NCAT Report 13-12

DYNAMIC FRICTION TESTER WORKSHOP AND ROUND-ROBIN TESTING SUMMARY

By

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December 2013

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NCAT
at AUBURN UNIVERSITY

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DISCLAIMER

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Dan Sajedi	Maryland SHA
Ms. Marlys Johnson	Maryland SHA
Edward Morgan	Texas DOT
Juan Gonzalez	Texas DOT
Bryan Wilson	TTI at Texas A&M University
Bob Rees	Indiana DOT
Ayesha Shah	North Central Superpave Center at Purdue University
Bryan Smith	Virginia DOT
Billy Hobbs	Virginia Tech University
Charles Holzschuler	Florida DOT
Patrick Upshaw	Florida DOT
Paul Gentry	Florida DOT
Robin Tallon	Larson Transportation Inst. at Penn State University
David Klinikowski	Larson Transportation Inst. at Penn State University
Tim Scully	University of Kentucky
Cliff Barber	American Civil Constructors, Benicia, CA
David K. Merritt	The Transtec Group, Inc.
RP Watson	The Transtec Group, Inc.
Bob Orthmeyer	Federal Highway Administration
Andy Mergenmeier	Federal Highway Administration
Toshiyuki (Tim) Kise	Shima American Corporation
Noboru Ishikawa	Nippo Sangyo
Tomoya Hamano	Shima Trading Co. Ltd

TABLE OF CONTENTS

Chapter 1 Background

1.1 Objective and Scope

A number of state agencies, consultants, and research centers are using a dynamic friction tester (DFT) as a quick, relatively simple, lightweight device for spot-testing pavement surface friction. Based on the experience of these users, a number of issues with the equipment and test standard have been noted. The scope of this workshop is to bring DFT users together to discuss these issues and collectively outline areas that should be addressed.

The objectives of the workshop are to:

- provide an open forum for discussion
- develop a list of concerns
- provide direction for further development of the equipment and test method
- provide an opportunity for side-by-side testing of DFT devices

1.2 Agenda

The workshop was divided into two primary events. On Monday afternoon, July 22, 2013, all of the groups arrived at the NCAT Pavement Test Track for round-robin testing. On Tuesday morning, July 23, participants met in a conference room at the NCAT Office for a half-day of open discussions.

The Monday round-robin testing was a structured event. All ten participating DFT units measured friction on three validation plates. The original plan included checking some simpler calibration steps on devices that measured outside a reasonable validation plate tolerance, but time did not permit calibration checks. Each DFT unit was then assigned a specific sequence of pavement surfaces to measure. In all, ten common asphalt surfaces and one high friction surface were tested by all ten DFT units. Each unit was provided two sets of rubber sliders for the testing. In total, 550 tests were performed plus tests on the validation plates. Details of the testing are provided in other sections of this report.

The discussions on Tuesday morning were informal and all participants contributed to the discussion topics. There were no prepared presentations. The agenda topics are listed below. A summary of the discussion on each topic follows.

- Features and Calibration
- Results of Round-Robin Testing
- Pavement Slope and Rutting
- Single Test Replicate Drops
- Use of Rubber Slider Pads
- Correlation with Skid Trailer
- Improvements to ASTM E1911

1.3 List of Participants

Table 1 lists the participants at the workshop. The table groups the individuals by their agency/company affiliation. Five state highway agencies were represented. Most groups included an engineer and senior technician. It was critical to the round-robin testing plan that an "experienced" DFT equipment operator was a part of the team from each group. The level of experience ranged from new users to those with many years of testing. It was also very beneficial to have the North American equipment representative, Shima American Corporation, and the equipment manufacturer, Nippo Sangyo, participating in the workshop. The Shima group responded to a number of questions from participating users.

TABLE 1 List of Workshop Participants

Name	Workshop DFT Testing	Agency/company	Report Abbreviation
Dan Sajedi	yes	Maryland SHA	MD
Ms. Marlys Johnson			
Edward Morgan	Yes	Texas DOT	TX
Juan Gonzalez			
Bryan Wilson	yes	TTI Texas A&M University	
Bob Rees		Indiana DOT	IN
Ayesha Shah	yes	North Central Superpave Center at Purdue University	
Bryan Smith	yes	Virginia DOT	VA
Billy Hobbs		Virginia Tech University	
Charles Holzschuler Patrick Upshaw Paul Gentry	yes	Florida DOT	FL
Robin Tallon David Klinikowski	yes	Larson Transportation Inst. at Penn State University	PA
Tim Scully	yes	University of Kentucky	KY
Cliff Barber		American Civil Constructors, Benicia, CA	
David K. Merritt RP Watson	yes	The Transtec Group, Inc.	TT
Bob Orthmeyer Andy Mergenmeier		Federal Highway Administration	FHWA
Toshiyuki (Tim) Kise		Shima American Corporation	
Noboru Ishikawa		Nippo Sangyo	
Tomoya Hamano		Shima Trading Co. Ltd	
Michael Heitzman Brian Waller Vickie Adams Mary Greer	yes	National Center for Asphalt Technology	NCAT

At the beginning of the workshop discussion Tuesday morning, each participant was asked how their DFT was used. Table 2 gives a summary of each participant's DFT use. This represents United States highway interest groups. Related to DFT use, Shima provided general numbers on worldwide distribution of DFT units. Most of the units are being used in Japan (approximately 130), there are approximately 30 units in the United States, and approximately 20 units located in other countries.

TABLE 2 Type of DFT Use by Workshop Participants

Type of Use	**Participating Groups**
Material or pavement surface acceptance	MD (aggregate in lab), FL (surfaces in field)
Field forensic evaluations	NCAT, TX, IN
Lab accelerated testing	NCAT, TX, IN
Research	NCAT, TX, IN, VA, PA
Promote safety and friction management	FHWA, TX, VA, PA, KY, TT

Chapter 2 Dynamic Friction Tester

The Dynamic Friction Tester is a portable device to measure friction that is exclusively available in the United States through Shima American Corporation. Details of the equipment can be found at http://www.nippou.com/en/products/dft.html. The details of the test method are described in ASTM test standard E 1911.

2.1 Features of the Equipment

The workshop discussed a number of key features of the DFT shown in Figure 1. It was not possible to have a detailed discussion of all DFT components in the time available, but important features that users needed to understand were addressed.

There are two models of the DFT hardware and software. The principle features of the test did not change. The new model added a mechanical feature to initiate the test, water spray bars on all four sides, and improved Excel compatible software.

Parallel spinning plates

The key feature of the DFT is the spinning plates assembly. The differential movement between the fly wheel plate and lower disc is where friction resistance is measured. Two critical components of this assembly are the displacement meter (load cell) and the balance spring. The load cell measures friction resistance as it interacts with the balance spring between the upper fly wheel plate and the lower disc that the rubber sliders are mounted on. Several users have had the balance spring break. When the balance spring breaks, the plates will move freely. The device will not test correctly when the spring is broken. A technician will likely begin seeing very irregular friction/speed measurement curves when the spring is broken. A skilled equipment technician can replace the spring, but the device will require a calibration to adjust the load cell.

Vertical load springs

Another key feature of the DFT is the pair of springs supporting the motor and plate assembly. These springs control vertical load of the assembly that is dropped onto a test surface. The springs must be properly set to maintain correct load transfer through the rubber sliders. This vertical load is a principle part of the definition of friction. Measured friction is the tangential force resisting movement based on the amount of vertical load. If the vertical load is too low, friction will also measure low. If the vertical load is too high, friction will also measure high. A skilled equipment technician can check the vertical load and, if necessary, adjust the pair of springs to apply the correct load.

Damper and screw valve

The damper assembly has two roles in the operation of the DFT. The first role is to support the motor and spinning plate assembly while the plates are accelerated to a designated drop speed. The second role is to release the plate assembly and allow it to drop onto a test surface. Supporting the plate assembly is accomplished by a magnetic field that is engaged when the cantilever arm pushes the steel rod into the damper. Releasing (dropping) the plate assembly involves two features: free movement of the steel rod in the damper and regulated flow of air into the damper as the rod moves. It is critical that the damper is kept clean so the steel rod moves freely. Air flow is regulated by the opening on the bottom of the damper that is controlled by a small set screw. If the screw is closed too tight, air flow is restricted and the plate assembly does not properly drop to a test surface. If the screw is opened too much, air flow is not regulated and the plate assembly will “bounce” when it makes contact with a test surface. There is no known calibration procedure to properly set the plate drop. A skilled equipment technician can use reasonable judgment to adjust the screw valve.

