

**DETECTION OF SEGREGATION IN ASPHALT PAVEMENT MATERIALS USING THE
ARAN PROFILE SYSTEM**

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ABSTRACT

Pavement life can be significantly affected by segregation in asphalt materials. Recently, automated devices have been investigated to identify segregation and its effect in the performance of asphalt materials (1). In a research project conducted for the New Jersey Department of Transportation (NJDOT) several segregation detection and measuring methods were evaluated to identify the best technology. These included; visual identification, thermal imaging, nuclear density gauges, sand patch testing and several laser texture-measuring devices. After evaluating the advantageous and disadvantageous of each method, the laser texture-measuring device was selected since it offered rapid data collection phase without interrupting traffic. The ARAN was selected because the NJDOT had one available. By combining the level of segregation and extent of each level of segregation, an AREA index was developed to determine the acceptance or non-acceptance of a pavement section. New segregation detecting and monitoring software, "NJTxt" was developed by combining the use of the ARAN-collected pavement-texture data and the above methodologies to determine whether a pavement section is acceptable or unacceptable based on the level of segregation present. If a pavement section is acceptable, the software determines the pay adjustment factor to be used; if segregation is present, it suggests remedial actions for the segregated areas. The software and the acceptance levels within the software are currently being reviewed to determine acceptable limits for projects.

INTRODUCTION

Segregation in asphalt materials can occur due to a variety of reasons. Its manifestation on site is an uneven aggregate surface texture caused by uneven distribution of aggregate, asphalt binder and/or air voids. The correlation between air voids and pavement durability is well documented. This project was aimed at establishing a relationship among surface texture measurements, surface segregation and air voids. It developed a screening tool to identify variations in surface texture that are typical of segregation and potentially locate pavement sections with high numbers of air voids.

Significant advances in detection of segregation have been recently undertaken by the National Center for Asphalt Technology (NCAT) as reported in NCHRP Report 441 (1). In their work a draft specification of a laser-based method for detecting segregation was developed in AASHTO format. This work was used as a starting point for the project reported here. In addition, considerable use has been made of the definitions given in ASTM specification E 1845-96 (2).

Over the past twenty years the use of laser technology to define surface texture has gained wide popularity. The basic concept of the measurement system involves the use

of a laser (or multiple lasers) with a detection system measuring the response from the pavement. Using mathematical algorithms the distance to the surface at a discrete point is obtained. Measurement can be made very rapidly by a vehicle-mounted laser that can define a surface profile at measurement points, which can be typically separated by 1 mm (1/25-inch).

The assessment of texture with laser-measuring devices is well established and a number of commercial devices are available. Based on the available information it appears that the devices of many different manufacturers can measure micro-texture to detect segregation. Based on our review of laser systems, the ROSAN appears to be the most advanced with respect to algorithms developed to determine segregation and has the widest application in this area to date (*1*). However, the application of the algorithms developed by them can be applied to the data collected from other laser devices. The level of technology employed in the ARAN device is considered to acceptable. Since the NJDOT owned this piece of equipment, the ARAN was selected.

FIELD EVALUATIONS

Representatives of the pavement management group at the NJDOT identified a site on Route 9, milepost 111.5 to 112, northbound fast lane, which had segregated materials in the pavement surface. Figure 1 gives a general view of the site. The area in the foreground shows the area of segregation that required subsequent patching.



Figure 1: Route 9 general view.

A field-testing program was developed that consisted of the following components:

1. Texture profile measurement using the ARAN
2. Sand-patch testing
3. Nuclear-density measurement
4. Coring to produce specimens for density testing and additional analysis
5. Visual observations

The test site was prepared by marking the pavement at five-foot intervals to enable location referencing. The length of the pavement surveyed was limited to 1500 feet, since this is the approximate capacity of the NJDOT's ARAN data unit when detailed laser texture data is being stored. Three test lines, located approximately 3, 5.5 and 8 feet from the edge of the lane were tested with the ARAN. The ARAN ran along each test line at a speed of 30 mph to capture texture profile. The ability of the ARAN to maintain a constant distance from the edge depended upon the skill of the driver. Due to the speed of the survey (approximately 30 mph) the precise transverse location was difficult to achieve.

Texture Measurements Using ARAN

All data collected by the measurement subsystem are stored at regular station intervals on the computer hard drive. A high-pass filter is used, with a base length of 50 mm, (ARAN Technical Documentation, "unpublished data"). The 50 mm length was found to be acceptable by ARAN to remove wavelengths that are a result of truck axle dynamics and fluctuations in pavement profile that were not attributable to texture. When each test line was completed by the ARAN, two separate data files were created and stored on the computer. One data file consists of the raw texture data after they have passed through the high-pass filter. The other file consists of texture summary data such as Root Mean Square (RMS) value and Mean Texture Depth (MTD). The RMS value is calculated as follows:

$$RMS = \sqrt{\frac{\sum_{i=1}^n (d_n)}{n}}$$

where: d_n = a valid data point number - n
 n = number of valid data points over measurement interval

The MTD calculation is based upon the ASTM specification E 965-96 "Measuring Pavement Macrottexture Depth Using a Volumetric Technique"(2) - commonly referred to as the sand-patch method. With the ARAN software this calculation was derived from a numerical integration of the area under a 50 mm base length compared to a horizontal line developed from the highest value within that base length. Figure 2 shows the RMS and MTD summary data for Test Line 1.

