Asphalt Pavement Compaction Assessment Using Ground Penetrating Radar-Arrays

Kyle Hoegh[1] and Shongtao Dai[2]

[1]Minnesota Dept. of Transportation, Materials and Road Research, 1400 Gervais Ave., Maplewood, MN 55109. E-mail: kyle.hoegh@state.mn.us

[2]Minnesota Dept. of Transportation, Materials and Road Research, 1400 Gervais Ave., Maplewood, MN 55109. E-mail: shongtao.dai@state.mn.us

Abstract

Air void content is a crucial parameter affecting long term pavement performance. Ground Penetrating Radar (GPR) offers a nondestructive method of determining relative asphalt air void content cheaply, quickly, and over an entire project. Previous implementations of GPR for the determination of air void content, including demonstrations as part of a recent SHRP2 study, were mostly positive, but suggested the need for a testing protocol. To explore various survey methodologies, a large-scale case study was conducted on US HWY 52 in Minnesota using the Rolling Density Meter (RDM), a commercially available device developed specifically for air void analysis in asphalt pavements. The lessons learned from the SHRP2 studies and initial Minnesota pilot projects were used on a full coverage trial implementation. The full coverage trial allowed for determination of the potential of the technology for improved QA/QC and resulted in development of best practice recommendations. This paper illustrates information provided by the full coverage data and outlines recommendations related to survey coverage, data file standardization and organization, verification of location and GPR measurements, and a rigid core collection procedure. The application of these recommendations allow an RDM crew to collect valuable relative compaction data for real time feedback without interfering with paving operations or traffic closures. Additionally, core calibration can be performed after surveying to convert data to air void content and project data analysis can be used to determine the construction practices most crucial to achieving sufficient compaction.

INTRODUCTION

Compaction of asphalt concrete substantially affects its early deterioration and long term performance. Linden et al. estimated that each 1% increase in air voids over 7 percent causes an approximately 10 percent loss in pavement life [1]. Typical evaluations of asphalt compaction efforts include methods that are limited in coverage such as the nuclear density gage and destructive such as coring. This creates a need for nondestructive quality assurance methods that can collect data continuously. Ground penetrating radar (GPR) provides a non-destructive testing alternative that allows for walk-behind or vehicle mounted measurements [2-4]. There are also array systems that allow for multiple antenna pair measurements at set spacing which can improve data collection productivity and coverage [5-8].

Various impulse radar versions of ground penetrating radar have shown that the dielectric properties determined from the asphalt surface reflection amplitude corresponds with core measured air void content [9-10]. Additionally, a step frequency array-based method improves the coverage and productivity of the measurements, making it an attractive alternative to current state-of-the-practice procedures [11]. While these studies showed the potential of new technology for improved quality assurance in selected locations, the focus of this study is on how full coverage implementation following the final roller could be utilized on a construction project. In the case of the step-frequency array system [11], these technologies can require intensive data processing from the frequency domain or can be cost prohibitive, while the single impulse array systems [9-10] do not provide necessary coverage for widespread implementation. The method presented in this study is based on a system that evolved from recent research conducted under a National Academies of Science sponsored Strategic Highway Research Program (SHRP-2) [12]. The GPR equipment used in this study is called the rolling density meter (RDM), which uses similar antenna to that presented in [12], but also applied in a 3 channel array to obtain some of the benefits in coverage explained in [11] where multiple antenna pairs are used in each pass.

The dielectric values used for comparison with cores in this study followed the surface reflection method with a single air coupled bistatic antenna where the amplitude of the reflection when impulse is reflected at the air/asphalt interface, A_0, as compared to the incident amplitude (represented by the reflection from the metal plate), A_i. This can be used to determine the bulk dielectric constant of the asphalt, e_r from each antenna pair, i, at the measurement location:

$$e_r = \left(\frac{1+\left(\frac{A_0}{A_i}\right)}{1-\left(\frac{A_0}{A_i}\right)} \right)^2 \qquad [1]$$

Since a higher proportion of air in the asphalt creates a lower electrical impedance mismatch, the dielectric constant can be empirically related to the relative ratio of pore volume for each specific asphalt mix using core calibration [9-13].

