A Demonstration of the Asphalt Pavement Scanner in a New Subdivision

C. Oden, R. North
October 2021

Introduction

The ESS Asphalt Pavement Scanner (APS) is a revolutionary new system that provides detailed and comprehensive quality information for new asphalt mats without the use of nuclear sources. The system is shown below in Figure 1, with the standard push cart configuration in the left photo and configurations for surface and puck measurements in the center and right photos. The scanner measures:

- surface temperature,
- asphalt compaction,
- asphalt thickness, and
- surface roughness.

Figure 1. The Asphalt Pavement Scanner. Left panel shows the cart configuration, center panel is gauge configuration, and the right panel shows the gauge measuring a gyratory compactor puck for mix calibration.

To demonstrate these capabilities, a short survey was conducted at a new subdivision under construction. This report demonstrates the benefits of the APS data and examines how the APS system can be used for both process control during construction and for inspection and acceptance after construction.

Figure 2. Subdivision site map from county records.

A county map of the site is shown in Figure 2 above. Each two-lane street was scanned with seven survey lines – three for each lane and one down the center joint. Four streets were scanned and each scan is labeled as Scan 1 – 4 as shown in the figure above. The scanner location was measured with an odometer and an RTK GPS system providing accuracy of about 1 cm with respect to a fixed base station. Surveys are conducted at walking speed (3 mph). This corresponds to a full-lane scan rate of about one mile per hour, which is much faster than standard paving rates (30 ft/min or 0.3 mph). The scan cart has an optional tow bar that can be connected to a tow hitch on an ATV or pickup truck. It took approximately 3 hours to cover the site, resulting in approximately three miles of continuous scan data. Since this is a new subdivision, the new construction had not yet been captured by the available online satellite imagery which only shows open field for the site, and therefor the county map in Figure 2 is used as an underlay for all of the APS data.

Survey Results

The scanner makes four different measurements which are each valuable for different reasons during and after the paving process. The results of each are discussed in the following sections.

Temperature

The scanner has a non-contacting IR temperature sensor that can be used as an indicator for non-uniformity of the mix during paving. For example, mix problems such as segregation often manifest as temperature anomalies. In Figure 3 below, the cooler parts of the image (blues and greens) correspond to pavement that was placed the day prior to the APS survey, and the hotter regions (purples and reds) were placed on the day of the survey. For Scan 1, the north-west part of the scan area was placed the same day that the APS scan was conducted. In Scans 2 and 3, some temperature variations can be seen which may be due to uneven heating and/or uneven mixing. Areas with anomalies like this should be visually inspected to look for segregation or other mix defects.

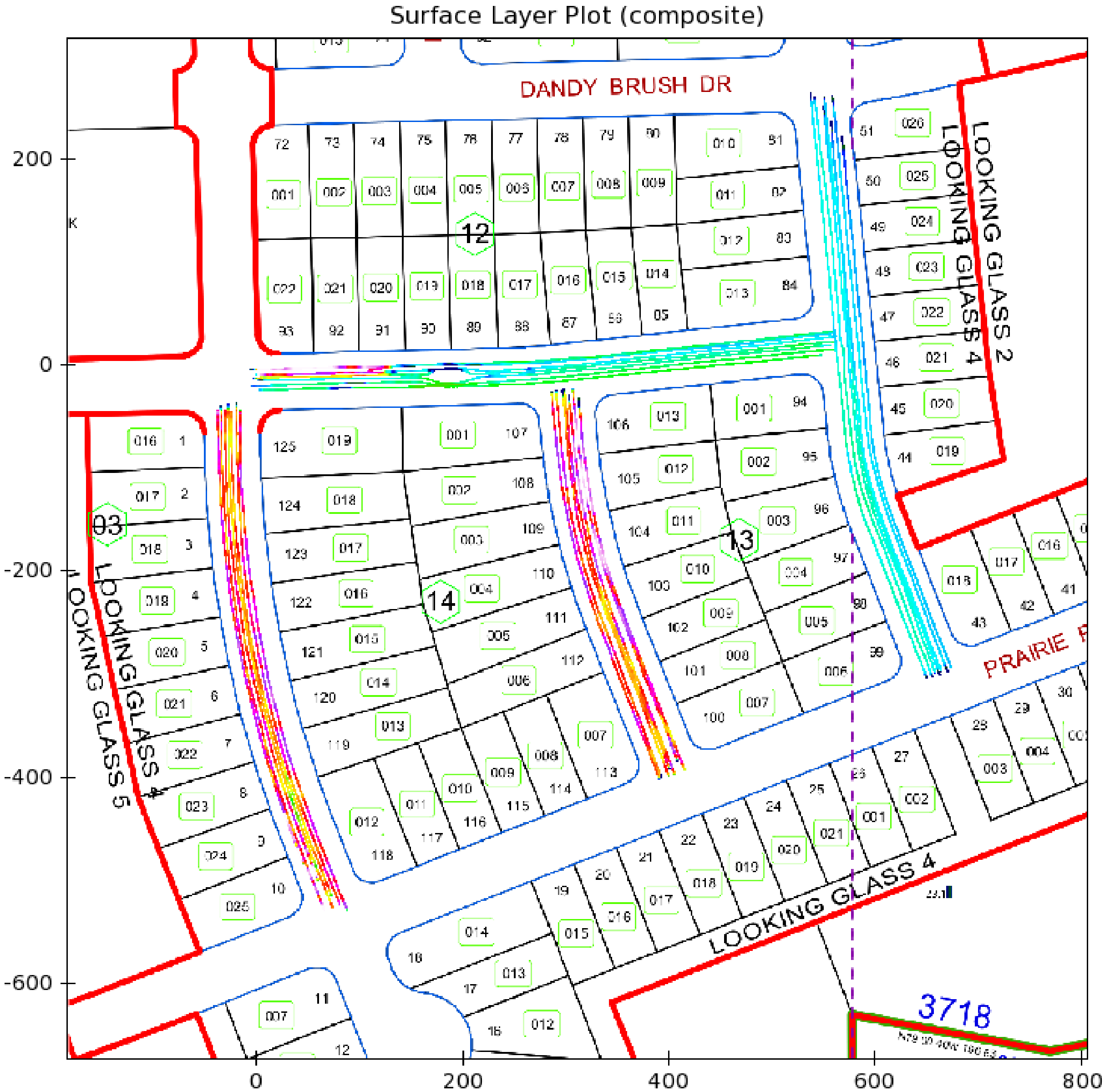

Figure 3. Surface temperature [23C 50C], horizontal and vertical axes in feet.