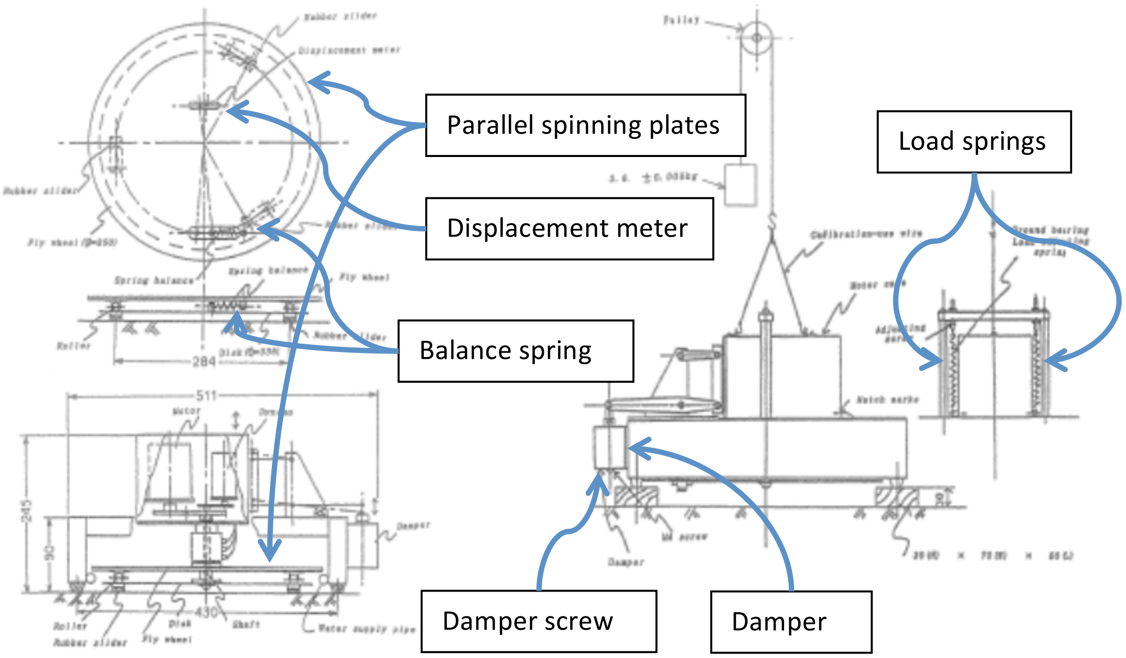


FIGURE 1 Key features of the DFT (*source: ASTM 1911*)

Water supply

The purpose of the water supply was discussed at length. The ASTM standard identifies a specific bucket, bucket height (0.6 m), and size/length of hose. This is critical to the test procedure because the operator must regularly replenish water in the bucket. The fundamental question is: what is the purpose of the water? The consensus of discussion was water is used to wet the contact surface and the only criterion is sufficient hydro-static pressure in the spray bar to disburse water. From the discussion it was considered acceptable to have a larger water supply further from a DFT test as long as sufficient water is distributed to the test surface. The spray bar must be inspected and cleaned regularly to insure all spray ports are open.

A related operational feature is the sequence for opening and closing the water valve during a test. Observations during round-robin testing found that there were several water valve sequences. Some operators were manually opening and closing the water line to conserve water and reduce the frequency to refill the bucket. Better instructions are needed and may be related to the type of surface being tested (dense, low macro-texture surfaces versus open, high macro-texture surfaces).

2.2 Calibration / Validation of the Equipment

Earlier versions of ASTM test standard E 1911 included an annex that described some calibration procedures. The 2009 version of the standard removed the calibration annex and added a section for use of a calibration panel. It was the consensus of the users that some of them have facilities and skilled equipment technicians to perform calibration checks included in the earlier ASTM version. It is important for most users to have the ability to perform routine maintenance, repair and validation/calibration of equipment. Users cannot afford to have their equipment go out-of-service for a long period of time. The users also agreed that the DFT is a mechanically demanding test and should be checked by manufacturer-trained technicians on a regular basis. One to two years between full calibrations was determined to be an appropriate length of time. The users identified some parameters that influence the period between calibrations, listed in Table 3. In general, more frequent and aggressive use requires a shorter period of time between calibrations.

TABLE 3 Factors that Influence Calibration Frequency

DFT Use	**Impact on Calibration**
Infrequent use	Devices that are not used regularly may change due to material aging and corrosion
High frequency use	Devices that are used for multiple tests every week and/or are shipped often wear faster
Severity of test surfaces	High friction surfaces (>0.60) wear the equipment more than conventional surfaces(<0.50)
Drop speed	Higher drops speeds (90 km/h and higher) wear equipment faster
Validation plate test target	Validation tests can monitor the DFT's accuracy and identify when the device is out-of-spec

The 2009 ASTM test standard calls for a calibration whenever the DFT unit measurement on a calibration panel differs by more than 0.03 at 40 km/h. There was general agreement among workshop participants that the 0.03 value does not correlate with the DFT precision value (about 0.04 for 40 km/h). If the precision standard deviation of 0.04 at 40 km/h is correct, then a calibration tolerance of 0.03 would likely require a re-calibration about 50 percent of the time a calibration panel test is performed. On the same subject of using a calibration panel to monitor measurement accuracy, participants noted that a comparison based on the last calibration panel test can lead to significant error if the DFT measurements begin to drift. Tolerance for a test on a calibration panel should be based on a test performed immediately after the last full calibration. The test immediately following a calibration should be considered the most accurate measurement to check future tests against.

For purposes of this workshop, a calibration panel is more appropriately called a validation plate. A plate is simply used to determine (validate) if a DFT unit is measuring correctly. If the measurement is not within a determined tolerance, then the calibration of the device needs to be checked. The DFT is not calibrated to a specific plate value.

Several users indicated that they use some form of a validation surface. Some are based on a plate with a controlled surface texture and others are based on an in-place laboratory surface such as a concrete floor slab. Everyone agreed that use of a validation plate is an important tool to check the operation of the DFT to insure the device is producing quality measurements. Shima brought the latest version of the DFT manufacturer's validation plate (a machine grooved steel plate) to the workshop. It was set alongside the NCAT textured steel plate and the Transtec inverted ceramic tile plate. The workshop participants encouraged Shima to price their validation plate reasonably if they want users to purchase it.

As part of the round-robin testing, each of the ten DFT units measured friction on each of the three validation plates, Nippo, Transtec, and NCAT. The measured friction varies as shown in Figure 2. The test plan for the validation plates was modified during the course of plate tests from five drops on each plate to two consistent drops. The reduction was necessary to move the DFT units from validation testing to test section testing as quickly as possible. Based on the test plan change, distribution of the DFT units based on validation plate testing should only be considered a relative ranking.

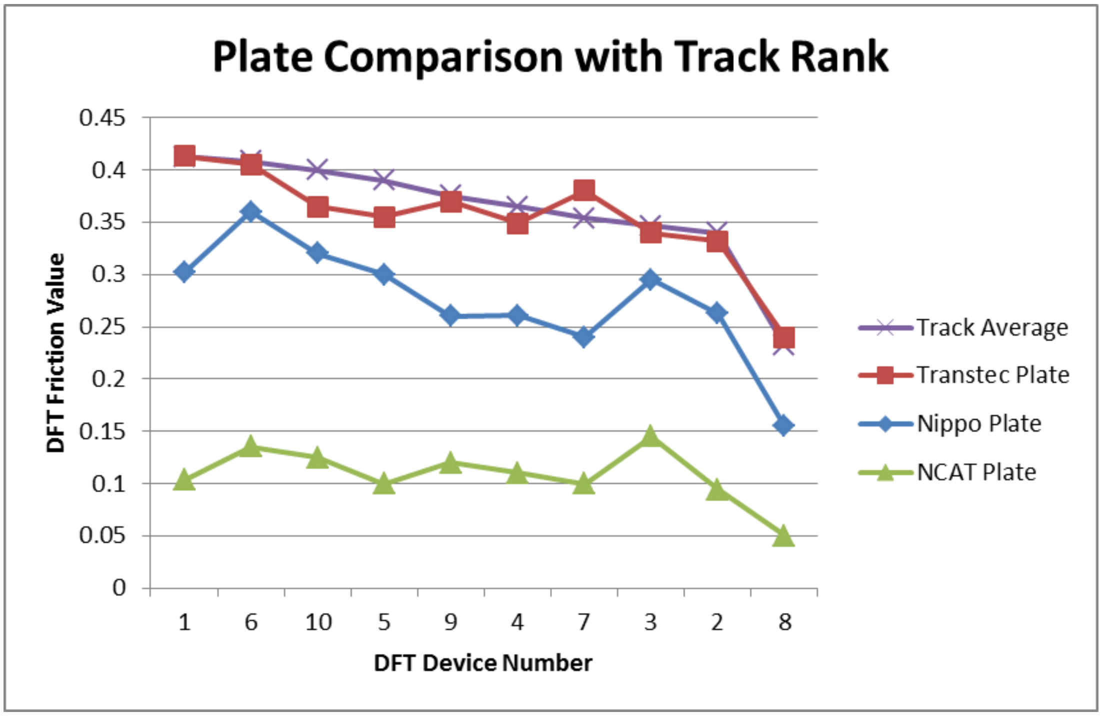


FIGURE 2 Relative distribution of DFT unit measurements on three validation plates

Chapter 3 Results of Round-Robin Testing

This section describes the testing plan and a summary of various analyses. Full statistical analysis details of the results of round-robin testing are provided in Appendix A. Ten DFT units were brought to the NCAT Pavement Test Track for round-robin testing. Seven devices were the older DFT models and three were the newer model. Each device made two or more measurements on each of three validation plates. Following validation plate measurements, each DFT unit team was given two sets of rubber slider pads for testing on selected Test Track pavement sections. Ten conventional asphalt pavement surfaces with skid trailer friction values (SN64R) between 25 and 45 were marked for testing. DFT units were assigned a specific sequence of test sections to measure. At each test section, a marked boundary of approximately 2 ft by 6 ft was placed in the left wheel path where the NCAT loaded trucks drive. Each DFT team independently selected one location for testing within the marked boundary. Each DFT made five replicate measurements on that one selected location. This process was repeated for a total of five test sections using the same set of rubber sliders. The second set of rubber sliders was used for the second group of five test sections. After a set of rubber sliders was used for 25 drops, the sliders were used for one more set of five replicate tests on a designated high friction surface (drops 26 through 30). In total, each DFT made 55 measurements on prescribed asphalt pavement surfaces. For each measurement, friction values at 60 km/h, 40 km/h and 20 km/h were recorded.

A number of analyses were made from the round-robin database. The analysis separates data from the ten standard test sections from data on the high friction surface. Seven analyses are based on the ten standard test sections and one analysis uses the high friction surface data.

The first analysis used all 1500 measurements (10 devices x 10 test sections x 5 replicate tests x 3 measurement speeds) to examine sources of variation using factors of device, measurement speed and test section. See Table 4 for the statistical summary. The dominating factors were device and test section. The analysis accounted for 98 percent of the overall data variation. Device variation was 50 percent (3.71/7.44) of total variation and test section variation was 38 percent (2.82/7.44) of total variation. The remaining 12 percent was from measurement speed, factor interactions, and random error.