LARGE COVERAGE STUDY RESULTS

A seven-mile stretch of a mill and overlay project on Highway 52 (HWY 52) was used to investigate the potential of RDM technology. This project included 2 lanes where the inside lane was paved first, followed by the outside lane. This created a longitudinal joint with unconfined compaction on the inside lane side of the joint and confined compaction on the outside lane side of the joint. The entire project was scanned using the 3-channel RDM with a measurement of 30 scans per foot, resulting in over 40 scan-miles when accounting for multiple transverse passes within each 500 ft section. The faster rate of RDM data collection relative to paving operations allowed for multiple passes in predefined 500ft sublots to be performed. Some patterns focused on joint or wheel path data while others were evenly distributed across the lane. Figure 1 shows the equipment used on-site to collect dielectric readings [A] prior to a 500 ft pass, and [B] during data collection moving behind the final roller compactor.

Figure 1. Equipment and Data Collection [A] prior to a 500 ft pass, and [B] during data collection moving behind the final roller compactor.

Forty cores taken along the 7 mile project final lift were used to develop a model relating RDM measurements to air void measurements using only core results matching the QA/QC criteria for AASHTO T 166. This model can be used to convert all RDM data to air void content along the survey length. The scatter in the model is not exclusively a function of the RDM accuracy in assessing relative air void content, but also of the precision of the "ground truth" core comparison. To put this uncertainty in perspective of previous studies and current Agency specifications, the scatter shown from Figure 1 referenced from NCHRP 531 and the current companion core bulk specific gravity, Gmb, MnDOT tolerances of +/-0.03 results should be noted [14]. The former shows scatter of up to 4% and bias increasing with increasing air voids for two AASHTO approved core measurements, while the latter accepted Gmb tolerance corresponds to a range of over 2% air void content difference in calculated air voids for the data collected in highway 52. It should also be noted that the AASHTO T 166 core measurements corresponding to all lower dielectrics (<5.1) under-predict the air void content. Considering the uncertainty of the currently accepted core measured air void content itself, obtaining better coverage such as those shown in this study using RDM to assess compaction efforts is critical.

