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Implementing a Smartphone Application for Assessing the Raveling Performance of Asphalt Pavements

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ABSTRACT

It is essential to evaluate the performance of pavements during their service life. Raveling is one of the important pavement performance defects, especially for Open Graded Friction Course mixes. The FC-5 is a type of friction course that has been used commonly in southern Florida. Florid Department of Transportation (FDOT) uses conventional qualitative visual inspection to assess pavement raveling performance. This study developed a data collection tool that uses a smartphone application and introduced a software to measure the raveling area and determine raveling location in video images, by implementing the smartphone GPS capability. This data collection tool enables users to identify the location and extension of raveling that can link the placement data with raveling performance. A project was surveyed to conduct a statistical analysis to investigate the effects of mix design, construction, and environmental factors on raveling at the lot level. Data analysis results show that raveling may affected by several parameters including ambient temperature, mix temperature, asphalt cement content and mix gradation. In light of this study, recommendations were made to enhance the longevity of the FC-5 mixtures.

Key Words: *Statistical Analysis, Ambient Temperature, Mix Design, Pavement performance, Porous Asphalt.*

1. INTRODUCTION

Due to the significant physical and institutional inertia in road infrastructure systems, undesirable serviceability of roads is very difficult to reverse [1, 2]. Therefore, the quality and durability of constructed structures are the major characteristics effecting pavement, buildings, and bridges performance [3-6]. The performance of a pavement during its service life largely depends on the construction, design and ambient conditions during the construction. The major defect that can degrade the pavement performance is cracks [7]. Overloading is a major source of pavement cracks. Additionally, in a rainy condition, water can penetrate to the pavement cracks and degrade the pavement performance which may pose the raveling [8]. Moreover, the penetration of water into the subsurface soil of pavement can cause soil expansion and degradation of pavement surface [9]. Raveling is defined as the separation of aggregates from the asphalt concrete pavement surface due to a lack of sufficient bonding between aggregates and the asphalt binder [10-12].

Asphalt concrete consists of aggregates and asphalt binder [13, 14]. Aggregates transfer load from passing wheels to the subgrade soil and provide skid resistance in the asphalt surface [15, 16]. Whereas, the asphalt binder provides the flexibility and cohesion between aggregates [17]. Raveling is caused by a cohesive failure or adhesive failure of the asphalt binder. Cohesive failure occurs within the binder at low ambient temperatures. Adhesive failure is caused by the stresses and deflections in an asphalt pavement at a high ambient temperature [18]. There are several parameters that affect pavement raveling, including the quality control of the pavement construction, mixture segregation, asphalt mix design, pavement compaction, void content, environmental condition, and pavement age [18]. The rehabilitation practices for a raveled pavement mainly include removal and patching for small areas, and placing an overlay for larger areas. In case of raveling distress, any surface treatment or thin overlay can be applied.

Porous asphalt is one of the types of asphalt mix that is more prone to raveling. This susceptibility is due to the high percentage of void content (more than 18%) in this type of asphalt mixes [19]. Raveling is the major defect in porous asphalt in the humid areas. Opera et al. found that 90 percent of distresses in porous asphalt is caused by raveling [20]. Thus, investigating the factors and conditions that influence raveling in a humid area is critical. Liu et al. [21] showed that the existence of water and cracks in the asphalt surface in a freezing weather could induce ice and pressure in asphalt concrete, leading to asphalt raveling. Previous studies showed that overall wear of the pavement, heavy traffic, ice, and pavement age are the main factors may affect raveling extension [20].

Since southern Florida has a tropical and humid weather, the use of FC-5 open graded friction courses is common to allow surface water drainage [8, 22]. FC 5 is a friction course mix with Nominal Maximum Aggregate Size of 12.5 with 100 percent crushed oolitic limestone or granite polished resistant aggregates [23]. However, Florida has had occasional performance problems with the FC-5 open graded friction courses that used oolitic limestone.

Although the visual inspection is the major method to assess raveling, this method is subjective. Further, there is no quantitative method to assess and evaluate pavement raveling [11, 24, 25]. The research team, investigate the causes of raveling using a smartphone with a high-resolution camera and GPS capability to determine the extent and causes of raveling. The research team performed a lot-level analysis and analysis of extreme values to investigate the effects of mix design, construction, and environmental factors on the raveling. The research team's previous work [26, 27] investigated the pavement raveling at the project level, and it was concluded that the average ambient temperature has a nonlinear relationship with raveling rate. Higher raveling occurred at temperatures lower than 65oF and higher than 90oF. Also, mix spread rate had a significant positive relationship with raveling rate. A spread rate more than 90 lb/SY (49 kg/m2) and less than 50 lb/SY (27 kg/m2) corresponds to a higher raveling rate. The mix spread rate near the design value which for mixes with limestone aggregates were 70 lb/SY (38 kg/m2) corresponded to the less raveling. There was a statistically significant reverse relationship between raveling and mix temperature. The use of coarser sieves (3/4" (19 mm), 1/2" (12.5 mm) and 3/8" (9.5 mm)) mostly led to a statistically significant reverse correlation coefficient between raveling and percentage of passing [16]. This means that coarser mixes were likely to increase raveling.

