Quantifying Segregation in HMA Pavements Using Non-nuclear Density Devices: Data Collection Report for Connecticut

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16. Abstract
This ConnDOT project complements the National Pooled Fund Study, SPR-3(082), Phase II. Phase II was to develop a method to quantify the level of volume segregation in HMA pavements using density profiles obtained from non-nuclear (electromagnetic) density gauges. The purpose of the ConnDOT project was to collect field density data on newly placed HMA pavements for submittal to the Pooled Fund contractor (University of Utah) and to evaluate the ability of two non-nuclear devices to collect data for determining severity of pavement segregation in Connecticut. Two locations were used for the evaluation: I-84 Waterbury and Route 66, Middlefield, CT. Density measurements were made within a pre-defined grid, using the two devices (and a nuclear density gauge at one of the sites (Route 66)). Cores were cut and removed from areas thought to represent low, medium and high density areas within the grids, as determined by the various gauges. The cores were sent to the University of Utah for analysis of gradation, air voids and asphalt content. The results indicate that the density variations measured with the non-nuclear devices were not very useful for determining volume segregation or uniformity at these two project sites.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Table of Contents

List of Figures

List of Tables

List of Photographs

Quantifying Segregation in HMA Pavements
Using Non-nuclear Density Devices:
Data Collection Report for Connecticut

Background and Significance

Identification, categorization and quantification of segregation* within newly constructed hot mix asphalt (HMA) pavements continues to be problematic. After many years of concentrated effort by ConnDOT and the paving industry to eliminate segregation, some paving contractors with certain paving mixes, (and especially if remixing equipment is not employed,) are still placing segregated HMA pavements in Connecticut. It is well established that pavement segregation leads to premature deterioration including raveling, oxidation, potholes and cracking. The onset of these distresses subsequently reduces the service life of the pavement./2/ It is therefore important for ConnDOT to be able to identify the presence of segregation during construction or as soon thereafter as possible, so that corrective action can be taken and/or appropriate penalties assessed. Traditional methods for identification of segregation are primarily visual observations, or surface texture measurement, and can be in combination with density measurements. These methods are not entirely foolproof, and are not always practical nor timely to use. Pavement coring is destructive and disruptive, and the use of nuclear density gauges can be costly. These methods, even when successful, provide information that is not timely enough for corrective action to be taken by the contractor. It has been postulated that non-nuclear devices such as electromagnetic density gauges offer some hope for quickly identifying changes in density during or immediately after construction./3/

During 1999 and 2000, the Connecticut Department of Transportation (ConnDOT) contributed to and participated with five other states (Maryland, Minnesota, New York, Oregon and Pennsylvania) in national pooled-fund study number SPR-3(082) entitled, “Evaluation of PQI.” A separate ConnDOT research project was also established at that time under the Connecticut SPR research program to supplement the Pooled Fund Study. That research project (SPR 2227) was titled, “Evaluation of the Next Generation Pavement Quality Indicator (PQI) Device.” (A final report for the study was published in May 2001, reference /4/.)

The PQI™, manufactured by TransTech Systems Inc., is marketed as a non-nuclear alternative to density measurement for use in quality control of pavement construction./5/ The PQI gauge does not measure density directly. Its operation is based upon the density of asphalt being directly proportional to the measured dielectric constant of the material, i.e. the material’s ability to store electrostatic energy per unit volume. The PQI establishes a toroidal electrical field in the pavement and measures the electrical impedance, which is a function of the composite dielectric constant of the pavement and air contained within the voids./6/

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*Segregation- The non-uniform distribution of coarse and fine aggregate components /1/

As part of the pooled-fund Study SPR-3(082), in 2000, ConnDOT upgraded its PQI unit to a Model 300 series. The field performance of the PQI gauge was evaluated for determination of HMA pavement density in all six of the participating states. Ten (10) sites were selected from ongoing paving projects in Connecticut for this purpose. For comparison, nuclear density tests were performed at the same locations where PQI readings were taken. Pavement cores were also cut and tested in accordance with AASHTO T 166.

Based upon the results of the ConnDOT research study, it was concluded that poor correlation existed between the density determined with the PQI Model 300 instrument and from pavement cores obtained in the field, as indicated by an average R-squared value of 0.28 for the ten (10) sites evaluated. This poor correlation was postulated to be due to the presence of moisture in the HMA introduced during compaction rolling operations./4/

TransTech Systems made additional enhancements to the Model 300 PQI shortly after Connecticut’s SPR study was completed. This Model, designated the 300+, was subsequently used by the other five (5) participating states during a second stage of the Pooled Fund Study. It was also evaluated by FHWA at the Turner-Fairbank Highway Research Center Laboratory in 2001. In addition, another non-nuclear device called the PaveTracker Plus™ was evaluated during the extension of the pooled fund study in 2001. ConnDOT did not participate in the second-stage portion of the pooled fund study.

In the Executive Summary from the final report for the pooled fund study, prepared at the University of Utah in 2002,/7/ it was reported that “in order to use non-nuclear gauges to obtain absolute pavement density, calibration using the same materials is needed. Since this is often difficult to accomplish neither the modified PQI 300+ nor the PaveTracker Plus were considered suitable to measure pavement density for quality acceptance (QA) purposes... however, the devices were accurate for quality control (QC) applications.” This is further elaborated in the conclusions of the same report where it is stated that “the ability to take multiple measurements in short periods of time makes them attractive devices for quality control of pavement density during construction.”/8/ Also in this report, it is further stated that, “The ability to take measurements in just seconds combined with their lightweight and portability makes them ideal devices to evaluate the uniformity of pavements. This includes detection of segregated, non-uniform, areas.”/3/

In 2004, Pooled Fund Study SPR 3(082) was again extended (or resurrected) into yet another phase, so that the use of the non-nuclear gauges could be evaluated for determining volume segregation.* ConnDOT elected to re-join the pooled fund study, along with Maryland, Oregon, Pennsylvania and New York, for the purpose of evaluating the gauges (both PQI and PaveTracker Plus) for the identification of volume segregation. A consultant (University of Utah, Department of Civil and Environmental Engineering) was contracted by FHWA to perform laboratory testing of mixes, and for the testing of participating state’s supplied

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* Volume Segregation- is the same as gradation segregation or particle segregation.

cores, in order to develop algorithms relating segregation to relative density measurements. Field measurements and cores were to be obtained by ConnDOT as well as the other four states. A second Connecticut SPR research study (SPR 2238) was established to perform the field activities in order to complement the latest phase of this Pooled-Fund Study.