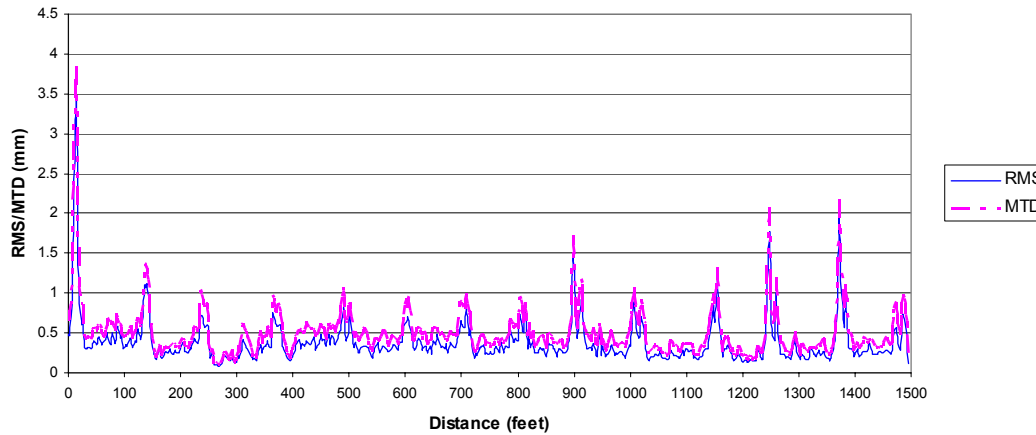


Figure 2: RMS/MTD summary data for Test Line 1

Sand-Patch Tests

Sand-patch tests (ASTM E 965-96) were performed at every 25 feet alternating between the three test lines tested with the ARAN resulting in a total of 58 sand patch tests. The diameters of the sand patches were transformed to Mean Texture Depth (MTD) using the following equation.

$$MTD = \frac{4V}{\pi D^2}$$

where: V = Volume of the sand used
 D = Diameter of the sand patch

Figure 3 shows the variation of MTD obtained from sand patch tests along the test section.

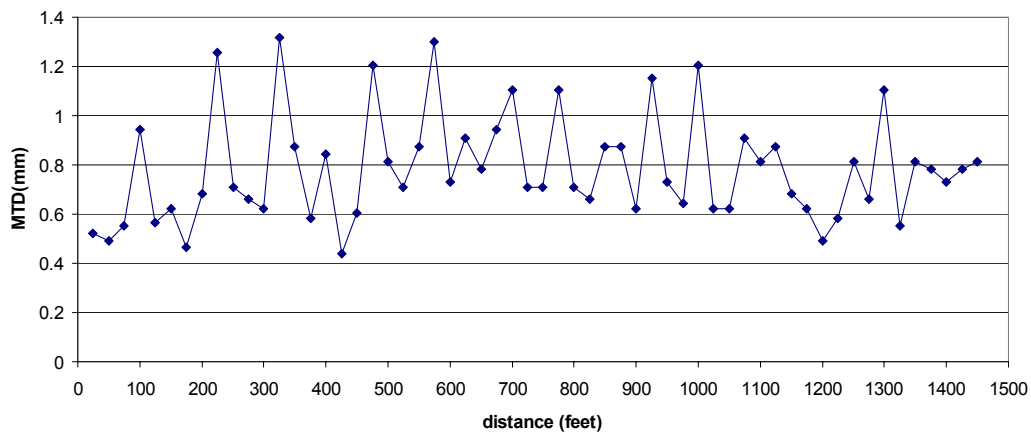


Figure 3: Sand-patch MTD along the test section

Nuclear Density Tests

Nuclear density meter (NDM) tests were conducted at each sand-patch location. Based on the measured density, the percent of Marshall density and air void percentage were calculated using the material properties from the mix design. Figure 4 illustrates the variation of air voids percentage along the test section as determined from NDM measurements.

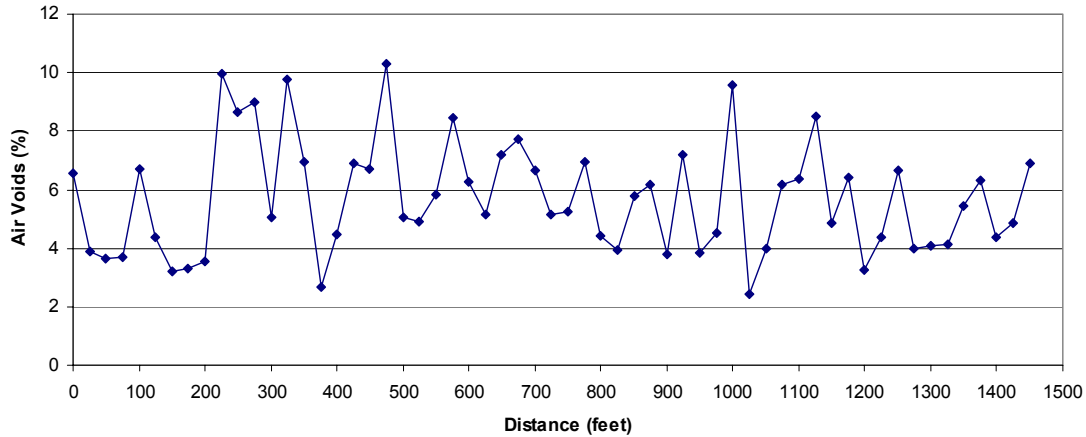


Figure 4: Variation of voids (determined from nuclear density)

Visual Observations

Visual observations were conducted to compare the laser, nuclear density and sand patch test results for consistency. Patches, segregated areas, cracks as well as sand patch and core locations were recorded on field evaluation sheets.