The current paper provides the statistical analysis at a lot-level on one of the good projects, where a sufficient amount of data was available. Each asphalt paving project includes several lot level basis. The asphalt mixes are tested in plant regarding the gradation and asphalt content to be accepted in lot-level basis. Each standard lot size contains 4,000 ton asphalt mix with four equal 1,000 ton sublot. The lot-level analysis was performed to identify the significant independent variables that effect on the raveling extension. Each standard lot size asphalt paved on several segments. Segments had 150 ft. (46 m) length per lane.

2. DATA COLLECTION

The data received from Florida Department of Transportation (FDOT) included ten projects; six projects were rated as good performance and four as poor performance from the raveling perspective. The performance rating was based on Pavement Condition Survey data, as well as windshield surveys conducted by FDOT personnel [17]. These correspond to approximately 500 lane-miles of pavement. The survey was conducted by FDOT experts and rating the asphalt pavement condition between zero and ten from raveling perspective. Then, the pavement was categorized as Good or Bad. The case study projects had age variety; some projects were older than others. Since the age of the mix is critical in raveling performance, the annual percentage of raveling was defined by dividing the amount of raveling to the project's age in years [20].

A software application written in Java script was also developed to measure the extent of raveling. The software was installed in a high-resolution smartphone camera that was mounted on the windshield of a van to videotape the roads at the speed of traffic (Figure 1). Each lane was recorded individually and reviewed later using a computer screen. In addition, another application was developed in MATLAB to allow the user to pause the video, select the appropriate speed for the video, mark the raveling area on the screen, and compile a table consisting of the raveling area (in square feet), location, and severity of raveling. All area computations were programmed in the software and used the lane width to scale the image. It should be noted that the longitude and latitude were determined using GPS data, which allows the analysis of raveling to occur at a high level of detail on segment and lot-levels.

Figure 1: Sample frame saved by software to quantify the raveling

The FDOT provided product data that was organized and compiled for each project lot. Data included the date of the samples taken, sample level, gradation, asphalt cement (AC) content, and the location of the lot/sub-lot station. The placement data was also extracted from the FDOT Electronic Document Management System (EDMS). The ambient data was obtained from the National Oceanic and Atmospheric Administration (NOAA) website [28].

The lane and station information was used to link placement data to actual raveling performance, as surveyed. It should be noted that the lane was divided into 150-ft (46 m). Long segments and the raveling conditions were selected as the closest 150-ft. segment to the station referenced in the roadway report. There was a very limited available data in the lot/sub-lot level, and they were out of sequence and discontinuous. This means that the data was not available for all the lot-level of a project. Therefore, it was not feasible to relate raveling performance to material property and placement conditions at the lot-level except for one project that had a "Good" raveling performance. This project that was selected to perform lot-level analysis was a part of I-75 highway in Broward County in Florida from milepost 30.054 to 18.870.

3. METHODOLOGY

In order to have an investigation of the raveling causes, a lot-level analysis was conducted. A smartphone with a high-resolution camera and GPS capability used to determine and videotape the area of raveling. To process the video, a smartphone application was developed by Java script. Another software was developed by MATLAB to measure and analyze the raveling area saved by the smartphone application.

Lot-level analysis and analysis of Extreme values were conducted to investigate the effect of mix design, construction, and environmental factors on the raveling. Analysis of Extreme values is a correlation analysis conducted between minimum, maximum and average values of independent variables (ambient, production and mix data) versus the average raveling measures for the project. Lot-level analysis uses the detailed raveling data and obtains multiple raveling readings at various lanes and stations, and correlates to materials test variables, placement variables, and ambient data. The lane and station information was used to link placement data to raveling performance, as surveyed. The Extreme Values of independent variables analysis is designed to detect whether or not raveling corresponds to extreme values of variables. FDOT used the qualitative method to rate raveling based on visual windshield surveys and the Pavement Condition Survey (PCS). This method classifies the project as Bad and Good according to the raveling performance perspective. This study proposed quantitative method used cameras mounted on a van to videotape each lane to determine the threshold between "Good" and "Bad" projects [16]. The threshold is the average distance between the mean of the annual percentage of Good and Bad raveling cases. To conduct a lot level analysis, one project which had sufficient data was selected. This means only for one of the 10 projects the data was available in all of the sub-lot level.