Study Objectives

The objective of the National Pooled Fund study Phase II is to develop a method to quantify the level of volume segregation in HMA pavements using density profiles obtained from non-nuclear (electromagnetic) density gauges. The ConnDOT research project, which complements the pooled fund study, evaluates, in the field, the ability of two non-nuclear gauges to collect data that may be able to be used to determine the severity of segregation. The collection and submittal of field samples to the University of Utah provides the pooled fund study with materials to verify and refine algorithms developed for categorizing the uniformity of a pavement.

Expected Benefits and Potential for Implementation

The motorists or highway users are the customers and major benefactors of safe, smooth and long-lasting pavements. Major disruptions to traffic are possible and many times unavoidable during milling, paving or maintenance of roadways. However, “Get in, get out, and stay out!” is the mantra of today’s motorist. ConnDOT, as with all state DOTs, is obligated to test and apply new technologies that have the potential to lengthen pavement service life, reduce time spent maintaining roadways, reduce the resultant user delays, and thus likely reduce the overall costs of transportation maintenance.

It was anticipated that the findings derived from this study would allow ConnDOT to determine the effectiveness of the PQI and PaveTracker Plus to identify and categorize segregation into severity levels. It was felt that if this study proved either or both of these to be effective tools, additional devices could be purchased for use by ConnDOT Construction inspectors (or consultants) for quality control of pavements.

Paving contractors doing business in Connecticut also have the potential to benefit from positive results of this study in that should the non-nuclear gauges prove useful for quick and easy identification of pavement uniformity or segregation, changes to placement techniques could be made almost immediately, on the fly, leading to improved pavement quality and reduced likelihood of assessed penalties.

Researchers will make presentations to the ConnDOT HMA Task Force for Pavement Improvement, at the conclusion of the Pooled Fund Study. Working in conjunction with the Task Force, steps will be determined on how to effectively present the results to the HMA industry and ConnDOT, as well.

Project Work Tasks

Since this project is to complement the Pooled Fund Study SPR 3-(082) phase II, the scope of work encompasses only four tasks within ConnDOT:

(1) Identification of up to five construction projects for data collection;
(2) Field data collection for density uniformity on the projects;
(3) Submittal of cores and data to the Pooled-Fund contractor; and,
(4)- Preparation of a summary report.

The work tasks being performed by the pooled fund study contractor (University of Utah) as part of the pooled fund study are as follows:

(1) Asphalt samples will be prepared in the laboratory with different levels of segregation. Based on measurements taken using non-nuclear devices a set of segregation criteria will be defined so that the segregation level recorded by the device can be correlated to actual asphalt mixture parameters./3/

(2) From cores provided by each state from actual construction projects, and data obtained with the non-nuclear density gauges in these same states, changes in density will be compared to changes in mixture parameters in the same way that is done with the laboratory samples./3/

(3) From the results of laboratory and field data, algorithms for determining uniformity across a pavement section from measurements or calculations of density at depths of approximately two (2) inches will be developed./3/

Data Collection Plan

Within each field project used for data collection, locations containing pavement segregation were to be selected, as determined from visual observation. At each selected location, the paving mat relative density would be measured and recorded at short intervals, approximately every 12 inches transversely across the pavement lane width. This would be repeated at several locations adjacent to the first area so that approximately 120 sf (10 ft length by 12 ft width) of pavement area was measured. Each site would be subsequently cored at places where high, medium and low densities have been determined to be present using the PaveTracker Plus, the PQI Model 301 and/or nuclear density gauge measurements. The cored specimens and density data would be forwarded to the University of Utah for their analysis of gradation, asphalt content and voids. The University was expecting to receive a total of at least 100 cores from the participating pooled-fund study states./6/ (See Appendix A for detailed description of field data collection.)

Study Sites in Connecticut

ConnDOT identified paving/construction projects suitable for data collection for field construction monitoring. Suitability for sampling was determined on the basis of accessibility, pavement layer thickness, and ability to locate differential segregation. Although the original study goal was to locate up to five projects, only two suitable projects were identified. Other sites considered were open to the public immediately after paving, so potentially had experienced additional compaction on the mix due to traffic loads. These sites also would have required lane closures for data collection.

The two construction projects selected for this study are on I-84 in Cheshire/Waterbury (Construction project 151-274) and State Route 66 in Middlefield (construction project 81-80) (see photos 1 & 2.) The variation in density found at these two locations appeared to meet the requirements of the Pooled Fund Study for collection of samples. Some pertinent information (location descriptors, traffic volume, pavement structure thickness, overlay thickness and geometry) about the study sites for these two locations is presented in Table 1. The pavement mixture design properties are given in Table 2 (later in this report.) Both sites had minimal traffic after paving and prior to sampling. Therefore, it is unlikely that additional compaction occurred that could be attributed to traffic. The paving contractors did not employ material transfer or remixing devices at either location for pavement laydown.

Photo #1, I-84 Eastbound, Waterbury (Project 151-274)

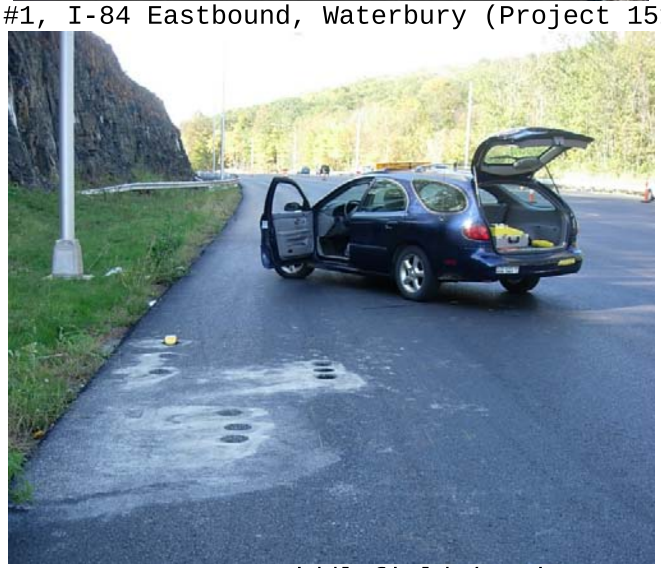
Photo #2, Route 66, Middlefield (Project 81-80)

Table 1, Study Site Attributes

Site Location	I-84 EB, Waterbury, log mile 37.43, low-speed travel lane	Route 66 EB, Middlefield, log mile 1.65, Right Shoulder
Surface Layer Thickness	3 in.	1.5 in.
Surface Layer Design Nomenclature	12.5 mm mix	0.5 in. mix
Leveling Course Thickness	1 in.	1.5 in.
Leveling Course Design Nomenclature*	9.5 mm mix	0.5 in. mix
Base Layer Thickness	6 in.	6 in.
Base Layer Design Nomenclature*	37.5 mm	1.5 in mix
2001 ADT	87,500	27,800
Geometry (grade %, # of through lanes)	1, 3	2, 2
Paving Date	NA	10/05/05
Sampling Date	6/9/05 & 6/21/05	10/17/05
GPS** ref. points (approx. lat and long.)	41 32.18’ N 72 57.77’ W	41 31.94’ N 72 44.18’ W

* Superpave Design

** Measured with TRIMBLE™ GeoExplorer CE 49050-60

Equipment Used by ConnDOT for Data Collection

A PaveTracker Plus™ was obtained via the FHWA project monitor at Turner Fairbank Highway Research Center, using Pooled Fund Study funds. The PaveTracker Plus is a model M2701B manufactured by Troxler Electronics (see photo #3). The previously-owned ConnDOT PQI was upgraded as part of the Pooled Fund study to be functionally equivalent to a Model 301+ (See photo #4.) There were no difficulties using either device when the field data were collected for this study.