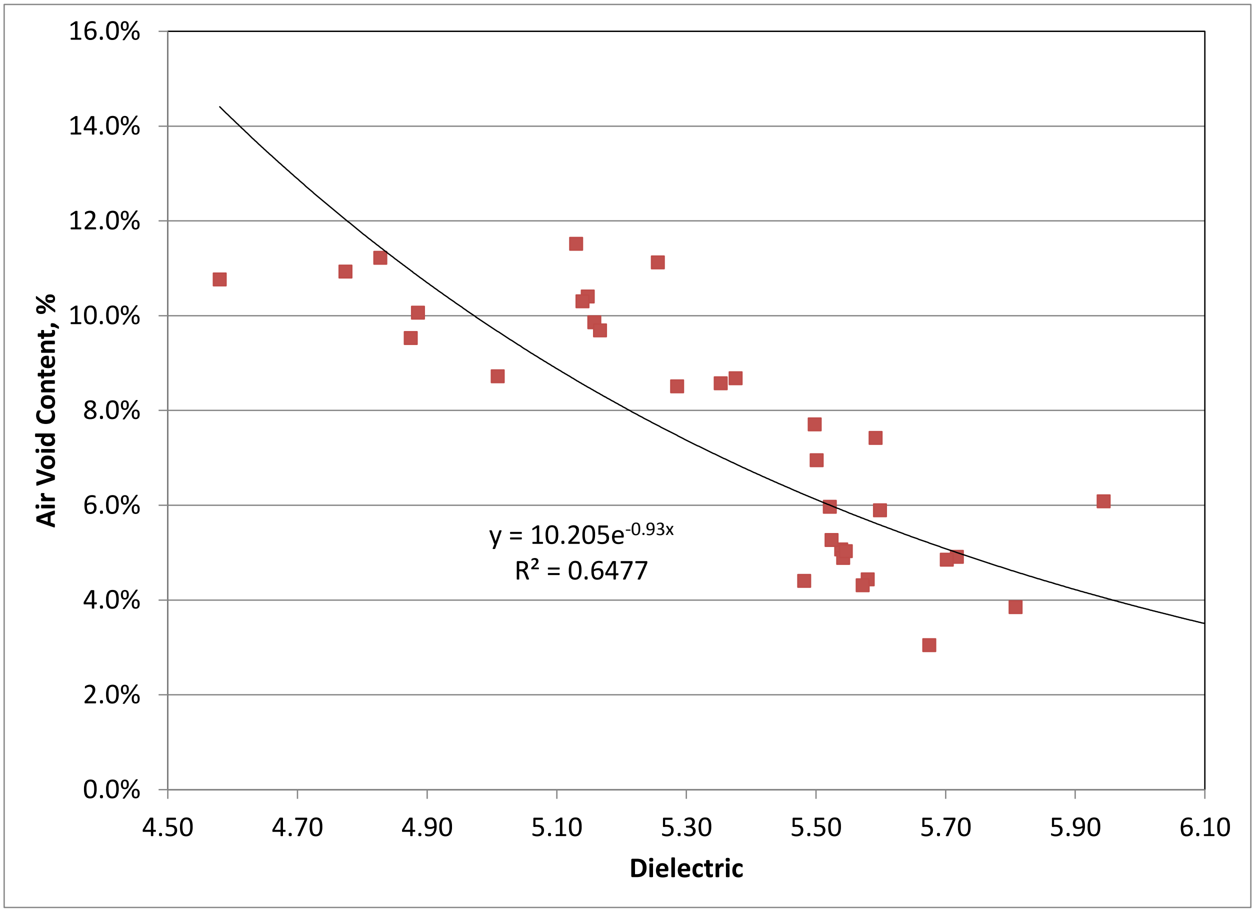

Figure 2. Model used to convert RDM data to air void content.

Using the model shown in Figure 2, general comparisons of as-built air void content at different locations can be compared using histograms and general statistics using post-processing tools that categorize the data based on location and other characteristics. A comparison of the mainline of the inside lane, mainline of the outside lane, confined side of the joint, and unconfined side of the joint with over 5 RDM scan-miles of each category show that the **unconfined side of the joint** had the highest air voids (**7.9%**), followed by the **confined side of the joint (7.4%)**, and **mainline (6.6% and 6.5%,** for the right and left lanes respectively). These types of comparisons give a good indication of the overall performance of the compaction efforts and as-constructed relative measures. As should be expected the mainline mat density performed better than the joint, with the unconfined side of the joint performing the worse overall.

The Highway 52 project included a change in roller pattern at several locations. Figure 3 shows roller pattern 2 in yellow and roller pattern 1 in green. Roller pattern 2 (see yellow curve) had a 0.22 dielectric increase as compared to roller pattern 1 (see green curve), which is equivalent to about 1.4% decrease as-built air void content. There were no randomly selected cores roller pattern 1 along this section. However, it can be observed that the drop in compaction indicated by the RDM occurred prior to roller pattern change (transition from yellow to green). There also happened to be a randomly selected core at that location confirming the drop (94% air voids as compared to 95.8%, 95.7%, and 95.2%). The lack of randomly selected cores in some of these areas of interest should be noted along with the ability of the RDM to identify changes, as this is indicative of the lack of coverage provided by limited coring in assessing compaction efforts which also shows the value of having a full coverage method for assessment.

