic Measurement and Performance, Chapter 6 and 8: Reviews recent noise studies and best practices.
- (Anderson, 2013A) – Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses: Project 3 – Final Report, Pages 13 to 21: Provides a review of OGAC noise performance in a harsh environment.
- (McDaniel, 2014) – Hot Mix Asphalt Surface Characteristics Related to Ride, Texture, Friction, Noise and Durability, Chapter 3: Reviews the process of predicting pavement noise levels based on pavement characteristics.
- (PIARC, 2013) – Quiet Pavement Technologies, Chapter 3: Describes in detail many of the quieter pavement technologies in use.

Annotated Bibliography

(Anderson 2013A)

Title: Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses – Project 3 – Final Report

Format: Research Report

Key Words: OBSI, Open-Graded Friction Course (OGFC), HMA, Longevity, Seasonal Effects, Studded Tires

Key Findings: OGFC was initially between 3.5 and 4.1 dB quieter than HMA. After 44 months, the improvement decreased to 0.6 to 1.2 dB. (Ed. All longevity results must consider that pavements were exposed to studded tires.)

(Anderson 2013B)

Title: Concrete Pavement Noise

Format: Research Report

Key Words: Diamond Grind, Carpet Drag, Longitudinal Tined, Texture, Transverse Tined, Next Generation Concrete Surface, OBSI, Studded Tires

Key Findings: Studded tires increase noise levels from concrete pavements on Washington highways. Levels tend toward 104 to 108 dB(A) with age. (Ed. Initial measurements were not made at the same point in the pavement lifecycle, so it is difficult to make comparisons for new pavements in this study.)

(Cahill 2013)

Title: Porous Pavement Operation and Maintenance Protocol

Format: Guidance Report

Key Words: Porous Pavement, Maintenance

Key Findings: Water-shedding functionality can be maintained for twenty years with maintenance

(Caltrans 2013)

Title: Technical Noise Supplement to the Traffic Noise Analysis Protocol

Format: Guidance/Synthesis Report

Key Words: OGAC, DGAC, PCC

Key Findings: In good conditions (no snow or freeze/thaw) OGAC maintains at least a 4 to 5 dB advantage to DGAC over a 13 year lifespan (Page 7–14)

(Donavan 2013A)

Title: Evaluating Pavement Strategies and Barriers for Noise Mitigation

Format: Research Report

Key Words: OBSI, Reference Energy Mean Emission Levels (REMELs), LCCA, TNM, Barriers

Key Findings: Presents a methodology to evaluate quieter pavement benefits over pavement life cycle: OBSI data accounts for pavement effect, Modify TNM to account for different new pavements, LCCA to compare costs of mitigation strategies, e.g. barriers and/or quieter pavements. (Other findings for specific example cases on page 58.)

(Donavan 2013B)

Title: Influence of Quieter Pavement and Absorptive Barriers on US-101 in Marin County, California

Format: Journal Article

Key Words: OBSI, Wayside Measurements, Barriers

Key Findings: Case study looking at effects of using quieter pavement and adding absorption to parallel barriers. Quieter pavements were more beneficial than adding absorption to barriers.

(INCE 2014)

Title: Cost-Benefit Analysis: Noise Barriers and Quieter Pavements – Final Report

Format: Synthesis Report

Key Words: OBSI, TNM, Barriers

Key Findings: Report summarizing presentations and discussions during workshop. Similar to Donovan (2013A). The Methodology Considerations section of the report includes a discussion of the challenges and potential solutions associated with quiet pavement, its costs, benefits and the measurements collected to describe it.

(Lodico 2018)

Title: Quieter Pavement: Acoustic Measurement and Performance

Format: Synthesis Report

Key Words: Best Practices, Low Speed, Interior Noise, PRAC, OBSI, Porous Pavement, Transverse Tining, Longevity, OGAC, DGAC, Continuous-Flow Traffic Time-Integrated Method (CTIM), Source Height, LCCA, HMA, ARFC, Bridge Decks, Pavement Joints

Key Findings: Chapter 1 to 5 similar to (Caltrans 2013). Key parameters include texture, porosity and stiffness. The quietest AC pavements are porous, rubberized, and have fine aggregate. The quietest rigid pavements have ground and drag textures. Pavement joints produce audible impulsive

sound increasing overall level by 1 to 3 dB. Potential noise reduction methods include: narrow joint groove width; fill groove; or add a substance to groove to increase effective flow resistance.