The nuclear density gauge (used on route 66 only) was a Model C-300 by Seaman™ (photo #5) operated in backscatter mode by Mr. Jim Sullivan of Keville Enterprises, Inc., East Berlin, CT. This unit is typical of those used for quality assurance at paving projects in CT. The nuclear gauges are calibrated using a granite block housed at the ConnDOT Materials Testing Laboratory in Rocky Hill. All ConnDOT and contractor gauges use this same calibration block. (Also, beginning in 2005, cores are used on specific projects for calibrating nuclear gauges.)

A ConnDOT-owned portable core drill (Dymodrill by Milwaukee™, see photo #6) was used for field cores. This provided 6-inch diameter cores, for submittal to the University of Utah. The core holes were re-filled by the construction contractor, per order of the ConnDOT inspectors.

Both of the electromagnetic density devices were easy to setup and use, following the manufacturer’s literature. There were initially some problems with the PaveTracker Plus, and it had to be returned to the manufacturer twice for analysis and repairs before it could be used in the field. The problems with it included some software glitches that affected calibration (a message popped up “reference value out of range”), and power management issues that prevented recharging the unit. These were repaired by Troxler under warranty.

Photo #3, ConnDOT PaveTracker Plus, Model 1701B

Photo #4, ConnDOT Pavement Quality Indicator (PQI), Model 301+

Photo #5, Seaman Model C-300 Nuclear Density Gauge

Photo #6, ConnDOT Portable Coring Rig Cutting Cores on I-84

Sampling and Submittal of Field Data

A recommended data collection plan was provided from the University of Utah for use by all participating states for field data sampling at each project site. The sampling instructions and data collection plan is included in Appendix A for reference. The plan ensured that all participating states collected the data in a consistent manner. The plan also made sample management and testing easier for the University of Utah.

Potentially segregated pavements were visually identified in the field at each site. A grid was measured and laid out on the pavement in accordance with the University of Utah plans (see photos #7 & 9). Then one or more of the density gauges was used to determine if a variation in density over the site could be measured (to confirm the visual observations). There was some risk in site selection due to the fact that only surface segregation can be seen visually, while the electromagnetic devices measure density (indirectly) at 1 to 2 in. below the surface. At each location, if the variation appeared to be insignificant another location was selected on the construction project, and a new grid was laid out. This was repeated until a suitable location was found for each paving project.

Each selected monitoring location represents approximately one lane width and a distance of at least 12 feet longitudinally within the lane. This area on the pavement (minimum 144 sf) was monitored with a density gauge and “mapped” by collecting density data every two feet in both the lateral and longitudinal directions (see photo #8). A plot or tabular format of the data was then used to determine the highest and lowest apparent density within the mapped area of pavement (see Table 3 in Appendix B). Six-inch diameter pavement cores were then taken at three areas, the highest, the lowest and a mid range density area (two cores per level of segregation for a total of six cores per site) (see photos #6 & 10). Due to a thinner pavement surface course on route 66, nine cores were removed (see photo #11) to ensure enough pavement material for performing the gradation analyses at the University of Utah.

Photo #7, Coring and Measurement Grid, I-84

Photo #8, Density Measurements with PQI, I-84


Photo #9, Coring and Measurement Grid, Route 66

Photo #10, Cores Removed (A9, B11), Route I-84

Photo #11 Cores Removed Route 66, Middlefield

ConnDOT ultimately provided a total of 15 cores to the University of Utah from the two sites. As of December 2005 cores had been provided from three other states as follows: New York-12; Pennsylvania-39; and Oregon-7. Maryland and New York were expected to provide additional cores for testing, so the goal of 100 was potentially still achievable.

All of the density measurements from the various gauges and the pavement cores were sent to the University of Utah for laboratory analysis. Their laboratory determined aggregate gradations, voids and asphalt content for all of the cores. These data were analyzed with similar data from the other states and with laboratory produced samples to check algorithms that relate the output of the electromagnetic gauges to the actual segregation in the field samples./3/ The job mix formula for the two ConnDOT projects and some of the results from the cores sent to Utah are given in Table 2

Data Presentation

All of the uncalibrated density data from the two field locations (Route 66 and I-84) are presented in Tables 3 and 4 respectively, in Appendix B. The grid used for field sampling varied somewhat from the original instructions. On route 66 sampling occurred at 2-ft intervals over a 6-ft wide by 12-ft long (direction of traffic) area, whereas on I-84, 2-ft intervals were used to measure over a 12-ft wide by 24-ft long section.

Route 66

The section selected and mapped on route 66 was on the right shoulder in the eastbound direction, at log mile 1.65 shortly after the highway changes from a median divided to undivided roadway (see photos #2 & 11).

Table 2
HMA Mix Design Properties and Measured Properties from Cores

	I-84 Design Job Mix Formula	I-84 Actual range from Cores* /ref 10/	Route 66 Design Job Mix Formula	Route 66 Actual range from Cores* /ref 10/
Design Properties	12.5 mm		12.5 mm	
Asphalt Content (percent)	5.0	4.75-5.06	4.9	4.24-5.02
VMA (percent)		6.14-7.10		4.39-15.40
Gradation	**% Passing Target**	**% Passing Actual**	**% Passing Target**	**% Passing Actual**
Sieve (mm,in.)				
19.0,3/4	100	100	100	100
12.5,1/2	98.0	96	95.0	91-97
9.5,3/8	81.0	77-79	86.0	72-80
4.75,#4	46.0	50-53	65.0	44-53
2.36,#8	33.0	37-38	45.0	31-38
1.18,#16	24.0	27-28	30.0	22-27
0.03,#50	12.0	12-13	14.0	11-12
0.0075,#200	3.3	2.9-3.2	4.0	3.5-3.8

*Information from tests on cores sent to University of Utah

All three density gauges were used on route 66. The ‘raw’ relative density (i.e., uncalibrated and therefore not true density) readings on route 66 varied from 154.0 to 159.2 (range of 5.2) for the PaveTracker Plus; from 148.4 to 162.5 (range of 14.1) for the PQI; and 144.9 to 163.9 (range of 19.0) for the nuclear density gauge. Although the highest and lowest values for each device do not coincide exactly, two of the three devices produced higher readings near grid cells C5 & C6 and lower readings in the neighborhood of cell B3 (see Table 3, Appendix B).