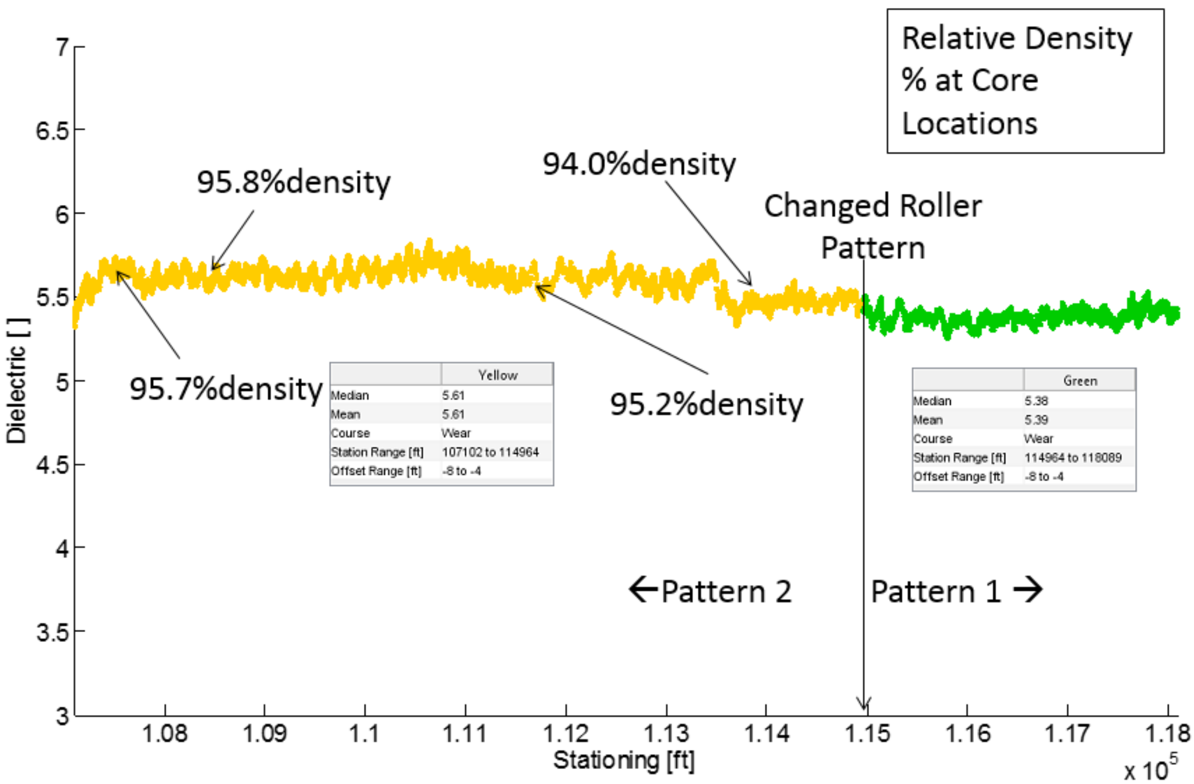

Figure 3. Experimental design comparison.

The coverage provided by RDM allows for comparison with other construction data such as thermal imaging to determine the most critical factors in achieving proper compaction. Figure 4 shows the example data from the transition from roller pattern 1 to roller pattern 2 after being imported into Intelligent Construction Software (VETA). The imported data can be compared to the thermal and other data to compare with pass counts of each roller, paver stops, and other factors that can be optimized to achieve higher as constructed density. The location of the high and low dielectric/compaction levels are displayed at the physical location where they were collected using the Minnesota virtual reference station (MnCORS) corrected GPS data with red indicating higher dielectric/compaction and blue indicating lower dielectric/compaction. The GPS mapping allows for flexibility in the testing patterns such as the swerving data shown in Figure 4. In this example, some locations where the dielectric value decreases correspond to the locations where the driver was on the shoulder, where fewer compaction passes are made. Also, the transition from blue/green to yellow/red shows the increase in compaction shortly after the roller pattern was changed from type 1 to type 2.