Compaction

Nuclear density gauges are used to measure asphalt density which increases with compaction. An asphalt mix-specific calibration is needed to convert from density to compaction, and this relationship is determined by measuring the density of the mix at the maximum possible compaction (i.e., the Rice value or G_{mm}).

Instead of nuclear radiation, the APS scanner uses the varying intensity of reflected radar waves from the asphalt surface to measure the dielectric constant of the mat, which also increases as compaction increases. To convert dielectric readings to compaction, the dielectric constant must be measured that corresponds to a particular compaction value. This calibration value along with the Bottcher mixing formula (see Appendix I) is used to calculate how the dielectric constant changes with compaction (see Figure 4). It is recommended to perform mix calibration on a daily basis or on each lot from the asphalt plant. With the APS, this calibration can be done in a variety of ways depending on project logistics and accuracy required.

1. The most accurate calibration method uses gyratory compactor pucks. The dielectric constant of the pucks can be measured with the APS scan head (see right photo in Figure 1), and then the density/compaction of the puck is measured using industry standard methods. The process is repeated for a few different pucks, and the mix calibration data are then entered into the software. If the mix calibration is done before conducting the survey, then compaction results will be available during the survey. Alternatively, if the pucks are not available prior to the survey, the mix calibration can be applied to the recorded measurements after the survey. This method is designed for pucks that are 6 inches (150 mm) in diameter and 4 inches (100 mm) tall.
2. Use the push cart to measure the dielectric constant of the mat at a location where a (nuclear) density gauge reading was taken. This method relies on a properly calibrated density gauge. Note also that the volume of investigation for the gauge and the APS is different: a hemisphere about 4 inches in diameter for the gauge and a cylinder about 24 inches in diameter and 3 inches thick for the APS. Because there can be variation of 1-2% in gauge readings taken in close proximity (see appendix) and the difference in volumes of investigation, it is recommended to use 5-10 gauge readings to obtain a representative value.
3. The final method uses cores taken from the job site. Cores need to be 6 inches (150 mm) in diameter and 4 +/-0.25 inches (100 +/-6 mm) tall, and the tops and bottoms of the cores must be cut flat to resemble a compactor puck. Care must be taken with this method and results may vary because the cores may contain material from different lifts and mixes.

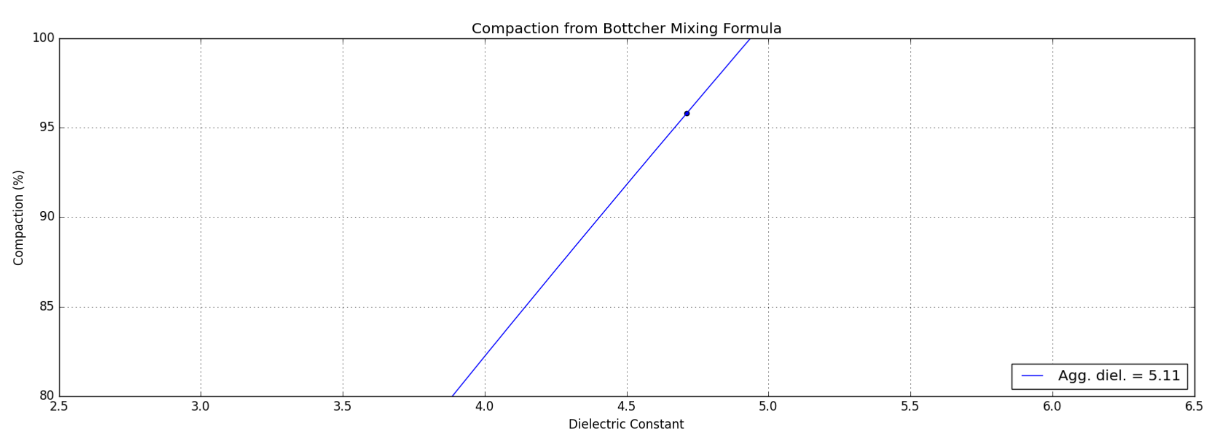

Figure 4. Asphalt mix calibration determined from a density gauge reading of 95.8% and a dielectric constant of 4.73.

The APS system measures the dielectric constant with two different sampling depths: 1.5 and 3.0 inches (37 and 75 mm). At this survey site a single gauge reading was used to obtain the mix calibration (see Figure 4, normally more calibration readings would be taken). The mix calibration was then used to obtain the compaction values shown in Figures 5 and 6 below. Because the gauge had a measurement depth of four inches, the three-inch deep APS readings are shown. In Figure 5, each reading is plotted successively for all seven scan lines in Scan 4 (the high dielectric readings indicate locations where the cart rolled off the edge of new pavement between scan lines). The common problem of under-compaction at joints in the mat can be seen in the lower compaction values obtained along line 4 which straddled the center joint. The lower compaction along the joints can be seen in Scans 1 – 4 in Figure 6, and more detail can be seen in Figure 7 which shows the compaction for Scan 4. There are some erroneous readings are the end of each scan line where the scanner was pushed beyond the extents of the new pavement.