The second analysis grouped data by device and compared the devices. See Table 5 for the summary. Statistically, all ten devices were determined to be independently significant, predominantly due to relatively large datasets (N=150). Further examination of device means showed that nine of the ten devices spread equally between 0.41 to 0.34. From a practical perspective, differences of less than 0.02 would not be considered significant. The last device mean was 0.23 and was determined to be outside the reasonable data range. As a validation of the field data, field testing means were compared to the earlier tests on validation plates. Figure 2, above, shows the comparison between the overall field means and validation plates datasets.

Table 4 Summary of First Analysis

```
General Linear Model: DFT versus Device, Speed, Section
Factor   Type   Levels  Values
Device   fixed      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Speed    fixed       3  20, 40, 60
Section  fixed      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Analysis of Variance for DFT, using Adjusted SS for Tests
Source                 DF    Seq SS    Adj SS    Adj MS        F      P
Device                  9  3.715244  3.715244  0.412805  3749.80  0.000
Speed                   2  0.013457  0.013457  0.006729    61.12  0.000
Section                 9  2.823384  2.823384  0.313709  2849.64  0.000
Device*Speed           18  0.034455  0.034455  0.001914    17.39  0.000
Device*Section         81  0.572555  0.572555  0.007069    64.21  0.000
Speed*Section          18  0.106572  0.106572  0.005921    53.78  0.000
Device*Speed*Section  162  0.044464  0.044464  0.000274     2.49  0.000
Error                1200  0.132105  0.132105  0.000110
Total                1499  7.442236

S = 0.0104923   R-Sq = 98.22%   R-Sq(adj) = 97.78%
```

Table 5 Summary of Second Analysis

```
Grouping Information Using Tukey Method and 95.0% Confidence
Device    N    Mean  Grouping
 1      150  0.4126  A
 6      150  0.4083    B
10      150  0.3996      C
 5      150  0.3898        D
 9      150  0.3749          E
 4      150  0.3651            F
 7      150  0.3538              G
 3      150  0.3464                H
 2      150  0.3400                  I
 8      150  0.2320                    J
```

The third analysis omitted the outlier device (Device No 8) data and used the remaining 1350 measurements to re-examine sources of variation. See Table 6 for the analysis summary. The analysis identified only one dominating factor, test section. The analysis still accounted for 97 percent of total variation and variation due to differences between test sections now accounted for 61 percent (2.71/4.44) of total variation. The variation due to device was reduced to 20 percent (0.89/4.44) of the total.

The fourth analysis examined the five replicate drops as a factor. The first analysis in Appendix A showed individual replicate drops had very little influence (less than one percent) in overall variation. The data were grouped by drop sequence and all five data sets were considered to be statistically independent. See Table 7 for statistical analysis. Further examination of mean values for each of the drops noted that drop two through drop five grouped closer than drop one. The 0.01 mean difference between drop one and drop two may (or may not) be considered practically significant. This analysis was performed to examine a practice of omitting the first drop of a drop replicate series.

Table 6 Summary of Third Analysis

```
General Linear Model: DFT versus Device, Speed, Section
Factor   Type   Levels  Values
Device   fixed       9  1, 2, 3, 4, 5, 6, 7, 9, 10
Speed    fixed       3  20, 40, 60
Section  fixed      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Analysis of Variance for DFT, using Adjusted SS for Tests
Source                  DF    Seq SS    Adj SS    Adj MS        F      P
Device                   8  0.887213  0.887213  0.110902   959.84  0.000
Speed                    2  0.016058  0.016058  0.008029    69.49  0.000
Section                  9  2.712635  2.712635  0.301404  2608.62  0.000
Device*Speed            16  0.030906  0.030906  0.001932    16.72  0.000
Device*Section          72  0.521717  0.521717  0.007246    62.71  0.000
Speed*Section           18  0.107742  0.107742  0.005986    51.81  0.000
Device*Speed*Section   144  0.036949  0.036949  0.000257     2.22  0.000
Error                 1080  0.124785  0.124785  0.000116
Total                 1349  4.438005

S = 0.0107490   R-Sq = 97.19%   R-Sq(adj) = 96.49%
```

Table 7 Summary of Fourth Analysis

```
Grouping Information Using Tukey Method and 95.0% Confidence
Drop    N    Mean  Grouping
1     300  0.3732  A
2     300  0.3639    B
3     300  0.3609      C
4     300  0.3577        D
5     300  0.3556          E
```

The fifth analysis took the overall mean value for each test section at each measurement speed and compared it to measured skid trailer value (SN64R) for each test section. The SN64R value is based on a historic trend of the pavement section and accounts for age (traffic) of the surface. DFT mean values were determined for data from the nine acceptable devices using drop-2 through drop-5 measurements. Figure 3 shows a linear regression based on the ten test surfaces. If drop-1 data was included, the regression would be slightly higher and closer to the line-of-equality with the SN data. The regression equations for drop 2-5 are:

SN64R = 109*DFT(60) – 0.66 $R^2 = 78\%$
SN64R = 115*DFT(40) – 3.51 $R^2 = 88\%$
SN64R = 110*DFT(20) – 1.69 $R^2 = 88\%$

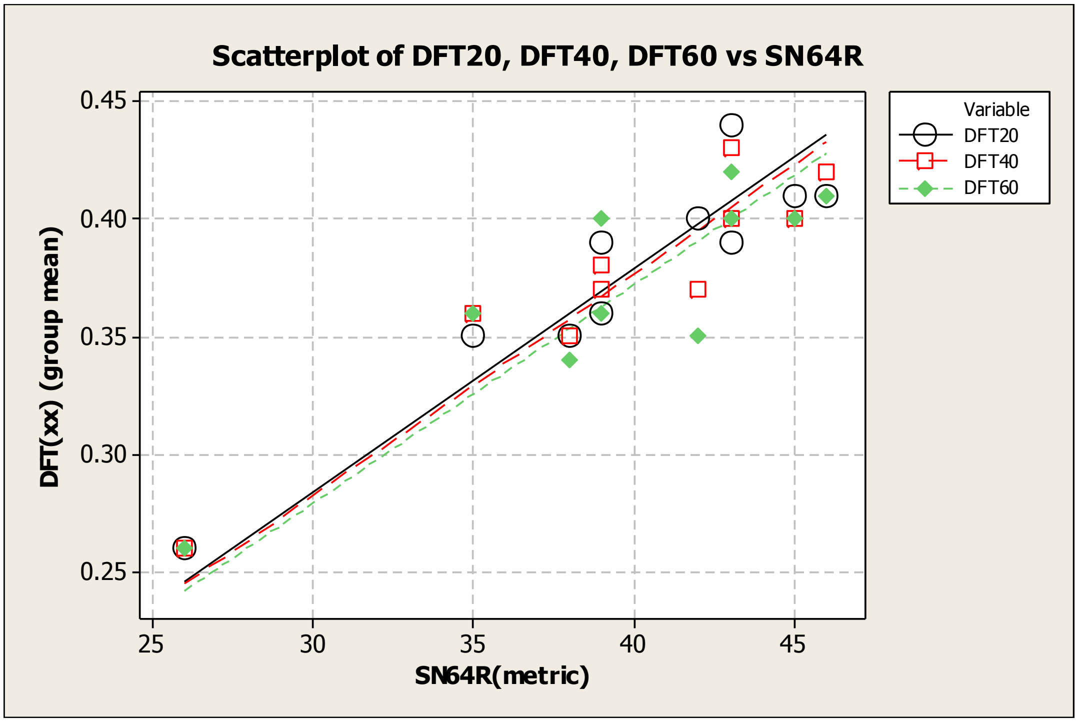


FIGURE 3 Correlation between DFT(xx)(metric) results and SN64R(metric) results

The sixth analysis divided data by test section to look at the influence of multiple drops (up to 25) on a set of rubber sliders. Raw data presented to the workshop participants was inconclusive. After the workshop, further analyses were performed to examine the influence of number of drops. The details of that analysis are discussed in Section 3.1 – Rubber Sliders.

The seventh analysis divided data by the five replicate measurement sets to examine DFT measurement precision. This analysis was done after the workshop to support discussion on the ASTM test standard precision statement. The details of that analysis are discussed in Section 4.2 – Improvement to the ASTM Standard.

The last analysis is based on measurements of the high friction surface. All ten devices used a set of rubber sliders that had previously been used for 25 drops on standard test sections. The purpose of this HFS analysis is to see if the devices still rank similar to other tests and to determine if repeatability of five tests on the high friction surface is similar to tests on other surfaces. In Figure 4, the mean value from each DFT for the combined ten standard sections is plotted in rank order. Mean values from each DFT for the high friction surface are added to the plot. The results show that DFT measurements on the high friction surface reflected the same general differences between devices. The “All Sections” means are less variable because they are the average of ten values. The “Section 1” means are added to show that individual section means will be more variable. Precision (or repeatability) of each device on the high friction surface was also very similar to precision of tests on the standard sections. The precision is shown in Figure 5. The precision analysis of tests for each DFT on ten standard test sections is expressed as the ten-test mean range (DFT(xx) ALL). The data point for the high friction surface is simply expressed as the range for five replicate measurements. Again, single surface range values will be slightly more variable than “All Sections” average ranges. The high DFT Unit 9 range for the HFS is due to one test result and would normally be omitted as an outlier.