3.1. Factors Affecting Raveling

Based on the literature review the potential design, construction, and ambient factors may influence on the raveling extension [29]. These factors are classified into four categories: mix design variables, mix property variables, construction condition variables, and ambient variables. Mix design data includes gradation, binder content and type, and mix temperature. Production data consists of the date that the sample was taken, the sample level, gradation, and AC content. The ambient condition data contains temperature and precipitation of the paving of a day.

3.2. Data Compiling

Since the data was extracted from different sources, the data has different structures. Thus, manipulating and compiling the data is necessary to produce the dependent and independent variables. The final independent database variables contained the construction, mix design, gradation, and ambient conditions, whereas the dependent variable was raveling area of the road. It is noted that when raveling attained unacceptable levels, the FDOT maintenance staff removed and patched the bad spots (a

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minimum of 100-ft. (30 m) long patches). As such, the “total raveling” include the areas of low, moderate and severe raveling, in addition to the patched areas. The Pearson correlation which investigate the linear relationship between two variables was conducted to investigate the correlation between the dependent variable and the independent variables. The correlation coefficient (R) represents the slope of the best fit line of the data points relating the two variables [30]. A correlation coefficient of 1.0 indicates that the variables are directly proportional at an angle of 45°. A correlation coefficient of 0.0 indicates that the line representing the relationship between the two variables is horizontal, and there is no dependency between the two variables. The p-value was computed to determine the parameters which have a significant impact to the raveling extension.

3.3. Software Description

Visual inspection is the traditional method used for fast and qualitative assessment of pavement performance. However, this method lacks many key quantitative measurements, such as total area of damaged surface and the location of each defect. To address the limitations of this traditional method, the research team automated the process using two software packages. The first software ran on an Android Galaxy S4 smartphone and captured consecutive images while logging the GPS location [31] of each frame was called “data collection software.” The images were stored on the smartphone’s SD card and later be transferred to the data analysis tool to perform further analyses. Further detail of software can be find in the research group previous publication [26].

4. RESULTS & DISCUSSION

4.1. Correlation Matrix

Table 1 displays the correlation coefficients between raveling and placement, ambient and mix parameters. None of the coefficients are significant at a 95% confidence level. Based on available data from this project, no significant trends are found between raveling and all other variables. Further analysis of the data follows.

Table 1. Correlation matrix based on lot-level analysis. The correlation between dependent variable (raveling area) and independent variables listed. None of the variables are significant according to the p-test analysis

Variables	Raveling Area (SF)
Tack Spread Rate (Gal/SY)	-0.14
Mix Spread Rate (Lb./SY)	-0.22
Mix temperature	-0.22
Precipitation (mm)	-0.18
Average Ambient Temperature (F)	-0.02
12.5 mm(1/2”)	0.0
9.5 mm(3/8”)	0.0
4.75 mm(#4)	0.0
2.36 mm(#8)	0.15
AC content (%)	0.18

4.2. Effect of Ambient Conditions on Raveling

Figure 2 is a scatterplot of raveling versus ambient conditions, average air temperature, and daily precipitation. The plot shows no raveling at a wide spectrum of temperature and precipitation. Based on the data from this project, no significant correlation was found between raveling and ambient condition. The linear trend line fitted in the data shows a nearly flat line, indicating no correlation between the variables. The previous studies concluded there is a non-linear relation between the raveling extension and an ambient temperature (TAVG) [10, 16]. They showed that more raveling exist at an ambient temperature below 65oF and above 90oF during the paving. Because this project was paved between 60oF and 82oF, no special trend was observed between the ambient temperature during the paving and raveling area.