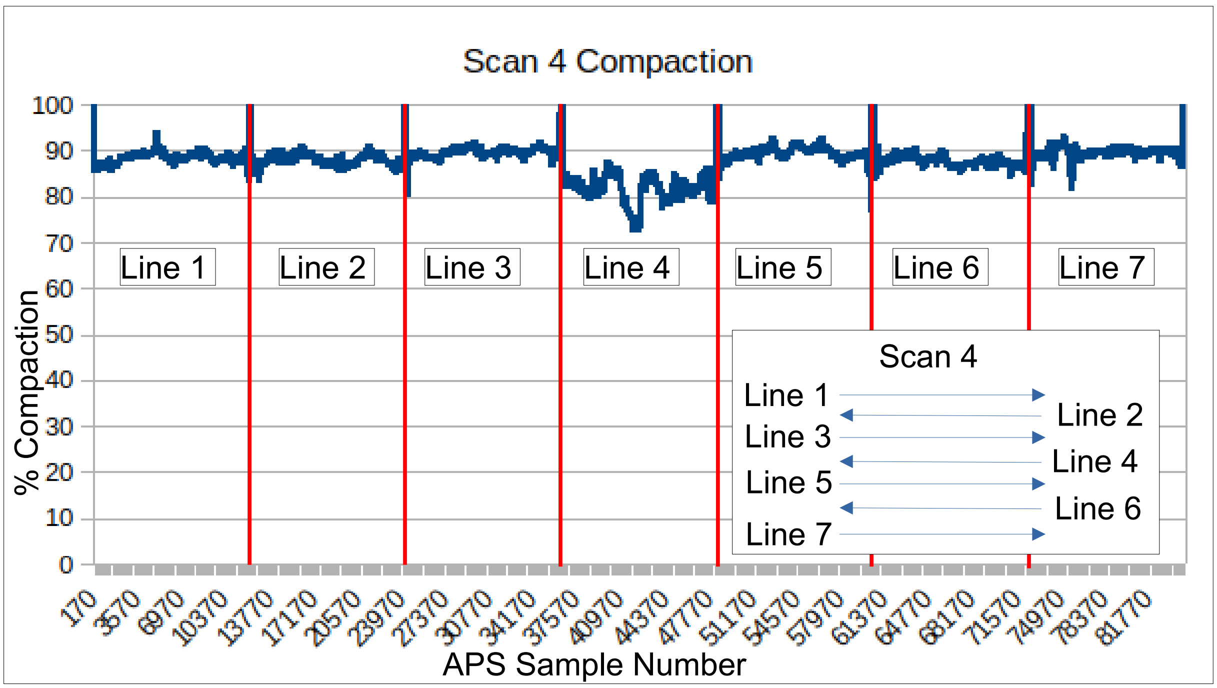

Figure 5. Compaction readings from all lines in Scan 4 where the spikes indicate the change between scan lines. The lower compaction values along scan line 4 that traverses the center joint are evident.

