Using Tire/Pavement Interface Noise Results to Define Statistically Similar Bituminous Pavements in Massachusetts

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ABSTRACT

In October 2010, the Center for Advanced Infrastructure and Transportation (CAIT) utilized the On-Board Sound Intensity Method in Massachusetts to evaluate seven Open-Graded Friction Courses (OGFC) and eight Asphalt Rubber Gap Graded (ARGG) pavements for MassDOT. Since major concerns regarding pavement selection in the northeast revolve around winter conditions and winter maintenance, if noise level similarities could be found between ARGG and OGFC pavements, pavement engineers would be able to specify more appropriate mixes to satisfy both noise concerns and maintenance concerns in their area.

The authors conducted a statistical analysis using student's t-test to compare overall noise levels on a matrix to determine which pavements were statistically similar, with a 95% confidence interval or greater. The purpose was to create a method to evaluate pavements side by side quickly to determine if there were any ARGGs that exhibited similar overall noise levels as the current OGFCs, not to complete a thorough noise evaluation. This type of analysis was sufficient to allow pavement engineers from MassDOT to alternatively choose ARGGs that could withstand intensive winter maintenance while retaining similar acoustic benefits observed in some of the OGFCs currently in place.

1. INTRODUCTION

The main focus of the Massachusetts study was to evaluate noise levels that resulted from twenty pavements throughout the eastern portion of the state using the On-Board Sound Intensity Method (OBSI). The pavements varied in age over a span of eight years and encompassed several different mix types, including ARGG and OGFC pavements. The secondary goal was to compare the tire/pavement interface noise differences between pavements and the effects due to mix type, mix design, and aging. The information gathered throughout the study was provided to MassDOT in the form of a standard report according to AASHTO TP 76-09 [1]. Due to intensive winter maintenance experienced in the northeast states, the lifespan of open graded pavements has been reduced [2,3]. MassDOT was interested in determining if there were any noise similarities between gap-graded mixes, which better withstand winter maintenance, and the in-place open graded mixes. MassDOT's focus for this project was to ascertain whether any other pavement types, specifically those that can withstand intense winter maintenance, also exhibit similar noise as those pavements typically associated with "quiet" pavements. To accurately determine whether any similarities existed between the different pavements in Massachusetts, the authors conducted a statistical analysis to evaluate the similarity of the overall noise levels recorded on each pavement with a 95% confidence interval. The purpose was to evaluate pavements side by side quickly to determine if any ARGGs exhibited similar overall noise levels as the in-place OGFCs, not to complete a thorough noise evaluation.

The project encompassed twenty different pavement surfaces which were located throughout eastern Massachusetts. The measurements were recorded between October 25, 2010 and October 29, 2010. Each pavement section was roughly two miles long, which helped the authors to choose appropriate testing sections according to AASHTO TP 76-09 specifications.

On I-295 near the Rhode Island-Massachusetts border, four different materials were tested: an Asphalt Rubber Gap Graded placed in 2008 (ARGG 2008), Asphalt Rubber Gap Graded with Advera warm mix additive placed in 2008 (ARGG w/Advera WM 2008), Novachip placed in 2008, and a Novachip with asphalt rubber placed in 2008 (Novachip w/AR 2008). On I-95 near Attleboro, MA two different contractors had placed similar ARGG mixtures in 2009. Both mixes were evaluated to see the variation in the noise characteristics between the contractors. On I-95 near Amesbury, MA, two pavements that were each paved one year apart, one OGFC placed in 2003 and the other an OGFC placed in 2002 were tested. I-495, where two different materials had been placed in 2009 between exits 21-23, provided an opportunity to examine an ARGG and an OGFC with similar environmental exposures. Near Littleton, MA on I-495 a two year old OGFC section, an ARGG laid in 2010, and a 9.5mm Superpave + 2% Latex mix laid in 2010 were tested. Rt. 2 provided a standard 19mm Superpave dense graded asphalt near Littleton, MA. Finally, on I-290 near Northborough, MA an OGFC laid in 2006 was tested. In conjunction with standard Superpave nomenclature the maximum nominal aggregate size for the Superpave mixes are noted for each, but gradations for each of the mixes utilized in this paper were unavailable. The Novachip, OGFC, and ARGG mixes refer to specialized functional overlays which are designed using many of the parameters encompassed in Superpave such as the binder grade and aggregate requirements, but are not typical dense graded mixes. The functional mixes as well as the Superpave mixes were subjected to approval by MassDOT prior to paving and were required to fulfill structural testing prior to paving.