Laboratory Density Tests

The cores were tested in the laboratory to identify bulk specific gravity (G_{sb}) at the test locations as shown in Table 1.

Table 1: Summary of laboratory test results

Core Reference Number	Distance (feet)	Specific Gravity
1	1425	2.510
2	1275	2.500
3	1250	2.490
4	1200	2.516
5	875	2.512
6	675	2.433
7	575	2.511
8	475	2.500
9	425	2.525
10	375	2.523
11	325	2.478

INTERPRETATION AND APPLICATION

Traditional Methods

The correlation of data from one test measurement to another relies upon the accuracy of position location to ensure that texture as measured with the ARAN corresponds to the exact same spot used for the sand patch results. The lateral position of the ARAN is difficult to control due to the high speed of testing and the difficulty in following a precise test line. Consequently, while similar observed responses were obtained from both the ARAN and texture measurements, the correlations between the relative MTD values were poor due to the inaccuracies of location fixing as shown in Figure 5.

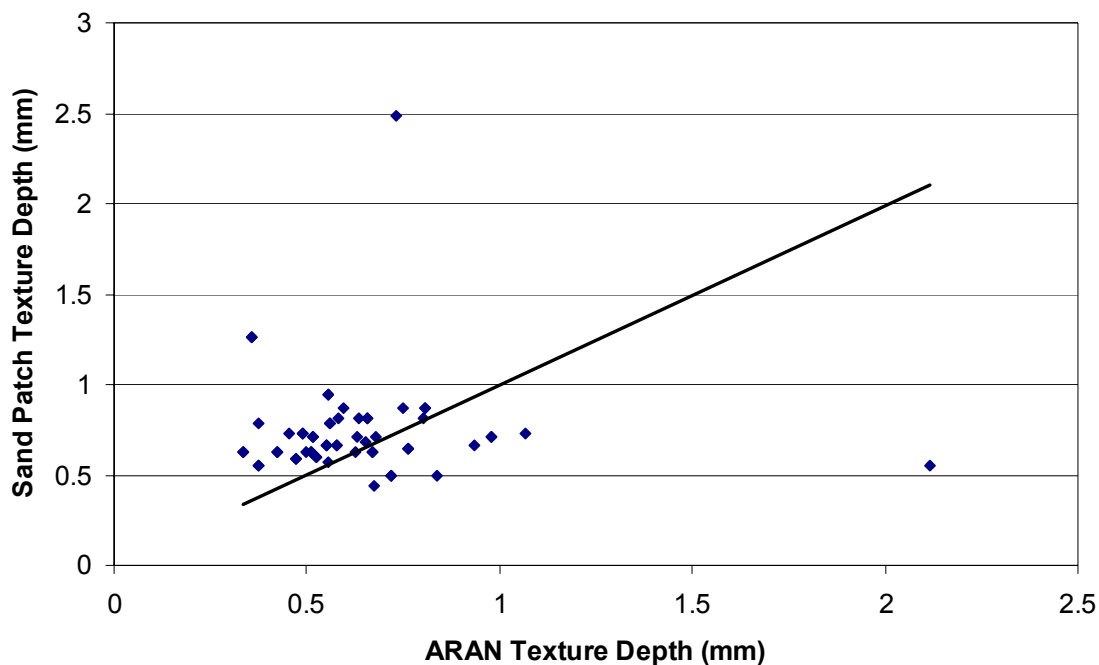


Figure 5: Correlation between textures from the ARAN versus Sand-patch Method

However, an alternate method of looking at the correlation between the different test methods is to consider a frequency distribution of defects. If test methods measure similar populations then the frequency distributions should be similar. It has been well known that laser devices produce different texture results to sand patch measurements (2) and consequently data sets have been normalized to the maximum value. Frequency distributions are compared in Figure 6 where it can be observed that both methods (ARAN and sand patch) produced nearly identical results.

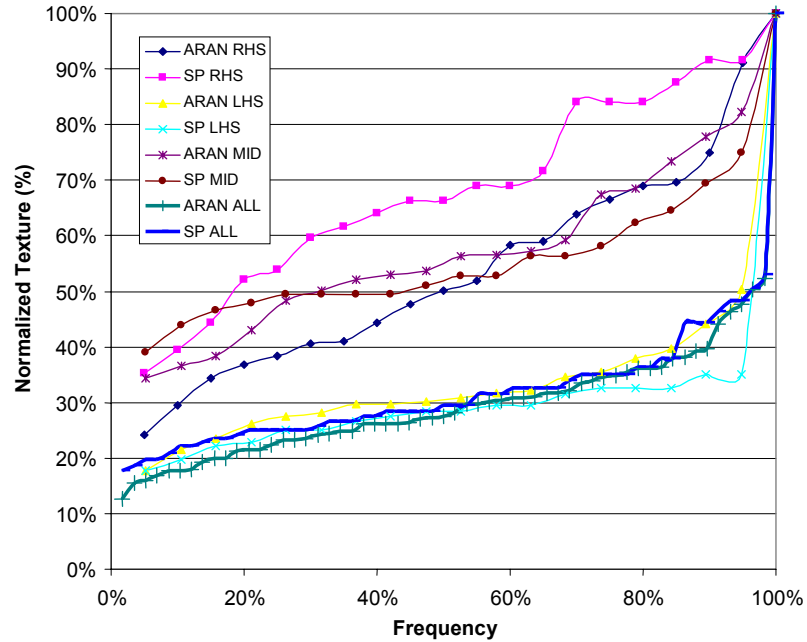


Figure 6: Frequency distribution curves for the ARAN and sand patch (SP) test results, normalized by maximum value