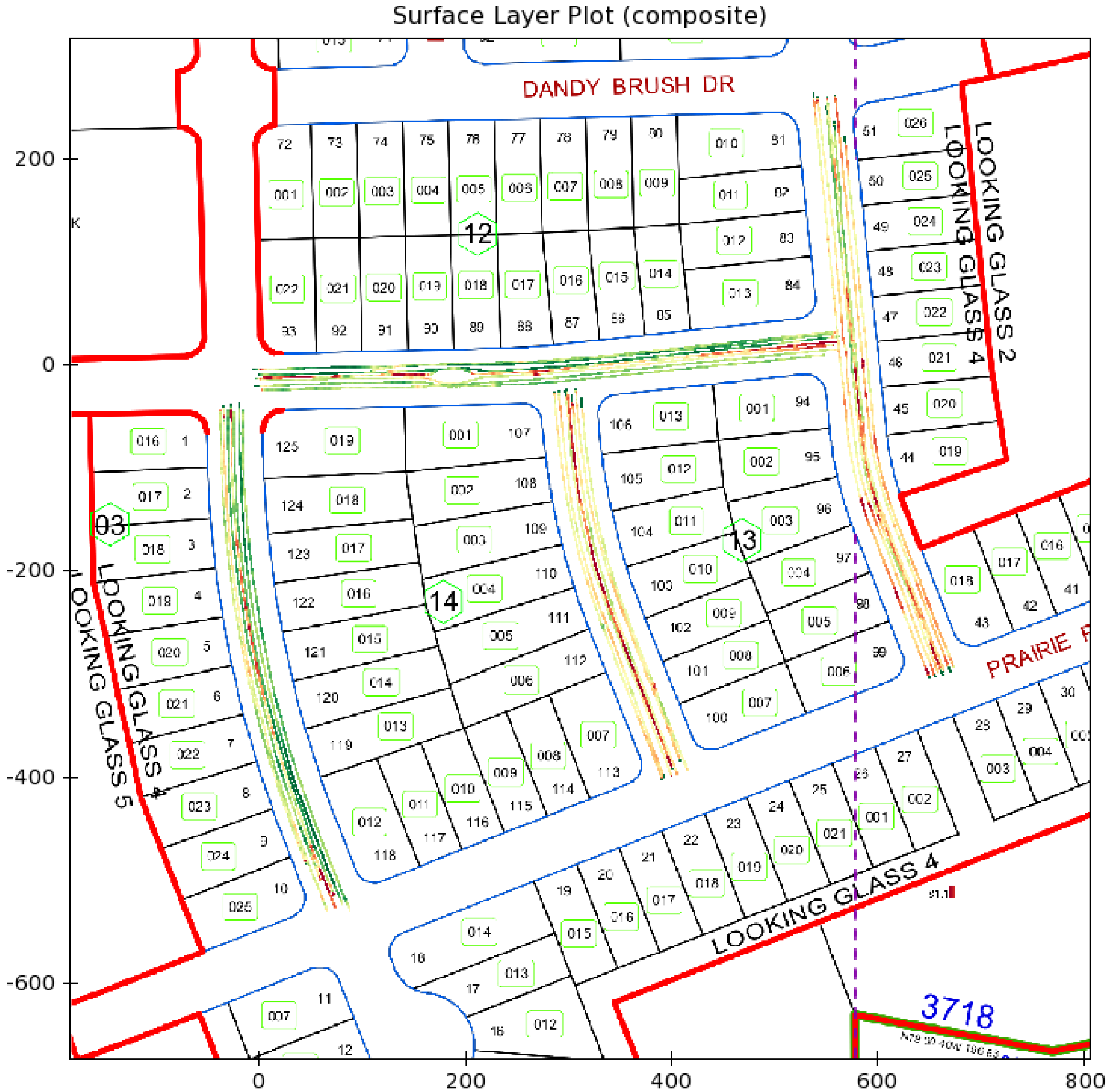

Figure 6. Compaction values obtained from the three inch depth readings [81% 97%], horizontal and vertical axes in feet.

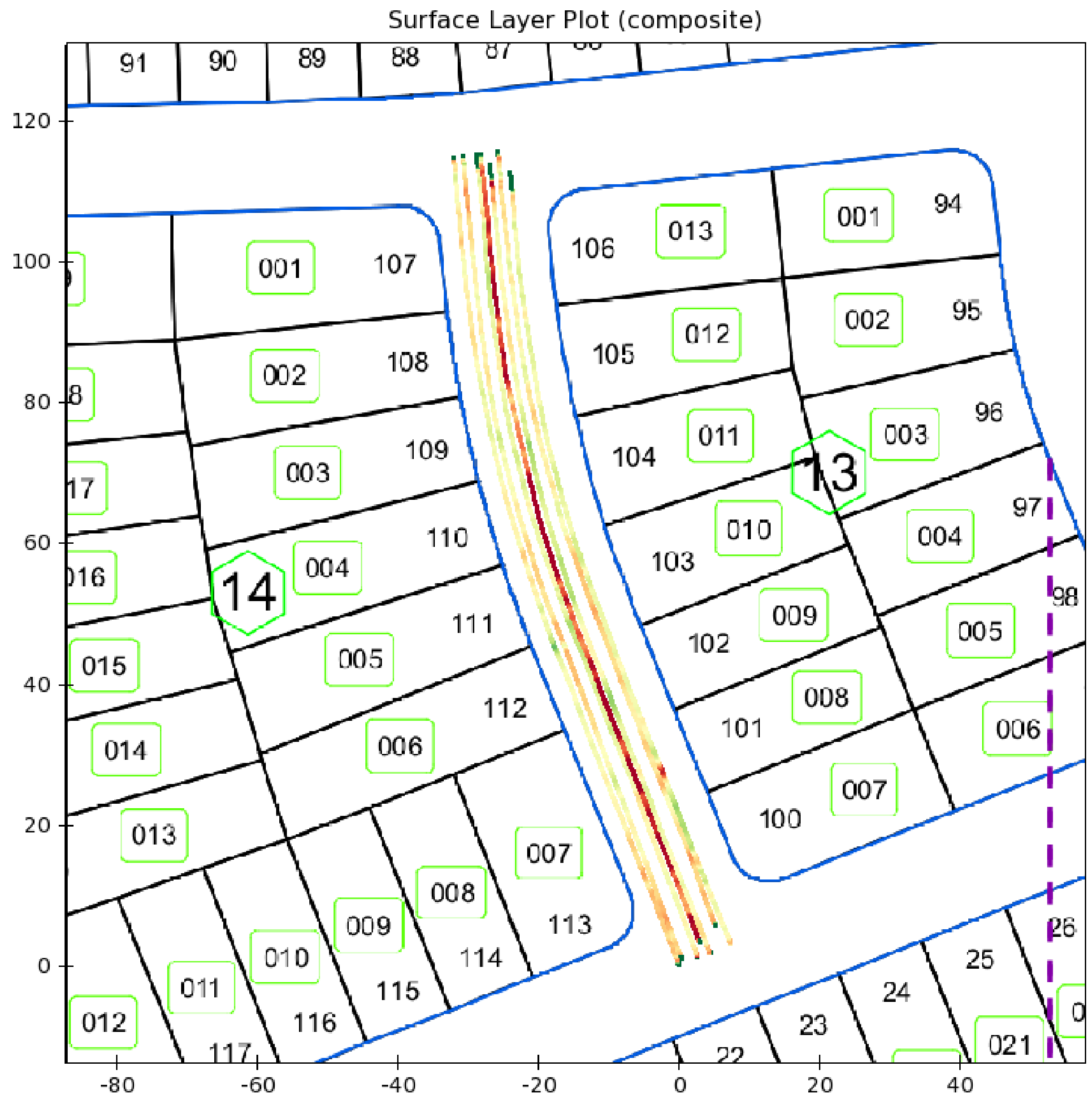

Figure 7. Compaction values obtained from the three inch depth readings for Scan 4 [81% 97%], horizontal and vertical axes in feet. The center of the road along the joint shows lower compaction than the rest of the road (red versus yellow).