2. TESTING PROCEDURES

The testing was conducted in the right wheel path of the right lane, at 96.5 ± 1.6 Km/h (60 mph ± 1mph). Any factor that could change the noise quality of each test (e.g. a large truck passing by, a sound wall, an overpass etc.) was documented throughout the testing. The equipment utilized to measure the tire/pavement noise on the outside of the vehicle is shown in Figure 1.

Figure 1 - Sound intensity testing apparatus

The equipment utilized to operate the OBSI equipment inside the car is shown in Figure 2, which met the guidelines of AASHTO TP 76-09 [1].

Figure 2 – Test setup from the inside of the vehicle

Coherence and the PI spectrum were monitored throughout each test to ensure the validity of each measurement. The PI spectrum is an index utilized to monitor the measured sound intensity for a given intensity probe. By evaluating the difference between the average sound pressure levels of both microphones minus the sound intensity level, directionality of the pressure can be monitored. Each probe is set up so that measured sound intensity is positive when the noise is louder at the tire. If an outside force (a sound opposite the tire) creates a pressure differential larger than that created by the tire, the resultant measurement's PI spectrum could be negative or outside the range of the specification, in which case the measurement would be considered invalid. At a minimum of one location along each different pavement material, the ambient air temperature, pavement temperature, tire temperature, wind speed, barometric pressure, and the tire pressure were recorded. The sound intensity levels of the two probes were energy averaged for each run in accordance with the specification [1]. The averages for all runs were then averaged together arithmetically. A minimum of three runs were completed for each section to ensure a valid comparison. Any runs that did not comply with the above listed criteria were discarded.

Test sections were determined on site for each location. Each test section was a standard 134.1 m (440 ft.) test section (5 second measurement at 96.5 Km/h (60 mph) [1]. A good section was considered a contiguous section of pavement with no pavement changes and no bridge decks or joints. Mile marker signs were utilized for section selection as they remained in the same location from run to run and were the easiest to find and distinguish between, throughout all of the runs. If future testing was required, measurements could be taken at the same locations as they were for this study. The minimum number of testing sections per pavement was four but for most materials more were utilized to provide better statistical analysis.

The analysis of the measurements was completed in several separate processes using the following methods. After determining appropriate discrete testing sections along each pavement site and gathering at least three viable measurements for each of the sections, they were averaged together to properly represent the acoustical properties of the pavement holistically. Typically, following the OBSI method, one 134.1 meter (440 foot) test section would be sufficient to complete a material analysis [1]; however the authors suggest that a better pavement characterization can be created by testing multiple discrete sections on a particular pavement and averaging all of the results for that pavement. A table (Table 1) and coinciding bar graph of the overall material average (Figure 3) were compiled for each roadway to show the range of differences between all of the different materials tested. A more detailed description of these materials can be found in the introduction.

Table 1 – Overall Noise Levels

Road	Material	dB(A) Overall	Stdev (1s)
I-495 S	9.5mm Superpave + 2% Latex	100.0	0.4
I-495 N	ARGG 2009	100.5	0.7
I-95 S	ARGG 2009	100.5	0.2
I-95 N	ARGG 2009	100.5	0.2
I-295 N	ARGG 2008	100.8	1.2
I-495 N	ARGG 2010	100.8	0.2
I-95 S	7 year old OGFC	101.2	0.6
I-95 S	Lynch ARGG 2009	101.2	0.2
I-95 N	Lynch ARGG 2009	101.3	0.2
I-495 S	OGFC 2008	101.3	0.7
I-295 N	ARGG w/advera warm mix 2008	101.4	0.3
I-95 N	8 year old OGFC	101.7	0.7
I-495 S	OGFC 2009	101.8	0.4
I-495 N	OGFC 2008	102.0	0.2
I-290 E	OGFC 2006	102.9	1.2
I-290 W	OGFC 2006	102.9	1.2
Rt-2 E	19mm Superpave	103.1	0.6
Rt-2 W	19mm Superpave	103.1	0.6
I-295 S	Novachip w/asphalt rubber 2008	104.5	0.2
I-295 S	Novachip 2008	105.1	0.2