In addition, an evaluation for variance of the data set was conducted to statistically determine if significant differences exist between the data sets. This analysis indicated that the data sets from the two methods had differences at a level of significance of 0.05 when the data were not normalized. However, when the data sets were normalized to the same maximum value the statistical tests deduced no significant difference. This means that while the numerical values were different (average difference computed as 17%), the two techniques capture the same trend for each of the test lines.

The correlation between density (air voids %) and texture (sand patch method) was reasonable since these test locations could be located with a reasonable degree of accuracy. However, a similar problem resulted when comparing density measurements with the ARAN results due to the lateral location position fixing of the ARAN device.

Several previous research efforts showed that laser texture measurements were well correlated with the sand patch test. The mean profile depth (MPD), a two-dimensional measurement correlated with the three-dimensional estimated texture depth (ETD) measurement in ASTM E1845 as follows:

$$ETD = 0.2 + 0.8MPD \quad (\text{Metric units, mm})$$

Based on the above discussion, it would appear that the ARAN laser texture measuring technology could be used for detecting and measuring segregation.

ARAN Performance Data

As discussed earlier, the Route 9 project was selected due to the extent of segregation observed on site. The ARAN data reveal that the segregation occurred at a distance of approximately 30 meters or every 15 to 20 tons of laid material (dependent on exact paving width and layer thickness). Consequently, it would appear that the ARAN clearly identified end-of-truck-load segregation. While the site had obvious segregated areas (identified visually), the frequency of the segregation was not immediately apparent by walking the project site.

SPECIFICATION DEVELOPMENT

Levels of Segregation

NCHRP report 441 (I) has used the ratio of Estimated Texture Depth (ETD) of segregated areas to ETD of non-segregated areas as the identification parameter for different levels of segregation. According to the report, the ratios of textures in segregated areas to those in non-segregated areas were used to detect and characterize segregation. The following limiting ratios were set:

- Low segregation - shall have a Texture Ratio (TR) between 1.16 and 1.56.
- Medium segregation - shall have a Texture Ratio (TR) between 1.57 and 2.09.
- High segregation - shall have Texture Ratio (TR) of greater than 2.09.

Either an average texture in a non-segregated area - or - a typical texture depth for a particular hot-mix asphalt type could be used to determine an anticipated texture depth in the non-segregated areas. These would then be used with the measured texture to compute the value of TR. Typical texture depths for different hot mix asphalt types are presented in Table 2.

Table 2: Typical texture depths for different hot mix asphalt surface courses

Surfacing Material	Texture Depth (mm)
Asphaltic concrete (fine graded)	0.4 – 0.6
Asphaltic concrete (coarse graded)	0.6 – 1.2
Open Graded Friction Course/ SMA	1.5 – 3.5

Texture Measurement using the ARAN

The ARAN texture subsystem (“Smart Texture”) measures the macro texture of the road at speeds up to 56 mph. Segregated areas will generally have textures statistically coarser than the texture in a non-segregated area. For texture measurement purposes, it was proposed that the pavement section be divided into lots consisting of 1,000 feet of one lane width. The texture was then measured with the ARAN longitudinally along three test lines for the each area considered. The width of the test area should be consistent with a single pass of a paving machine or a standard lane width, as defined by the local

policy. Each test line is tested on the centerline of a strip representing one third of the area to be considered.

Development of Numerical Procedures and Specification Concepts

The amount of data produced by laser texture devices was very large and consequent manipulation by conventional spreadsheet programs was difficult and awkward due to the file sizes. This resulted in the project team developing a numerical software application “NJTxtr,” which could handle the numerical procedures. This application enabled data to be re-running while changing analysis parameters to perform functions such as sensitivity analysis. The definitions used within this software were based upon ASTM E1845 (2) with the unit of measurement for texture as the “Estimated Texture Depth” (ETD). NJTxtr used the ARAN- collected profile data to determine the ETD.

While this software was developed with ARAN data its use would be extended to any laser collection device with similar performance to the ARAN. However, it would be anticipated that the actual numerical values could differ due to equipment dynamics and specification and a correlation assessment would be needed to review this aspect. The software makes use of an ASCII text file and any data collected or presented in the correct format could be analyzed.

Levels of segregation are defined by considering ratios of ETD for non-segregated areas to the segregated areas in the same manner as discussed in the NCHRP report 441 (1). To obtain the values of ETD for non-segregated areas, two methods can be considered as follows:

1. The segregated and non-segregated areas are identified during the survey stage by traveling along the pavement section and marking the areas of the mat with acceptable texture. The ARAN-collected profile data for the marked non-segregated areas was used to determine the average texture depth. This value is used to compute the texture ratios in the pavement sections.
2. The anticipated texture in a non-segregated area can be estimated using typical material information as presented in the Table 3.

Upper and lower texture ratio limits defined previously are used to detect and measure low, medium and high levels of segregation. Texture ratios are calculated by dividing measured texture depths using the ARAN by measured or estimated ETD of non-segregated areas.