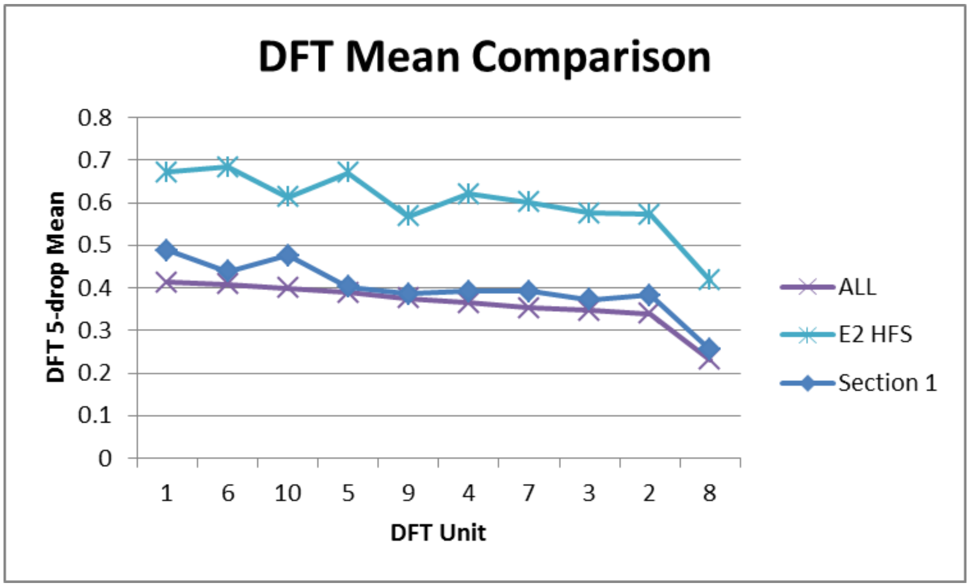


FIGURE 4 Comparison of test means for standard test sections and a high friction surface

3.1 Rubber Sliders

The rubber sliders are an important factor in measurement of friction using the DFT. The two issues regarding the rubber sliders are restriction on number of tests per set of pads and cost of each set. The current ASTM test method restricts use of a set of pads to 12 tests (drops). Among the workshop participating groups, only two groups were adhering to the ASTM standard, Maryland and Florida. They are bound by the ASTM standard in order to use the test for specification compliance. Most of the other groups were using a set of rubber sliders for up to 45 drops on conventional asphalt pavement surfaces. Group consensus was the allowable number of drops is related to level of friction being tested. Everyone agreed that less than 12 drops are permitted when testing high friction surfaces (typically above 0.60), but there was very little rubber pad wear after 12 drops on conventional surfaces (typically less than 0.45). Participants identified a number of ways that may be viable to determine when a set of rubber sliders should be discarded. Concepts included placing a wear marker (or color change) in the rubber, using a validation plate, and setting a graduated scale for maximum number of drops based on level of friction.

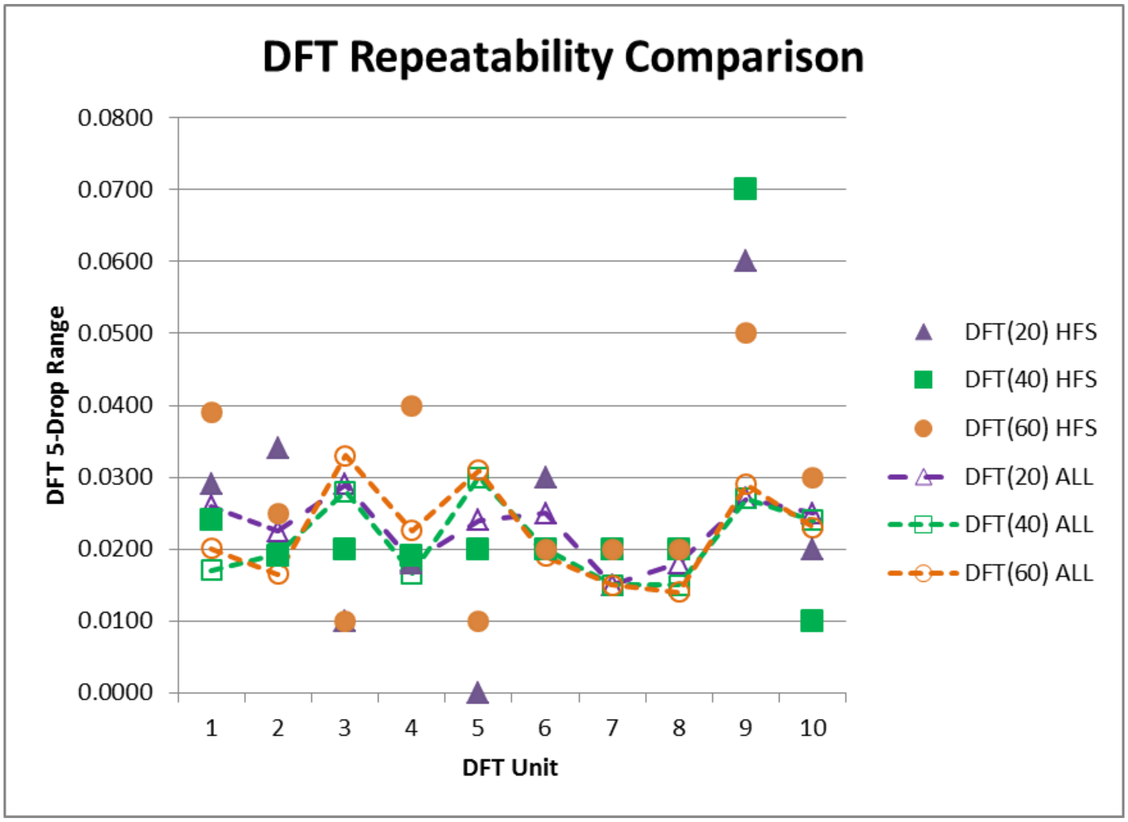


FIGURE 5 Comparison of DFT precision for standard test sections and a high friction surface

At the time of the Tuesday morning workshop discussion, results of round-robin testing regarding the number of drops were incomplete. It was not possible to discuss the impact of 25 drops on measured friction. Figure 6 shows raw data from round-robin testing for one of the ten test sections. Scatter in the data is due, in part, to variation in measured friction between DFT units. The data was adjusted based on the difference between the DFT unit mean and the over-all round-robin mean. Difference between these means was used to adjust the DFT device measured values. The adjustment did not include data from DFT Unit 8 nor data from Section 8. Both of these data sets were considered outside the norm. Figure 7 shows the impact of the number of drops after data was adjusted for device variation. Use of multiple devices to accumulate 25 drops added variation to the analysis that is difficult to sort out. A new evaluation will need to be performed with a study protocol that uses the same DFT for each set of accumulated 25 drops. A figure of raw data and adjusted data for each test section is included in Appendix B. This information is included in a document to the ASTM committee for consideration.

One unusual observation in the Appendix B data is found in pavement section 9, where each set of measurements from each drop trend significantly downward from DFT(60)=0.40 to DFT(20)=0.36. This trend was consistent among all DFT units. Normal trend for DFT data is flat to increasing values from DFT(60) to DFT(20) as shown in Figure 6. Pavement section 9 was one of three porous friction surfaces used for the round-robin testing.

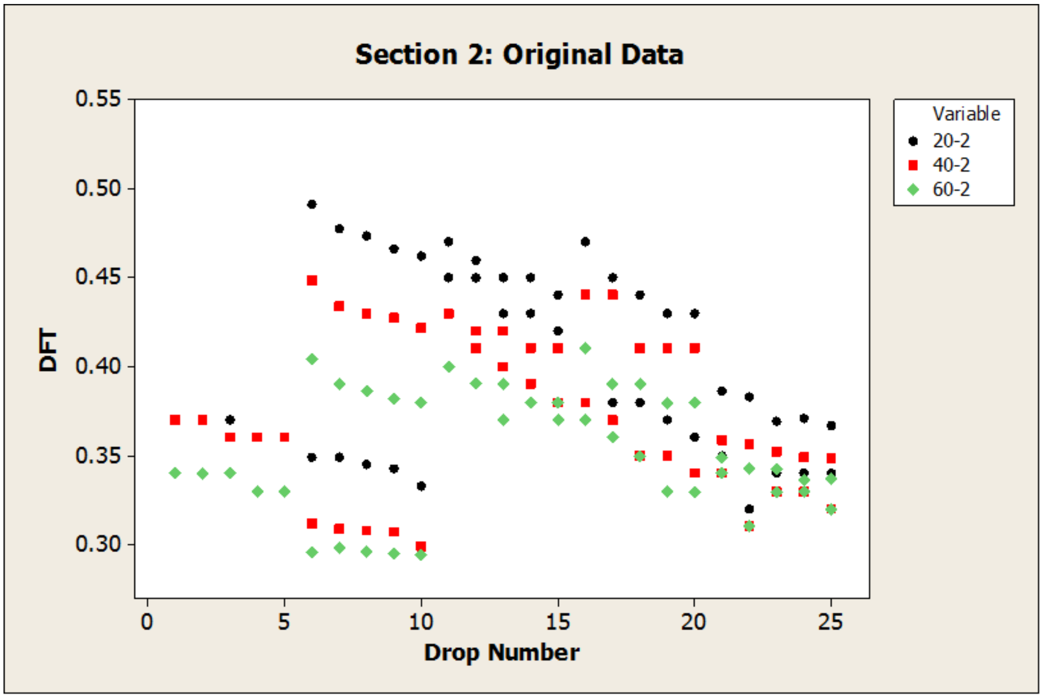


FIGURE 6 Raw test data for Section 2 based on number of drops per set of rubber sliders

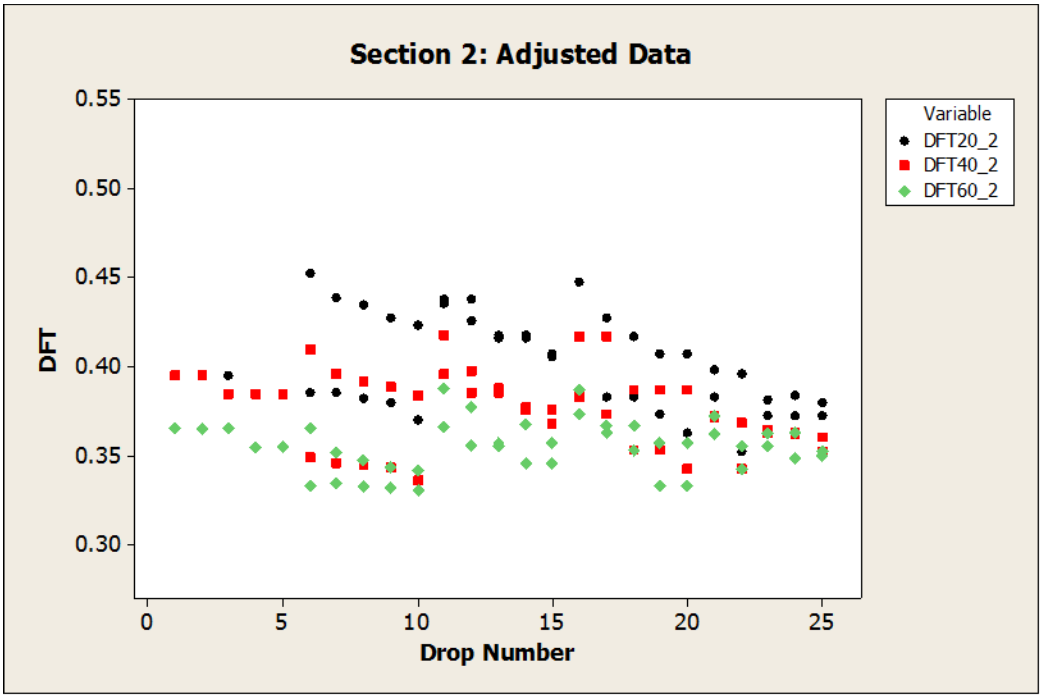


FIGURE 7 Adjusted test data for Section 2 based on number of drops per set of rubber sliders

The cost of a set of rubber sliders was discussed briefly. There is only one known source for this component. The combination of cost and limited ASTM use (12 drops) was a concern for most participants.