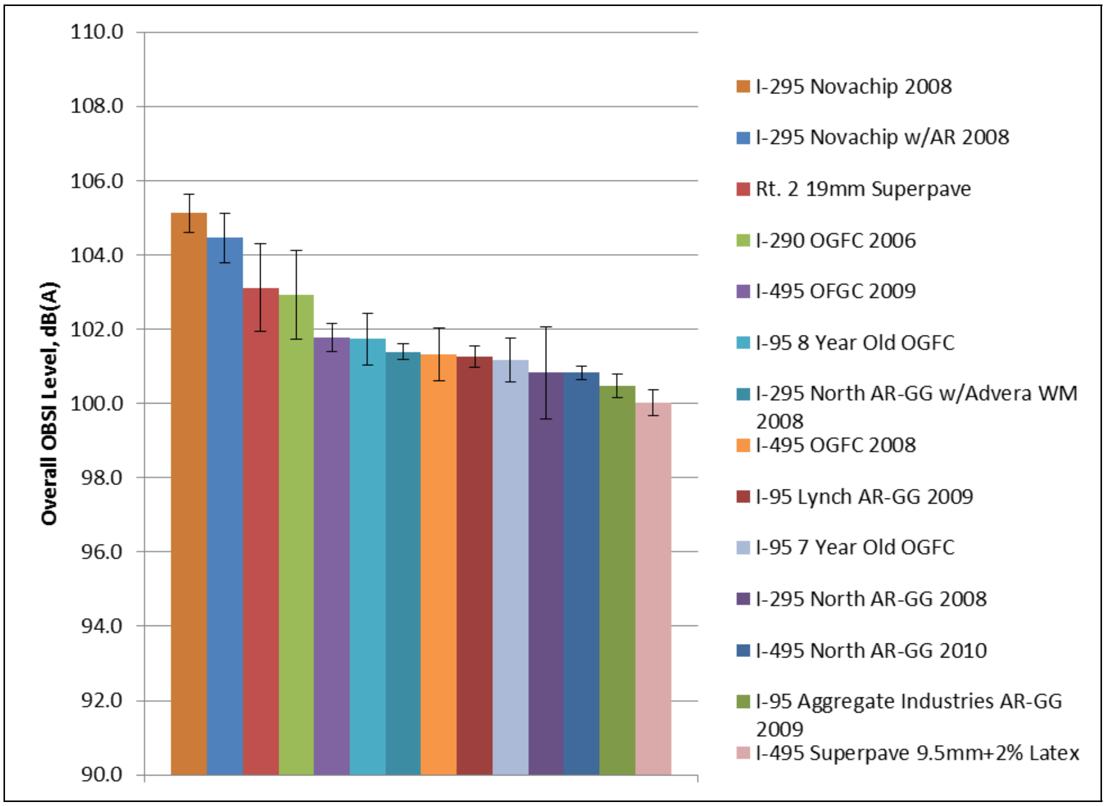

Fig. 3 - Overall levels for the pavements tested in MA reported in A-weighted decibels (dBA)

The benefit of the bar graph is the ability to see the variation of the overall noise levels from the pavements tested. Secondly, one-third octave band frequency spectrum graphs

(Figure 4) were created for each discrete section and then compiled to represent each pavement.