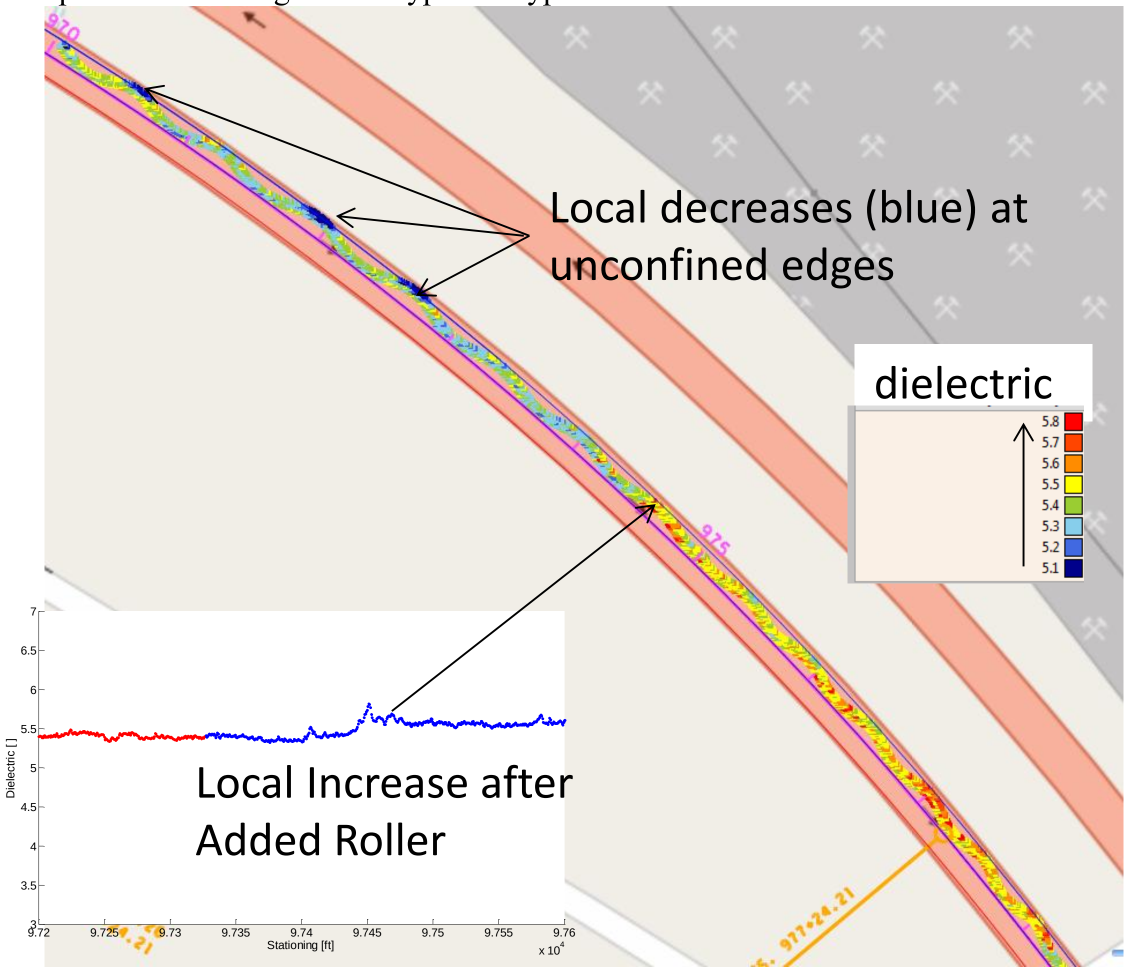

Figure 4. Mapping the compaction results using the corrected GPS location.

RDM data can be used to provide feedback to the paving crew or for determination of most critical factors to achieving proper compaction. For example, relative compaction information from RDM measured dielectric data can be compared to roller speed and asphalt temperature as shown in figure 6. There are three results mapped in the same location including [A] RDM dielectrics was wells as infrared scanner (IR) measured [B] paver speed, and [C] pavement temperature after placement. The approximately 300 ft stretch of pavement covers both lanes moving south from 1070+00 stationing. This stretch was selected since there were discrete differences in the RDM compaction results, which suggested there where some effects of changing construction operations or conditions. These differences are outlined in black boxes in Figure 5 and labeled 1 through 3. The following trends were observed in the RDM dielectric map:

1. Region 1 had the most compaction as indicated by higher dielectric readings shown in red (5.6-5.7) on the map.
2. Region 2 showed a decrease as compared to region 1 with lower dielectrics shown by mostly green/yellow/orange dielectrics (5.3-5.5)

3. Region 2 showed a gradual increase in compaction moving from mostly yellow (~5.4) in the North end up to orange/red (5.5-5.6) toward the South end of the region.
4. Region 3 was generally lower in compaction with mostly blue/green/yellow (5.2-5.4) dielectrics.

While increases or decreases in compaction is a result of many factors, the full map comparison with as-constructed data can provide insights as to some of the most critical reasons for different levels of compaction performance. For example, the paver speed data shown in [B] seems to be the main contributing factor to the lower compaction levels in region 3. Region 3 is consistently 40 to 49 ft/min in paving speed (shown in green), while the other regions are between 10 to 39 ft/min (orange/yellow/light green). The higher paving speed may contribute to the lower compaction for multiple reasons. For example, it can be more difficult to keep the rollers caught up and rolling at the specified pattern, speed, and pavement temperature for proper compaction when the paver is moving too fast. The pavement temperature data during placement given by IR seems to indicate one of the major causes of the trends observed in regions 1 and 2. The temperature data shows a very similar pattern to the difference in compaction between region 1 and region 2 as well as within region 2. Along these regions, the sections where the asphalt was placed around 275 to 299 degrees Fahrenheit (yellow) correspond to better compaction in region 1. The change to green (250 to 274 degrees Fahrenheit) in the beginning of region 2 corresponds to the lower compaction observed by the RDM. Further, the southern portion where the compaction started to improve shown in [A] corresponds to where the temperature shown in [C] also started to increase with some yellow spots in the South.

