Student Guide

Product 0-6746-01-P2

Validation of TxDOT Flexible Pavement Skid Prediction Model: Workshop

Published: May 2017

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VALIDATION OF TXDOT FLEXIBLE PAVEMENT SKID PREDICTION MODEL: WORKSHOP

by

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Texas A&M Transportation Institute

Product 0-6746-01-P2
Project 0-6746-01
Project Title: Validation of TxDOT Flexible Pavement Skid Prediction Model

Performed in cooperation with the
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and the
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Published: May 2017

TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

TxDOT Flexible Pavement Skid Prediction Model: Workshop

Date: TBD
Location: TxDOT Construction Division, Cedar Park, Texas
Contacts: Arif Chowdhury, a-chowdhury@tamu.edu, 210-321-1210

Agenda

Time	Module	Instructor

Course Materials:

- Background summary of Research Project 0-5627.
- Short presentation of research tasks and findings from Research Project 0-6746.
- Aggregate characterization with Aggregate Imaging Measurement System (AIMS) and Micro-Deval device.
- Demonstration of Skid Analysis of Asphalt Pavement (SAAP) software (installation, new features).
- Several examples that run the revised program, including hot-mix asphalt (HMA), seal coat, aggregate sources and properties, aggregate combinations, average annual daily traffic (AADT), and truck traffic.
- Limitations of SAAP.
- Future work.
- Open discussion.

Module 1:

Background and Research Findings of

TxDOT Research Project 0-5627

and

TxDOT Research Project 0-6746

PowerPoint Presentation

0-6746: Validation of TxDOT Flexible Pavement Skid Prediction Model

PD: Caroline Heinen

Arif Chowdhury
Emad Kassem

February 2017

Overview

- Brief introduction and project background
- Brief description of experimental design
- Field testing
- Laboratory testing
- Data from lab, field, and TxDOT database
- Analyses of data—prediction models for HMA and seal coat
- SAAP software modification and demonstration

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Background

- Previously developed prediction models for the IFI and SN of asphalt mix surface as functions of traffic, aggregate texture, and aggregate gradation.
- Developed **S**kid **A**nalysis of **A**sphalt **P**avement (SAAP) software.
- Used the models to classify aggregates based on their impact on skid resistance.

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0-6746 Objectives

- Investigate and examine 60 HMA and seal coat field test sections.
- Validate and modify the skid prediction model:
  - Improve the method of traffic analysis.
    - Lane distribution of traffic data.
    - Effect of percentage of truck traffic.
  - Expand the model to include skid-surface-treated roads.
- Provide training materials on the application of the new model(s).

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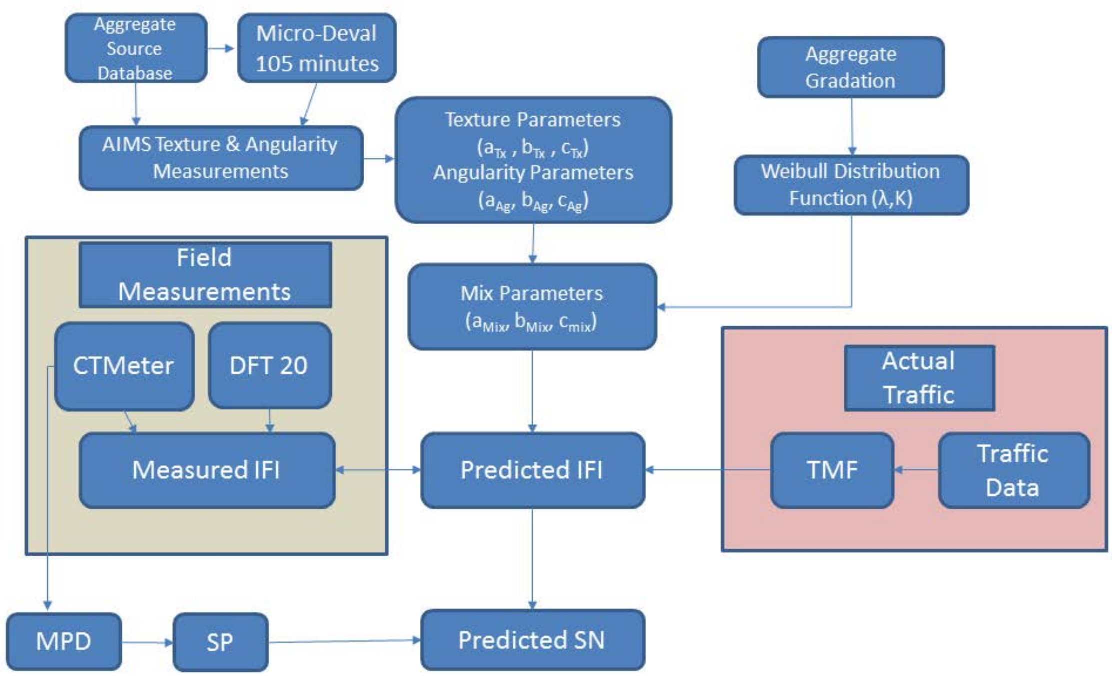
Work Plan

- Task 1: Meet with TxDOT project personnel.
- Task 2: Conduct literature search.
- Task 3: Design experiment and select field test sections.
- Task 4: Conduct field and laboratory testing.
- Task 5: Refine and validate skid prediction model.
- Task 6: Modify desktop application for skid prediction.
- Task 7: Develop and deliver training materials.
- Task 8: Document findings.

Research Plan



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List of HMA Test Sections

- **Locations**: ATL, AUS, BMT, ODA, BRY, SAT, YKM, HOU, LRD, PHR, LFK
- **Mix Types**: SMA-D, SMA-C, CMHB-F, Type C, Type D, TOM, PFC, CAM, SP-C, SP-D
- **Year of Construction**: 2004 to 2013
- **Aggregate Types**: Limestone, Gravel, Granite, Dolomite, Sandstone, Rhyolite, Traprock

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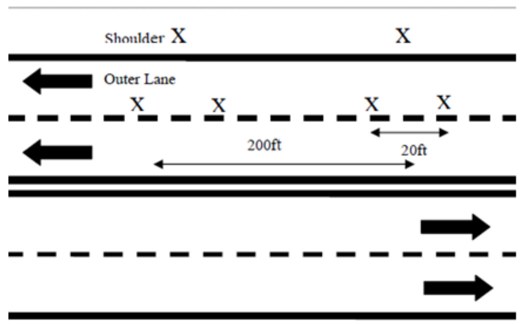
List of Seal Coat Test Sections

- **Locations**: ATL, BMT, ODA, SAT, YKM, LRD, PHR, LFK, BRY
- **Grade**: Grade 3, Grade 4, Grade 5
- **Year of Construction**: 2008 to 2013
- **Aggregate Types**: Limestone, Gravel, Traprock, Sandstone, Dolomite, Rhyolite, LRA, Lightweight
- **Coating**: Pre-coated and Virgin

Conduct Field and Lab Testing

- Field Testing: Friction measurement using DFT, CTMeter.
  - The outer lane experiences the most polishing because most of the truck traffic uses this lane.
  - Left wheel path of the outside lane.
  - Six locations: two locations at the shoulder, and four locations in the outer lane.
  - Skid measurements are shoulder assumed to represent the initial skid measurements.

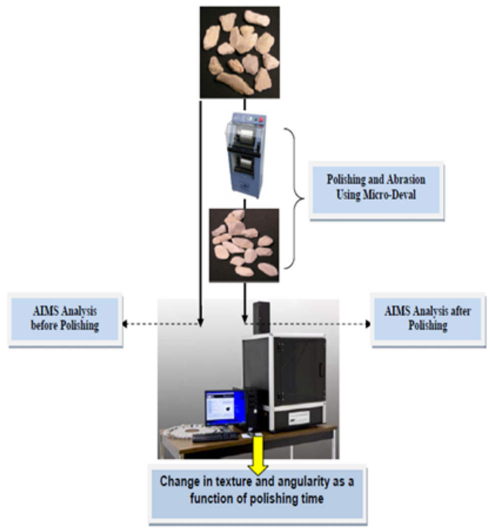


Layout of the measurement locations

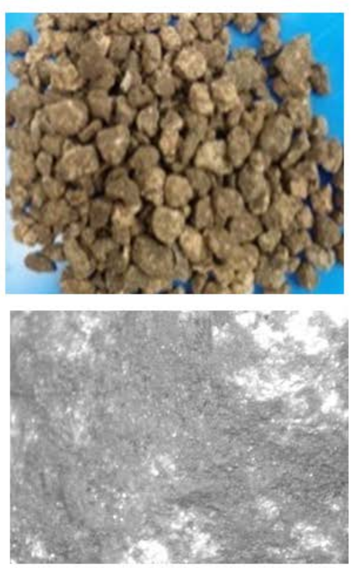
Aggregate Characterization

Aggregate Characteristics:

- AIMS to quantify texture, form, and angularity of aggregates.
- AIMS before and after Micro-Deval.
- Obtain texture regression constants: a_{tx}, b_{tx}, and c_{tx}.
- Obtain angularity regression constants: a_{GA}, b_{GA}, and c_{GA}.



Issues with Pre-coated Aggregates



Lightweight aggregates before MD

Lightweight aggregates after MD

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Issues with Pre-coated Aggregates

Aggregates after ignition oven

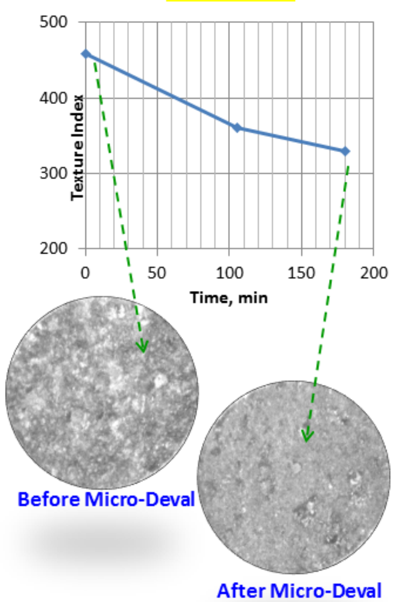
SH-16-ATS

Aggregates before binder extraction

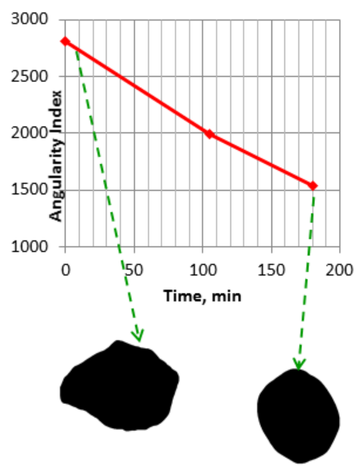
Aggregates after binder extraction

SH-16-McMullen

TEXTURE



ANGULARITY



Abrasion performed at 100 rpm for 105 and 180 minutes

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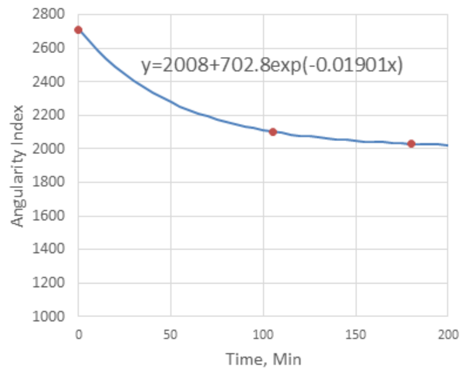
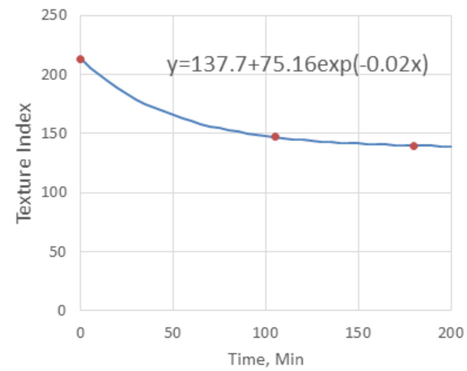
HMA Texture and Angularity Models