Effect of the Selection of Base Length

Base length is the length of the profile segments used in the analysis of pavement texture. In ASTM E1845 (2) this is defined as 100 mm. However, the use of this length restricts the identification of a feature to multiples of 100 mm. Consequently, a sensitivity analysis was conducted to assess the use of different base lengths that would be outside the ASTM definition. The base length is used within the software to determine the MPD that is then used to calculate the ETD. A linear regression of the profile values in each

segment is performed and the regression line is subtracted from the profile values. This produces a segment profile with a zero mean and slope. The maximum value of profile is then determined for the two lengths, each corresponding to half of the selected base length. These two values are averaged to obtain the mean segment depth. These values are then averaged for various lengths of pavements to obtain the MPD. However, for the work considered in this project the texture needed to be defined specified intervals of pavement length and consequently the MPD for each segment was calculated as illustrated in Figure 7. In this case MPD and ETD are calculated as follows:

$$MPD = \frac{(y_1 + y_2)}{2}$$

$$ETD = 0.2 + 0.8(MPD)$$

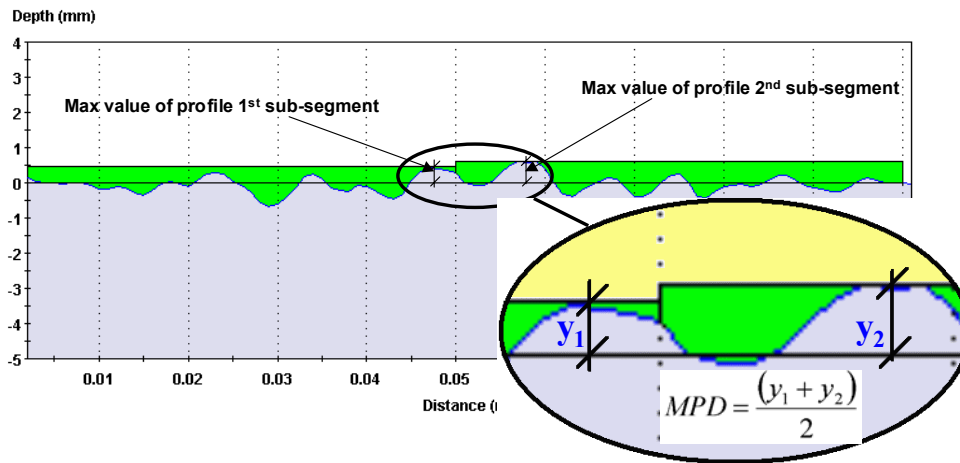


Figure 7: Determination of Mean Profile Depth (MPD) from a 100 mm base length

The selection of base length plays an important role in computing mean segment depths and texture ratios. The effect of the selection of the base length was studied during the evaluation stage of the NJT_{xtr} software. This evaluation was performed using the Route 9 data. Base lengths were varied from 25 mm to 200 mm and the mean of the mean segment depths (MMSD) was computed for each test line as shown in Figure 8. All three profile runs for Route 9 display similar variations of the MMSD and the rate of change diminishes with the increase of the base length.

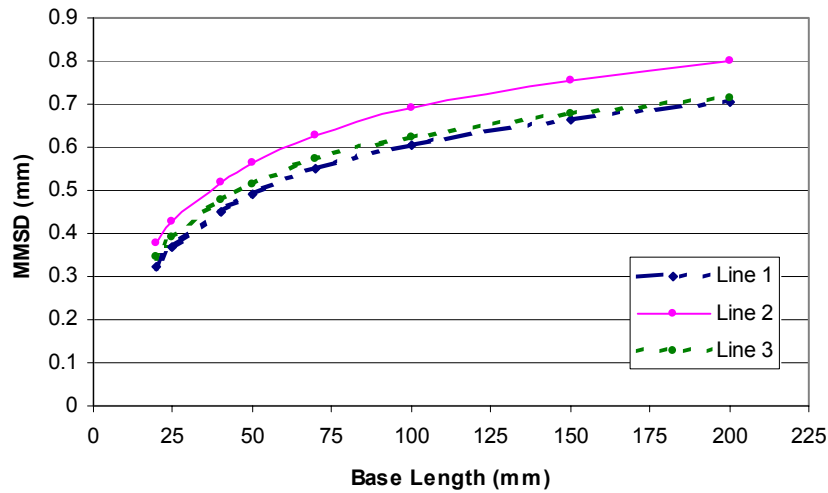


Figure 8: Variation of mean segment depth with base length

Figure 9 shows the ratio of MMSD obtained at different base lengths to that obtained at 100 mm for all three lines tested. It can be seen that a unique relationship exists between the base length and this ratio that can be defined as follows:

$$\text{Ratio (MMSD}_x\text{/MMSD}_{100}) = 0.2652\text{Ln}(x) - 0.2318$$

$$(r^2 = 0.9953)$$

This ratio could be used to determine the effect of calculated texture depths, if a need exists to move to a different base length in order to define areas of measurement in multiples different than 100 mm.