There was a short discussion on the fit of rubber sliders onto the DFT. Some of the users noted that they received rubber slider pads with steel plates (springs) that would not fit on the mounting brackets. Shima acknowledged that some steel plates were fabricated slightly out-of-spec and would not correctly mount in the DFT mounting bracket. It is important that the rubber slider steel plate is not forced onto the mounting bracket. The fit should be precise, not forced or loose. Users were instructed to file the edge of the steel plate or return the rubber slider to Shima for a replacement.

Chapter 4 Summary

This chapter takes the information collected during the workshop and summarizes it into three distinct areas for improving the practice of using the DFT. Section 4.1 is a collection of statements that can be immediately implemented as a DFT users guide to improve the quality of the friction values measured. Section 4.2 is a list of items that require formal action by ASTM to improve the test standard. And Section 4.3 identifies topics that will require further research to quantify variations in test protocols.

4.1 Operating Practices and Tips

This section provides a list of good practices for getting quality data from the DFT. Guidance is based on collective knowledge and advice of the workshop participants with years of experience using the DFT. A separate document with more details on this guidance is included as Appendix C. This guidance does not replace instructions in the operation manual.

Critical components for wear and replacement

These components should be checked regularly. When they fail, the DFT will no longer generate accurate measurements.

- Rubber slider pads - The rubber slider pads should be replaced regularly to maintain a consistent contact area with a pavement surface. See detailed discussion on replacement frequency.
- Plate spring – The plate spring is located between the two spinning discs. It ties the two spinning discs together and is an integral part of friction measurement. This spring will break due to repeated use and testing on high friction surfaces. Check the stiffness of the disc assembly. If the lower disc appears to be loose, the spring is probably broken.

- Vertical load springs – The two springs supporting the rotating disc assembly will permanently extend (stretch) after repeated testing. They need to be checked (validated) frequently to insure vertical load on the rubber sliders is correct.
- Damper – The sleeve for the damper post must be kept clean and dry. Frequently remove the post and wipe the sleeve to remove dirt. A very light film of WD-40 protects the metal surfaces from moisture and reduces friction in the sleeve to keep the damper moving freely.

Critical components for smooth operation

These items are particularly important for extended periods of field testing.

- Adequate water supply – The DFT software should control the valve to open and close the water supply. On some units water is flowing for an extended time. A supplemental water tank in the vehicle is necessary for extended testing periods, particularly in remote areas.
- Lower platform mounted to the vehicle for the DFT – A lower platform to place the DFT on improves the ergonomics of the test. Raising the DFT up to a truck tailgate is difficult and causes poor body mechanics for a repeated motion.
- Raised shelf for the laptop computer – A raised shelf for the laptop allows the operator to enter data without reaching into the vehicle. It also separates the computer from the area around the DFT which is typically wet.
- Properly filtered power supply – Placing some type of filter between the car battery and the DFT equipment reduces electrical noise generated by the vehicle's generator and alternator. Placing a separate vehicle battery in the electrical series is one solution.
- Validation surface – A validation surface is a good tool to check operation of the DFT. In a lab setting, a specific location on the floor slab works. For field use, a portable plate with a textured surface is being used by a number of DFT operators.

Calibration frequency

There is no specified time or test frequency for having the DFT re-calibrated. The current ASTM standard recommends using a calibration panel (validation plate) to check the ability of the DFT to repeat the measurement of the panel friction. The panel is an excellent method to monitor accuracy of the DFT. Measurement tolerance should be based on the value obtained from the DFT immediately following the last calibration. Based on the repeatability of testing performed in the workshop round-robin, the range between five replicates is 0.035 (0.022 avg + 0.013 std error) or less for 84 percent of 100 tests.

In addition to regular calibration checks, every time a critical component fails (such as springs) the device must be re-calibrated.

Placement on test surface

Orientation of the DFT can play a factor in obtaining quality measurements. Two factors that need to be considered are direction of maximum slope and direction of wheel rut. There is no written guidance for DFT orientation in the ASTM test method nor DFT operation manual. The primary factor in selecting the DFT orientation is direction of water flow. Orientation of the device is more critical for the older DFT models with a water spray bar on only two sides. The new model has a spray bar on all four sides. Orientation to maximum test surface slope should place one spray bar on top of the slope. Orientation to direction of wheel rut should place the spray bar transverse to direction of the rut.

Geometric orientation and condition of a test surface is discussed in the ASTM standard, but does not provide any practical limitations. Slopes up to 30 percent are permitted and rut depth is not addressed.

Standard testing pattern

The ASTM test procedure does not specify a minimum testing pattern or number of replicates. Patterns used by workshop participants varied as listed below. There are inherent risks in applying a single test (drop) procedure. This practice cannot verify precision of DFT tests. A suggested field test pattern should include a stratified random site selection of no less than three test sites, perform three replicate drops per test site, and discard the first drop to reduce test variation.

Current field testing patterns

- 1 drop at three locations (total of 3 drops)
- 1 drop at five locations (total of 5 drops)
- 3 drops at three locations (total of 9 drops)

Current lab testing patterns

- 3 drops on two test surfaces (total of 6 drops)
- 5 drops on one test surface, discard the first drop (total of 5 drops, analysis of 4 drops)

4.2 Improvements to the ASTM Standard

One purpose of the DFT workshop was to examine the current ASTM test method E1911 and identify parts of the test protocol that need to be strengthened based on experience of the DFT users participating in the workshop. The following text is a brief overview of critical areas identified by the workshop participants. A more detailed discussion of each item was prepared separately for submittal to ASTM Technical Committee E17.

Precision statement

The current precision statement appears to be based on data which does not support the standard deviation values listed. Further, the precision statement states that the standard deviation values are based on eight replicate tests. Reviewing the data listed in the test method reference number 3 from Transportation Research Record 1536 shows that listed precision values are based on 80 replicate tests, not 8. The data is also based on measures on test surfaces with friction coefficients above 0.70. The second stated concern is the precision is based on a number of replicates that far exceeds any standard practice. Most users are applying three or less replicates. The precision statement needs to be reviewed for compliance with precision and bias protocol and needs to be based on the number of test replicates used in common practice.

The workshop round-robin testing generated 100 sets of five replicate measurements from ten different DFT devices. Analysis of this data found a mean standard deviation for five replicates of 0.0089 at 40 km/h with the standard error of the standard deviations of 0.0046. Combined, these statistical values would conclude that 84 percent of all five replicate tests should have a standard deviation of 0.0135 or less; and almost 98 percent of all five replicate tests should have a standard deviation of 0.0181 or less. Results of the workshop round-robin testing are significantly lower than stated precision values in the ASTM test standard.

Number of drops per set of rubber sliders

The current 12 drop limit is only practiced by two agencies using the DFT for material acceptance. Compliance with the limit is necessary for the agency to legally defend their material acceptance decision. All of the current users believe a set of rubber sliders, making measurements on standard pavement surfaces (with friction values below 0.50), can be used for up to 45 drops without compromising the accuracy of measured friction values. Current users also acknowledge that the rubber sliders should be replaced more frequently (less than 12 drops) for tests on aggressive pavement surfaces, such as high friction surfaces. The limit on the number of drops needs to be re-examined.

Results of extended rubber slider use as part of the workshop round-robin testing were inconclusive. Figure 7 shows results for one test section. The use of multiple devices to accumulate 25 drops added variation to the analysis that was difficult to filter from the data. A new evaluation will need to be performed with a study protocol that uses the same DFT for each set of accumulated 25 drops.

Use of a validation plate

The current ASTM test protocol language calls for use of a calibration panel to determine the need to re-calibrate the DFT. There are three issues regarding this section.

- The term *calibration panel* is misleading and should be replaced. The panel is not used as part of the calibration process and the DFT is not calibrated to a specific panel value. The panel is used to validate operation of the DFT. The panel should be more appropriately called a validation panel.
- The procedure compares the last two measurements on the panel. This procedure implies that the previous measured value represents an accurate measurement from a correctly calibrated DFT. If the device is gradually deviating from a correct calibration, the comparison to the last measurement will not identify this accumulated error. The recommended procedure should make all comparisons to the first test on the validation panel immediately following a thorough calibration.
- The allowable deviation (range) from the last measured value is smaller than the currently listed test precision standard deviation (0.044 at 30 km/h and 0.038 at 60 km/h). If the precision statement is accurate, then the probability of a test on the validation panel reading outside the 0.03 tolerance is very high. This failed validation test could simply represent normal test variation (based on the precision criteria), not a need for re-calibration.