The PaveTracker Plus had the smallest variation in density measurement within the area tested on route 66, and it would have been nearly impossible to select the high and low density areas of the pavement using that device alone. The three highest readings occurred in cells D3, C5 and A4, lowest in cells C2, C4 and D4 (see Table 3, Appendix B). These high and low areas are somewhat scattered and do not coincide with the two areas noted above, which were selected for the cores.

Cores were taken from cells of the grid in Table 3 labeled as: C5, C6 (high); B3 (low); and D1, D3 (medium). The core holes can be seen in photos #2 & #11. The average density measured with each device for these three areas is given at the bottom of Table 3.

I-84

The site selected for sampling on I-84 is located in a right through travel lane, which was being added to increase capacity of this highway. It is located at log mile 37.43 in the eastbound direction. The raw relative density readings for I-84 (Table 4, Appendix B) varied from 143.6 to 163.7 for the PQI, (range of 20.1), and 134.9 to 155.9 (range of 21.0) for the PaveTracker Plus. The nuclear density gauge was not used on I-84. The PaveTracker Plus measured a wider range of densities (by a factor of four) at this location compared to route 66. The PQI density range was also greater on I-84, but only by a factor of one-half, i.e., 50 percent.

The cores for I-84 (photos #6 & #10) were taken at grid locations: A9, B11 (high); D5, E6 (low); and, E10, F11 (medium) (see Table 4, Appendix B.) The average density measured with each device for these three areas is given at the bottom of Table 4. Since this was a thicker pavement surface layer than route 66, only two cores per density location were removed, vs. three cores at each area on route 66.

Even though two locations (I-84, Route 66) is not a large population from which to draw rigorous conclusions, since the data sets exist, it was decided to compare the PQI, PaveTracker Plus and nuclear density readings. Graphs of PQI vs. PaveTracker Plus, PaveTracker Plus vs. nuclear gauge and PQI vs. nuclear gauge densities are given in Figures 1A, 1B, 2, and 3 in Appendix C. The graphs contain R-squared values for a straight line calculated to pass through the points for each graph. These R-squared values, which represent the coefficient of determination, or the correlation squared, show very poor correlation between any of the device's measured output for the sites on I-84 and Route 66. A comparison with the core data is not done for this report. This information will be available in the final report of the Pooled Fund Study from University of Utah.

General Discussion of Findings

On the I-84 location selected for data collection, looking at the tabular data presented in Table 4 of Appendix B, it can be noted that the highest density appears to be along a longitudinal strip on the left side of the lane that is close to the longitudinal paving joint. In table 4, this appears as the top row of data. This could lead to speculation that the compaction was not uniform throughout the section, which would violate the premise that change in measured density is due to segregation levels for this location. The results of the analysis done on the cores at the University of Utah (Table 2) show this to be likely as very little difference in gradation was found between the cores taken from the high density area vs. those taken from the low density area.

On the route 66 study location, the highest and lowest areas of relative density occurred in patches, somewhat more randomly than on I-84. On 66, the cores indicate a much greater variation in gradation across the roadway than was found on I-84 (see Table 2). This leads to a finding that the route 66 pavement tested is less uniform than the I-84 section that was selected for the study.

Unfortunately, it is not intuitively obvious from the data obtained with the non-nuclear devices alone that the route 66 pavement is less uniform than I-84. The range of PQI data (14.1 on 66 and 20.1 on I-84) and PaveTracker Plus data (5.2 on 66 and 21.0 on I-84) might lead one to conclude that I-84 was less uniform than Route 66. This is the opposite of the findings from aggregate gradations measured from pavement cores taken in the field. There was also a greater variation in voids as determined from the cores (Table 2) for route 66. Thus, there appears to be inconsistency in the ability of the non-nuclear gauges to measure variation in density, as well as interpreting what it means when they do measure significant variation in density in a given area. The reason for this is not known.

Conclusions

Spatial variations in density for a new pavement can be the result of one or more factors. The primary factors are level of compaction applied, the mix design itself (particularly the aggregate sizes and proportions) and construction irregularities such as particle segregation. Therefore, even if the non-nuclear density gauges could accurately detect variations in density, this information alone would not be positive proof that segregation exists. Accurate measurements of density could only provide information on the level of uniformity of the mix. Cores or other measurements would need to be taken to confirm the presence or absence of segregation. On the other hand, a pavement that contains uniform measurements of density is unlikely to contain segregation. The Pooled-Fund project report, which is due for publication in mid-2007 by the University of Utah, Department of Civil and Environmental Engineering will address categorizing uniformity and segregation in detail. This is beyond the scope of this current SPR study. ConnDOT has pledged $32,000 to the Pooled-Fund Study and is a member of the technical advisory committee.

From Connecticut’s experience collecting data for input to the Pooled Fund Study, it was determined that although they are relatively fast and easy to use, due to the variability of data results the non-nuclear gauges do not appear to be useful for detecting non-uniformity. The cores taken from the study sites on I-84 in Waterbury and route 66 in Middlefield, which were tested at the University of Utah, indicate that there is non-uniformity in gradation and air void content for the site on route 66; while the I-84 site is very uniform. Whereas, using the results of the measurements from the PQI and/or the PaveTracker Plus, due to the range of densities measured one might conclude that the opposite is true, i.e., I-84 study site contains more non-uniformity than route 66. It is unclear why these results occurred.

The nuclear density gauge showed the greatest range of density on route 66 (compared to the other two gauges,) which could indicate a better chance of determining that route 66 contained non-uniformity. Unfortunately, the nuclear gauge was not available for testing on I-84, so it cannot be stated whether it would have been used to categorize the two study sites correctly, relative to the core information.

Additional work may need to be performed with the PaveTracker Plus and PQI to completely rule out their use for non-uniformity detection. However, for the Connecticut portion of the Pooled Fund Study, a cursory analysis of the data does not support continued use of either the PQI or PaveTracker Plus to determine severity of segregation in HMA pavements immediately after construction.