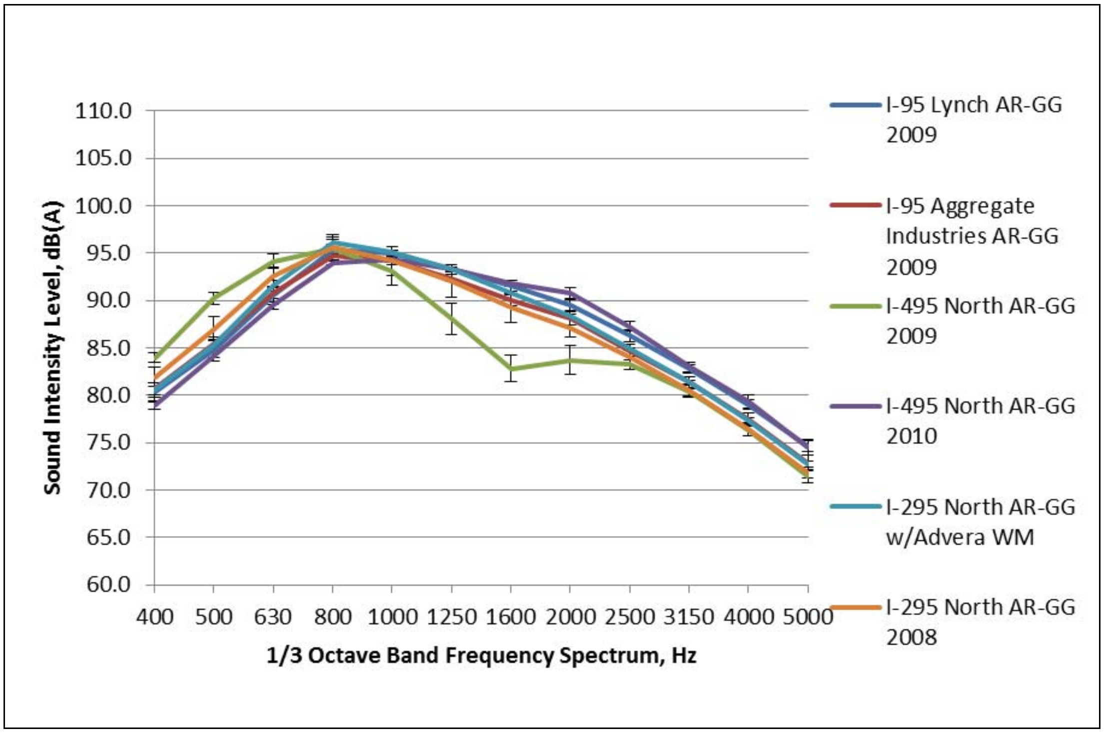

Figure 4 – An example of ARGG Spectrum Comparison for MassDOT

The one-third octave band enables the comparison of unique spectral signatures for different materials while avoiding frequency clutter. Each different spectral signature was then compared to determine differences in the way the tire generated noise would be perceived by a receiver. This allowed for simple comparisons to show that one pavement exhibited similar loudness, but differed at certain frequencies. This is the standard way that the authors compare the results, but it is still vague and focuses on an observational and possibly opinionated comparison. The simple statistics utilized for this paper was a more pragmatic approach.

3. STATISTICAL COMPARISON

The purpose of completing a statistical analysis after providing the standard overall and frequency charts was in the interest of trying to determine if any of the pavement surfaces tested in Massachusetts had statistically the same overall noise levels. If different materials had similar overall noise levels, possibly they could be interchanged for other materials to fulfill design criteria. The variance between each overall level for each material was determined using the f-test for two-sample variance analysis. If the variances were statistically similar, t-tests for two-samples assuming equal variance was completed. If the variances for each material were statistically not similar, t-tests for two-samples assuming unequal variances was completed. A 95% confidence interval was used to determine whether two pavements were significantly similar or not. The resultant data was compiled into a statistical matrix (Figure 5) which easily displayed which materials exhibited statistically similar loudness. Within the matrix, Y values were those materials that showed 95% similarity. These cells were colored green to provide visual aid for the similar pavements found within the matrix. The N values were not found to be statistically similar and as a result were not colored.