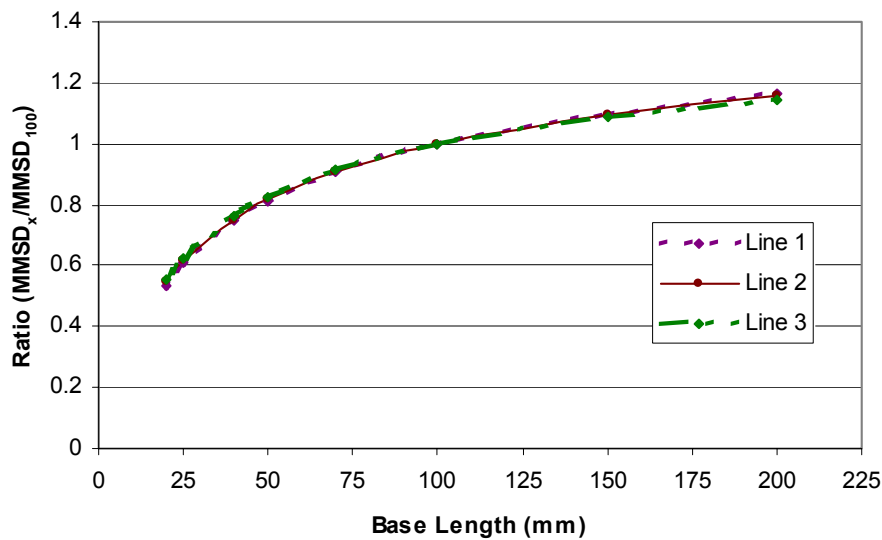


Figure 9: Variation of texture depth ratios with base length

Area of Each Level of Segregation

The “NJTxtr” software calculated the MSD using the ARAN-measured profile data and determined the number of MSD measurements that fall within the limits for each level of segregation. After determining the level of segregation, the class of segregation was determined (proposed scheme) as presented in Table 3.

Table 3: Categorization of extent of the individual segregated areas

Segregation Class	Longitudinal Extent (mm)
1	≤ 200
2	$200 < \text{and } \leq 400$
3	$400 < \text{and } \leq 800$
4	$800 < \text{and } \leq 1600$
5	> 1600

For pavement areas of continuous segregation, the level was taken as that representing the poorest quality material (the highest level) present in the area. The extent of each level of segregation at each class in each lot was calculated as a percentage as presented in the following equation. The area of each class of segregation at each level is computed by considering the segregated area extended to the full one-third of the lane width.

$$A_i = \frac{\sum_{n=1}^3 \sum_{k=1}^N l_{ink}}{A_{Total}} \times \frac{W}{3} \times 100$$

- where:
- A_i = Percentage area of segregation in each level (i = low, medium or high)
 - l = Length of a segregated area in meters
 - W = Width of the test area in meters
 - A_{total} = Total area of the lot in square meters
 - n = considered one-third of test area (test line)
 - k = Segregated area identification number
 - N = Total number of segregated areas in each test line

AREA Index for Lot Acceptance

Generally, the extent and severity of segregation determines the pavement life and its performance with time. When the segregation exceeds a certain level, it is recommended to reject the section to overcome future high maintenance and rehabilitation costs. An AREA index is defined to determine the overall effect and extent of different severity levels on a given pavement section. The percentage-segregated area of each level is multiplied by weighing factors to determine the AREA index. Proposed weighing factors for each level of segregation are defined as follows.

Table 4: Weighing factors for different level of segregation

Segregation Level	Weighing Factor
Low	1.0
Medium	1.43
High	2.5

Weighing factors are then used to calculate the AREA index for each pavement section as follows:

$$AREA = A_{low} \times 1.0 + A_{medium} \times 1.43 + A_{high} \times 2.5$$

where: A_{low} = Percentage area of low segregation
 A_{medium} = Percentage area of medium segregation
 A_{high} = Percentage area of high segregation

A threshold value is proposed for acceptance or non-acceptance of a pavement lot based on AREA index. If segregation is present in a pavement lot accepted on the basis of the AREA index, appropriate pay-adjustment factors should be assessed for different levels of segregation as defined earlier. If the AREA index of any lot is greater than 45.0, the lot should be rejected and the contractor required to reconstruct the section.

Policy Decisions

To implement a specification with the need to control segregation it will be necessary for the specifying agency to develop policy decisions with regard to pay adjustment factors and remedial works. Currently, these have not been defined in New Jersey. However, a possible scheme could be based on the AREA index, appropriate pay adjustment factors should be used to account for loss of pavement life due to segregation. An increased pay-adjustment factor of 105 is proposed for pavement areas with none to very low segregation (AREA Index 0–5.0) as an incentive. Since the AREA index accounts for both level and extent of segregation, pay adjustment factors can be defined based on the AREA index. The following pay-adjustment factors are proposed for pavement sections with different segregation levels based on the AREA index.

Table 5: Pay-adjustment factors

Range of the AREA Index	Pay Adjustment Factor
0 – 5.0	105
5.0 – 15.0	95
15.0 – 25.0	85
25.0 – 35.0	65
35.0 – 45.0	25

Remedial actions would depend on the extent of the pavement segregation and would require the NJDOT to define various policy decisions. The developments in this study should be considered as a framework for how actions can be implemented.

Table 6: Remedial actions for segregation

Extent of Individual Segregated Area (mm)	Level of Segregation		
	Low	Medium	High
≤ 200	No Action	No Action	Localized patch
$200 < \text{and } \leq 400$	No Action	Localized Patch	Remove and replace
$400 < \text{and } \leq 800$	Localized Patch	Localized Patch	Remove and replace
$800 < \text{and } \leq 1600$	Localized Patch	Remove and replace	Remove and replace
$1600 \leq$	Remove and replace	Remove and replace	Remove and replace

When the choice is to remove the segregated areas, the segregated area as well as 600 mm (2 feet) on all sides of these areas, should be removed and replaced. For pavement areas of continuous segregation, the remedial action should represent the poorest quality material (the highest level) present in the area.