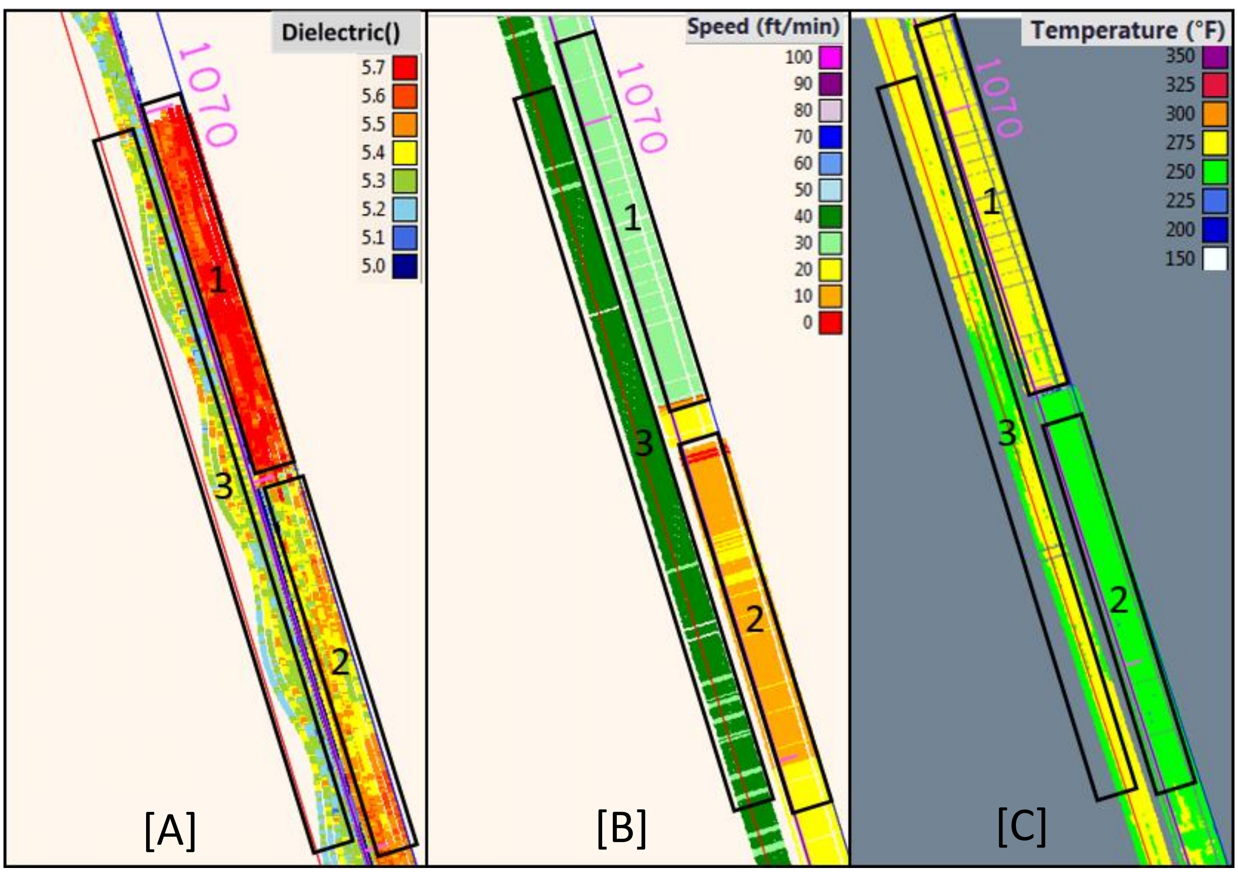

Figure 5. Dielectric, Temperature and Roller Speed comparison

CONCLUSIONS

Early deterioration and long term performance of asphalt pavements is highly affected by quality of compaction. A GPR-based rolling density meter, recently developed under SHRP 2 study, was used to conduct on-site continuous coverage of the relative compaction levels by mapping dielectric values (higher dielectric = higher compaction). The results of the trial implementation show the ability of the method to assess relative compaction levels nondestructively, and at a greater coverage and speed than traditional methods allow. By collecting data along the entire paved area, the conclusions can potentially be used as quality assurance of compaction efforts and to determine the most critical aspects of achieving improved as-built density in asphalt pavement construction through comparison with other performance measures and construction practice measurements. For implementation of this technology, a specification should be developed outlining the necessary steps that should be taken for the equipment to be approved for use. The RDM information that can be used for the following:

- Provide on-site feedback to contractor of high and low compaction locations that they can use as an input for QC operations
- As-built quality assurance of compaction uniformity
- Core air void results can be used to convert dielectric values to estimated air voids or relative density with continuous coverage.
- Assessments of the in-place compaction spatial variation and summary results using scatter plots, heat maps, histograms and general statistics
- RDM results can be cross-checked with IC, IR, and other data to determine the most critical factors in achieving higher density.