$$GA(t) = a_{GA} + b_{GA} * e^{(-c_{GA} * t)}$$

$$TX(t) = a_{TX} + b_{TX} * e^{(-c_{TX} * t)}$$





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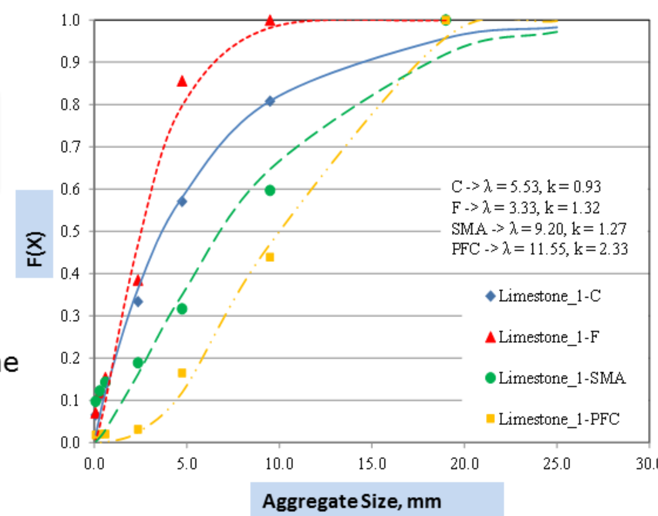
Aggregate Gradation (Weibull Distribution Function)

$$F(x; \lambda, k) = 1 - e^{-(x/\lambda)^k}$$

x: aggregate size in mm

λ: scale parameter

κ: shape parameters of the Weibull distribution



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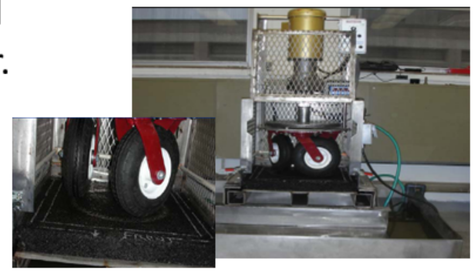
Laboratory Polishing of Seal Coat Slab

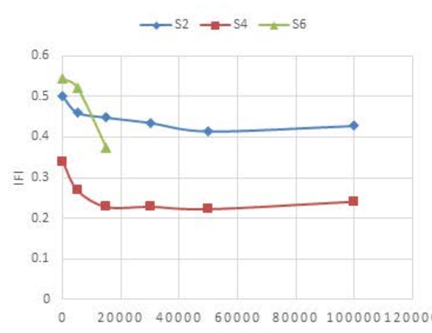
- To better understand change in skid and textures of seal coat roads.
- Difficult to produce realistic seal coat slabs in the laboratory.
- Six slabs extracted from in-service pavements (three different projects).
- Periodic measurements of skid and texture using the DFT and CTMeter.



SH 16_SAT_GR4_Atascosa_TRM 626

SH 16_SAT_GR4 _Bexar

SH 7_BRY_GR4



Skid Data

- TTI measurement—one time.
- TxDOT PMIS Database:
  - Typical measurement cycle Feb-Aug.
  - HMA on major roads more frequent.
  - Seal coat or HMA on FM/SH roads less frequent.
  - Always on left wheel path.
  - Not on the same lane each time.
  - Usually at the beginning of PMIS section.
  - Considered median value for a given section.

Skid Testing by TTI Crew

- Testing conducted by TT crew using TTI equipment.
- Tested at all test sections between Jan-Apr 2015.
  - Controlled testing.
  - LWP (regular).
  - BWP.
  - Shoulder.
  - Inside lane, LWP (account for truck traffic).

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Traffic Data

- Extracted from PMIS database
- AADT and percent truck traffic over the years
- Some additional data from WIM stations
- A few data from other TTI–TxDOT IAC projects

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Predicting IFI for HMA

$$IFI(N) = a_{mix} + b_{mix} * e^{(-c_{mix} * N)}$$

Where:

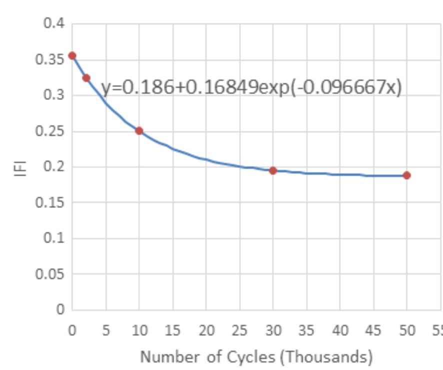
a_{mix} , b_{mix} , c_{mix}: mixture parameters dependent on texture and angularity.

a_{mix}: terminal IFI.

$a_{mix} + b_{mix}$: initial IFI.

c_{mix}: rate of IFI change.

N: number of cycles in thousands.



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International Friction Index (IFI)

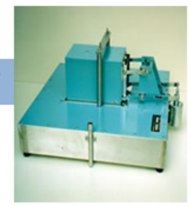
$$IFI = 0.081 + 0.732 DFT_{20}\, e^{\frac{-40}{S_P}}$$

$$S_P = 14.2 + 89.7 MPD$$

$$IFI = 0.045 + 0.925 \times 0.01 \times SN(50) e^{\frac{20}{S_P}}$$

CTMeter

DFT



MPD is mean profile depth measured by CTMeter.

DFT_{20} is dynamic friction at 20 km/h measured by DFT.

SN(50) is measured skid number at 50 mph using skid trailer.

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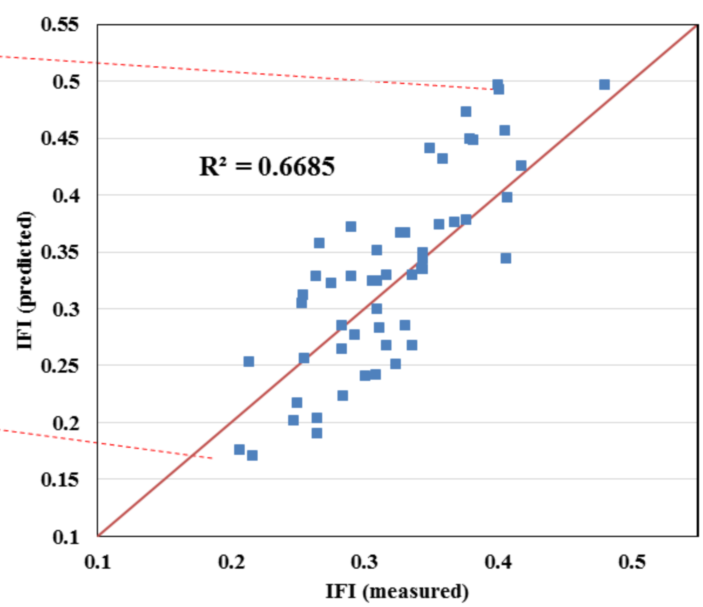
IH 20_ODA_PFC_2004

SH 36_YKM_TY D_AUSTIN



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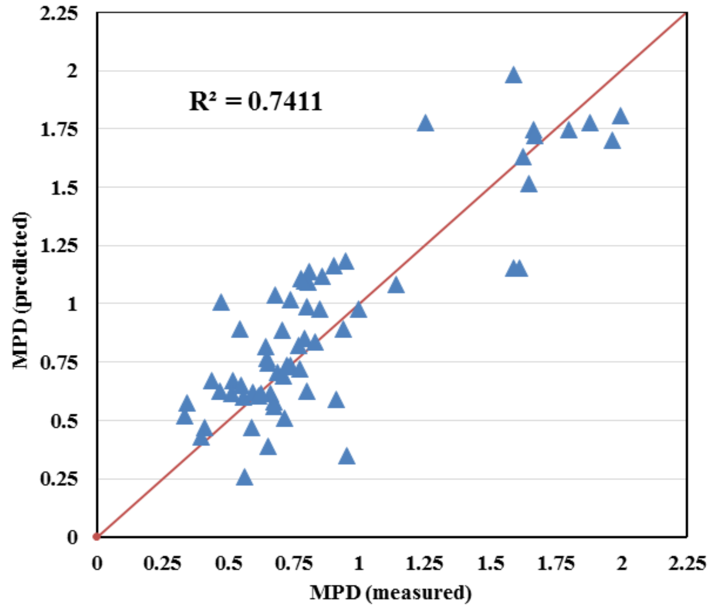
$$MPD = (\lambda/34.18)-(0.398/k)+(k^{0.416}) - 0.003\ N$$

Where:

λ, **K:** Weibull distribution parameters.



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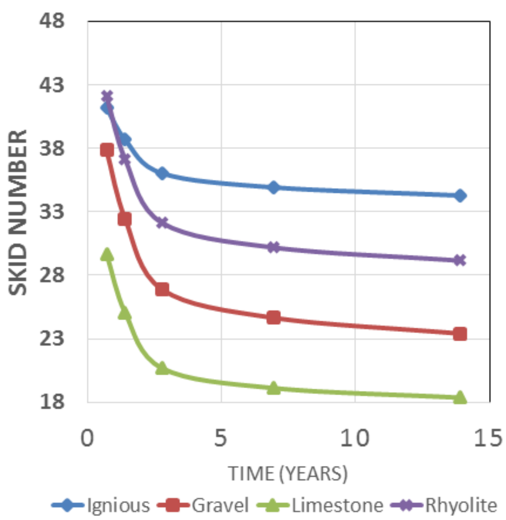
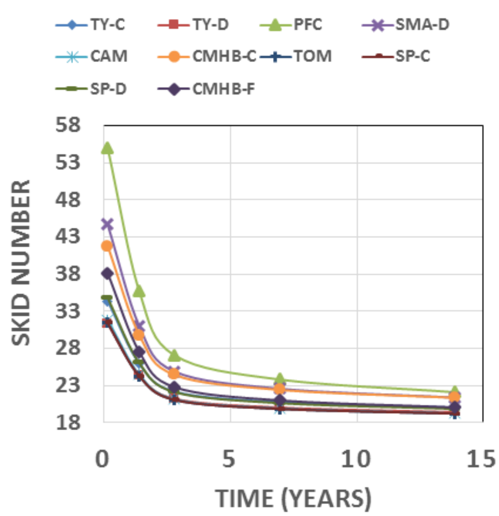
Skid for HMA

Aggregate Type



Gradation Type



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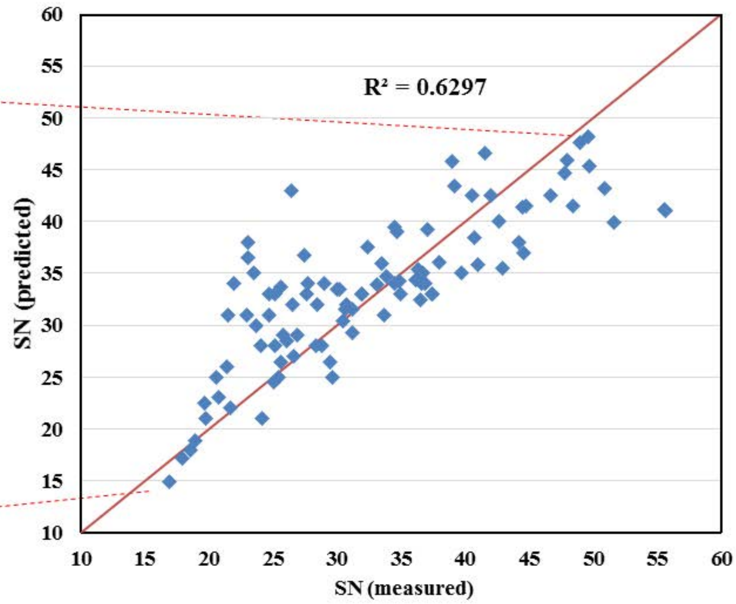
IH 20_ODA_PFC_2004

IH 10_YKM_TY D_AUSTIN



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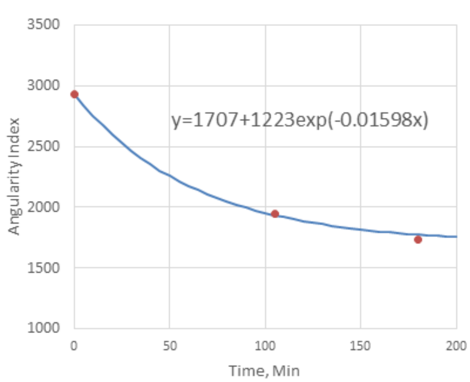
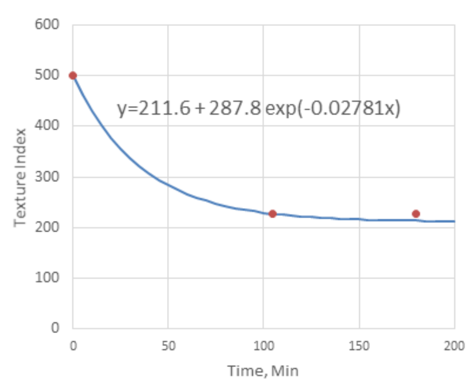
Seal Coat Texture and Angularity Models

$$GA(t)=a_{GA}+b_{GA}*e^{(-c_{GA}*t)}$$

$$TX(t)=a_{TX}+b_{TX}*e^{(-c_{TX}*t)}$$





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Predicting IFI for Seal Coat

$$IFI(N)=a_{mix}+b_{mix}*e^{(-c_{mix}*N)}$$

Where:

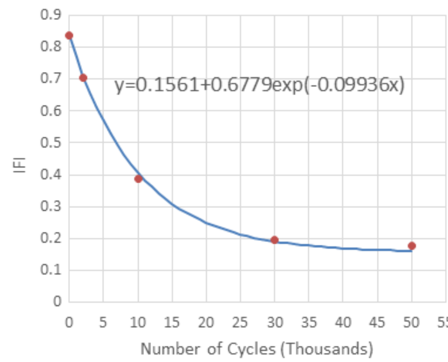
a_{mix} , b_{mix} , c_{mix}: mixture parameters dependent on texture and angularity.

a_{mix}: terminal IFI.

a_{mix} + b_{mix}: initial IFI.

c_{mix}: rate of IFI change.