The schemes above are given as possible examples. The implementation of any policy scheme would require detailed review of agency policies.

NJTxtr Software for Segregation Monitoring

NJTxtr software was developed to detect and monitor segregation based on the ARAN laser texture measurements. It uses either an average texture in a non-segregated area or user-specified asphalt surface course information to compute ETD. ETD was used to compute TR to differentiate different levels of segregation.

Practical Application of NJTxtr Software

A practical application of NJTxtr software was performed by using texture data collected from the Route 9 study. The data from three test lines were used to detect and monitor segregation using NJTxtr software.

The NJTxtr software can be used to view the mean segment depth of the each individual test line. Route 9 data were analyzed using NJTxtr software with following specifications.

Base Length = 100 mm

Mean segment depth of the non-segregated area= 0.6

The calculated mean segment depths for Route 9 data were categorized in accordance with the severity level of segregation. Color-coded plots were prepared based on different severity levels observed in the pavement section. Figure 10 presents the color-coded mean segment depth plot for the test line 1 of the Route 9 profile data. Severity and extent of each segregated pavement area can be easily identified using this plot. It can be noticed that segregation occurred in a uniform frequency over the entire test section. The observed peaks in the plot appear to be related to end-of-truck-load segregation.

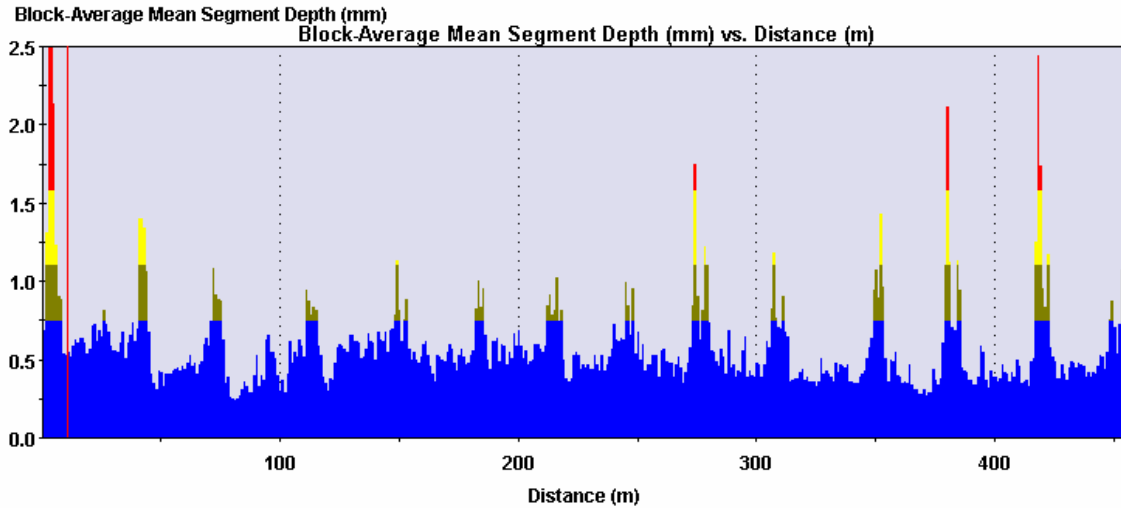


Figure 10: Block-average mean segment depths, 100 mm blocks

The above plot represents approximately 457 meters (1500 feet) of profile measurements on Route 9. NJTstr software can be used to view the segregation data more closely to analyze each segregated area. Using the zoomed view included in the software, the user can identify the starting and end points of each level of segregation and severity of segregation.

The NJTstr software can be used not only to visualize segregation on a particular pavement section but also as a decision-making tool for segregation monitoring. The user can specify base length, threshold values for different levels of segregation, threshold values for segregation class and mean segment depth of the non-segregated areas for analysis. The user has to specify three data sets measured in three separate test lines on an individual pavement lot to determine the percentage areas of each level of segregation, the AREA index, pay factor as well as individual treatments for each segregated area. The data from three test lines performed at Route 9 were analyzed using NJTstr software and Figure 11 presents the graphical representation of treatments for the first 10 meters of Route 9 and the suggested treatments for each individual segregated area of the pavement section. Darker areas correspond to the “Remove & Replace” option and lighter areas correspond to the “Localized Patch” treatment option. The suggested treatments should be used with the discretion of the engineer and each individual area can be combined with other areas together to apply more practical treatments. The analysis performed for the Route 9 data resulted in the summary results presented in the Table 7.