4.3 Need for further research

There are a number of DFT test protocols and guidelines that warrant further examination and/or research. The DFT is a valuable tool for spot measurement of pavement surface friction. The test is dynamic and measures friction across a range of speeds. Use of DFT measured friction values must be based on sound test protocols and a clear understanding of the device's precision. Based on discussions during the workshop, the following topics should be considered for more study.

What is the appropriate precision?

It does not appear that the current precision statement is based on sound data. The precision statement should be based on a practical, recommended number of replicates or provide precision for a range of replicates. Further, it is very likely that the precision could change as the test surface changes. Figure 8 shows the computed range for DFT(40) values from workshop round-robin tests. There is a clear difference in range precision based on number of replicates measured.

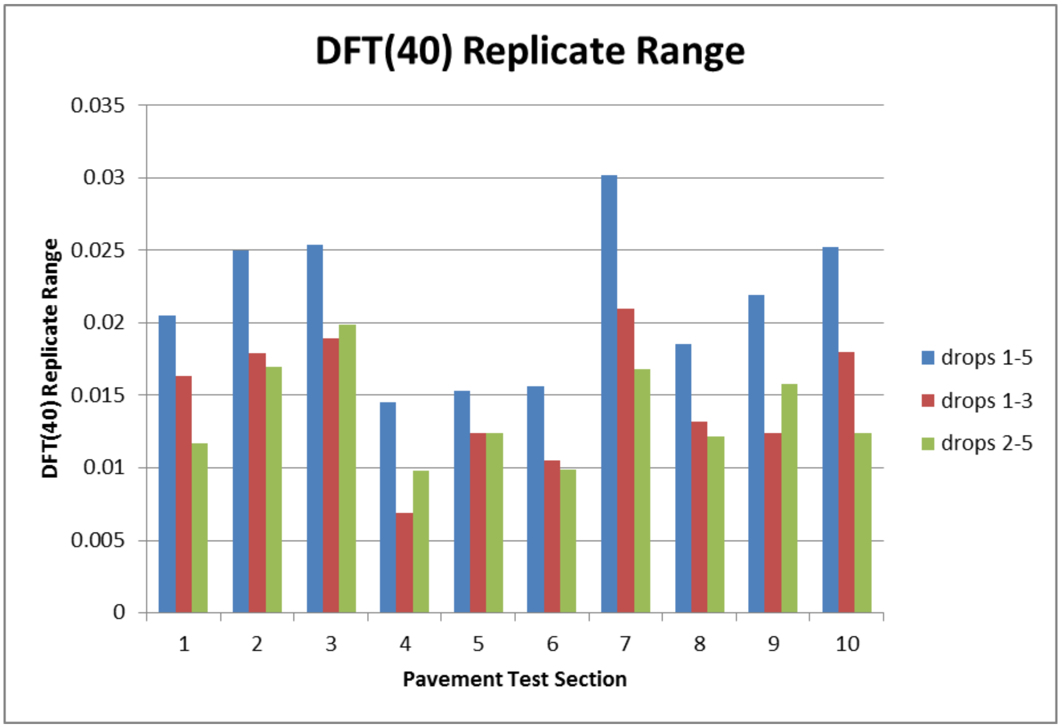


FIGURE 8 Comparison of precision based on replicate range

A study should combine use of multiple DFTs and a variety of pavement surfaces to quantify precision of the test. The number of replicates should represent current practice. Other variables such as surface temperature, surface geometry (slope and rut), and amount of water may be factored into the test matrix.

How is the test influenced by the amount of water?

The current ASTM protocol specifies a bucket size and height above the DFT. It appears the only purpose of water is to “wet” the test surface. There are questions about accuracy of the test when water delivery is changed and there are different test surface conditions. Can water be supplied from a larger tank with more hydrostatic pressure? Will the rubber sliders hydroplane if there is excessive water on the pavement surface, like water ponding in a wheel rut? Is there adequate water on open-graded surfaces or surfaces with significant macro-texture?

A study should include surfaces with different macro-texture, different levels of friction, a variable water source, and both models of DFT. The test surfaces must mimic degree of slope and amount of rutting.

Can allowable rubber slider wear be defined and quantified?

The current ASTM criteria (12 drops) does not adequately quantify allowable amount of rubber surface wear. This component of the DFT test is critical to friction measurement, but will wear differently when testing high friction or low friction surfaces. The test protocol must consider when the level of rubber slider wear impacts the resulting friction measurement. A number of methods to define allowable wear need to be explored. Three alternatives are a wear indicator (slot, hole or color change in the rubber slider), minimum thickness of the rubber slider, or test on a validation plate.

A study should include test surfaces with different amounts of macro-texture and micro-texture. The new evaluation will need to be performed with a study protocol that uses the same DFT for each set of accumulated 25 drops. This workshop round-robin testing used multiple devices to accumulate 25 drops which added variation to the analysis that was is difficult to filter out. Measurement accuracy of the DFT must be checked frequently. Condition of the rubber sliders should be measured as wear progresses. The study will need to involve the rubber slider manufacturer to fabricate prototype sliders.

What is the allowable variation between friction tests measured with different DFT units?

The workshop included preliminary testing of each DFT unit on three validation plates. Each DFT unit was at a unique level of equipment calibration and used rubber sliders with different levels of use. The only constant between the tests was the use of the validation plates. There are trends between the validation plate measurements and the mean values from ten sets of field tests by each DFT unit shown in Figure 2The range of mean values from the field tests was more than 0.05.

A study is needed to examine test differences between DFT units and determine what attributes of the test and equipment must be watched for variation from the calibration. This effort could establish a multi-lab precision and bias for the test standard.