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APPENDIX A – Sampling Instructions and Data Collection Plan for Pooled Fund Study
Segregation of Hot-Mix Asphalt Using Electromagnetic Density Gauges

Instructions

The purpose of this project is to collect samples from areas within a newly constructed mat that might have differences in composition (i.e., segregation). In other words, a core from one area might have a different composition (gradation, voids, and asphalt content) than a core from another area. The project selected should be a newly paved surface mixture that has not seen significant traffic. The work will concentrate on dense graded mixtures but gap graded mixes (i.e., SMA, OGSC) can be investigated.

The samples will be sent to the laboratory at the University of Utah for further analysis.

Density Measurements

1- Select a newly constructed project with 2 or more inches of HMA (1.5 inches can be acceptable if nothing else is available)
2- Wait for the compaction/rolling process to be completed. Old projects are not acceptable since compaction under the wheel path, debris, anti-icing chemicals, etc. can affect the correlation with the electromagnetic gauges.
3- Identify an area, approximate 25-feet long along a lane where non uniformity might exist. Record this location (milepost, Lat and Long) using a handheld GPS unit for future reference and take a digital image.
    a. This is an area where unusual conditions might exist. Perhaps it is a transition area, the hoper cleared the wings, the roller had to stop, or some other construction related condition. However, stay clear of shoulders and such.
    b. A visual assessment can also be used to select an area. Look for indications of segregation, fat spots, draindown of asphalt, etc.
    c. Other methods such as infrared cameras or surface texture, etc. can also be used and would be a great supplement to the study.
4- Starting at the edge of the lane determine the relative density of the mat using an electromagnetic density gauge (i.e., PQI, PaveTracker Plus). Record this value.
    a. The electromagnetic gauge should be calibrated when possible but since the readings are relative, it is not a critical step.
    b. There is no need to rotate the gauge, only one <u>stable</u> measurement is needed.
5- Take a small step (~2 feet) across the mat (along the transverse direction) and record the relative density at the new spot.
6- Repeat this process until the end of the lane is reached.
7- Once the relative density along the transverse direction has been recorded, move 2-3 feet along the longitudinal direction, then record the relative density.
8- Repeat steps 4 through 7 until the relative density of the mat has been mapped (see example).

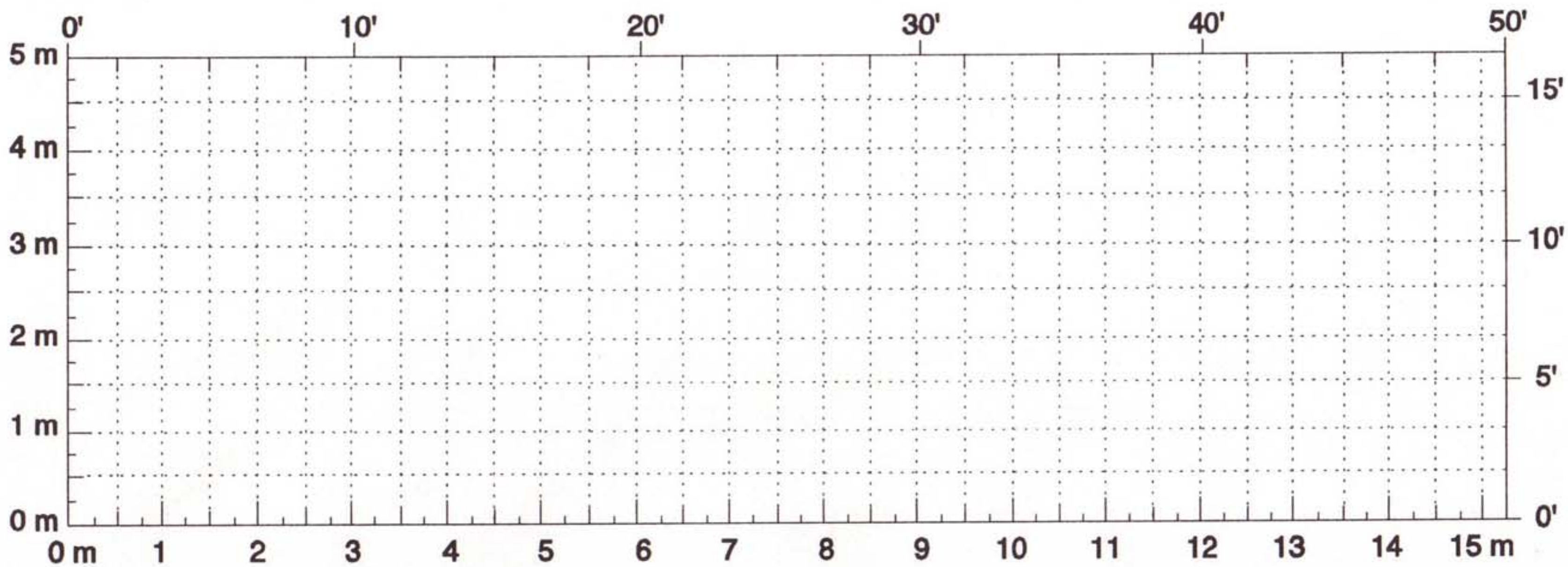
9- The values can be easily entered into an MS Excel worksheet.

Selection of Cores

1- Once a relative density profile of the mat has been established, look for areas of low and high density values. Mark these locations on the sketch.
2- Within the low and high density area mark the spot to take 2 cores from the low density area, 2 cores from the high density area, and 2 cores from and intermediate area. The cores should be 6-inch in diameter. The cores should be next to each other. If the layer is less than 2-inch thick, 3 cores will be needed. The idea is to have enough material to get representative gradations.
3- Label the cores then pack them for mailing. Be aware that during the summer the heat might damage the cores. PVC pipes or other suitable packing material is encourage
4- Mail samples to the University of Utah at the following address

Pedro Romero / Oscar Moreno
Department of Civil and Environmental Engineering
122 South Central Campus Drive, Suite 104
Salt Lake City, UT 84112-0561
Phone: 801-587-7725