N: number of cycles in thousands.



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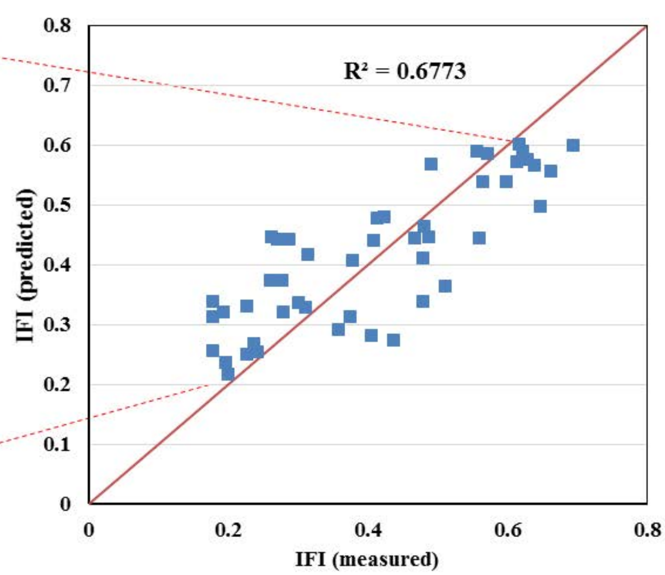
US 80_ATL-GR4_Harrison

US 385_ODA_GR4_Ector



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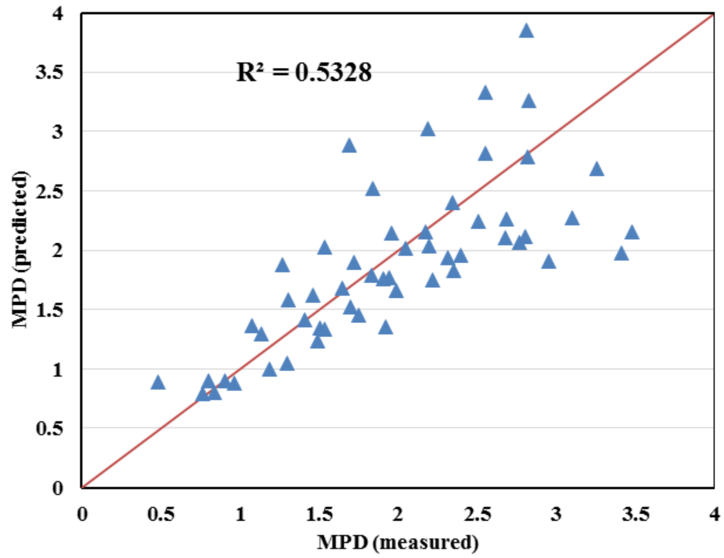
$$MPD = (\lambda/5.403)-(3.491/k)+(k^{0.104})+N^{-0.47}-2.594$$

Where:

λ, **K:** Weibull distribution parameters.



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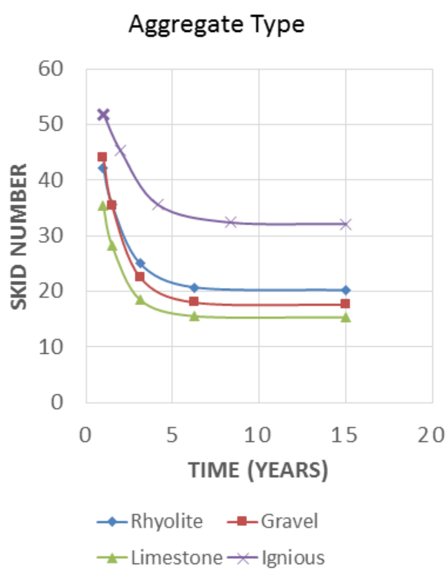
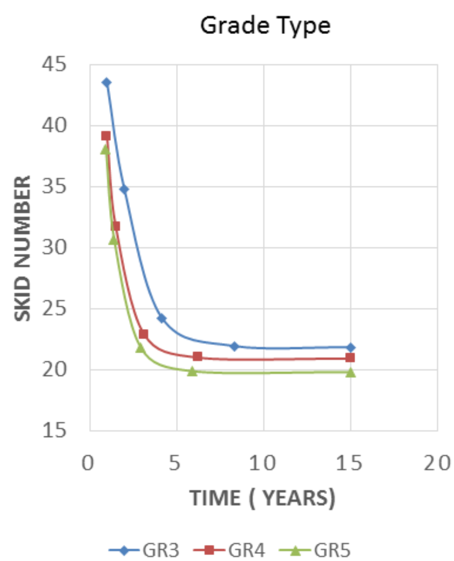
Skid for Seal Coat





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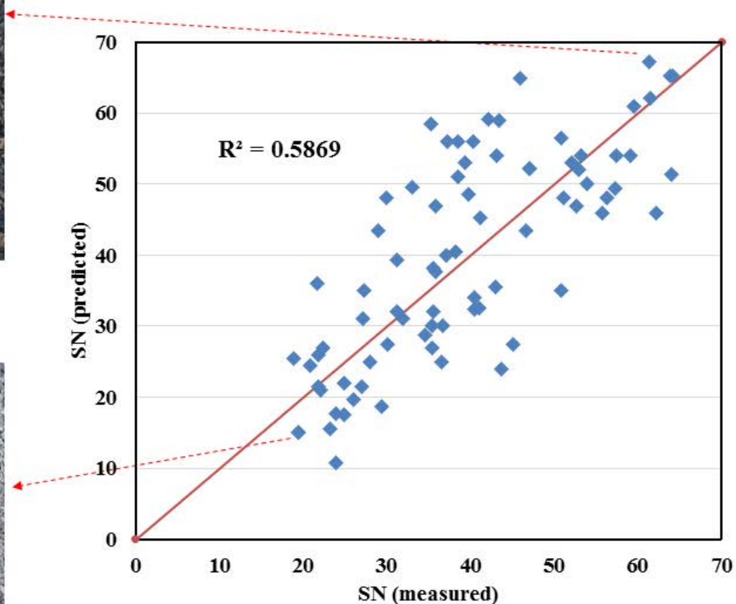
FM 105_BMT_GR4_Orange

US 281_PHR_GR3_Brooke_TRM 752



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SAAP Modification

- Rewrote the whole code using VBA.
- Standalone Windows-based application.
- MS Access instead of MS Excel.
- Print.
- Save input parameters and output in Excel.
- Windows 7, Windows 8.1, Windows 10.

SAAP Modification

- Incorporated skid prediction model for seal coat surface.
- Incorporated modified model for HMA.
- Added aggregate angularity as input.
- Modified traffic input parameters.
    - Percent truck traffic.
    - Clarified AADT, divided vs. undivided.
    - Rural vs. urban.

Calculation of TMF

$$\boldsymbol{TMF_{RUL1}} = \frac{\text{Number of days between construction and field testing x a} = \text{adjusted traffic}}{1000}$$

$$\text{Adjusted traffic} = \frac{AADT x \ (100-PTT) x \ DL_{AADT}}{100} + \frac{AADT \ x \ PTT \ \text{ x } DL_{truck} \ x \ 20}{100}$$

TMF = traffic multiplication factor

R = rural

Ur = urban

U, D = undivided or divided roadbed

AADT = average annual daily traffic (per roadbed)

PTT = percent truck traffic

L1, L2, L3 = number of lanes in each direction

Calculation of TMF—Rural

Number of Lanes in Each Direction	Undivided		Divided	
	DL_{AADT}	DL_{truck}	DL_{AADT}	DL_{truck}
1	0.50	0.50	N/A	N/A
2	0.40	0.45	0.80	0.90
3	0.30	0.40	0.40	0.50

Calculation TMF—Urban

Number of Lanes in Each Direction	Undivided		Divided	
	DL_{AADT}	DL_{truck}	DL_{AADT}	DL_{truck}
1	0.50	0.50	N/A	N/A
2	0.30	0.40	0.70	0.90
3	0.25	0.35	0.40	0.50
4	N/A	N/A	0.30	0.40

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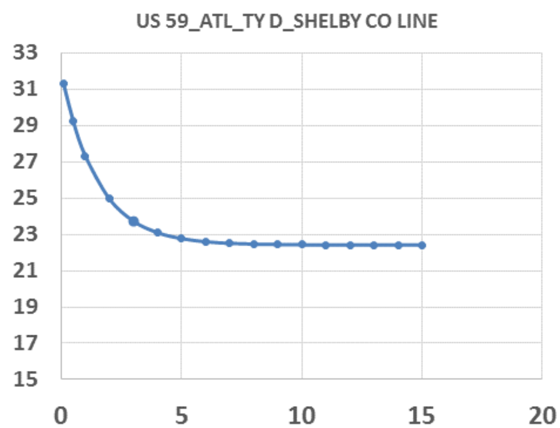
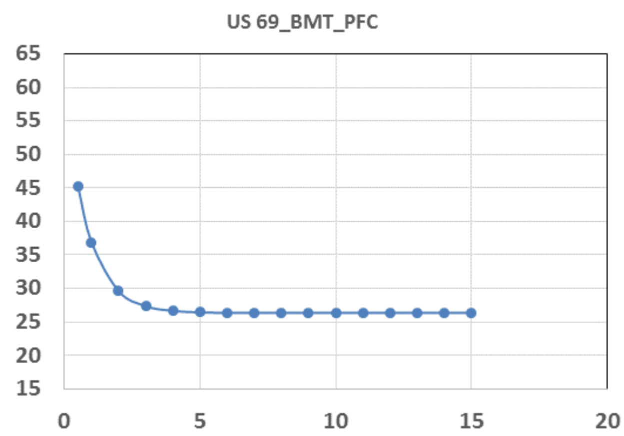
Estimation of Skid Resistance

- Step 1: Calculate aggregate texture parameters (AIMS).
- Step 2: Calculate aggregate angularity parameters (AIMS).
- Step 3: Calculate mixture gradation parameters.
- Step 4: Calculate pavement macrotexture (gradation).
- Step 5: Calculate traffic on design lane.
- Step 6: Calculate IFI and TMF.
- Step 7: Estimate skid number as function of traffic/time.