Surface Roughness

The APS also measures the height of the scan head above the surface using radar. With this measurement and consideration of the wheel geometry of the cart, a surface roughness indicator is provided. This is similar to the measurements made by the Dipstick Profiler, but with the ability to measure continuously. The APS surface roughness measurement is a useful quality indicator that measures roughness in inches per mile (or m/km). The roughness as measured by the APS on new subdivision pavement is shown in Figure 8 below, where values less than 100 in/mi are considered good. Some rough areas may be caused by the scanner rolling over a pebble or other debris at the job site, and user may choose to average the results over 10 – 50 foot intervals which would reduce the appearance of localized roughness and speckle in the image.

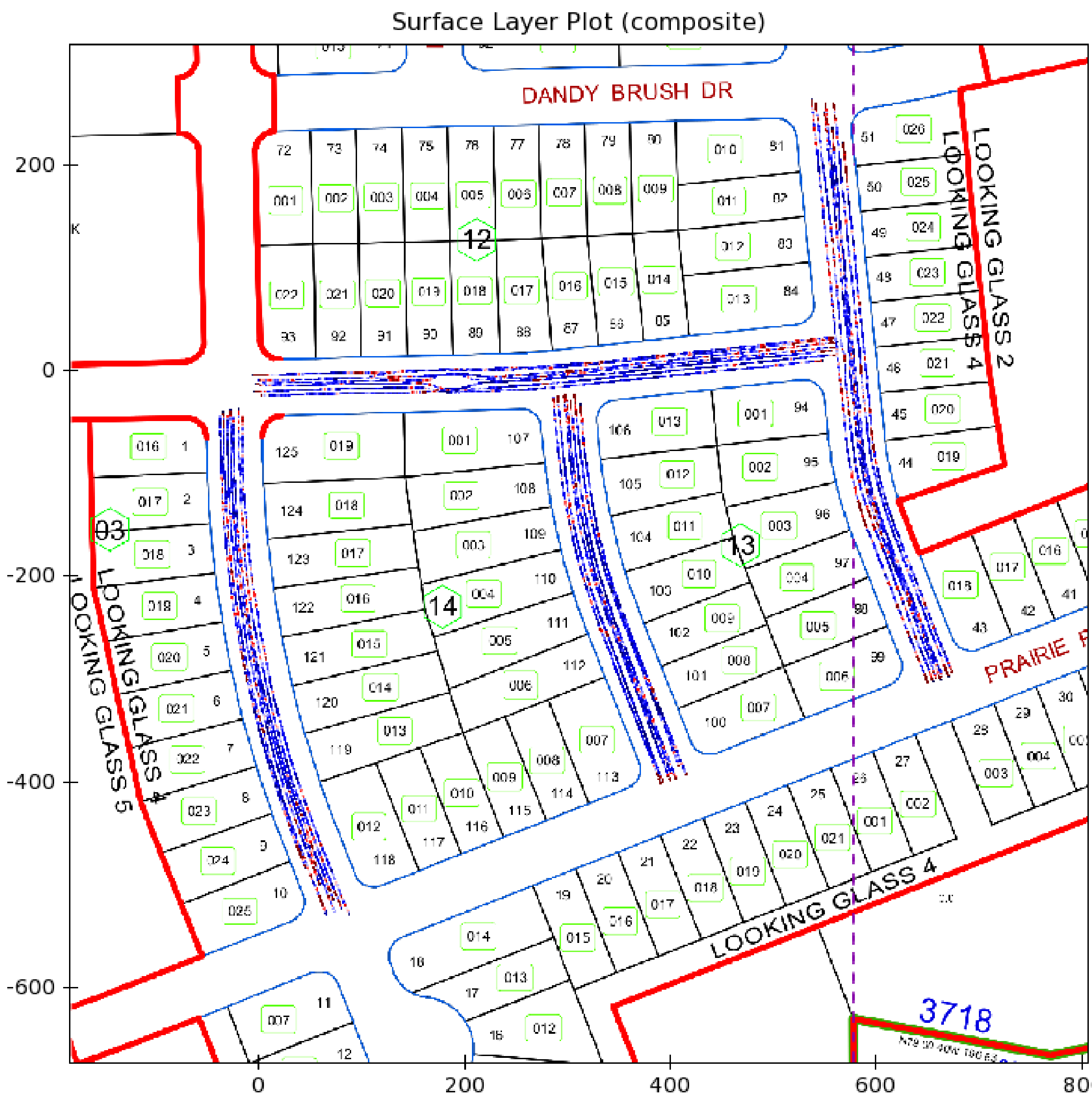

Figure 8. Surface roughness [0 190 in/mile], horizontal and vertical axes in feet.

Asphalt Thickness

The final measurement made by the APS is the asphalt thickness. When the subgrade material below the asphalt has different properties (dielectric or moisture) than the mat, a radar wave reflection from the bottom of the mat is can be seen as shown in Figure 9. By measuring the travel time of the radar wave to the bottom of asphalt, the depth can be determined. Figure 10 shows the asphalt thickness for all of the scanned areas. In most locations this method works well, however in some locations it is possible (although unlikely) that the reflection from the bottom of the asphalt is not evident and thickness cannot be measured.