	OGFC 2003 I-95 S	OGFC 2002 I-95 N	ARGG 2009 I-95 Lynch S	ARGG 2009 I-95 Lynch N	ARGG 2009 I-95 Aggregate Industries S	ARGG 2009 I-95 Aggregate Industries N	Novachip w/AR 2008 I-295 S	ARGG 2008 I-295 N	Novachip 2008 I-295 S	ARGG 2008 I-295 N w/advera WM	OGFC 2006 I-290 W	OGFC 2006 I-290 E	19mm DGA Rt. 2 W	19mm DGA Rt. 2 E	ARGG 2010 I-495 N	9.5mm DGA I-495 S	ARGG-2009 I-495 N	OGFC 2009 I-495 S	OGFC 2008 I-495 N	OGFC 2008 I-495 S
OGFC 2003 I-95 S		N	N	N	Y	Y	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N
OGFC 2002 I-95 N			N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	Y	N
ARGG 2009 I-95 Lynch S				Y	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
ARGG 2009 I-95 Lynch N					N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
ARGG 2009 I-95 Aggregate Industries S						Y	N	N	N	N	N	N	N	N	N	N	N	Y	N	Y
ARGG 2009 I-95 Aggregate Industries N							N	N	N	N	N	N	N	N	N	N	N	Y	N	Y
Novachip w/AR 2008 I-295 S								N	N	N	N	N	N	N	N	N	N	N	N	N
ARGG 2008 I-295 N									N	N	N	N	N	N	Y	N	N	N	N	Y
Novachip 2008 I-295 S										N	N	N	N	N	N	N	N	N	N	N
ARGG 2008 I-295 N w/advera WM											N	N	N	N	N	N	N	N	N	N
OGFC 2006 I-290 W												N	N	N	N	N	N	N	N	N
OGFC 2006 I-290 E													N	N	N	N	N	N	Y	N
19mm DGA Rt. 2 W														N	N	N	N	N	N	N
19mm DGA Rt. 2 E															N	N	N	N	N	N
ARGG 2010 I-495 N																N	N	N	N	Y
9.5mm DGA I-495 S																	N	N	N	N
ARGG-2009 I-495 N																		N	Y	N
OGFC 2009 I-495 S																			N	Y
OGFC 2008 I-495 N																				N
OGFC 2008 I-495 S																				

Figure 5 – Statistical Matrix

To more easily understand the results determined by in the statistical matrix, Table 2 was compiled to show a summary of the pavements that were determined to be statistically similar. The reference pavement is the pavement being compared, while the statistically similar pavement was the one that showed a Y value on the statistical matrix from Figure 5.

Table 2 – Summary of Statistical Matches

Reference Pavement	Statistically Similar Pavement
OGFC 2003 I-95 S	ARGG 2009 I-95 N Aggregate Industries
OGFC 2003 I-95 S	ARGG 2009 I-95 S Aggregate Industries
OGFC 2003 I-95 S	ARGG 2008 I-295 N
OGFC 2003 I-95 S	ARGG 2008 I-295 N w/advera WM
OGFC 2003 I-95 N	ARGG 2009 I-495 N
OGFC 2003 I-95 N	OGFC 2008 I-495 N
ARGG 2009 I-95 S Lynch	ARGG 2009 I-95 N Lynch
ARGG 2009 I-95 S Lynch	ARGG 2008 I-295 N w/advera WM
ARGG 2009 I-95 N Lynch	ARGG2008 I-295 N w/advera WM
ARGG 2009 I-95 S Aggregate Industries	ARGG 2009 I-95 N Aggregate Industries
ARGG 2009 I-95 S Aggregate Industries	OGFC 2009 I-495 S
ARGG 2009 I-95 S Aggregate Industries	OGFC 2009 I-495 S
ARGG 2009 I-95 S Aggregate Industries	OGFC 2008 I-495 S
ARGG 2009 I-95 N Aggregate Industries	OGFC 2009 I-495 S
ARGG 2009 I-95 N Aggregate Industries	OGFC 2008 I-495 S
ARGG 2008 I-295 N	ARGG 2010 I-495 N
ARGG 2008 I-295 N	OGFC 2008 I-495 S
OGFC 2006 I-290 E	OGFC 2008 I-495 N
ARGG 2010 I-495 N	OGFC 2008 I-495 S
ARGG 2009 I-495 N	OGFC 2008 I-495 N
OGFC 2009 I-495 S	OGFC 2008 I-495 S

By completing the statistical matrix analysis simply using the overall values, several ARGG pavements were determined to be statistically similar to OGFC pavements. Compaction of any pavement varies slightly throughout the paving process, which can lead to a slightly different pavement even with the same mix design, due to over-compaction or under-compaction [4]. This issue can be exacerbated when a mix is paved by two different paving companies [4]. When looking at pavements using the OBSI method, the air voids are believed to play a pivotal role in the reduction of noise in the higher frequency ranges compared to other pavements [4,5], so it was interesting to note that the ARGG 2009 paved on I-95N by Lynch was similar to its counterpart on the southbound side, but the same mix placed by Aggregate Industries less than a mile down the road, was different from the Lynch pavement. Four of the seven OGFC pavements were similar to each other, while only three of the eight ARGGs were similar to each other. Of the fifteen OGFC vs. ARGG pavements, five OGFCs that were placed within two years of ARGGs were statistically similar, and five OFGCs that were placed more than two years before the ARGGs were statistically similar. The two Novachip pavements were not statistically similar to each other or any other type of pavement.