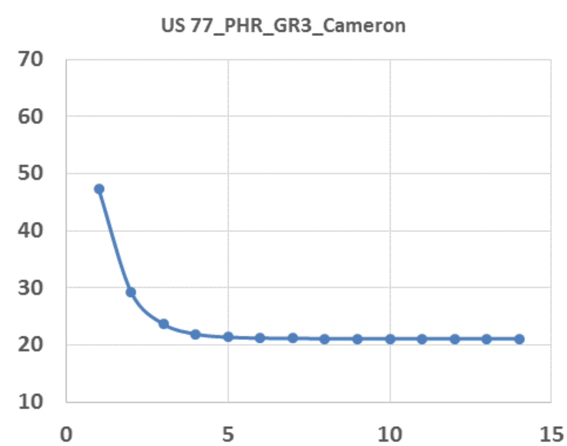
Shelby Co Line	
Class	Two lanes each way divided
AADT	6572
Percent truck	22.22
Mix type	TY-D
Texture BMD	340.0984
Texture AMD	235.4876
Angularity BMD	3051.622
Angularity AMD	2412.691



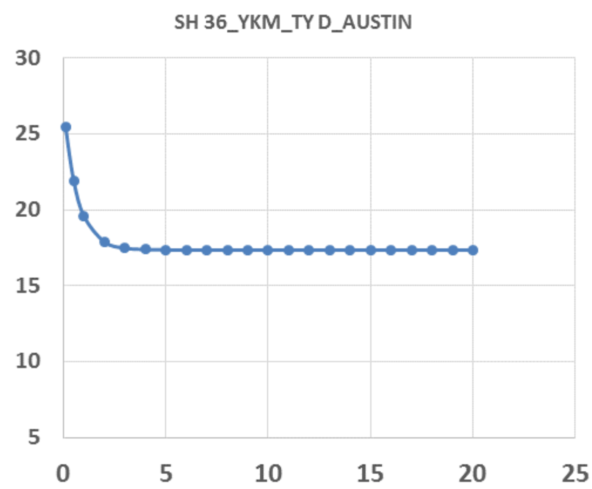
Class	Two lanes each way divided
AADT	28164
Percent truck	8.8
Mix type	PFC
Texture BMD	259.8978
Texture AMD	215.7289
Angularity BMD	2646.732
Angularity AMD	2271.563



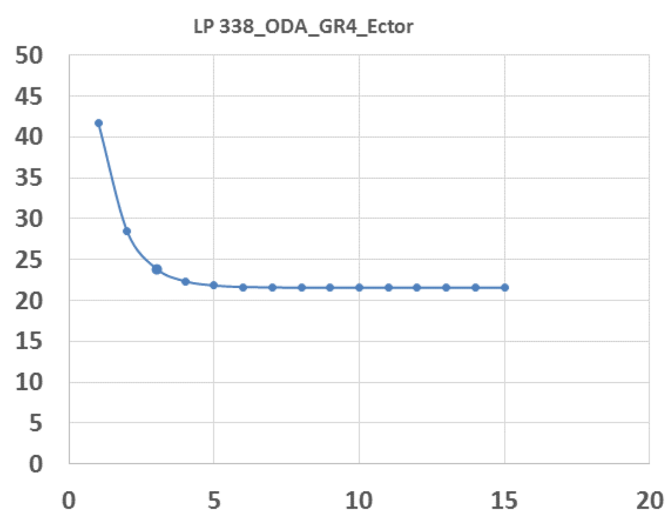
Class	Two lanes each way divided
AADT	8500
Percent truck	22
Mix type	GR-3
Texture BMD	499.3658
Texture AMD	227.1218
Angularity BMD	2926.364
Angularity AMD	1945.145

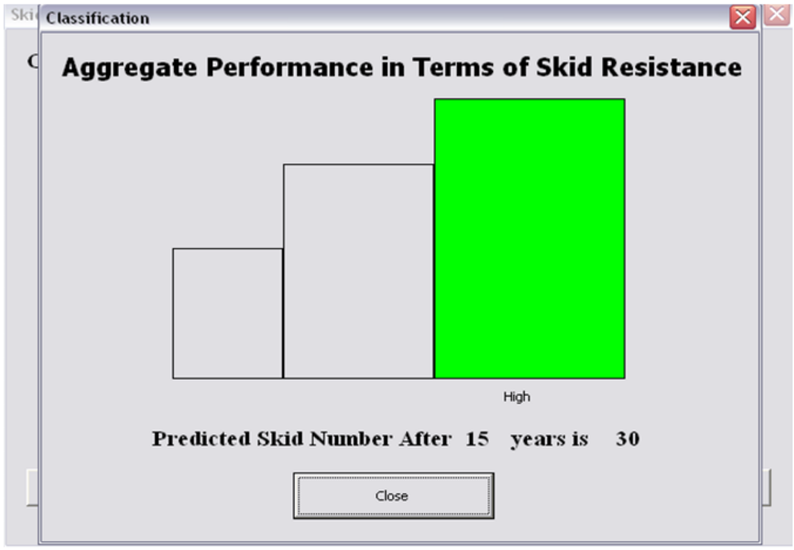


Class	Undivided, one lane each way
AADT	5500
Percent truck	18
Mix type	TY-D
Texture BMD	263.4463
Texture AMD	105.022
Angularity BMD	2652.319
Angularity AMD	1602.676



Class	Undivided, one lane each way
AADT	4171
Percent truck	27
Mix type	GR-4
Texture BMD	427.542
Texture AMD	309.2665
Angularity BMD	2768.035
Angularity AMD	1999.971





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Conclusions & Recommendations

- HMA skid prediction model with some modifications was successfully used for seal coat.
- Inclusion of angularity parameter improved HMA skid prediction model.
- The quality of seal coat construction has a great influence on its skid performance.
- For a given aggregate, a coarser mixture maintains higher skid life throughout the service life.
- Aggregate texture and its rate of change is the most influential factor.
- Truck traffic causes as much as 20 times more polishing.
- Blending of high textured aggregate improves skid number.

Conclusions & Recommendations

- The proposed method of predicting skid using AIMS and MD to characterize aggregates can replace the current aggregate classification system.
- A three-wheel polisher could be a good tool to evaluate the HMA and seal coat in the lab.
- Lane distribution factors of traffic need to be further examined.

Module 2:

Aggregate Characterization

Aggregate Polishing with Micro-Deval

Aggregate Image Measurements System

Module 3:
SAAP User Guide

Research Report 0-6746-1 documents the research effort and the skid prediction models for asphalt mixtures and seal coat surfaces, respectively, under TxDOT Research Project 0-6746. Both of these models feature similar inputs and equations with only minor variations. In order to simplify the calculation of predicted skid numbers, a desktop computer application was developed based on the macro tool developed earlier under Research Project 0-5627.

Under the follow-up study, Research Project 0-6746, a computer application named SAAP was developed using Access-based Visual Basic Application (VBA) language to execute the steps needed to calculate the skid resistance of asphalt pavement as a function of traffic. This section describes the program and the steps needed to calculate the pavement skid resistance for both asphalt mixture surfaces and seal coat surfaces.

In the folder named Application, the application has two Microsoft Access files—an application file and a data file—and another folder called Export. Once the user opens the application file by double clicking, he/she will notice the first page (Figure 1). This “About” page describes the function of the SAAP application. On the next page (Figure 2), the user needs to input a new project name or select one of the existing projects in order to proceed to the next window. Next, the user selects the type of pavement surface (Figure 3)—asphalt mixture or surface treatment. Depending on the type of surface selected, the application uses the appropriate prediction model. The inputs for both asphalt mixtures and seal coat surfaces are similar. In the next step (Figure 4), the mixture gradation is inputted to the application. The user can either enter the gradation or select one of the standard mixture gradations used in the state of Texas. Similarly, if surface treatment is selected as the pavement surface, the user can either enter the gradation or select the standard aggregate grade. If the user elects to enter the gradation manually by selecting the Input Gradation radio button, a separate window pops up (Figure 5), where the amount of percent passing for selected sieves is entered. The user can select any number of sieves (minimum four) and enter the percent passing values for each selected sieve. This information is used to calculate the scale and shape factors (λ and κ) of the combined gradation.

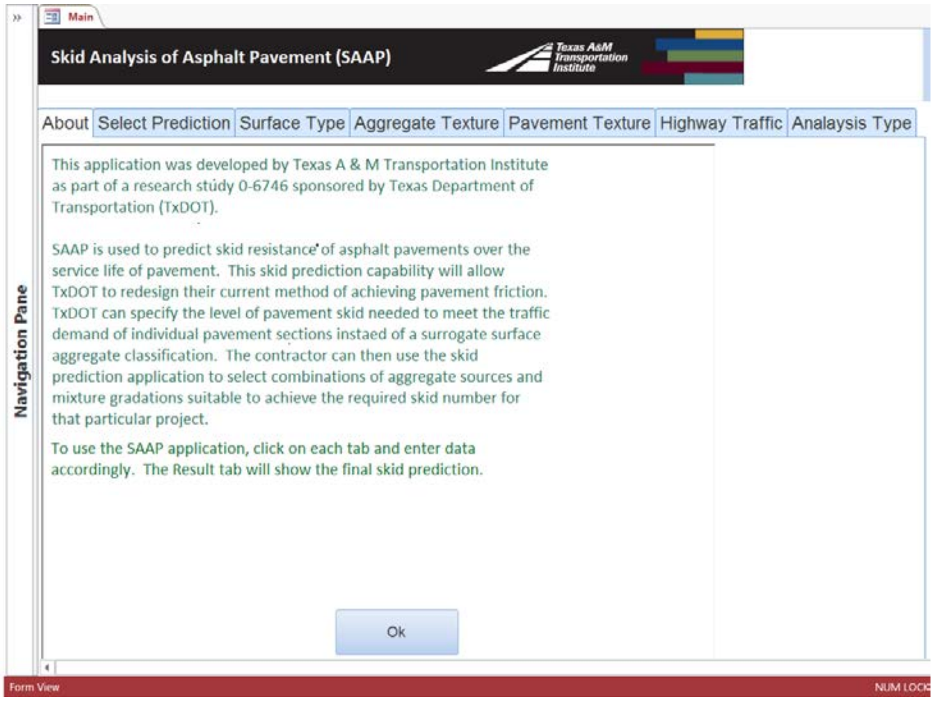


Figure 1. Initial Window of the Program.

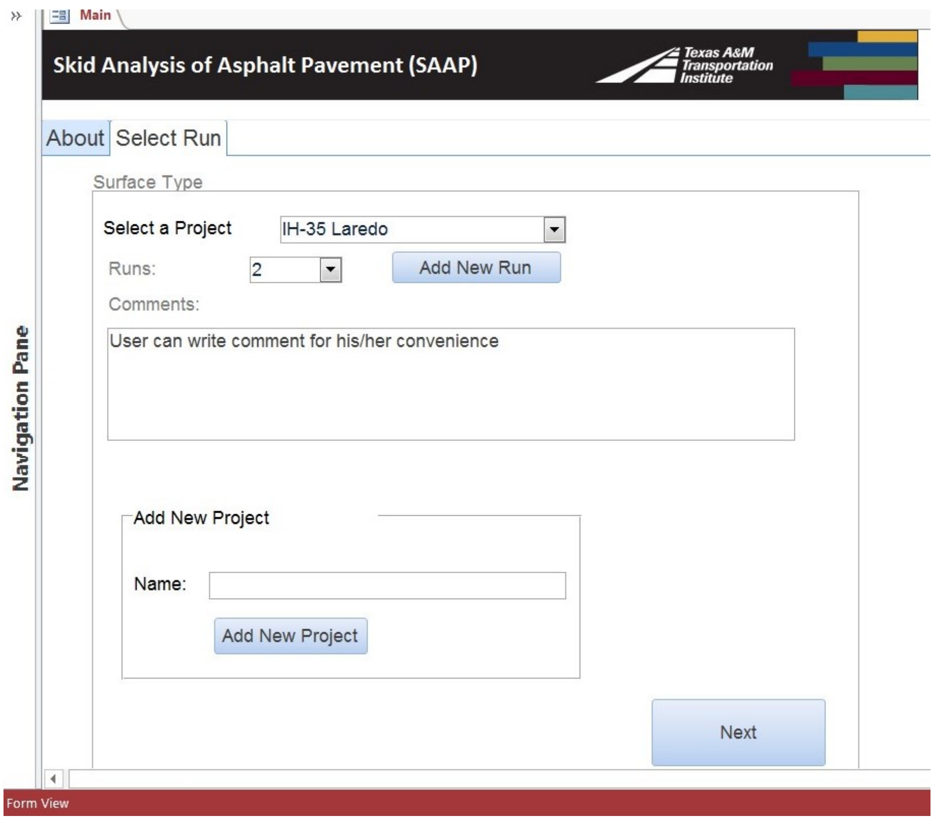


Figure 2. Project Name Input.