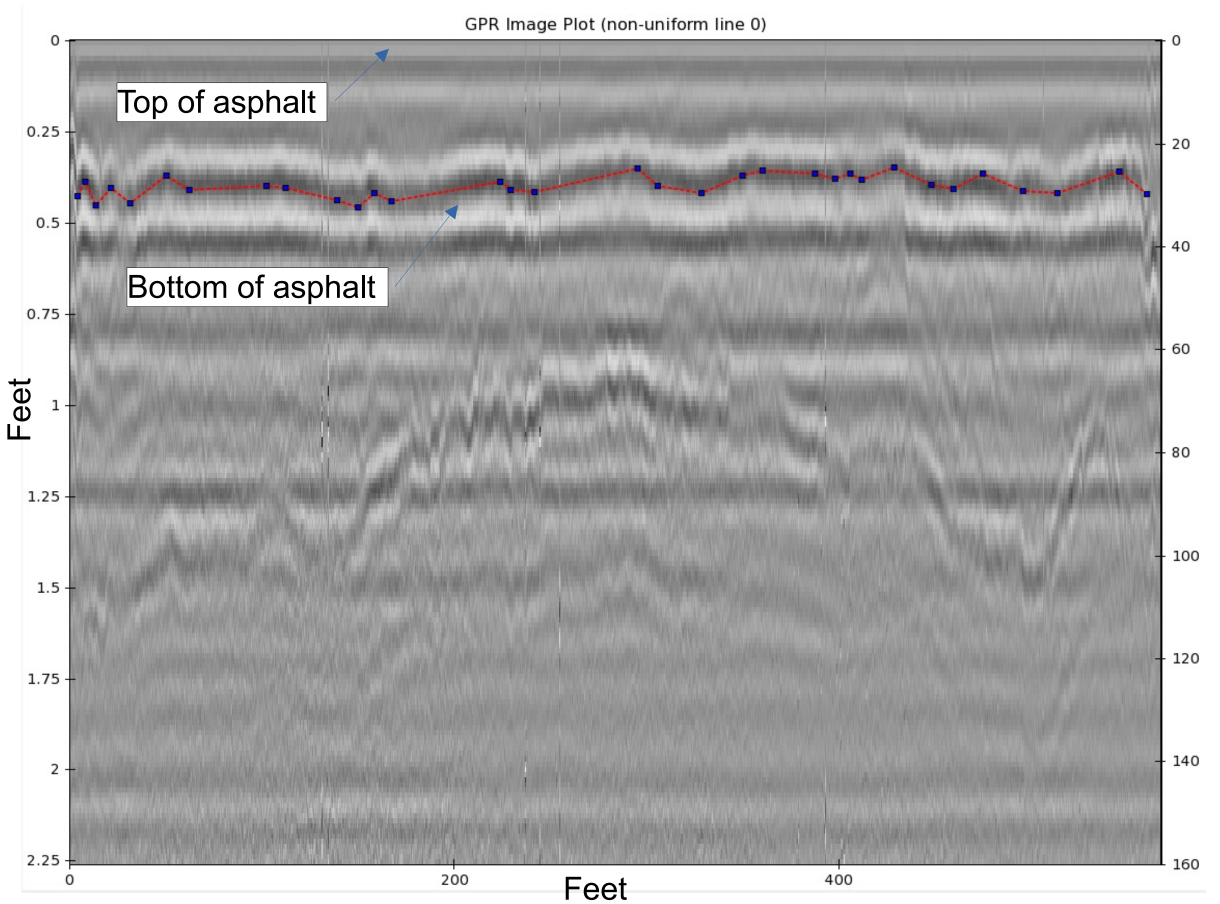

Figure 9. Picking the asphalt thickness along a survey line. Both the vertical and horizontal scales are in feet.