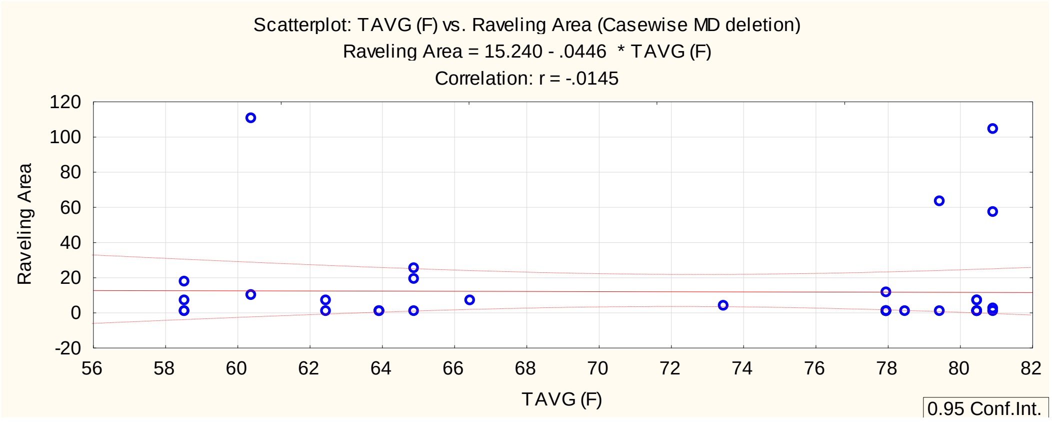
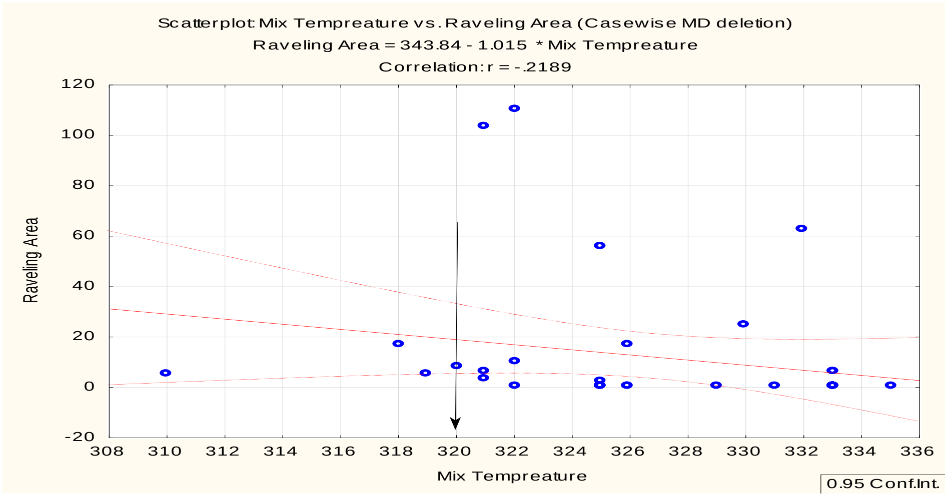


Figure 2. Raveling vs. ambient conditions during paving

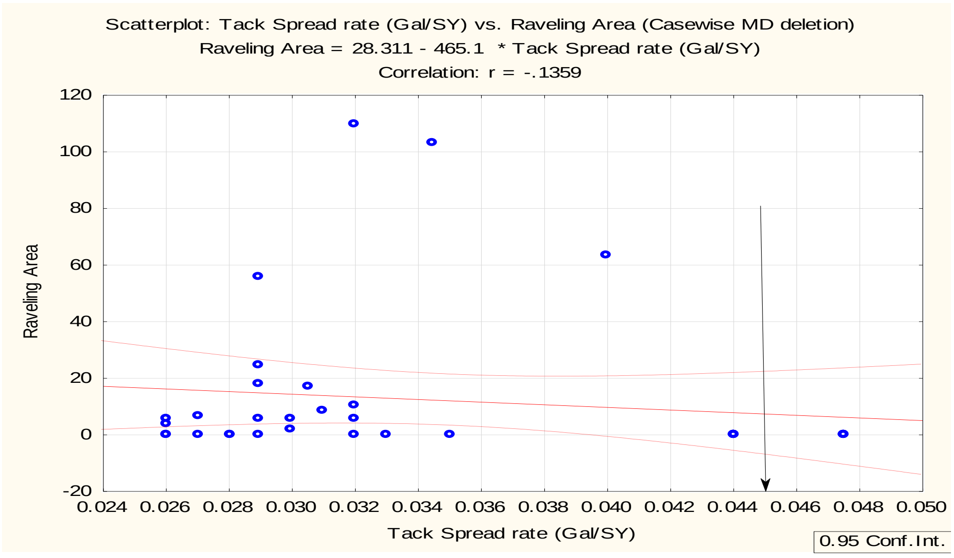
4.3. Effect of Placement Parameters on Raveling

Figure 3 is a scatterplot of raveling (dependent variable) versus placement parameters (predictors), tack spread rate, mix spread rate, and mix temperature. The linear trend line fitted to the data shows a nearly flat line, indicating no correlation between the variables and higher raveling values do not follow a specific pattern. Based on the data from this project, no significant correlation was observed between raveling and placement parameters.