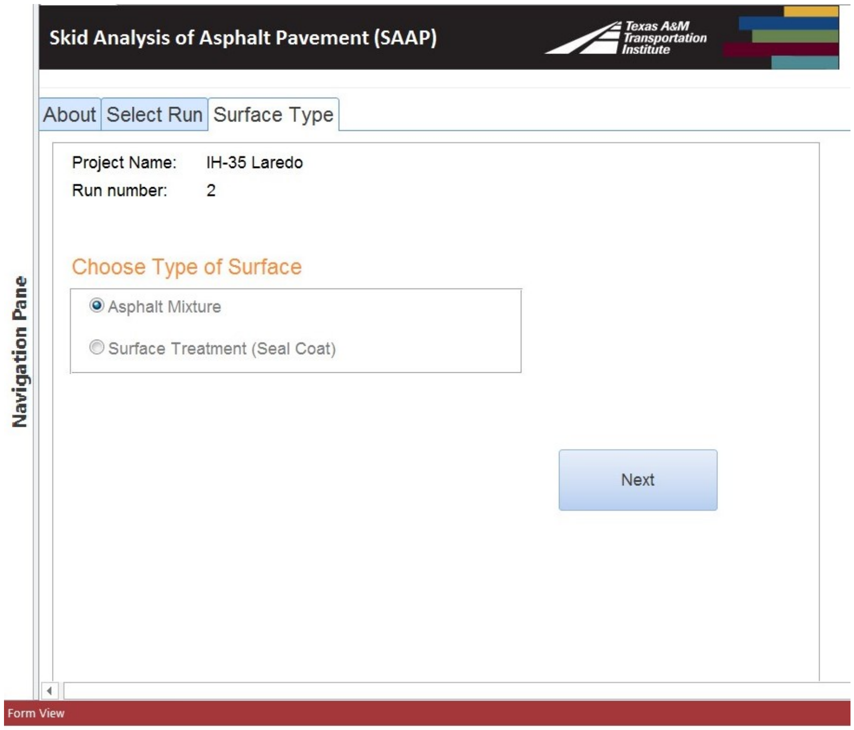


Figure 3. Pavement Surface Type Input.

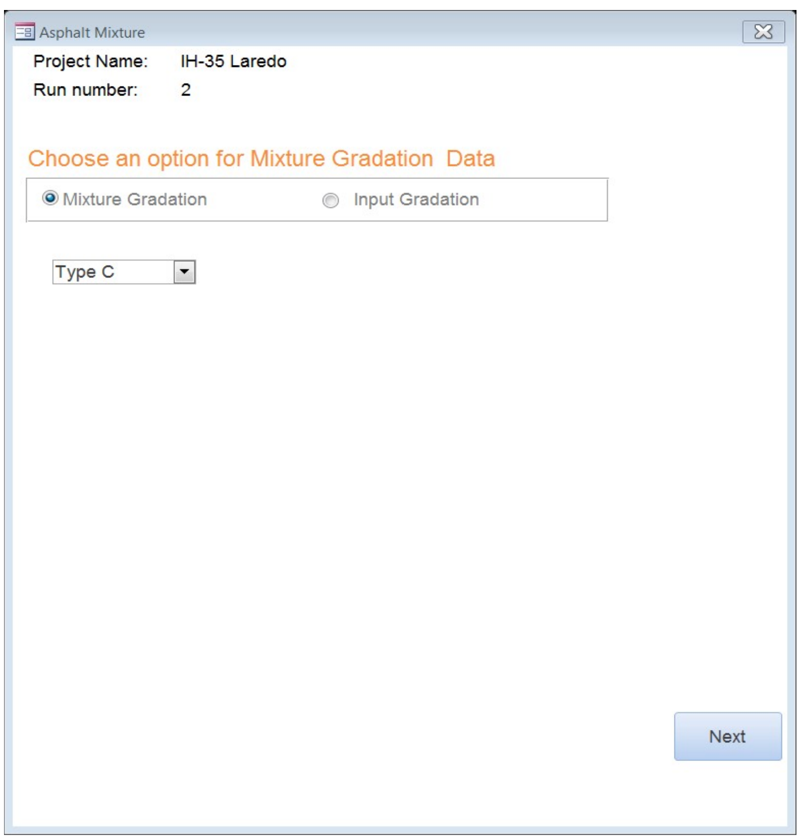


Figure 4. Choice of Mixture Type.

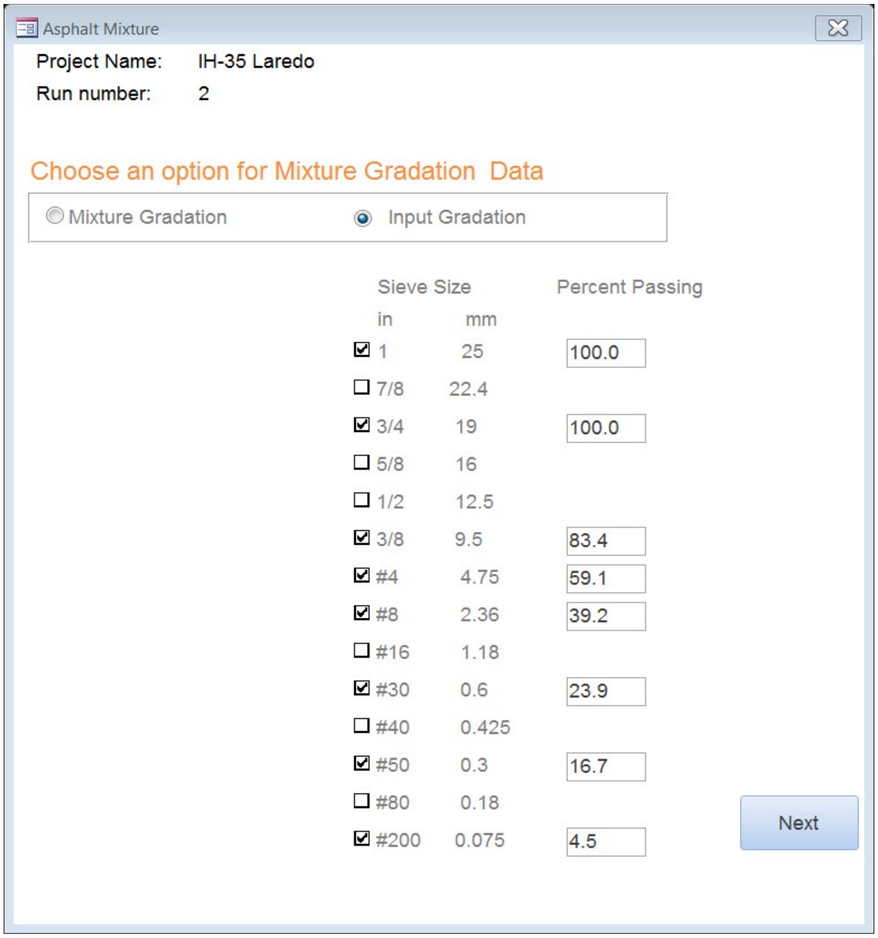


Figure 5. Manual Aggregate Gradation Input.

In the next few steps, the aggregate texture and angularity values measured using AIMS are entered. The window shown in Figure 6 provides the option to input either the texture/angularity measured at two points (before polishing and after polishing for 105 minutes in the Micro-Deval) or the texture/angularity measured at three points (before polishing, after polishing for 105 minutes in the Micro-Deval, and after polishing for 180 minutes). The use of three data points provides a more accurate estimation of aggregate resistance to polishing. This step will be followed by the appearance of windows to enter the texture data of aggregates from one or more sources. The user can select up to three aggregate sources used in the mixture. As shown in Figure 7, users can input the texture value of the component aggregate source(s). In the same window, the user needs to input the percentage ratio of each aggregate source relative to the combined gradation and the percent retained on the No. 4 sieve for each of the sources. This information is required to calculate the weighted average of texture and angularity of combined gradation when two or more aggregate sources are used.

Figure 8 shows the window that pops up if the user opts for three data points (Figure 6). Similar to Figure 7, the user inputs the ratio of aggregate in combined gradation and amount of percent retained on the No. 4 sieve for each source as well as the texture data measured by AIMS at three different polishing levels.

For the next step, the user inputs aggregate angularity data similar to aggregate texture data. The screen shown in Figure 9 or Figure 10 pops up, depending on whether the user selected two data points or three data points for the texture/angularity measurement (Figure 6).

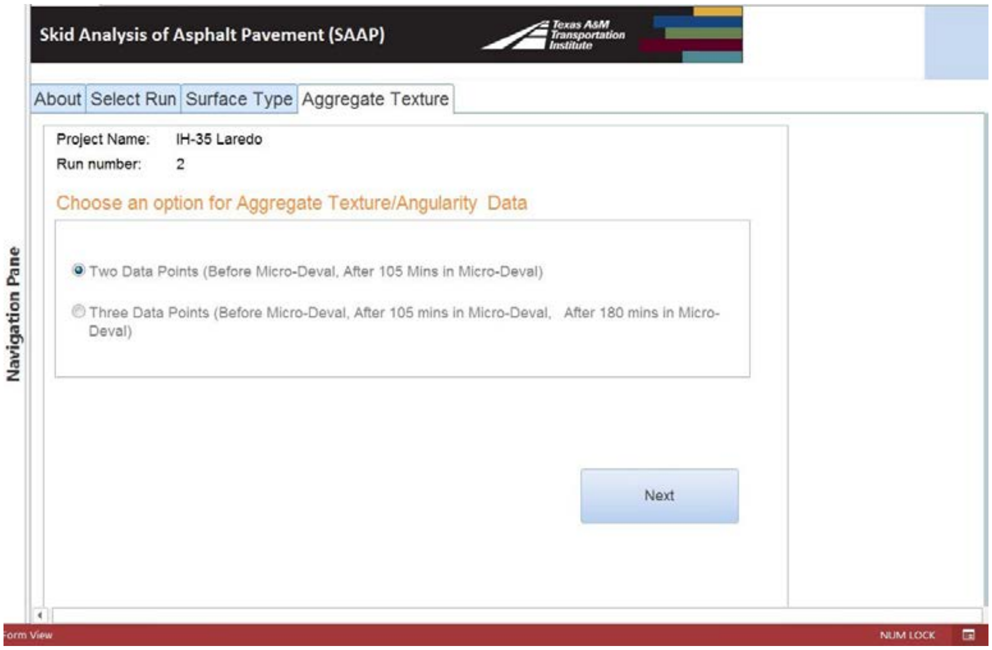


Figure 6. Selection of AIMS Test Data Points.

Figure 7. Aggregate Texture Input for Two Data Points.

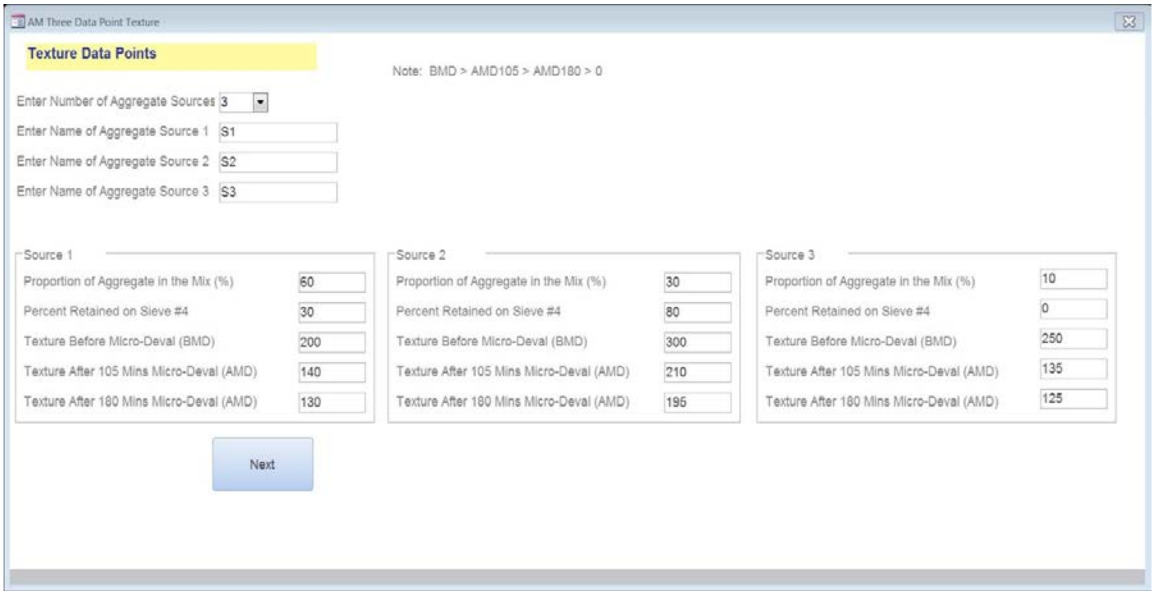


Figure 8. Aggregate Texture Input for Three Data Points.