(McDaniel 2014)

Title: Hot Mix Asphalt Surface Characteristics Related to Ride, Texture, Friction, Noise and Durability

Format: Synthesis/Research Report

Key Words: HMA, Temperature Effects, Seasonal Effects, Tire-Pavement Noise Models, OBSI, Statistical Pass-by (SPB), Controlled Pass-by (CPB)

Key Findings: Reviews noise generation mechanisms. Increased temperature causes increases in high frequency noise and decreases in low-frequency noise (page 15). Environmental factors causing asphalt pavement distress include: changing moisture conditions (secondary cause of alligator cracking, bleeding, block cracking, corrugations, depressions, edge cracking, potholes, pumping, raveling, rutting, shoving and swelling/bumps); temperature changes (primary cause of thermal cracks and a contributing factor in the development of alligator cracking, bleeding, block cracking, corrugations, longitudinal cracking in and outside the wheel path, raveling, rutting, shoving and swelling/bumps). Summarizes several models that can be used to predict tire noise sound intensity levels. Tire noise sources: sidewall (500 – 800 Hz), treadband (800–1250 Hz), air pumping and tangential tread block vibrations (>1250 Hz). Culminates in a Tire Noise Model. There was not enough analysis to quantify the quality of the model.

(McGhee 2013)

Title: Virginia Quieter Pavement Demonstration Projects: Initial Functional Assessment

Format: Journal Article

Key Words: Demonstration Project, OGFC, Porous Friction Course (PFC)

Key Findings: Quiet asphalts (two open-graded asphalt concrete mixes using a polymer-modified binder and a third using a similar aggregate gradation but with a rubber-modified binder) were slightly less noisy [2 dB(A) or less] than were asphalt references on average. The Next Generation Concrete Surface (NGCS) was noticeably less noisy than concrete references [5 dB(A)]. (See McGhee 2015 and 2016 for more information.)

(McGhee 2015)

Title: The Virginia Quiet Pavement Demonstration Program

Format: Presentation

Key Words: Demonstration Project, AC, PCC, OGFC, PFC

Key Findings: Quieter Pavement (QP) technologies provide beneficial spray reduction and improved skid resistance in wet weather. For asphalt QPs—Noise reduction levels are not noticeable compared

to control surfaces after 4 winters (< 2dB). For concrete QP—Noise reduction levels are noticeable compared to control after 4 winters (~5dB). None of the technologies provided sufficient noise reductions to singularly meet federal regulations – Minimum of 7dB for single receptor and, minimum of 5dB for at least 50% of receptors.

(McGhee 2016)

Title: Virginia Quieter Pavement Demonstration Program

Format: Journal Article

Key Words: Demonstration Project, AC, PCC, OGFC, PFC

Key Findings: PFC materials provide beneficial spray reduction and improved skid resistance. QP materials and finishes exhibit excellent ride quality. PFC materials require special attention and treatment to avoid specific safety hazards during winter weather events. Close monitoring, as well as early and aggressive application of deicing chemicals, is necessary. Material performance for PFC materials is affected by the severity of winter weather and the aggressiveness of the resulting maintenance activities. The northernmost demonstration projects see the most freezing precipitation and heavy plow action, which has contributed to early material failures. For asphalt technologies (PFCs), noise reduction levels are indistinguishable from asphalt control surface after four winters [<2 dB(A)]. For concrete technologies (NGCS), noise reduction levels are noticeable (~4 dB) after four winters.

(PIARC 2013)

Title: Quiet Pavement Technologies

Format: Synthesis Report

Key Words: Tire-Pavement Noise Review, SPB, CPB, OBSI, Close Proximity Method (CPX), Two-Layer Porous Asphalt, Stone Mastic Asphalt (SMA)

Key Findings: This report provides a review of tire-pavement noise and provides detailed discussions of various types of pavements.

(Rezaei 2013)

Title: Investigation of Noise, Ride Quality and Macrottexture Trends for Asphalt Pavement Surfaces: Summary of Six Years of Measurements

Format: Research Report

Key Words: OGAC, RAC-Gap Graded an RAC-Open Graded, Longevity

Key Findings: OGAC, RAC-Gap Graded an RAC-Open Graded where quieter than DGAC by 0.1 (This seems small, Ed.), 1.0, and 1.9 dB at year 0. The main advantage of OGAC is that it reduces high frequency noise. RAC-Open Graded had the longest lasting noise benefit.

(Rochat 2013)

Title: Investigations of the Effects of Porous Pavement on Traffic Noise and Traffic Noise Prediction

Format: Journal Article

Key Words: EFR, TNM

Key Findings: Sound absorption produced by porous pavements will have a noise-reducing effect on both measured and predicted traffic noise levels.

(Shirke 2013)

Title: A Solution to Clogging of Porous Pavements

Format: Journal Article

Key Words: Porous Pavement, Maintenance, Reverse Water Flushing

Key Findings: Article proposes a new method of unclogging porous pavements, whereby, instead of washing and or vacuuming, water is forced through the pavement from the “bottom up”. The research found that this method was effective. (Ed. It is not clear from the article that there is any performance benefit from this method over traditional methods, nor is it clear how this could be practically implemented.)

(VDOT 2015)

Title: Virginia Quiet Pavement Implementation Program under Section 33.2-276 of the Code of Virginia – Final Report

Format: Research Report

Key Words: Demonstration Project, AC, PCC, OGFC, PFC

Key Findings: see (McGhee 2016)

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525