(a)



(b)



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(c)

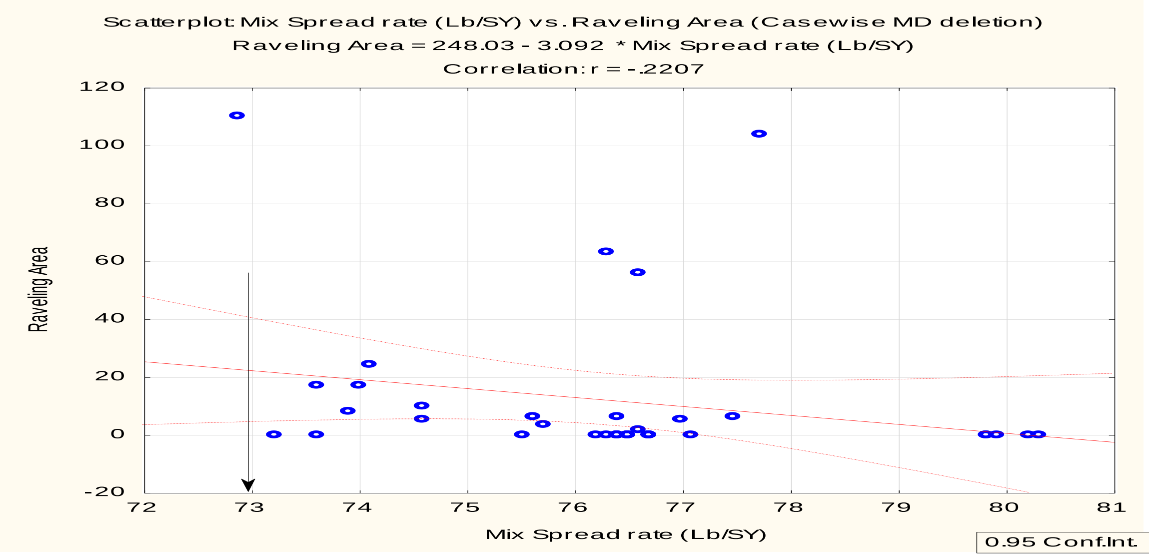

Figure 3. Raveling vs. placement parameters. (a) mix temperature vs. raveling area, (b)tack spread rate vs raveling area and (c) mix spread rate vs. raveling area

It is noted that the majority of the tack spread readings were lower than the target of 0.045 Gal/SY (0.2 L/m2). Also, the majority of mix spread rate readings were higher than the target of 73 lb/SY (40 kg/m2). There seems to be a partial trend of increased raveling as the mix spread rate increases, past the design acceptable range value (Figure 4). Since mix spread rate values ranged between 73 and 81 lb/SY and it is in the acceptable design range (70-80 lb/SY (38-43 kg/m2)), there is no special trend between mix spread rate and raveling. This result is consistent with the project level analysis that showed spread rates more than 90 lb/SY (49 kg/m2) and less than 50 lb/SY (27 kg/m2) corresponded with a higher raveling rate. This may occur due to inadequate compaction of paved asphalt mix.

4.4. Effect of Mix Properties on Raveling

Figure 4 is a scatterplot of raveling versus mix properties based on Quality Control (QC) and Visual Testing (VT) test results (independent variables), % Passing 3/8 Sieve, % Passing #4 Sieve, % Passing #8 sieve and asphalt content. The plot shows no raveling in the full spectrum of all four variables. Data mostly centered on the design values, denoted by an arrow in the graph. Most of the high raveling values corresponded with mid-range values of the independent variables. The majority of the data points support a flat line between the variables. The linear trend line fitted to the data shows a nearly flat line, indicating no correlation between the variables. Based on the data from this project, no significant correlation was found between raveling and mix properties. However, there is a partial trend in AC content showing increased raveling as the AC content increases beyond the design value. It should be noted that project level analysis showed that AC content beyond the design value promote raveling.