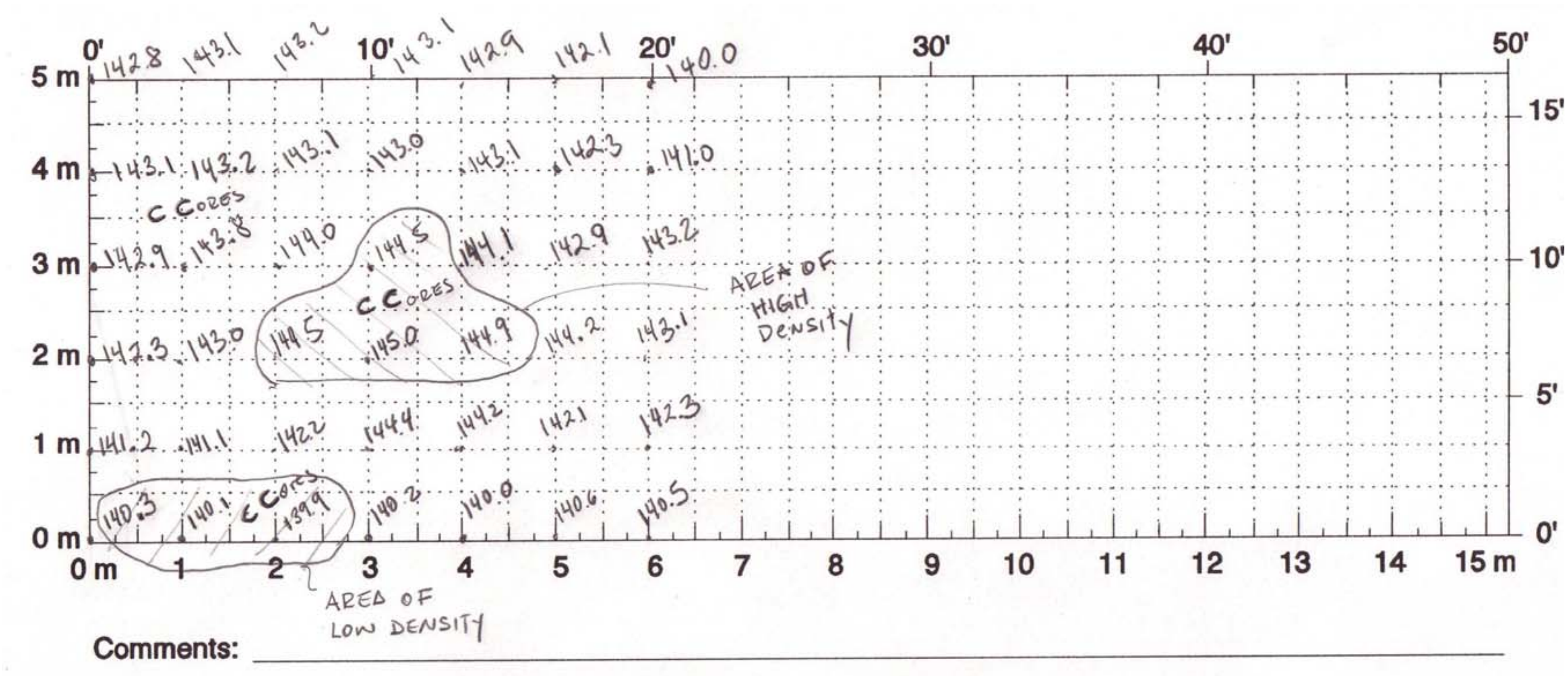
State____________________
Project ID________________
Date____________________
Location_________________



Comments: ____

Notes: (1) Select an area approximately 25-feet long where non-uniformities are likely to exists
(2) Take density profiles at every 2-3 feet along the transverse direction and record the values on the sketch.
(3) Move 2-3 feet along the longitudinal direction and repeat until the area is profiled.
(4) Only one reading is required; however, reposition the instrument if the reading is not consistent with the rest.
(5) Obtain 6-inch cores, two from an area of low density, two from an area of medium density and two from an area of high density. Mark the location on the sketch above.

Example data collection



Appendix B, Table 3

Relative Density Readings from the PQI, nuclear and PaveTracker Plus
Route 66 Site, Middlefield*

		1	2	3	4	5	6
PQI	**A**	153.8	160.3	161.2	160.7	158.1	154.7
Nuc. Gauge	**A**	160.1	159.0	157.1	156.8	157.8	158.4
PaveTracker Plus	**A**	155.9	156.3	156.5	157.2	155.8	156.5
PQI	**B**	155.4	154.9	***148.7***	148.4	152.5	158.8
Nuc. Gauge	**B**	150.1	148.7	***144.9***	149.0	152.0	152.3
PaveTracker Plus	**B**	157.1	156.7	***155.8***	157.0	159.2	154.2
PQI	**C**	162.1	157.9	160.0	161.0	**158.9**	**162.5**
Nuc. Guage	**C**	161.3	160.0	162.1	160.2	**162.8**	**163.9**
PaveTracker Plus	**C**	156.3	155.3	156.1	154.0	**157.4**	**156.4**
PQI	**D**	***151.7***	***151.3***	***149.2***	156.0	153.2	161.4
Nuc. Gauge	**D**	***157.2***	***156.8***	***154.9***	156.6	155.6	155.6
PaveTracker Plus	**D**	***156.0***	***156.6***	***158.6***	155.5	157.4	156.3

*NOTE: A-D = 6 feet transversely across pavement **CORES WERE TAKEN in CROSS-Hatched AREAS:**
1-6 = 12 feet longitudinally (direction of traffic)

SUMMARY OF TABLE 3		**Average Density (pcf)**		
Density Category	**Grid Locations**	**PQI**	**Nuclear**	**PaveTracker Plus**
High	***C5-C6***	160.7	163.4	156.9
Medium	***D1-D3***	150.7	156.3	157.1
Low	***B3***	148.7	144.9	155.8
	Range of Averages	12.0	18.5	1.3
	Range of all values	14.1	19.0	5.2

Appendix B, Table 4

Relative Density Readings from the PaveTracker Plus and PQI,I-84 Site, Waterbury

		1	2	3	4	5	6	7	8	9	10	11	12
PQI	A	158.4	162.8	163.2	163.7	163.1	153.8	162.9	158.1	***160.7***	***160.8***	***161.0***	162.2
PaveTracker Plus	A	147.2	153.3	153.6	152.5	152.7	151.3	151.8	151.3	***151.6***	***151.7***	***155.9***	153.7
PQI	B	152.9	156.4	152.1	153.7	156.8	155.6	156.4	155.5	***158.3***	***160.9***	***159.2***	161.6
PaveTracker Plus	B	147.6	150.6	147.4	146.4	148.4	149.9	149.5	150.8	***151.7***	***149.5***	***150.8***	147.7
PQI	C	154.3	148.1	159.9	157.8	157.2	154.2	158.3	156.0	162.1	156.4	157.2	157.9
PaveTracker Plus	C	149.3	149.8	152.3	149.8	141.8	149.3	143.3	141.0	154.7	151.5	150.3	147.2
PQI	D	156.5	158.4	159.8	160.9	***151.5***	***147.3***	149.5	149.5	157.4	155.2	156.3	157.9
PaveTracker Plus	D	151.5	150.7	151.0	147.8	***141.7***	***145.7***	144.5	142.8	149.1	147.9	145.1	146.3
PQI	E	153.6	153.7	148.0	152.0	***147.2***	***143.6***	151.4	150.1	151.3	**154.0**	**150.2**	155.2
PaveTracker Plus	E	149.0	151.3	143.8	150.8	***144.5***	***144.0***	144.6	145.0	150.1	**151.0**	**150.0**	148.8
PQI	F	157.0	153.6	155.2	151.6	152.7	153.3	151.3	154.1	151.0	**152.8**	**153.3**	149.5
PaveTracker Plus	F	146.3	145.5	149.5	144.5	146.5	137.5	134.9	148.2	151.6	**151.7**	**150.8**	150.9