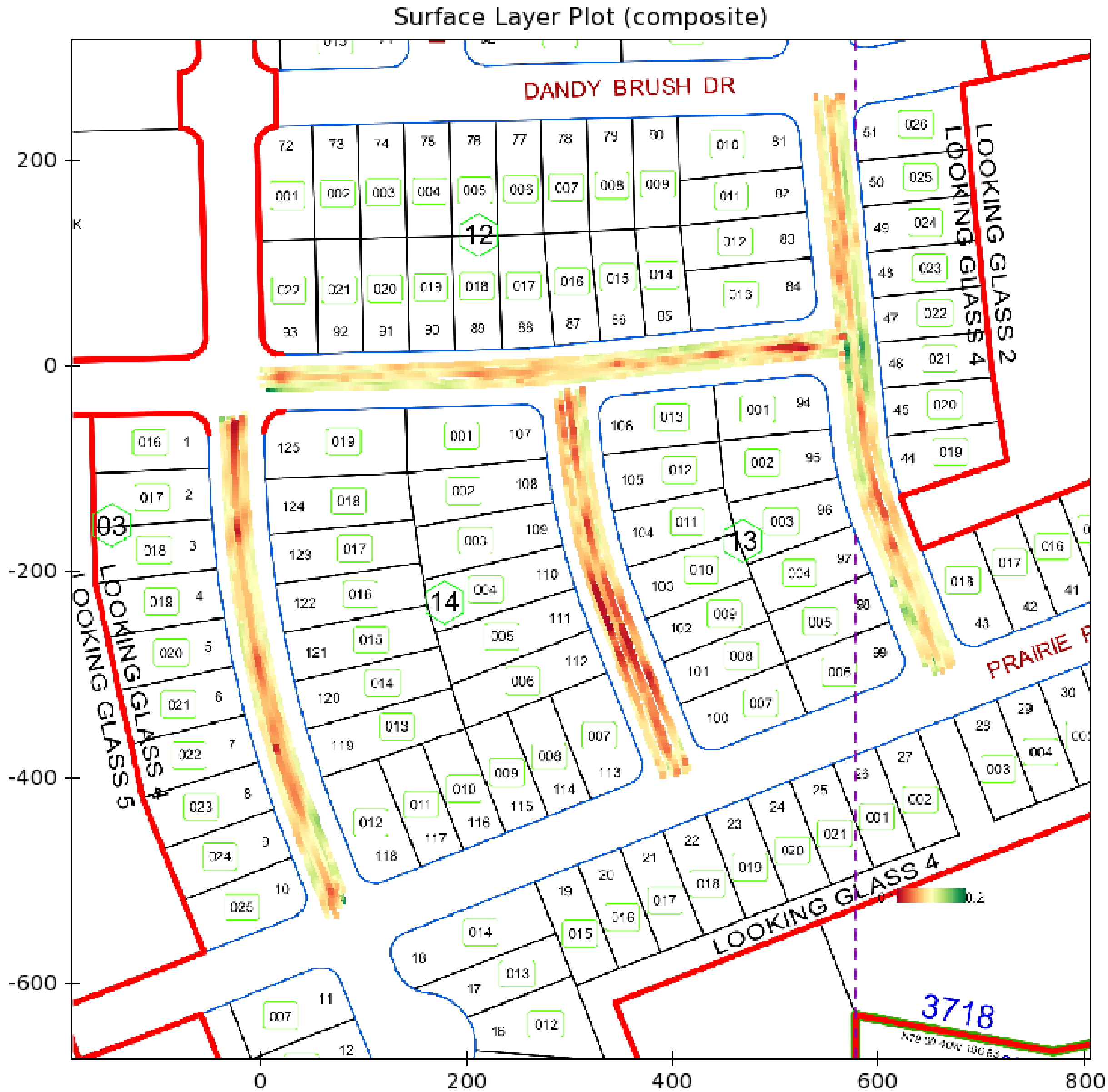

Figure 10. The asphalt thickness at this site is nominally 5 inches thick (yellow), with some localized minor deviations. [3.1 6.7 in], horizontal and vertical axes in feet.

Histograms and Statistics

Using the data collected by the APS system, users can generate histograms and calculate percent within limits (PWL) for compaction, thickness, and roughness. The PWL values are often used to determine incentives and penalties in paving contracts. Due to the large number of samples and locations tested with the APS, the results more truly represent the in-place material and provide a valuable tool to reduce the risk assumed by both the buyer and the contractor. In other words it will be less likely for the contractor to be falsely penalized for acceptable work and for the buyer to pay for defective work. Figure 11 has an example compaction histogram for Scan 2. The tail in the distribution below 90% is largely due to under-compaction of the center joint.

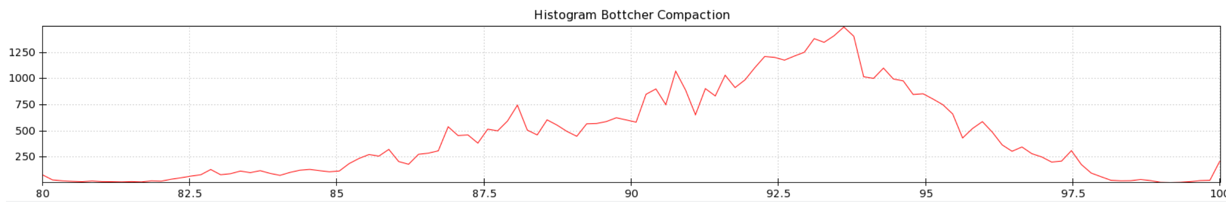

Figure 11. Histogram of measured compaction values (%) for Scan 2.

VETA Intelligent Construction Software

In addition to the large number of data plotting and report generating capabilities provided by the APS software, users can export APS data into the VETA intelligent construction software that is used by a number of transportation departments. This software is used to display temperature, compaction, and stiffness data that are recorded by instruments mounted on screeds and roller compactors. Like the APS software, the VETA overlays data onto Google Map views; and VETA allows users to combine views of data collected from sensor equipment provided by multiple vendors, that may be mounted in different platforms (screed, roller compactor, survey vehicle, etc.). For example, some practitioners are mounting thermal imagers on screeds. Figure 12 below shows a screenshot from the VETA software.