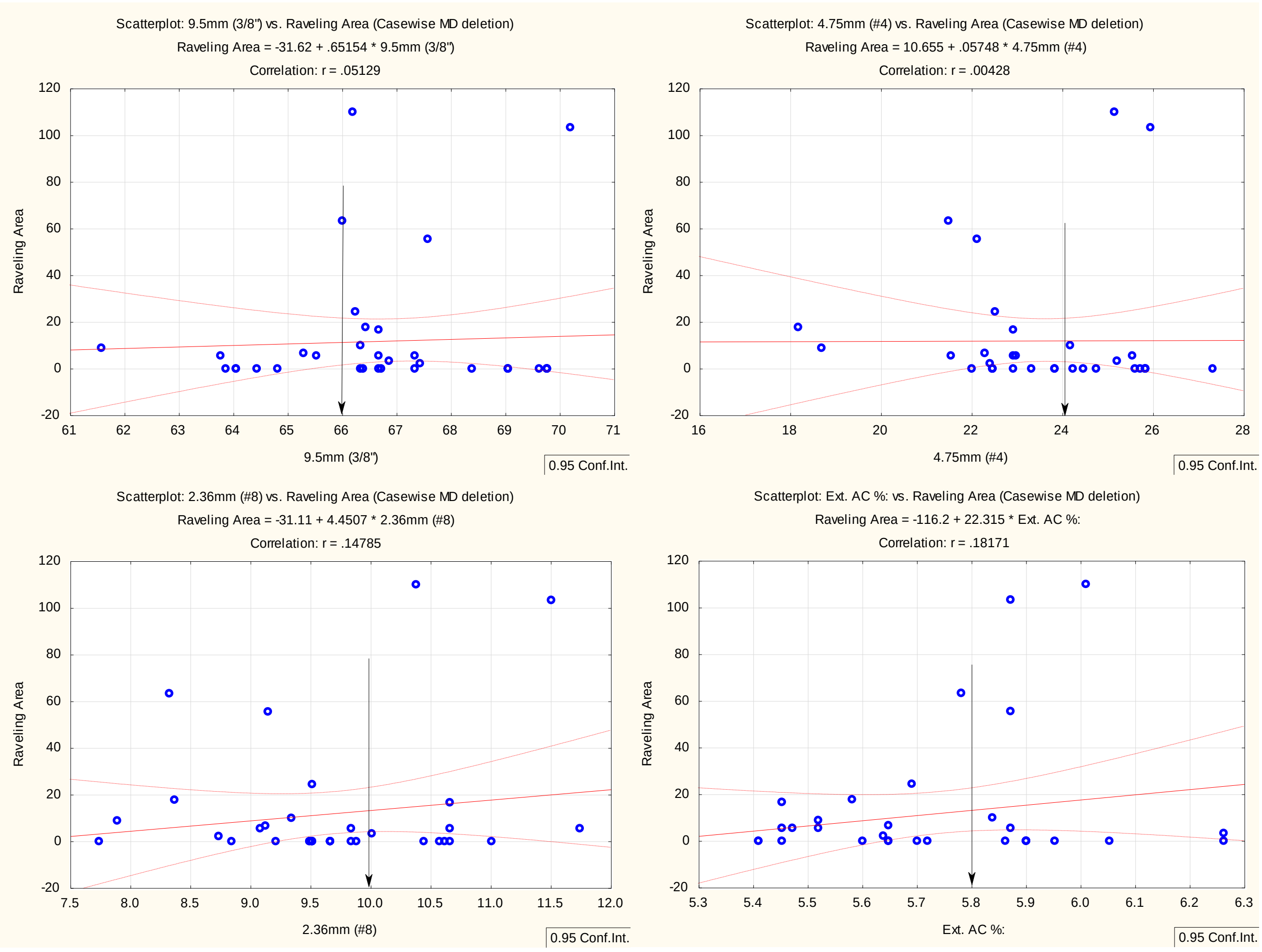

Figure 4. Raveling v. mix properties

4.5. Analysis of Extreme Values of Independent variables

A correlation analysis was conducted between minimum, maximum and average values of independent variables (temperature during paving and compacting, production and mix data) versus the average raveling measures for the project. This analysis is designed to detect whether or not raveling corresponds to extreme values of variables. For instance, if more raveling coincided with the lowest level of mix temperature, etc. The correlation matrix was examined and none of the correlation coefficients were significant. The research team did not detect any correlation between extreme values and raveling. The only exception is the correlation coefficient between % area raveled and the average % passing ¾ inch sieve. The correlation coefficient, was -0.74, indicating that finer materials tend to improve raveling performance (Figure 5).

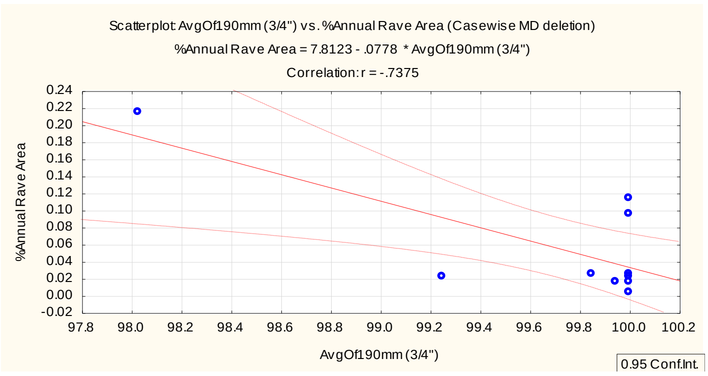

Figure 5. Scatterplot of raveling vs. % passing ¾ inch Sieve

Figure 5 shows the relationship between raveling and % passing ¾ inch sieve. It is noted that the graph relays an important expected trend. The FC-5 is placed ¾ inch thick.