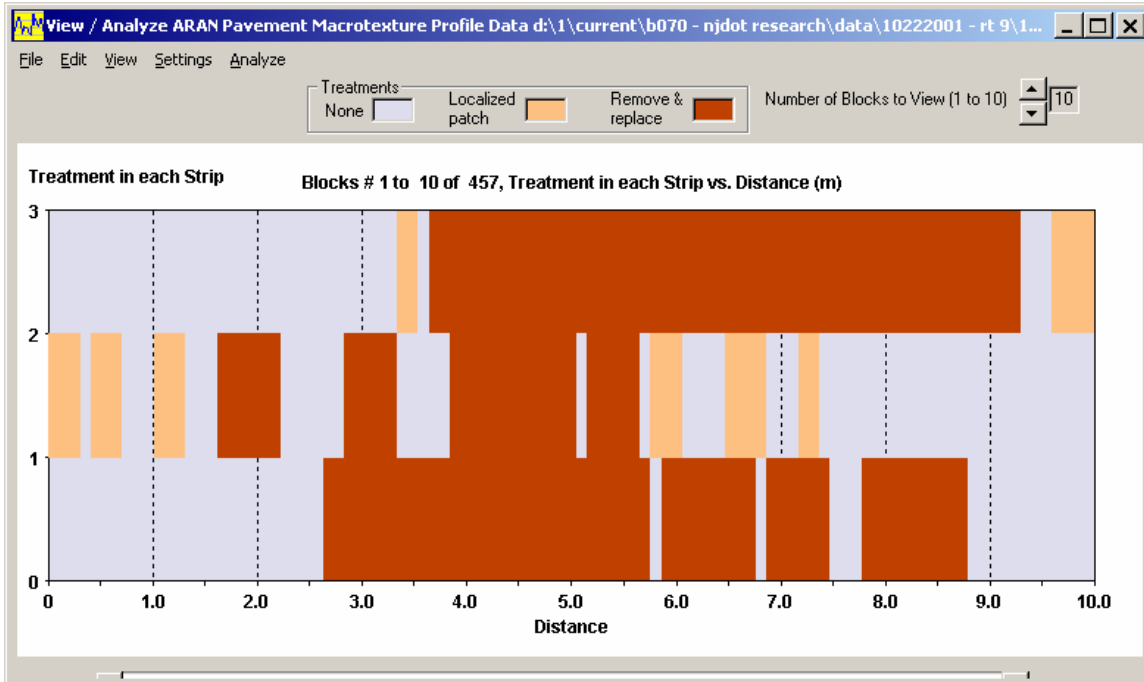


Figure 11: NJTxr suggested treatments for 0-10 meters of route 9

Table 7: Route 9 summary results

Parameter	From 0 To 304 meters (0 To 1000 feet)	From 304 To 403 meters (1000 To 1500 feet)
Percentage of Low Segregation	12.74	6.31
Percentage of Medium Segregation	4.92	3.55
Percentage of High Segregation	5.82	8.78
Total Segregation Percentage	23.48	18.64
AREA Index	34.32	33.34
Pay Factor	65	65

CONCLUSIONS AND RECOMMENDATIONS

A method of texture assessment for the definition of areas of segregated material has been developed with ARAN test device. This work built upon developments conducted by NCAT with an alternate laser device (1). Specifically, the implementation of the test methods with the ARAN device has led to the conclusions as follows:

1. Ratios of texture in segregated areas to that in non-segregated areas were set for detection and monitoring of different levels of segregation. The work conducted by NCAT was used as the basis for much of the development work on this project. Texture ratios less than 1.15 indicate no segregation, between 1.16 and 1.56 indicate low levels, between 1.57 and 2.09 indicate medium levels and ratios above 2.09 indicate high levels. These ratios were defined based on the NCHRP Report 441 (1).

2. By combining level of segregation and extent of each level of segregation, an AREA index was developed to determine the acceptance or non-acceptance of a pavement section. This index is useful for NJDOT to monitor newly laid pavements for acceptance. It is proposed that pavement lots should be accepted only if the AREA index is less than 45.0. However, testing additional sites should assess the application of this numerical value.
3. If segregation exists in a pavement section pay adjustment and/or acceptance could be based on AREA index, pay adjustment factors are defined to determine the reduction of payment to account for loss of pavement life due to segregation. Further remedial actions are defined to correct segregated in pavement sections with acceptable AREA index.
4. New segregation detecting and monitoring software, “NJTxtr” was developed by combining the above-developed methodologies. This software uses the ARAN-collected pavement texture data and determines whether the pavement section is acceptable or unacceptable based on the level of segregation present within the pavement section. If pavement section is acceptable, the software determines the pay adjustment factor to be used if segregation is present and it suggests remedial actions. The developed software was tested on data collected from the Route 9 site.
5. A draft proposed specification was developed for detection and monitoring of segregation based on the ARAN-collected pavement texture data.

Additional work is recommended on sites to assess the functionality of a specification based on these concepts. In addition, pilot scale projects could be constructed with segregation based performance specification. The researchers consider that the use of laser technologies has a great potential for the assessment of pavement structures during the construction process. The work conducted on this project demonstrates that the laser techniques are viable and support the conclusions developed by earlier research conducted at NCAT (1).

ACKNOWLEDGEMENTS

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DISCLAIMER

The views expressed in this report do not represent the policy or decisions made any of the employing organizations. The paper is written to facilitate discussion and the development of ideas within the research community.

REFERENCES

1. Stroup-Gardiner, M. and Brown, E.R. *Segregation in Hot-Mix Asphalt Pavements*, NCHRP Report 441, Transportation Research Board, Washington, D.C. 2000.

2. American Society for Testing and Materials *Road and Paving Materials; Vehicle Pavement Systems*, 04.03. ASTM, Vol. 04.03.
3. Croney, D. and Croney, P. *The Design and Performance of Road Pavements*, McGRAW-HILL Book Company Europe, Berkshire, England, 1991.