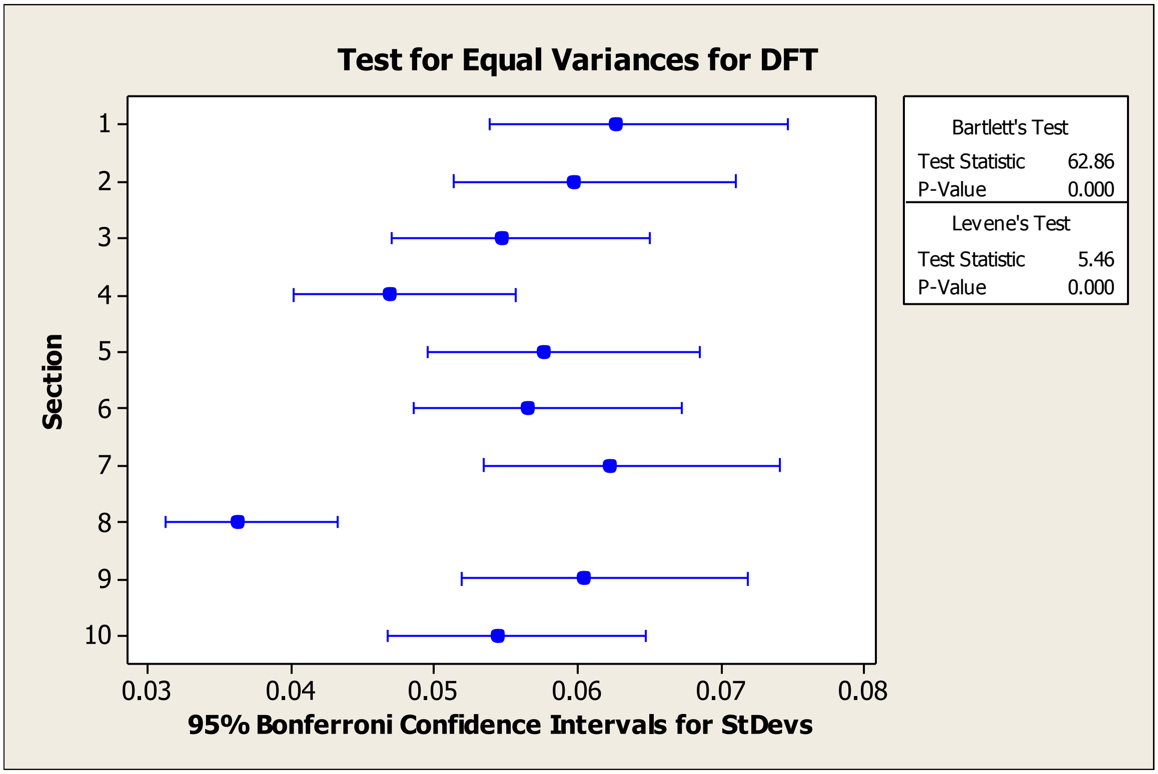
APPENDIX A
WORKSHOP ROUND-ROBIN TESTING - TEST RESULT ANALYSIS

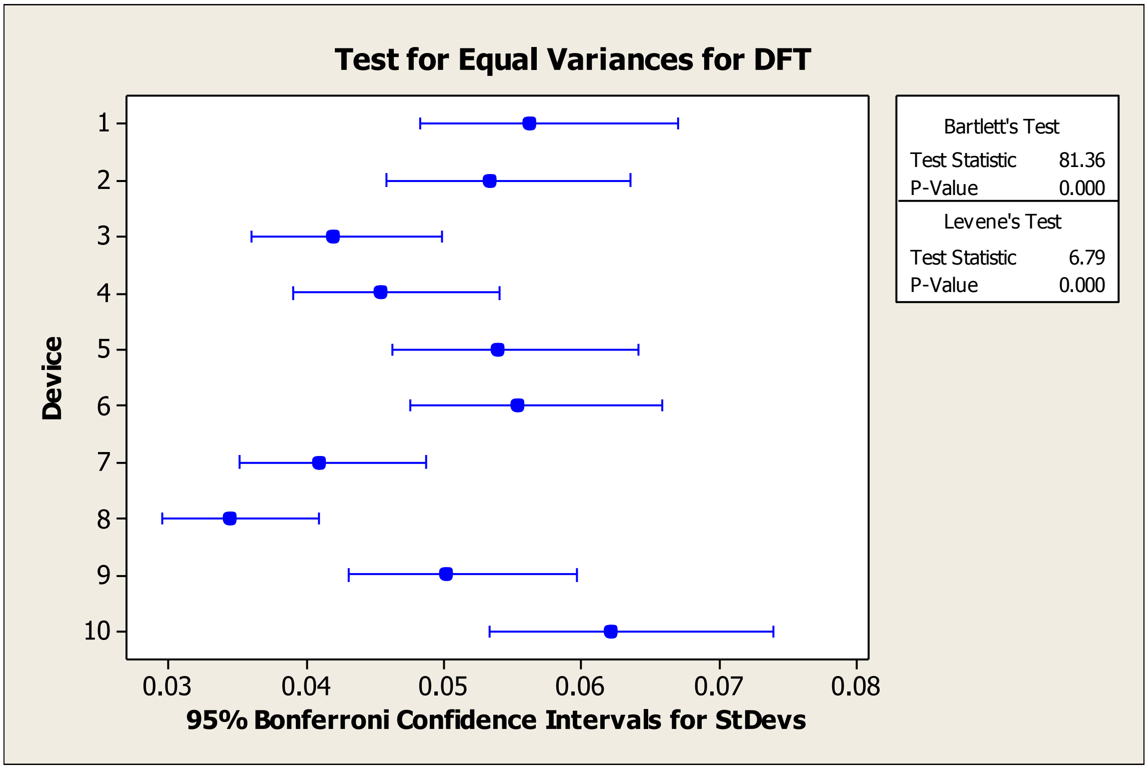
General Linear Model: DFT versus Drop, Device, Speed, Section

```
Factor   Type   Levels  Values
Drop     fixed       5  1, 2, 3, 4, 5
Device   fixed      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Speed    fixed       3  20, 40, 60
Section  fixed      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10


Analysis of Variance for DFT, using Adjusted SS for Tests

Source                  DF    Seq SS    Adj SS    Adj MS        F      P
Drop                     4  0.056467  0.056467  0.014117   223.22  0.000
Device                   9  3.715244  3.715244  0.412805  6527.36  0.000
Speed                    2  0.013457  0.013457  0.006729   106.40  0.000
Section                  9  2.823384  2.823384  0.313709  4960.44  0.000
Device*Speed            18  0.034455  0.034455  0.001914    30.27  0.000
Device*Section          81  0.572555  0.572555  0.007069   111.77  0.000
Speed*Section           18  0.106572  0.106572  0.005921    93.62  0.000
Device*Speed*Section   162  0.044464  0.044464  0.000274     4.34  0.000
Error                 1196  0.075638  0.075638  0.000063
Total                 1499  7.442236


S = 0.00795250   R-Sq = 98.98%   R-Sq(adj) = 98.73%


Unusual Observations for DFT

 Obs       DFT       Fit    SE Fit   Residual  St Resid
 122  0.321000  0.376405  0.003580  -0.055405     -7.80 R
 124  0.388000  0.370278  0.003580   0.017722      2.50 R
 125  0.389000  0.368155  0.003580   0.020845      2.94 R
 126  0.405000  0.419318  0.003580  -0.014318     -2.02 R
 131  0.400000  0.416318  0.003580  -0.016318     -2.30 R
 275  0.280000  0.305755  0.003580  -0.025755     -3.63 R
 277  0.347000  0.331605  0.003580   0.015395      2.17 R
 278  0.345000  0.328645  0.003580   0.016355      2.30 R
 280  0.295000  0.323355  0.003580  -0.028355     -3.99 R
 285  0.299000  0.324755  0.003580  -0.025755     -3.63 R
 288  0.369000  0.352445  0.003580   0.016555      2.33 R
 290  0.330000  0.347155  0.003580  -0.017155     -2.42 R
 299  0.334000  0.352678  0.003580  -0.018678     -2.63 R
 312  0.370000  0.387605  0.003580  -0.017605     -2.48 R
 313  0.400000  0.384645  0.003580   0.015355      2.16 R
 317  0.320000  0.339605  0.003580  -0.019605     -2.76 R
 322  0.310000  0.327605  0.003580  -0.017605     -2.48 R
 327  0.310000  0.327605  0.003580  -0.017605     -2.48 R
 333  0.300000  0.342645  0.003580  -0.042645     -6.01 R
 335  0.360000  0.337355  0.003580   0.022645      3.19 R
 338  0.290000  0.332645  0.003580  -0.042645     -6.01 R
 339  0.350000  0.329478  0.003580   0.020522      2.89 R
 340  0.350000  0.327355  0.003580   0.022645      3.19 R
 341  0.360000  0.340918  0.003580   0.019082      2.69 R
 343  0.280000  0.328645  0.003580  -0.048645     -6.85 R
 344  0.340000  0.325478  0.003580   0.014522      2.05 R
 345  0.340000  0.323355  0.003580   0.016645      2.34 R
```

```
 362  0.290000  0.319605  0.003580  -0.029605     -4.17 R
 367  0.290000  0.317605  0.003580  -0.027605     -3.89 R
 368  0.330000  0.314645  0.003580   0.015355      2.16 R
 372  0.290000  0.317605  0.003580  -0.027605     -3.89 R
 373  0.330000  0.314645  0.003580   0.015355      2.16 R
 431  0.440000  0.424918  0.003580   0.015082      2.12 R
 448  0.360000  0.374645  0.003580  -0.014645     -2.06 R
 551  0.463000  0.424918  0.003580   0.038082      5.36 R
 615  0.370000  0.387355  0.003580  -0.017355     -2.44 R
 621  0.430000  0.412918  0.003580   0.017082      2.41 R
 625  0.380000  0.395355  0.003580  -0.015355     -2.16 R
 691  0.480000  0.460918  0.003580   0.019082      2.69 R
 696  0.450000  0.432918  0.003580   0.017082      2.41 R
 700  0.400000  0.415355  0.003580  -0.015355     -2.16 R
 701  0.460000  0.444918  0.003580   0.015082      2.12 R
 711  0.310000  0.294918  0.003580   0.015082      2.12 R
 712  0.270000  0.285605  0.003580  -0.015605     -2.20 R
 715  0.260000  0.277355  0.003580  -0.017355     -2.44 R
 716  0.310000  0.288918  0.003580   0.021082      2.97 R
 741  0.410000  0.392918  0.003580   0.017082      2.41 R
 746  0.410000  0.390918  0.003580   0.019082      2.69 R
 799  0.350000  0.369478  0.003580  -0.019478     -2.74 R
 956  0.360000  0.374918  0.003580  -0.014918     -2.10 R
1115  0.200000  0.183355  0.003580   0.016645      2.34 R
1126  0.280000  0.294918  0.003580  -0.014918     -2.10 R
1155  0.210000  0.227355  0.003580  -0.017355     -2.44 R
1161  0.150000  0.166918  0.003580  -0.016918     -2.38 R
1171  0.210000  0.244918  0.003580  -0.034918     -4.92 R
1172  0.220000  0.235605  0.003580  -0.015605     -2.20 R
1173  0.250000  0.232645  0.003580   0.017355      2.44 R
1175  0.250000  0.227355  0.003580   0.022645      3.19 R
1176  0.240000  0.260918  0.003580  -0.020918     -2.95 R
1180  0.260000  0.243355  0.003580   0.016645      2.34 R
1202  0.370000  0.391605  0.003580  -0.021605     -3.04 R
1207  0.370000  0.387605  0.003580  -0.017605     -2.48 R
1212  0.360000  0.383605  0.003580  -0.023605     -3.32 R
1275  0.360000  0.345355  0.003580   0.014645      2.06 R
1276  0.480000  0.464918  0.003580   0.015082      2.12 R
1280  0.430000  0.447355  0.003580  -0.017355     -2.44 R
1291  0.450000  0.432918  0.003580   0.017082      2.41 R
1295  0.400000  0.415355  0.003580  -0.015355     -2.16 R
1331  0.440000  0.424918  0.003580   0.015082      2.12 R
1332  0.400000  0.415605  0.003580  -0.015605     -2.20 R
1341  0.450000  0.430918  0.003580   0.019082      2.69 R
1366  0.470000  0.454918  0.003580   0.015082      2.12 R
1372  0.440000  0.423605  0.003580   0.016395      2.31 R
1386  0.430000  0.414918  0.003580   0.015082      2.12 R

R denotes an observation with a large standardized residual.


Grouping Information Using Tukey Method and 95.0% Confidence

Drop    N    Mean  Grouping
1     300  0.3732  A
2     300  0.3639    B
3     300  0.3609      C
4     300  0.3577        D
5     300  0.3556          E

Means that do not share a letter are significantly different.
```

```
Grouping Information Using Tukey Method and 95.0% Confidence

Device    N    Mean  Grouping
 1      150  0.4126  A
 6      150  0.4083    B
10      150  0.3996      C
 5      150  0.3898        D
 9      150  0.3749          E
 4      150  0.3651            F
 7      150  0.3538              G
 3      150  0.3464                H
 2      150  0.3400                  I
 8      150  0.2320                    J

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Speed    N    Mean  Grouping
20     500  0.3657  A
40     500  0.3627    B
60     500  0.3584      C

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Section    N    Mean  Grouping
 6       150  0.4190  A
 1       150  0.3990    B
 7       150  0.3909      C
10       150  0.3858        D
 9       150  0.3701          E
 2       150  0.3638            F
 3       150  0.3620            F
 4       150  0.3438              G
 5       150  0.3339                H
 8       150  0.2542                  I

Means that do not share a letter are significantly different.
```


Test for Equal Variances for DFT
Section
1
2
3
4
5
6
7
8
9
10
0.03
0.04
0.05
0.06
0.07
0.08
95% Bonferroni Confidence Intervals for StDevs
Bartlett's Test
Test Statistic 62.86
P-Value 0.000
Levene's Test
Test Statistic 5.46
P-Value 0.000


Test for Equal Variances for DFT
Device
1
2
3
4
5
6
7
8
9
10
0.03
0.04
0.05
0.06
0.07
0.08
95% Bonferroni Confidence Intervals for StDevs
Bartlett's Test
Test Statistic 81.36
P-Value 0.000
Levene's Test
Test Statistic 6.79
P-Value 0.000