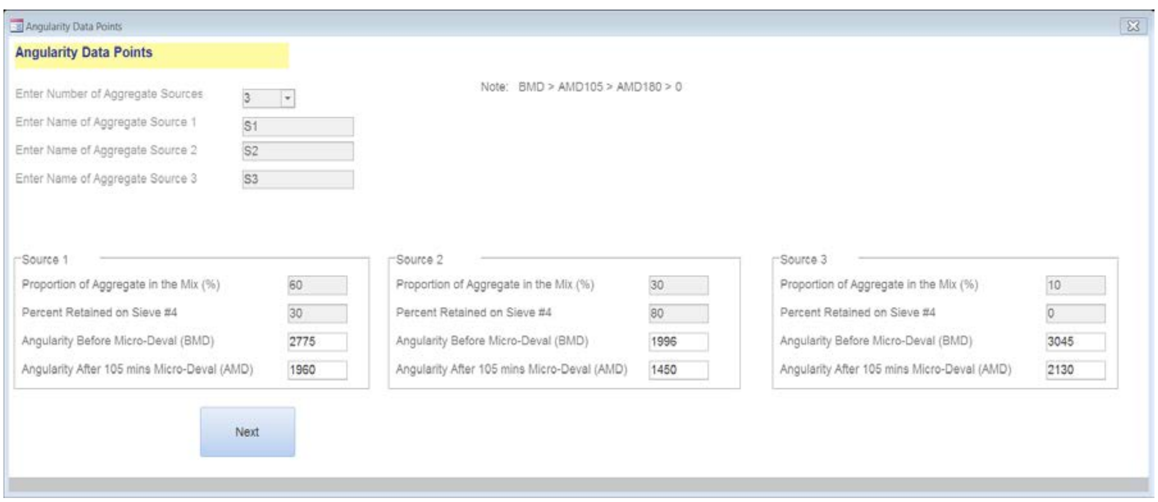


Figure 9. Aggregate Angularity Input for Two Data Points.

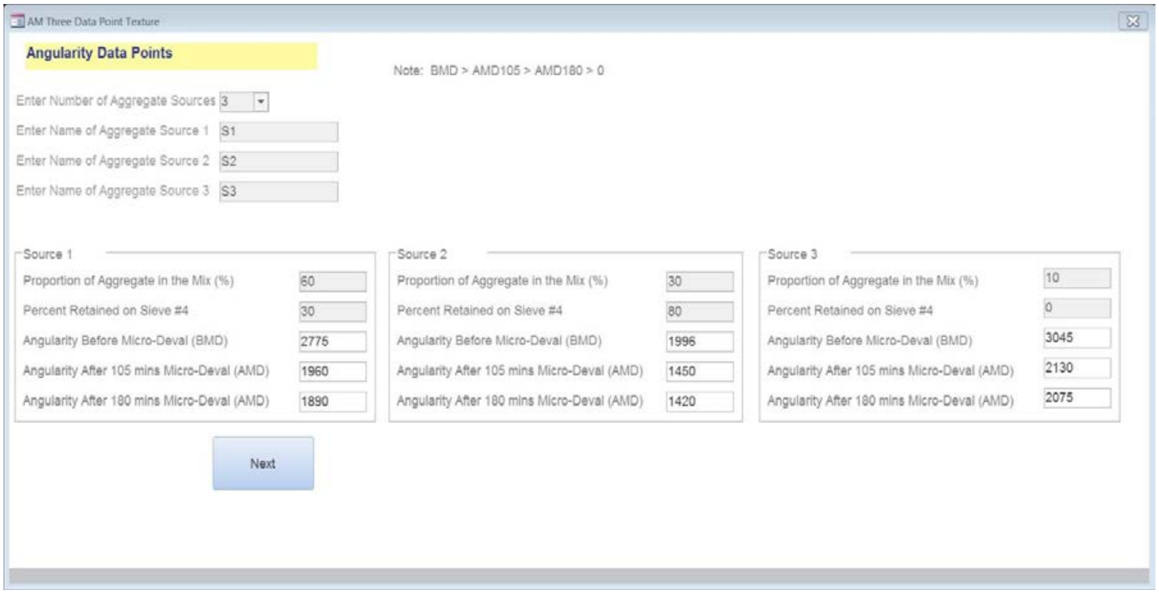


Figure 10. Aggregate Angularity Input for Three Data Points.

Once the user enters the aggregate angularity data and clicks the Next button, a new window (Figure 11) appears. At this stage, the user enters the mean profile depth (MPD) of the pavement. There are two options: the user can enter the MPD value or let SAAP estimate the MPD values. The user can input the measure of MPD for that particular mixture or grade (seal coat). It is preferred to have the measurement done at the initial stage of the pavement's service life. The SAAP projects the reduction of the MPD throughout its service life based on the traffic count. Alternately, the user can select the SAAP estimation option. That way, SAAP estimates the MPD values based on the shape and scale factors calculated from combined aggregate gradation and traffic count.

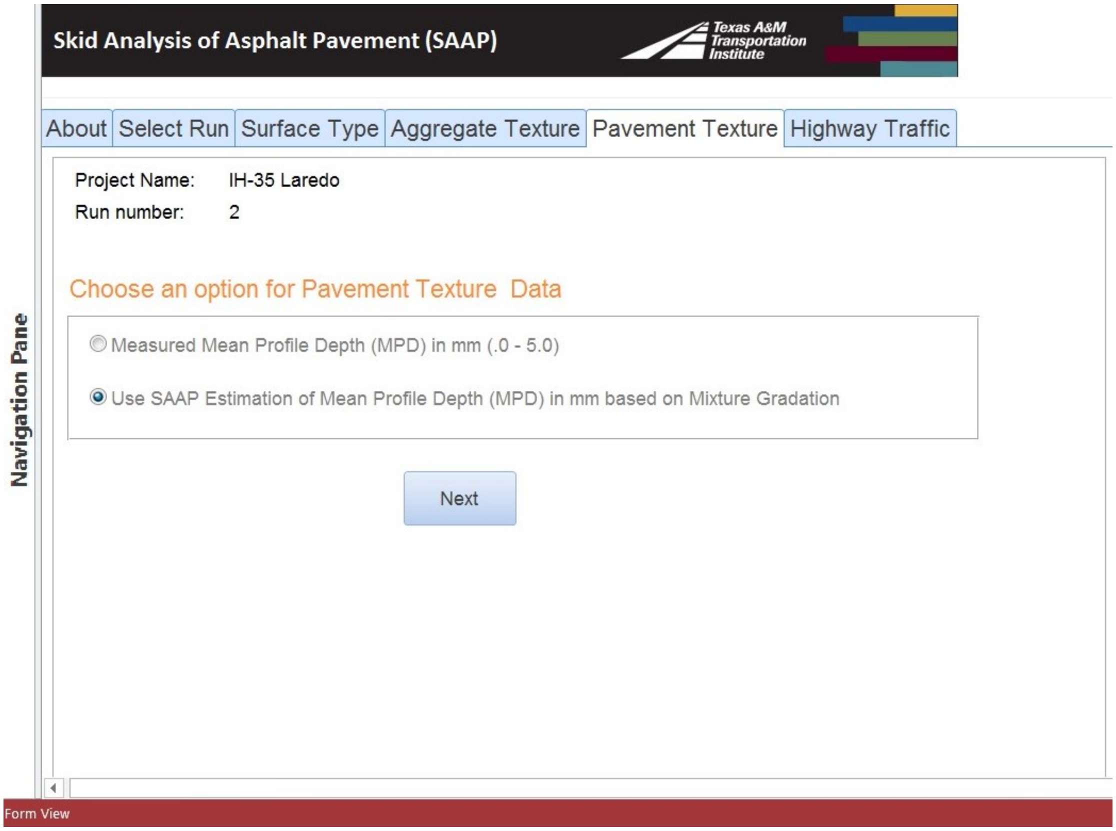


Figure 11. Mean Profile Depth Input.

After entering the MPD information, the user inputs the highway configuration and traffic data (Figure 12). In this step, the user enters the information about the highway type (rural/urban or divided/undivided), the total number of through traffic lanes in each direction, the total AADT for both directions (for undivided highway, K roadbed) or the AADT for each direction (for divided highway, R or L roadbed), and the percent truck traffic (Figure 12). Using this information, the application calculates the adjusted AADT for the design lane. Again, the adjusted AADT is used to calculate the Traffic Multiplication Factor (TMF). Please note that the current application does not consider the traffic growth factor.

When the user clicks the Next button, as shown in Figure 12, the software generates the skid number for 15 years at 1-year intervals starting from Year 1.

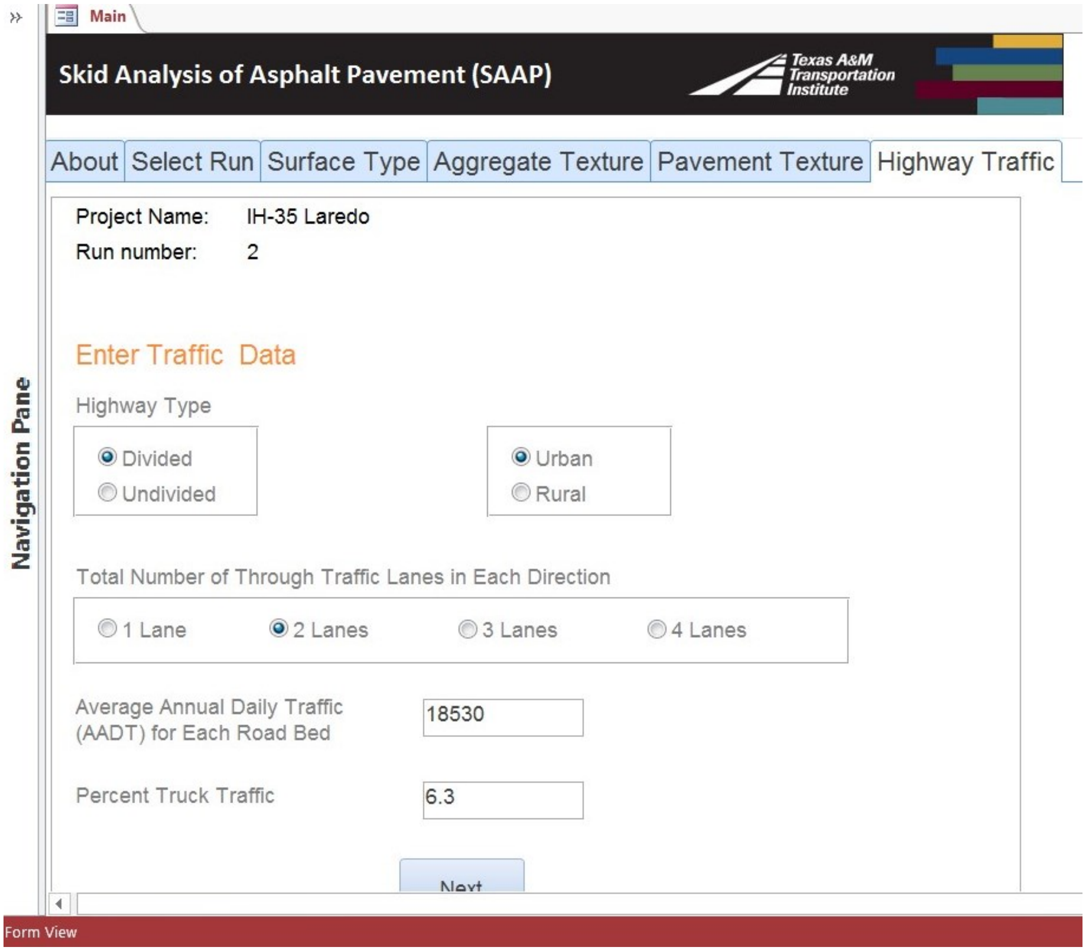


Figure 12. Highway Type and Traffic Data Input.