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If the aggregate thickness and layer thickness are the same, the aggregate will tend to flow freely under the screed of the paver, which will result in an irregular surface texture that will lead to raveling. Or, the aggregate will get crushed during the paving operation, which can lead to raveling. Further, the thickness varies, as seen in the mix application rate. When the thickness is less than ¾ inch, the ¾-inch rocks may be crushed during compaction, which may also promote raveling.

5. CONCLUSION AND SUMMARY OF OBSERVED TRENDS

This research effort aimed at investigating the raveling of FC-5 mixes in South Florida using an innovative data collection method. A vehicle-mounted high-resolution camera was designed to capture a video of the pavement surface in a controlled condition. A software package was developed to determine the severity and area of ravelling sopts and identify their locations using GPS data. To facilitate a case study for this method, the construction and performance data for a particular project with a Good raveling performance was provided by FDOT. Several statistical analyses including the Student t-test and multivariate correlation analysis were performed at lot-level. The following is a summary of the analysis results.

- No significant correlation was found between raveling and ambient conditions. No significant correlation was found between raveling and placement parameters because all the lots were constructed in an acceptable ambient condition.
- The FDOT data showed that majority of the tack spread readings were lower than the target of 0.045 Gal/SY. Also, the majority of mix spread rate readings were higher than the designed target rate. These data indicates that in many cases, the raveling incresed with an increase in the mix spread rate.
- In areas that there weren't raveling the average values of the mix spread rate, tack spread rate, and mix temperature were higher than locations with raveling.
- Data were mostly centered on the design values of the mix properties. Most of the high raveling values corresponded with mid-range gradation levels. As a partial trend, an increased raveling was observed when the AC content exceeded the design values.
- The correlation between minimum, maximum and average values of independent variables and raveling were computed. The porpuse from this correlation was to test if raveling is affected by very cold or very hot temperatures, gradation, etc. The only significant trend was a negative correlation between percent passing the ¾ inch sieve and raveling, indicating that finer mixes ravel less. This trend is consistent with the trend observed in the project-level analysis.

5.1. Recommendation for Further Work

A more comprehensive analysis may be performed as a district-wide lot-level analysis, upon availability of more roadway reports. More recent projects should have plenty of roadway data.

In this research, the test results reflect material conditions at the plant on the day of production, not at the roadway, nor at the current time. It is understood that mix properties can change during transport and placement. A sampling program can be designed in conjunction with resurfacing efforts to study the aged mix properties. The other advantage of such an approach will be eliminating the possibility of location mismatch based on stations.

6. ACKNOWLEDGMENTS

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7. DISCLAIMER

The content of this paper reflects the views of the authors, who are solely responsible for the facts and accuracy of the data, as well as for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Florida Department of Transportation. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. Rasoulkhani, K., B. Logasa, M.P. Reyes, and A. Mostafavi, *Agent-Based Modeling Framework For Simulation Of Complex Adaptive Mechanisms Underlying Household Water Conservation Technology Adoption*, In *Winter Simulation Conference*. 2017.
2. Rasoulkhani, K., M.P. Reyes, and A. Mostafavi, *Emergence of Resilience from Infrastructure Dynamics: A Simulation Framework for Theory Building*, in *Computing in Civil Engineering 2017*. 2017. p. 256-264.