*NOTE: A-F = 10 feet transversely across pavement **CORES WERE TAKEN in CROSS-Hatched AREAS:**
1-6 = 24 feet longitudinally (direction of traffic)

SUMMARY OF TABLE 4		**Average Density (pcf)**		
Density Category	**Grid Locations**	**PQI**	**Nuclear**	**PaveTracker Plus**
High	***A9-B11***	160.2	NA	151.9
Medium	***E10-F11***	152.6	NA	150.9
Low	***D5-E6***	147.4	NA	144.0
	Range of Averages	12.8	--	7.9
	Range of all values	20.1	--	21.0

Appendix C Comparison of PaveTracker Plus, PQI and Nuclear Density Gauge Measurements

Figure 1A – PaveTracker Plus as a Function of PQI for I-84, Waterbury

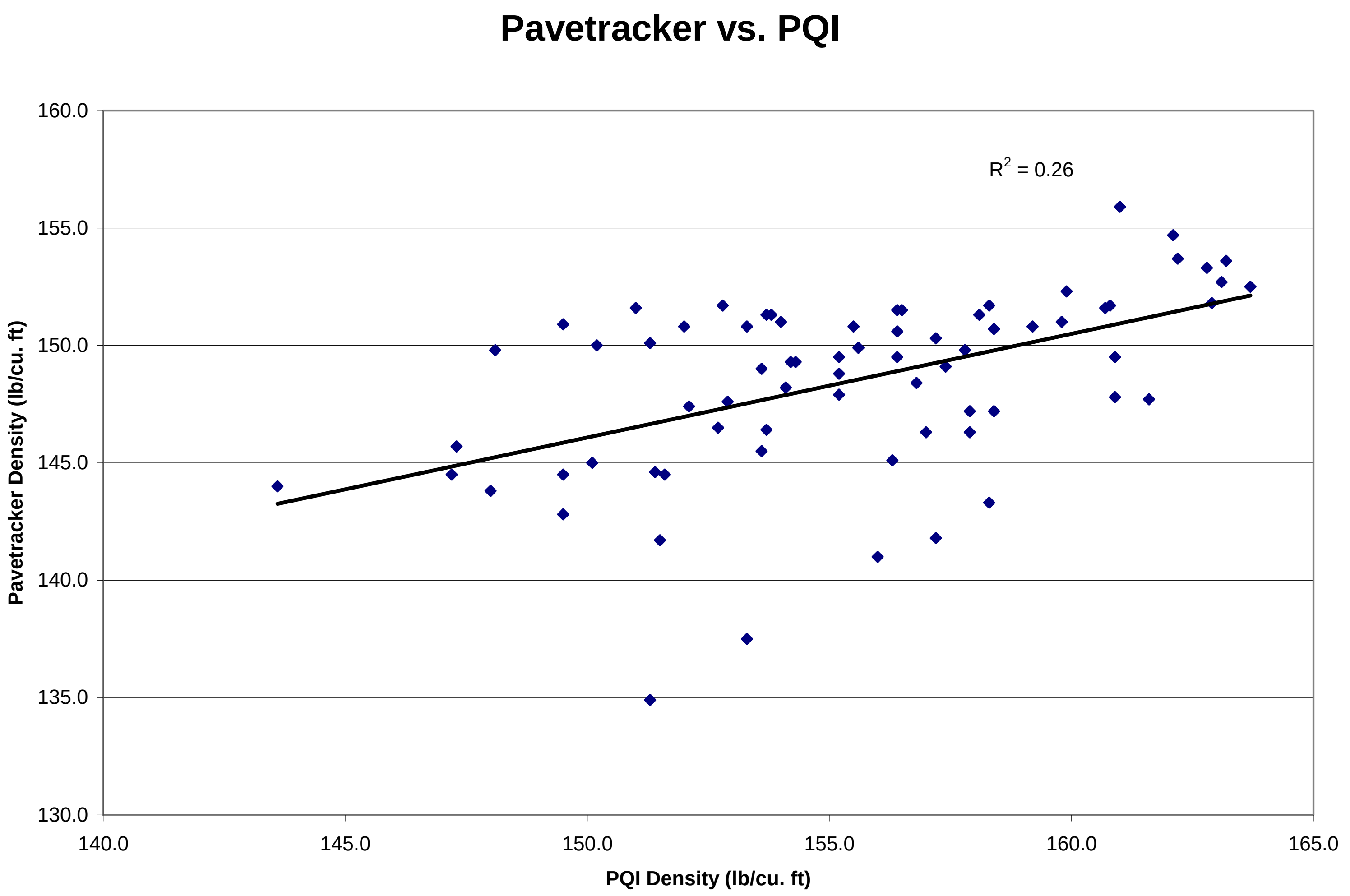


Figure 1B – PaveTracker Plus as a Function of PQI for Route 66, Middlefield

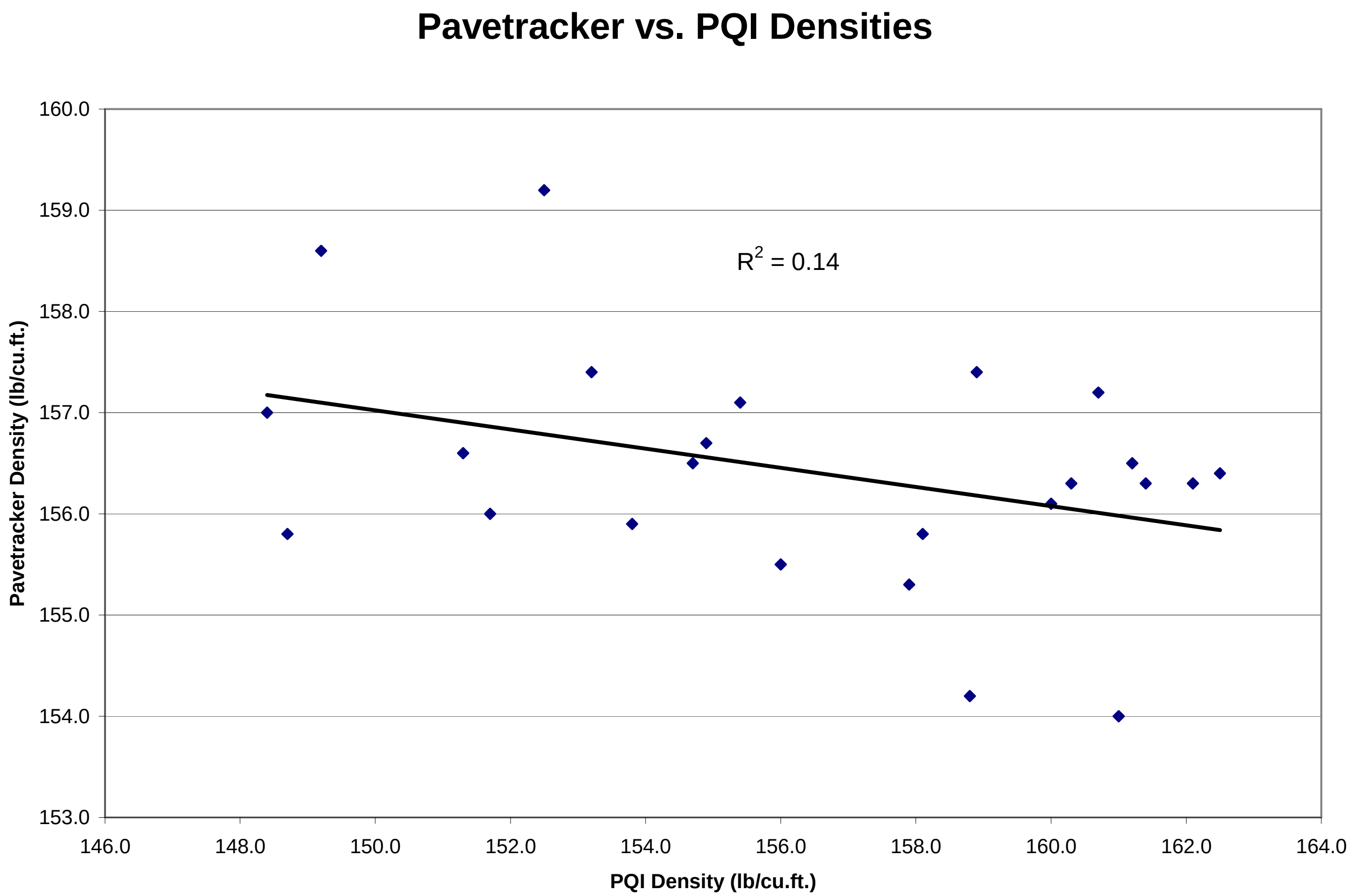


Figure 2 PQI as a Function of Nuclear Gauge Density for Route 66 Middlefield

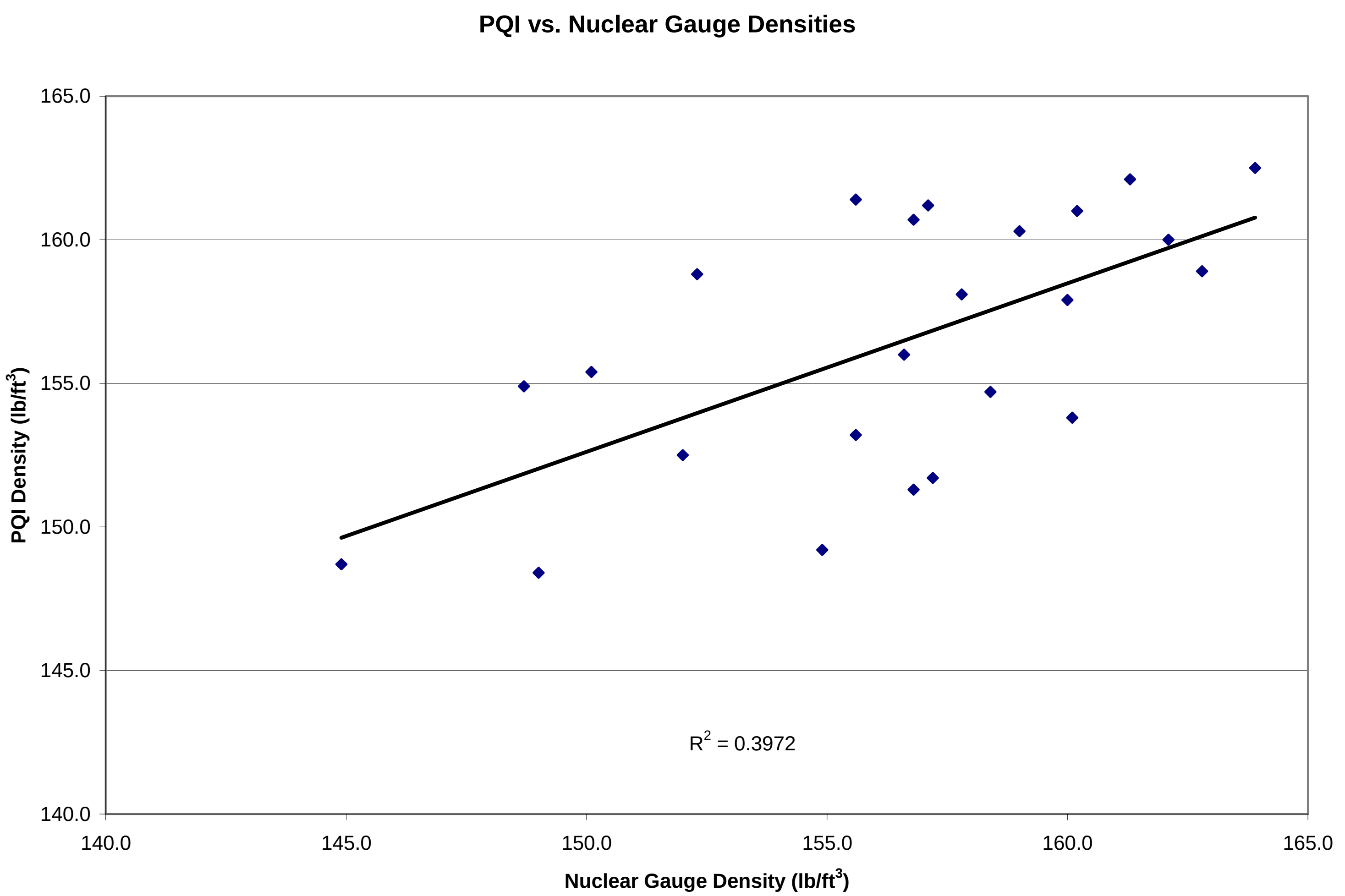


Figure 3 PaveTracker Plus as a Function of Nuclear Gauge Densities for Route 66, Middlefield