The next step (Figure 13) in the software provides options on how the user wants to see the output. In this window, there are three options for the display of results. The first option is to obtain a prediction of skid resistance as a function of years in service (up to 15 years). This chart also contains the project and prediction (iteration) number in the top left corner. The user can also print the chart by clicking the Print tab (Figure 14).

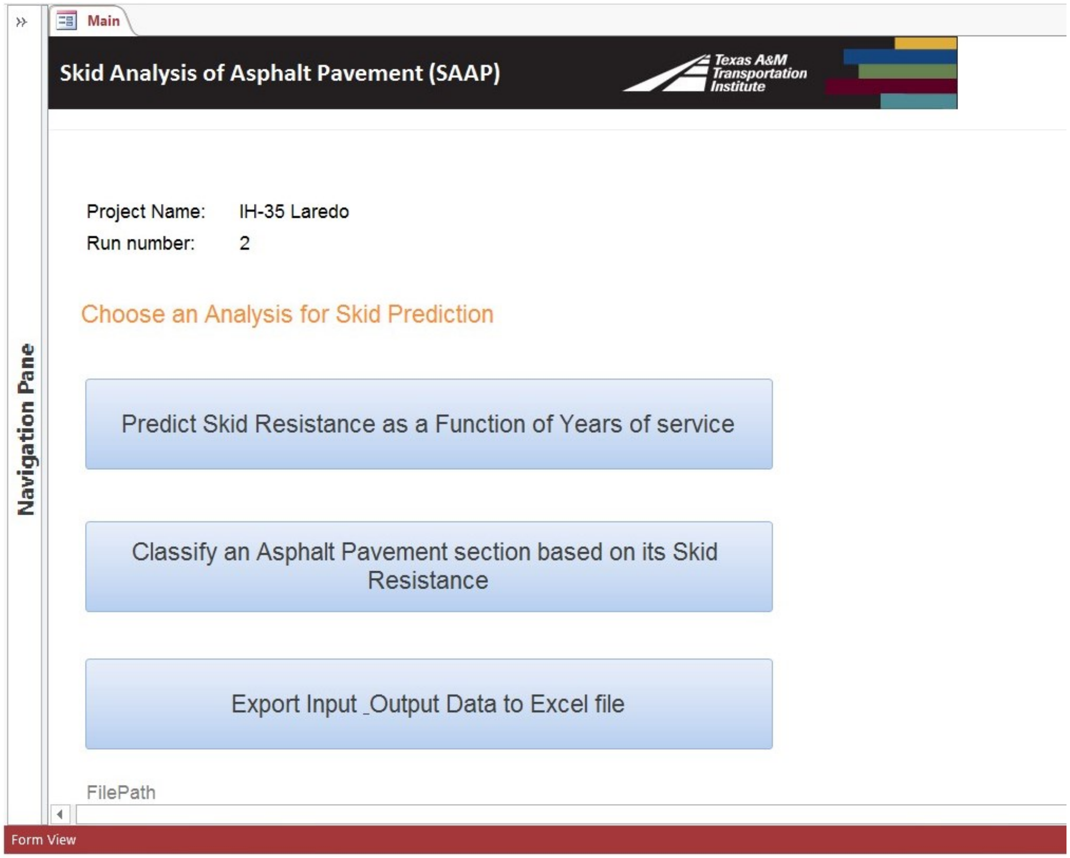


Figure 13. Output Data Display Options.

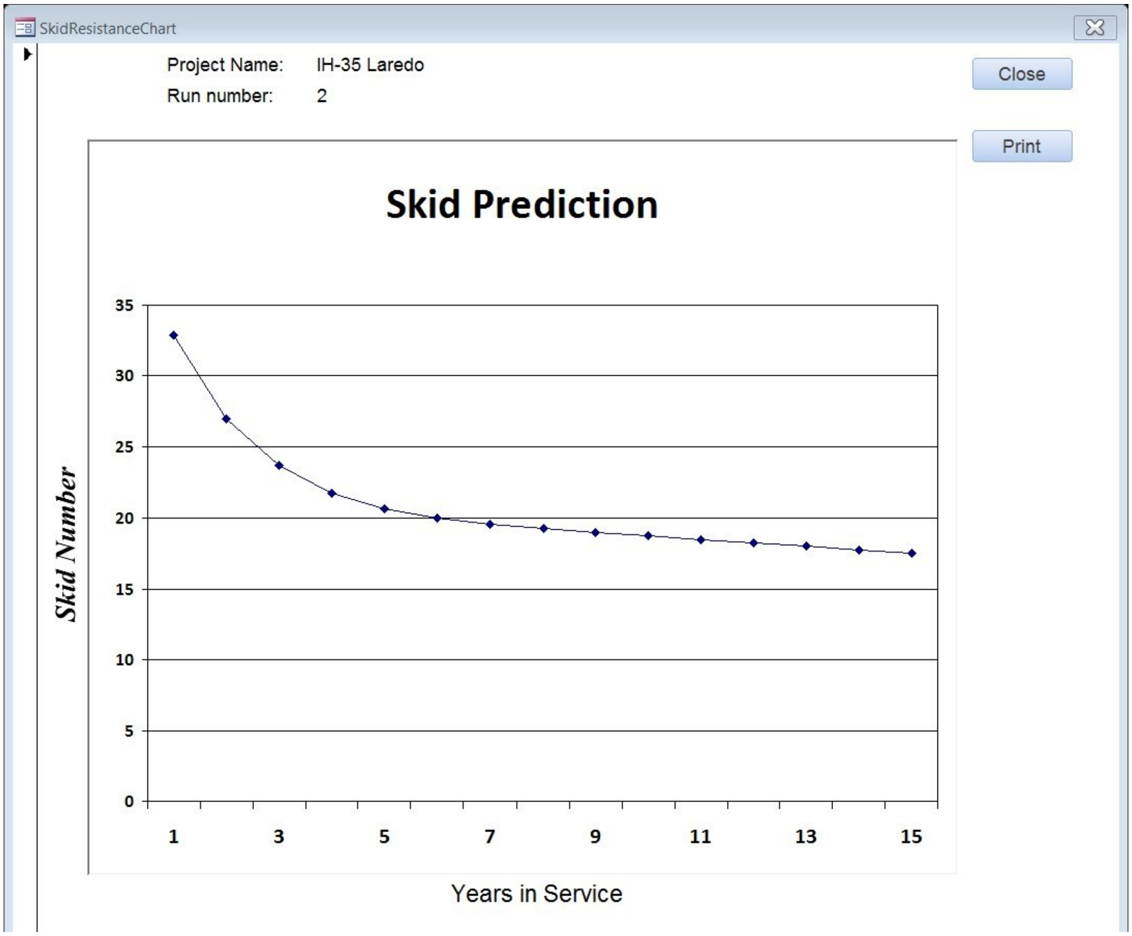


Figure 14. Skid Prediction Chart for 15 Years.

The second option is to get a classification of the pavement section based on its skid resistance after a specified number of years and corresponding threshold values. If the user selects "Classify an Asphalt Pavement Section Based on Its Skid Resistance," a window (Figure 15) pops up in which the user needs to input some additional information required for pavement classification. These input parameters are:

- The length of service life in years for which a pavement section will be classified.
- The skid resistance threshold values based on how a pavement section will be classified (Figure 14). The first threshold value is the acceptable skid number above which the designer is not concerned. The second threshold value is the skid number above which (but below the acceptable value) one should monitor the surface condition more frequently and below which one should take corrective measure to restore surface friction.

After clicking on the Set button, a window with the pavement classification will be presented (Figure 16). Depending on the predicted skid number at the end of service life and designer-selected threshold values, the pavement skid performance is classified as high, medium, or low. For display purposes, the high, medium, and low skid performances are shown in a green, yellow, and red bar chart, respectively.

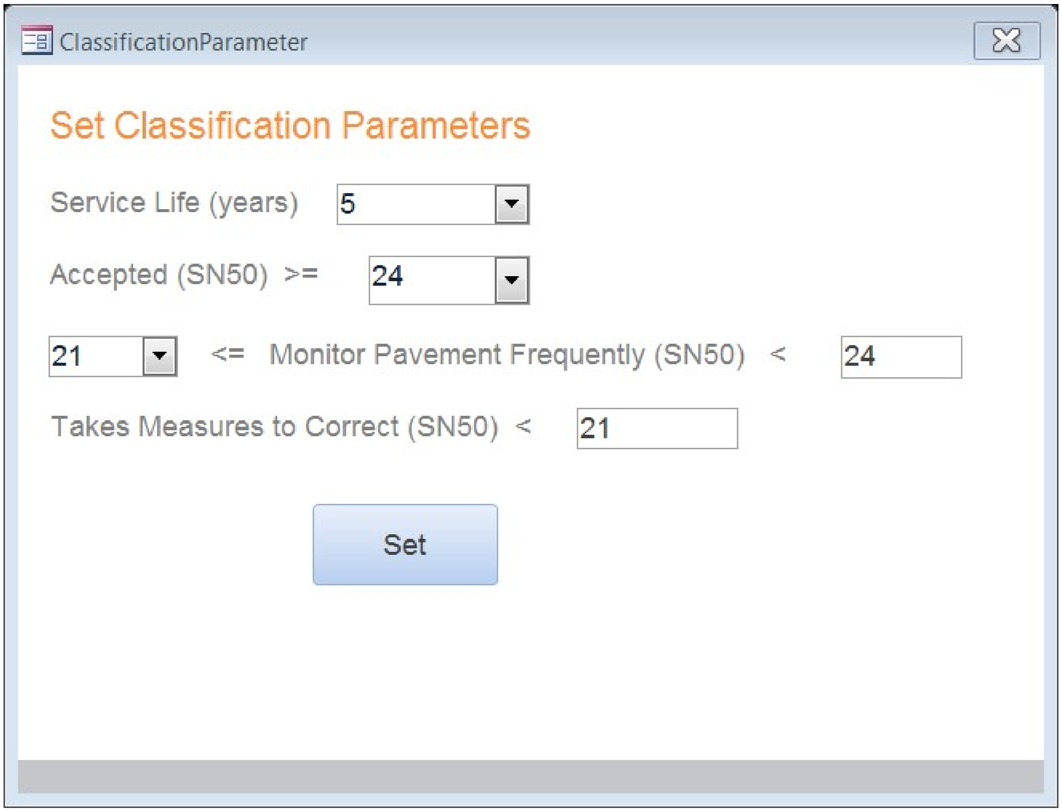


Figure 15. Selection of Thresholds or Aggregate Classification.