3. Shafieifar, M., M. Farzad, and A. Azizinamini, *Experimental and numerical study on mechanical properties of Ultra High Performance Concrete (UHPC).* Construction and Building Materials, 2017. **156**: p. 402-411.
4. Shafieifar, M., A. Azizinamini, and A. Director, *Alternative ABC Connections Utilizing UHPC.* 2016.
5. Sadeghnejad, A., et al., *Non-Destructive Testing (NDT) of a Segmental Concrete Bridge Scheduled for Demolition, with a Focus on Condition Assessment and Corrosion Detection of Internal Tendons.* 2017.
6. Baqersad, M., E.A. Sayyafi, and H.M. Bak, *State of the Art: Mechanical Properties of Ultra-High Performance Concrete.* Civil Engineering Journal, 2017. **3**(3): p. 190-198.
7. Hasaninia, M. and F. Haddadi, *The characteristics of hot mixed asphalt modified by nanosilica.* Petroleum Science and Technology, 2017. **35**(4): p. 351-359.
8. Arambula, E., C.K. Estakhri, A.E. Martin, M. Trevino, A. Smit, and J. Prozzi, *Performance of Permeable Friction Course (PFC) pavements over time.* Introduction to Unmanned Aircraft Systems, 2015: p. 427.
9. Baqersad, M., A.E. Haghighat, M. Rowshanzamir, and H.M. Bak, *Comparison of Coupled and Uncoupled Consolidation Equations Using Finite Element Method in Plane-Strain Condition.* Civil Engineering Journal, 2016. **2**(8): p. 375-388.
10. Miradi, M. *Neural network models for analysis and prediction of raveling*. in *Cybernetics and Intelligent Systems, 2004 IEEE Conference on*. 2004. IEEE.
11. Mo, L., M. Huurman, S. Wu, and A. Molenaar, *2D and 3D meso-scale finite element models for ravelling analysis of porous asphalt concrete.* Finite elements in analysis and design, 2008. **44**(4): p. 186-196.
12. John S, M. and W.Y. Bellinger, *Distress Identification Manual for long term pavement performance program*. 2013, US Department of Transportation, F.H.A.
13. Mohammadafzali, M., H. Ali, J.A. Musselman, G.A. Sholar, and A. Massahi, *The Effect of Aging on the Cracking Resistance of Recycled Asphalt.* Advances in Civil Engineering, 2017. **2017**.
14. Mohammadafzali, M., H. Ali, J.A. Musselman, G.A. Sholar, and A. Massahi, *Evaluation of Cracking Resistance and Durability of 100% Reclaimed Asphalt Pavement Mixtures.* Advances in Civil Engineering, 2017. **2017**: p. 7.
15. Tsai, Y.J. and Z. Wang, *Detecting Asphalt Pavement Raveling Using Emerging 3D Laser Technology and Macrotexture Analysis*. 2015.
16. Baqersad, M., M. Mohammadafzali, B. Choubane, C. Holzschuher, A. Hamedi, and H. Ali, *Precision Assessment of the Florida Texture Meter in Hot Mix Asphalt.* Journal of Transportation Engineering, Part B: Pavements, 2018. **144**(2): p. 04018003.
17. Baqersad, M., A. Hamedi, M. Mohammadafzali, and H. Ali, *Asphalt Mixture Segregation Detection: Digital Image Processing Approach.* Advances in Materials Science and Engineering, 2017. **2017**: p. 6.
18. Mathavan, S., M. Rahman, M. Stonecliffe-Jones, and K. Kamal, *Pavement raveling detection and measurement from synchronized intensity and range images.* Transportation Research Record: Journal of the Transportation Research Board, 2014(2457): p. 3-11.
19. Huurman, M., L. Mo, M. Woldekidan, R. Khedoe, and J. Moraal, *Overview of the LOT meso mechanical research into porous asphalt raveling.* Advanced Testing and Characterisation of Bituminous Materials, Vols, 2009. **1**: p. 507-518.
20. Opara, K.R., M. Skakuj, and M. Stöckner, *Factors affecting raveling of motorway pavements—A field experiment with new additives to the deicing brine.* Construction and Building Materials, 2016. **113**: p. 174-187.
21. Liu, Q., W. Yu, E. Schlangen, and G. van Bochove, *Unravelling porous asphalt concrete with induction heating.* Construction and Building Materials, 2014. **71**: p. 152-157.
22. Ali, H. and M. Mohammadafzali, *Asphalt Surface Treatment Practice in Southeastern United States.* 2014.
23. Baqersad, M., M. Mohammadafzali, B. Choubane, C. Holzschuher, A. Hamedi, and H. Ali, *The Application of Laser Macrotexture Measurement for Detection of Segregation in Asphalt Pavements.* Journal of Transportation Engineering, Part B: Pavements, 2018. **in press**.
24. Ong, G.P., W. Flora, A.S. Noureldin, and K.C. Sinha. *Statistical modeling of pavement raveling using texture measurements*. in *Transportation Research Board 87th Annual Meeting*. 2008.
25. Office, F.D.o.T.S.M., *Flexible Pavement Condition Survey Handbook*. 2012.
26. Massahi, A., H. Ali, F. Koohifar, M. Baqersad, and M. Mohammadafzali, *Investigation of Pavement Raveling Performance using Smartphone.* International Journal of Pavement Research and Technology, 2017.
27. Massahi, A., H. Ali, F. Koohifar, and M. Mohammadafzali. *Analysis of pavement raveling using smartphone*. in *Transportation Research Board 95th Annual Meeting*. 2016.
28. Administration, N.C.f.E.I.N.O.a.A. *http://www.ncdc.noaa.gov/cdo-web/datasets#GHCND*. 2014.
29. Parsons, T. and B. Pullen. *Relationship between Climate Type and Observed Pavement Distresses*. in *International Conference on Transportation and Development 2016*. 2016.
30. Ott, R.L. and M.T. Longnecker, *An introduction to statistical methods and data analysis*. 2015: Nelson Education.
31. Mafi, M., H. Azizi, and H.Y. Alborz, *A new Model of Free Global Positioning System using Triple DME.* International Research Journal of Engineering and Technology, 2017. **04**(08).

DOI: dx.doi.org/10.7324/IJASRE.2018.32640