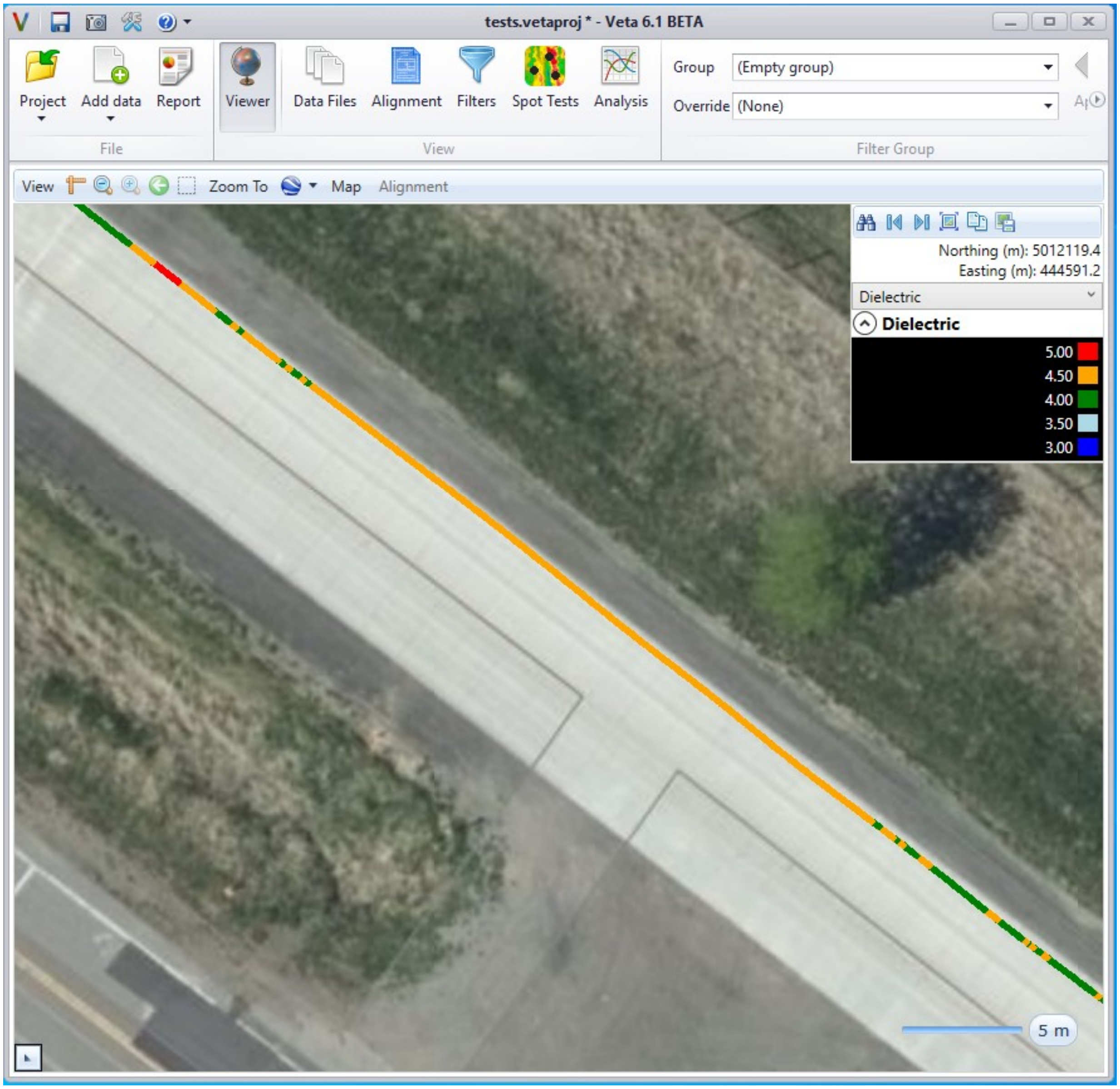

Figure 12. A screenshot of an APS scan line in the VETA Intelligent Construction software.

Conclusions

The data collected at the subdivision and the measurements presented in the preceding figures provide a very detailed account of the construction quality. For future surveys, a few suggestions are offered below to improve provide even better results.

1. The map underlays shown in the preceding plots were taken from online county maps because Google Maps satellite imagery shows an open field at this location. In locations where the roads previously exist, users would use the APS software to plot survey data on top of satellite imagery.

2. This survey only used one asphalt mix calibration point which is not typically adequate for obtaining a representative mix calibration. In normal cases either more gauge measurements are used or gyratory compactor pucks are used. The later method provides more accurate results with fewer measurements.
3. The gauge configuration of the APS was not used in this survey, but it is often useful for taking point measurements next to the joints. This configuration can be used for determining which side of the joint has more compaction issues.

The ability of the APS system to collect so many useful measurement from a single pass is truly revolutionary. Although there are other instruments available to measures surface temperature, asphalt compaction, asphalt thickness, and surface roughness, no other instrument can provide all of these measurements continuously from a single pass. The APS provides the data needed by builders to develop processes to meet specifications and demonstrate compliance. Owners and transportation departments can use the APS insure that the entire asset was built properly rather than only verifying a few points. With more and more transportation departments moving to contracts with incentives and disincentive based on percent-within-limits measurements, the APS is becoming an invaluable tool for both contractors and owners.

Appendix I: Bottcher Mixing Formula

With theoretical mixing formulas, one can calculate the expected dielectric constant of a mixture from the volume fractions and dielectric constant of the constituents (i.e., aggregate, binder, and air). The Bottcher mixing formula is given below,

$$\frac{\epsilon_{ac}-\epsilon_{bind}}{3\,\epsilon_{ac}}=\phi_{agg}\frac{\epsilon_{agg}-\epsilon_{bind}}{\epsilon_{agg}-2\,\epsilon_{ac}}+\phi_{air}\frac{\epsilon_{air}-\epsilon_{bind}}{\epsilon_{air}-2\,\epsilon_{ac}}$$, with

$$\phi_{agg}=\frac{1-\phi_{bind,max}}{1+\phi_{air}}$$

where ε_{ac}, ε_{bind}, ε_{agg}, and ε_{air} are the dielectric constant of asphalt concrete, binder, aggregate, and air respectively, and φ_{agg}, φ_{air}, are the volume fraction of aggregate, and air respectively, and $\varphi_{bind,max}$ is the volume fraction of binder at maximum compaction.

Appendix II: Variability of Nuclear Gauge Readings

When taking nuclear gauge readings on a mat, the Colorado Department of Transportation requires four measurements: two repeat measurements with the gauge on one orientation (i.e., right orientation), and two more readings with the gauge at the same location be turned 180 degrees (i.e., left orientation). ESS conducted a survey in a newly paved parking lot where nuclear gauge readings were taken at 25 different locations, with some locations in the middle of the lot and some near the edges. The standard deviation between the left and right readings at each location was 2.1% compaction. The offset in the sensor locations in the nuclear gauge (Instrotek model 3500 Explorer) was about 30 cm (12 inches) between the left and right orientations. In another study, the Wisconsin Department of Transportation (Schmitt, 2006) compared densities obtained from cores to nuclear gauge readings at 128 different locations on 16 different paving projects and found that the difference standard deviation between compaction readings from the two methods was 1.5%. The conclusion is that the variability in nuclear gauge readings is too high to use as a calibration standard for the APS system.

References

Leng, Z., 2011, Prediction of In-Situ Asphalt by Mixture Density Using Ground Penetrating Radar: Theoretical Development and Field Verification, PhD Thesis, University of Illinois at Urbana-Champaign, 144 p.

Schmitt, R., 2006, Non-Nuclear Density Testing Devices and Systems to Evaluate In-Place Asphalt Pavement Density, Wisconsin Highway Research Program, WHRP-06-12, 131 p.

Stroup-Gardiner M., and Newcomb D., 1988, Statistical evaluation of nuclear density gauges under field conditions, Transportation Research Record 1178, TRB, USA.