Since the major concern for MassDOT for pavement selection is the susceptibility to winter maintenance and longevity of a pavement, it was beneficial to determine that there were ARGG pavements currently in-place that were similar to some of the other OGFC pavements that were in-place. Incongruously, the statistical approach worked well to determine equal loudness, but it did not account for any of the spectral differences associated with different pavements. There was some discrepancy based on the age of the in-place pavements where the matrix showed that relatively new ARGG pavements were similar to relatively old OGFC pavements, which could be explained by the voids in the OGFC filling over time or compaction over time from being in service. Some of the statistically similar pavements from the matrix, when graphed across a one- third octave band, showed significantly different results. The matrix was a powerful tool to compare loudness, but any conclusions drawn from it must be thoroughly analyzed. For instance, the matrix detailed that the OGFC paved in 2008 on I-495 was significantly different in loudness on the south side vs. the north side, although it was paved by the same company both north and southbound. This drew more attention to that particular section of OGFC from 2008. With the information that the authors were provided at the time of the study, the authors were unable to determine the cause of this difference, but by providing the matrix to MassDOT, engineers there can follow up by examining the possible reasons for the differences by looking at traffic loading data, any quality control data for the construction, and possibly by conducting site surveys.

4. CONCLUSIONS

The main focus of the Massachusetts project was to look at the noise levels generated on different in-place pavements utilized in Massachusetts over the last ten years. Initially the goal was to provide MassDOT with the overall noise levels and respective one-third octave band frequencies measured on in-place pavements in Massachusetts. This project encompassed twenty different materials which were located throughout eastern Massachusetts. The measurements were recorded over a one week span in October, 2010. Each pavement that was tested was roughly two miles long, which allowed the authors to choose appropriate discrete testing sections within each section according to the AASHTO TP 76-09 specifications. The pavements selected for analysis provided a wide array of materials that ranged in age from less than one year to eight years old. The overall OBSI levels for the pavements tested varied about 5 dB(A). After quantifying the overall OBSI levels, spectrum graphs were created for each material, and comparisons were initially drawn between each type of material.

The effects of age were not as apparent as expected. Some of the pavements, such as the I-495 OGFC that was placed in 2009 that was louder than some of the oldest pavements tested, such as the I-95 OGFC that was paved in 2002. The ARGG pavements tested only varied in age by a maximum of two years and no correlation between age was found. The effect of asphalt rubber in the Novachip pavements was not found to be beneficial from a noise perspective, since it only reduced the noise level by 0.5 dB(A).

A statistical analysis was completed comparing the overall noise levels measured on each pavement to each other. The comparisons were completed using the overall levels, so the pavements that were determined to be similar would exhibit an equal loudness. The resultant matrix was relatively quick to put together and provided an unbiased analysis of whether any of the pavements tested had statistically similar overall values. Since MassDOT was interested in determining whether there were any alternative pavements to the OGFCs pavements that are currently in-place, because of problems occurring due to winter maintenance [6], the matrix was a useful tool that provided a discrete analysis of each pavement compared to each other pavement and defined the pavements that were statistically similar to each other. MassDOT was presented with an analysis of the pavements that were similar with a specific focus on ARGG and OGFC pavements. Due to the susceptibility to heavy winter maintenance, the ARGG mixes that exhibited statistically similar overall noise levels will be considered by MassDOT as interchangeable counterparts to OGFC pavements when pavement engineers are considering tire/pavement interface noise during the pavement selection process. Care was taken by the authors to ensure that MassDOT understood that tire/pavement interface noise did not suffice for a complete noise study and that the OBSI method in no way provided a definitive or official noise reduction measurement. MassDOT was appreciative of the information, which they intend to use as a starting foundation to aid them in understanding the holistic benefits that each of the different pavements used in Massachusetts contributes.

5. ACKNOWLEDGEMENTS

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