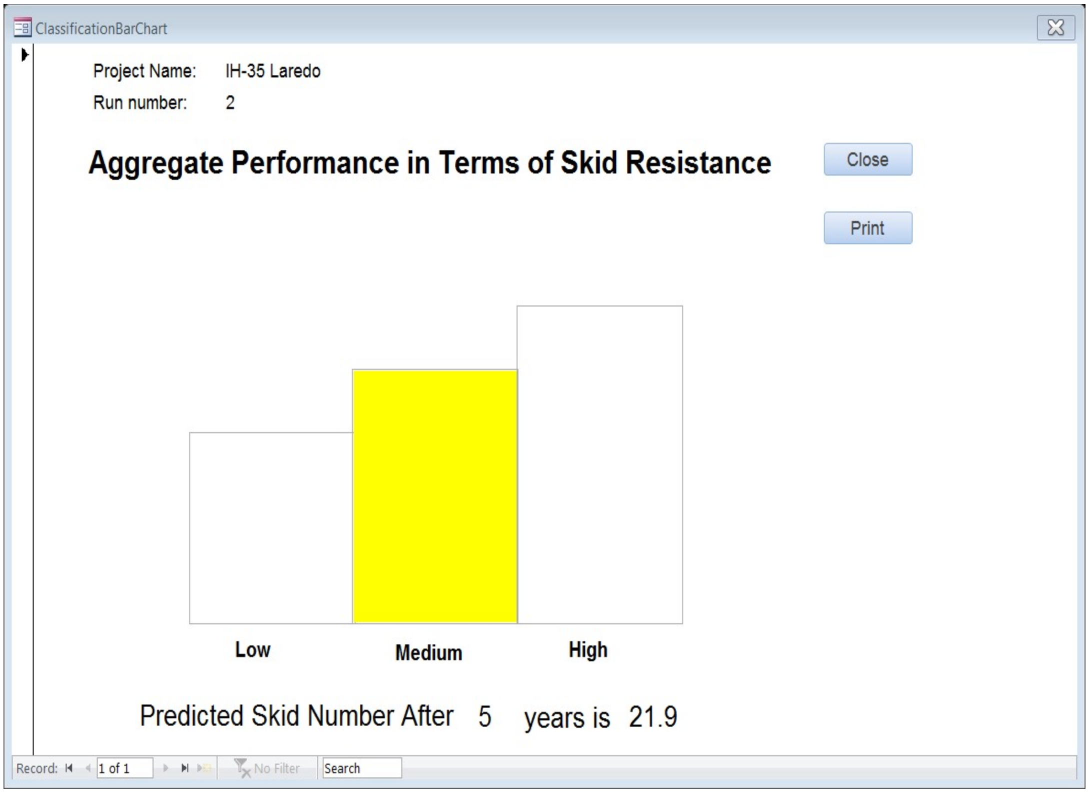


Figure 16. Sample Aggregate Classification Based on Skid Performance.

The third option for displaying the data is to export the input and output data into a Microsoft Excel spreadsheet. By clicking this button, the user can export the input and output file in a separate folder. Once the user selects this option, a new window (Figure 17. Saving Input and Output Spreadsheet Files. opens. The user has the option to change the input file name and the location folder. Once the input file is saved, the same window provides the option to save the output file, where the user can save the output file in a different name and location folder. Figure 18. Sample Input Spreadsheet. and Figure 19. Sample Output Spreadsheet. show sample input and output data in a spreadsheet. The Input file records all the data or preferences selected by the user, including the comments. The output file shows the projected skid number, IFI, MPD, and adjusted traffic count for each year starting from Year 1 to 15.

The application can be terminated by clicking the Exit Application button. The application saves all the input data entered previously. The user can also navigate through the application by clicking the tabs located on top of the windows.

Detailed information regarding the development of these models and software can be found in Research Report FHWA/TX-17/0-6746-1, “Validation of Asphalt Mixture Pavement Skid Prediction Model and Development of Skid Prediction Model for Surface Treatments” at http://tti.tamu.edu/documents/0-6746-1.pdf.

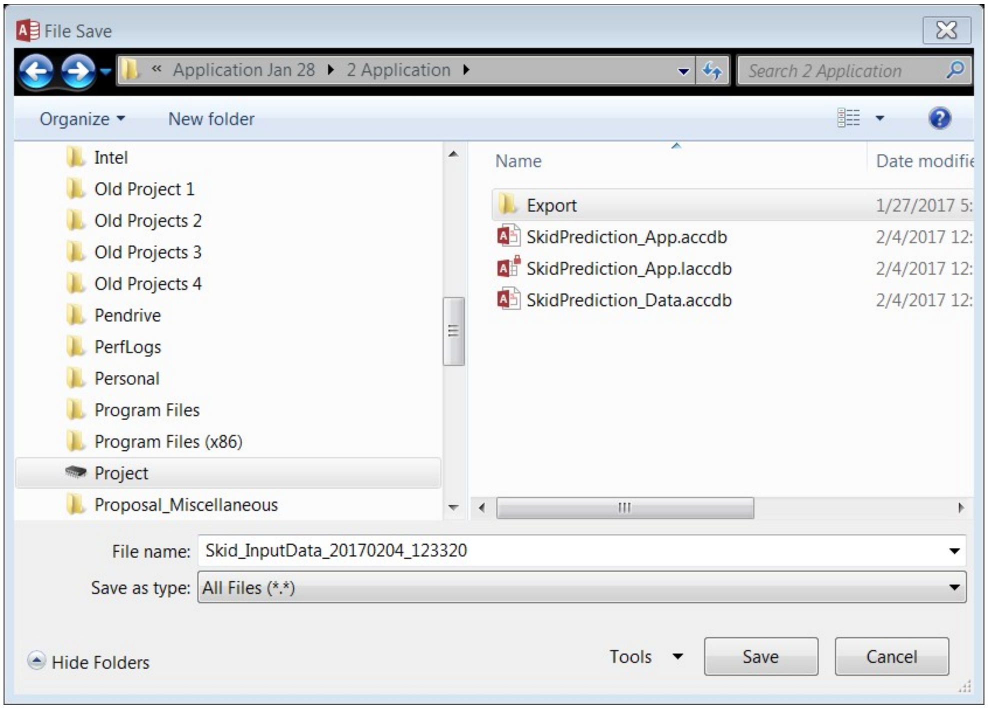


Figure 17. Saving Input and Output Spreadsheet Files.

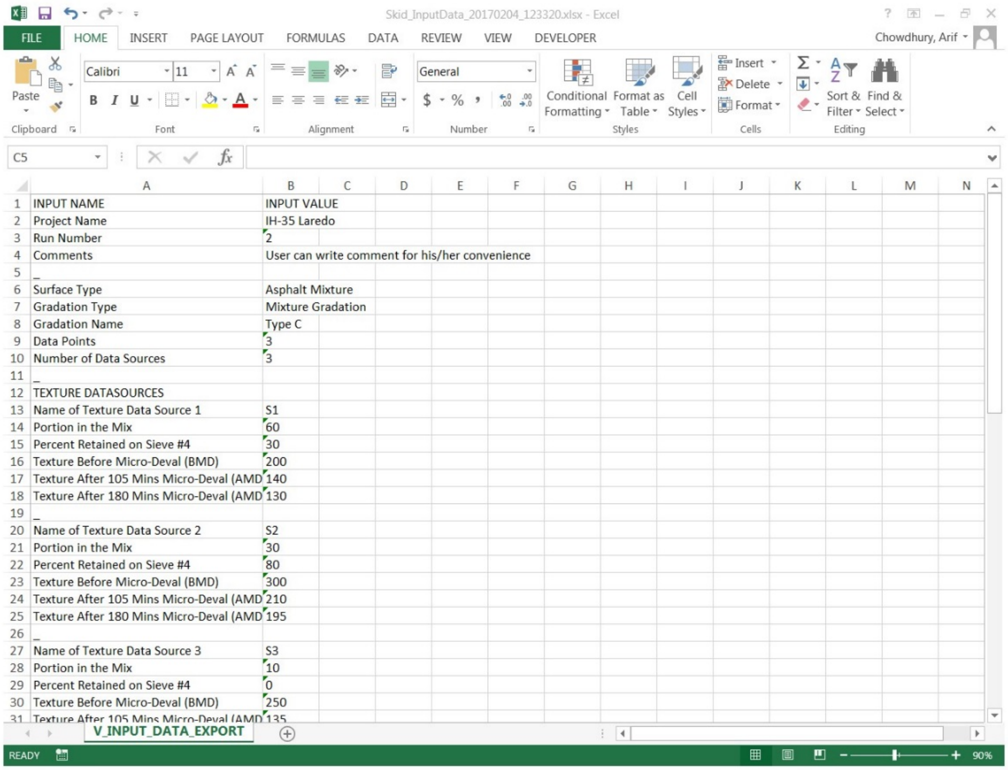
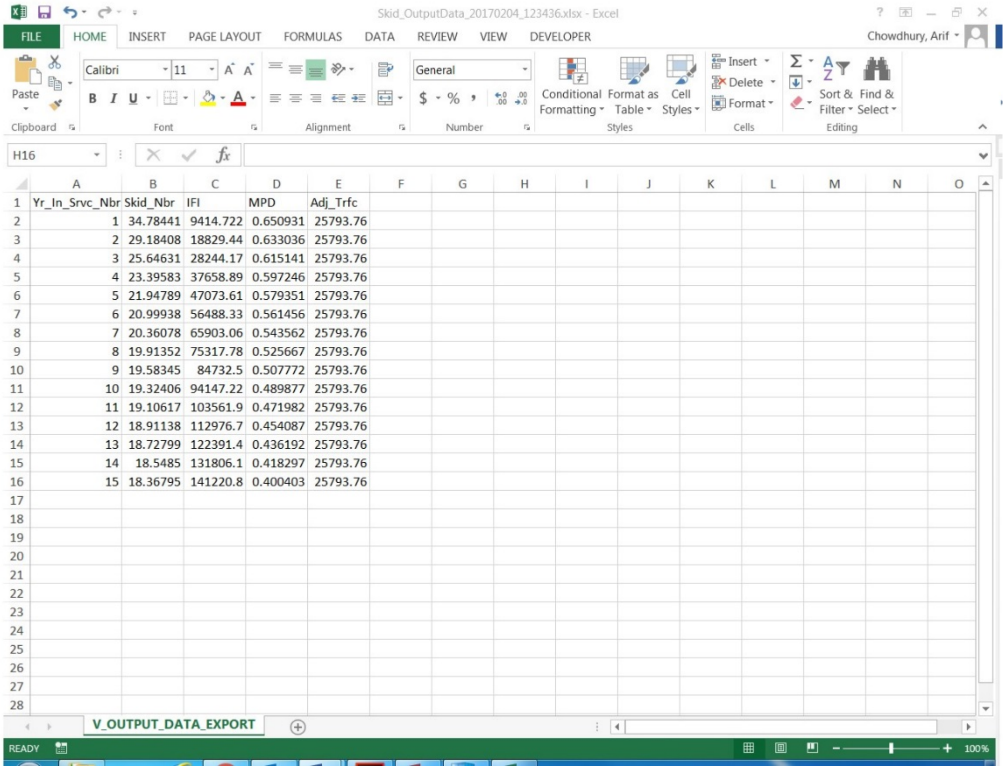


Figure 18. Sample Input Spreadsheet.



Yr_In_Srvc_Nbr	Skid_Nbr	IFI	MPD	Adj_Trfc
1	34.78441	9414.722	0.650931	25793.76
2	29.18408	18829.44	0.633036	25793.76
3	25.64631	28244.17	0.615141	25793.76
4	23.39583	37658.89	0.597246	25793.76
5	21.94789	47073.61	0.579351	25793.76
6	20.99938	56488.33	0.561456	25793.76
7	20.36078	65903.06	0.543562	25793.76
8	19.91352	75317.78	0.525667	25793.76
9	19.58345	84732.5	0.507772	25793.76
10	19.32406	94147.22	0.489877	25793.76
11	19.10617	103561.9	0.471982	25793.76
12	18.91138	112976.7	0.454087	25793.76
13	18.72799	122391.4	0.436192	25793.76
14	18.5485	131806.1	0.418297	25793.76
15	18.36795	141220.8	0.400403	25793.76

Figure 19. Sample Output Spreadsheet.

Limitations of SAAP

The limitations of SAAP include the following:

- Software cannot be used to predict the skid resistance of concrete pavement.
- Software can handle up to three aggregate sources but can be modified to include more sources.
- Software cannot handle mixture with Recycled Asphalt Pavement (RAP) or Lime Rock Asphalt (LRA). AIMS cannot characterize them.
- Prediction model is based on skid number measured at 50 mph and with smooth tires. Calibration of models is required for different conditions.
- AIMS characterization (texture especially) of multicolored rocks is challenging.
- Skid prediction does not work for pavements with excessive bleeding and flushing.
- Aggregates passing a No. 4 sieve have no effect. They can be modified down to a No. 8 sieve, though. The limiting factor is the ability of AIMS to characterize the texture of aggregate smaller sizes.
- Traffic growth factor was not included in the cumulative traffic calculation, but it can be modified in the future.
- Lane distribution factors for passenger vehicle and truck traffic are based on limited data. Future work should revisit this issue.
- Default shape and scale factors (λ & κ) for a given mixture gradation were calculated based on a gradation curve passing through the middle of the respective gradation band. Inputting the actual combined aggregate gradation provides the most accurate shape and scale factor.