REFERENCES

1. Linden, Robert N., Joe P. Mahoney, and Newton C. Jackson. "Effect of compaction on asphalt concrete performance." Transportation Research Record 1217 (1989).
2. Maser, K R, T J Holland, R Roberts, and J Popovics. 2006. “NDE Methods for Quality Assurance of New Pavement Thickness.” International Journal of Pavement Engineering 7 (1): 1–10. DOI: http://dx.doi.org/10.1080/10298430500501985
3. Evans, Robert, Matthew Frost, Martyn Stonecliffe-Jones, Neil Dixon. 2008. “A Review of Pavement Assessment Using Ground Penetrating Radar (GPR).” Proceedings of the 12th International Conference on Ground Penetrating Radar, Birmingham, UK. URI: https://dspace.lboro.ac.uk/2134/3590
4. Lai, W., T. Kind, S. Kruschwitz, J. Wöstmann, and H. Wiggenhauser, 2014 “Spectral absorption of spatial and temporal ground penetrating radar signals by water in construction materials,” NDT & E International, Volume 67, Pages 55-63, ISSN 0963-8695, http://dx.doi.org/10.1016/j.ndteint.2014.06.009
5. Chen, D.H., F. Hong, W. Zhou, P. Ying, 2014 “Estimating the hotmix asphalt air voids from ground penetrating radar,” NDT & E International, Volume 68, December 2014, Pages 120-127, ISSN 0963-8695, http://dx.doi.org/10.1016/j.ndteint.2014.08.008

6. Sala, J., and N. Linford. 2012. "Processing stepped frequency continuous wave GPR systems to obtain maximum value from archaeological data sets." *Near Surface Geophysics*, Volume 10: 1873-0604.
7. Scott, M. L., N. Gagarin, M.K. Mills, and M. Oskard. 2006. “Step Frequency Ground Penetrating Radar Applications to Highway Infrastructure Measurement and System Integration Feasibility with Complementary Sensors.” AIP Conference Proceedings. 820, 1, 1624-1631. ISSN: 0094243X.
8. Grasmueck, M, R Weger, and H Horstmeyer. 2005. “Full-Resolution 3D GPR Imaging.” *Geophysics* 70 (1): K12–K19. Print ISBN: 90-9017959-3
9. Saarenketo, Timo, and Tom Scullion. 2000. “Road Evaluation with Ground Penetrating Radar.” *Journal of Applied Geophysics* 43 (2-4). doi:10.1016/S0926-9851(99)00052-X
10. Leng, Z., and Imad L Al-Qadi. 2014. “An Innovative Method for Measuring Pavement Dielectric Constant Using the Extended CMP Method with Two Air-Coupled GPR Systems.” *NDT & E International: Independent Nondestructive Testing and Evaluation* 66 (0): 90–98. doi:10.1016/j.ndteint.2014.05.002
11. Hoegh, K., Khazanovich, L., Dai, S., & Yu, T. (2015). “Evaluating asphalt concrete air void variation via GPR antenna array data.” Case Studies in Nondestructive Testing and Evaluation, 3, 27-33.
12. Sebesta, S., T. Scullion T. Saarenketo. 2013. “Using Infrared and High-Speed Ground-Penetrating Radar for Uniformity Measurements on New HMA Layers,” Strategic Highway Research Program. REPORT S2-R06C-RR-1 ISBN: 978-0-309-12934-3
13. PANK 4114, Asfalttipäällysteen tyhjätila ja muut tilavuussuhteet (in Finnish).
14. 2014. Materials Lab Supplemental Specifications for Construction. Department of transportation St. Paul, Minnesota. Access: http://www.dot.state.mn.us/pre-letting/spec/2014/2014-Materials-Lab-Supplement.pdf