General Linear Model: DFT versus Device, Speed, Section (remove device 8)

```
Factor   Type   Levels  Values
Device   fixed       9  1, 2, 3, 4, 5, 6, 7, 9, 10
Speed    fixed       3  20, 40, 60
Section  fixed      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10


Analysis of Variance for DFT, using Adjusted SS for Tests

Source                  DF    Seq SS    Adj SS    Adj MS        F      P
Device                   8  0.887213  0.887213  0.110902   959.84  0.000
Speed                    2  0.016058  0.016058  0.008029    69.49  0.000
Section                  9  2.712635  2.712635  0.301404  2608.62  0.000
Device*Speed            16  0.030906  0.030906  0.001932    16.72  0.000
Device*Section          72  0.521717  0.521717  0.007246    62.71  0.000
Speed*Section           18  0.107742  0.107742  0.005986    51.81  0.000
Device*Speed*Section   144  0.036949  0.036949  0.000257     2.22  0.000
Error                 1080  0.124785  0.124785  0.000116
Total                 1349  4.438005


S = 0.0107490   R-Sq = 97.19%   R-Sq(adj) = 96.49%


Unusual Observations for DFT

 Obs       DFT       Fit    SE Fit   Residual  St Resid
  31  0.494000  0.470800  0.004807   0.023200      2.41 R
  41  0.421000  0.400400  0.004807   0.020600      2.14 R
 101  0.440000  0.419000  0.004807   0.021000      2.18 R
 122  0.321000  0.374800  0.004807  -0.053800     -5.60 R
 246  0.417000  0.396800  0.004807   0.020200      2.10 R
 275  0.280000  0.312400  0.004807  -0.032400     -3.37 R
 280  0.295000  0.330000  0.004807  -0.035000     -3.64 R
 285  0.299000  0.331400  0.004807  -0.032400     -3.37 R
 290  0.330000  0.353800  0.004807  -0.023800     -2.48 R
 299  0.334000  0.357200  0.004807  -0.023200     -2.41 R
 333  0.300000  0.344000  0.004807  -0.044000     -4.58 R
 338  0.290000  0.334000  0.004807  -0.044000     -4.58 R
 341  0.360000  0.330000  0.004807   0.030000      3.12 R
 343  0.280000  0.330000  0.004807  -0.050000     -5.20 R
 362  0.290000  0.318000  0.004807  -0.028000     -2.91 R
 367  0.290000  0.316000  0.004807  -0.026000     -2.70 R
 372  0.290000  0.316000  0.004807  -0.026000     -2.70 R
 431  0.440000  0.414000  0.004807   0.026000      2.70 R
 551  0.463000  0.414000  0.004807   0.049000      5.10 R
 555  0.394000  0.414000  0.004807  -0.020000     -2.08 R
 615  0.370000  0.394000  0.004807  -0.024000     -2.50 R
 621  0.430000  0.402000  0.004807   0.028000      2.91 R
 625  0.380000  0.402000  0.004807  -0.022000     -2.29 R
 686  0.490000  0.468000  0.004807   0.022000      2.29 R
 691  0.480000  0.450000  0.004807   0.030000      3.12 R
 695  0.430000  0.450000  0.004807  -0.020000     -2.08 R
 696  0.450000  0.422000  0.004807   0.028000      2.91 R
 700  0.400000  0.422000  0.004807  -0.022000     -2.29 R
 701  0.460000  0.434000  0.004807   0.026000      2.70 R
 711  0.310000  0.284000  0.004807   0.026000      2.70 R
 715  0.260000  0.284000  0.004807  -0.024000     -2.50 R
```

```
 716  0.310000  0.278000  0.004807   0.032000      3.33 R
 736  0.410000  0.390000  0.004807   0.020000      2.08 R
 741  0.410000  0.382000  0.004807   0.028000      2.91 R
 746  0.410000  0.380000  0.004807   0.030000      3.12 R
 799  0.350000  0.374000  0.004807  -0.024000     -2.50 R
 841  0.490000  0.468000  0.004807   0.022000      2.29 R
1052  0.370000  0.390000  0.004807  -0.020000     -2.08 R
1062  0.360000  0.382000  0.004807  -0.022000     -2.29 R
1071  0.380000  0.358000  0.004807   0.022000      2.29 R
1076  0.370000  0.348000  0.004807   0.022000      2.29 R
1111  0.380000  0.358000  0.004807   0.022000      2.29 R
1126  0.480000  0.454000  0.004807   0.026000      2.70 R
1130  0.430000  0.454000  0.004807  -0.024000     -2.50 R
1136  0.460000  0.438000  0.004807   0.022000      2.29 R
1141  0.450000  0.422000  0.004807   0.028000      2.91 R
1145  0.400000  0.422000  0.004807  -0.022000     -2.29 R
1146  0.430000  0.408000  0.004807   0.022000      2.29 R
1151  0.440000  0.418000  0.004807   0.022000      2.29 R
1181  0.440000  0.414000  0.004807   0.026000      2.70 R
1186  0.430000  0.408000  0.004807   0.022000      2.29 R
1191  0.450000  0.420000  0.004807   0.030000      3.12 R
1195  0.400000  0.420000  0.004807  -0.020000     -2.08 R
1196  0.450000  0.428000  0.004807   0.022000      2.29 R
1201  0.510000  0.490000  0.004807   0.020000      2.08 R
1206  0.500000  0.478000  0.004807   0.022000      2.29 R
1216  0.470000  0.444000  0.004807   0.026000      2.70 R
1226  0.410000  0.390000  0.004807   0.020000      2.08 R
1236  0.430000  0.404000  0.004807   0.026000      2.70 R
1241  0.420000  0.398000  0.004807   0.022000      2.29 R
1296  0.400000  0.380000  0.004807   0.020000      2.08 R
1321  0.470000  0.448000  0.004807   0.022000      2.29 R
1326  0.480000  0.460000  0.004807   0.020000      2.08 R

R denotes an observation with a large standardized residual.


Grouping Information Using Tukey Method and 95.0% Confidence

Device    N    Mean  Grouping
 1      150  0.4126  A
 6      150  0.4083    B
10      150  0.3996      C
 5      150  0.3898        D
 9      150  0.3749          E
 4      150  0.3651            F
 7      150  0.3538              G
 3      150  0.3464                H
 2      150  0.3400                  I

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Speed  Section   N    Mean  Grouping
20      6       45  0.4467  A
40      6       45  0.4362    B
60      6       45  0.4202      C
40      1       45  0.4181      C
60      1       45  0.4140      C D
20      7       45  0.4138      C D
20      1       45  0.4129      C D
60      7       45  0.4072        D E
```

```
40      7       45  0.4068        D E
60     10       45  0.4028          E F
40     10       45  0.4015          E F G
60      9       45  0.4008          E F G
20      2       45  0.4005          E F G
20     10       45  0.3951            F G
20      3       45  0.3932              G H
40      9       45  0.3857                H
40      2       45  0.3758                  I
40      3       45  0.3747                  I J
20      9       45  0.3671                    J K
40      4       45  0.3621                      K L
60      3       45  0.3604                      K L
60      4       45  0.3569                        L M
20      5       45  0.3563                        L M
60      2       45  0.3551                        L M
20      4       45  0.3516                          M
40      5       45  0.3494                          M N
60      5       45  0.3428                            N
20      8       45  0.2671                              O
40      8       45  0.2662                              O
60      8       45  0.2612                              O

Means that do not share a letter are significantly different.
```

Results for: Worksheet 3

General Linear Model: DFT versus Drop, Device, Speed, Section (remove drop 1)

```
Factor   Type   Levels  Values
Drop     fixed       4  2, 3, 4, 5
Device   fixed       9  1, 2, 3, 4, 5, 6, 7, 9, 10
Speed    fixed       3  20, 40, 60
Section  fixed      10  1, 2, 3, 4, 5, 6, 7, 8, 9, 10


Analysis of Variance for DFT, using Adjusted SS for Tests

Source                  DF    Seq SS    Adj SS    Adj MS        F      P
Drop                     3  0.012031  0.012031  0.004010    68.17  0.000
Device                   8  0.689200  0.689200  0.086150  1464.40  0.000
Speed                    2  0.013374  0.013374  0.006687   113.66  0.000
Section                  9  2.145525  2.145525  0.238392  4052.25  0.000
Device*Speed            16  0.024135  0.024135  0.001508    25.64  0.000
Device*Section          72  0.400629  0.400629  0.005564    94.58  0.000
Speed*Section           18  0.086213  0.086213  0.004790    81.42  0.000
Device*Speed*Section   144  0.030067  0.030067  0.000209     3.55  0.000
Error                  807  0.047475  0.047475  0.000059
Total                 1079  3.448649


S = 0.00767004   R-Sq = 98.62%   R-Sq(adj) = 98.16%


Unusual Observations for DFT

 Obs       DFT       Fit     SE Fit   Residual  St Resid
   3  0.488000  0.474510  0.003856   0.013490      2.03 R
  25  0.321000  0.376010  0.003856  -0.055010     -8.30 R
```

```
  56  0.347000  0.331510  0.003856   0.015490      2.34 R
  57  0.347000  0.333010  0.003856   0.013990      2.11 R
  63  0.370000  0.389760  0.003856  -0.019760     -2.98 R
  64  0.320000  0.339760  0.003856  -0.019760     -2.98 R
  65  0.310000  0.327260  0.003856  -0.017260     -2.60 R
  66  0.310000  0.327260  0.003856  -0.017260     -2.60 R
  73  0.290000  0.319760  0.003856  -0.029760     -4.49 R
  74  0.290000  0.319760  0.003856  -0.029760     -4.49 R
  75  0.290000  0.319760  0.003856  -0.029760     -4.49 R
 183  0.390000  0.404760  0.003856  -0.014760     -2.23 R
 211  0.370000  0.392260  0.003856  -0.022260     -3.36 R
 212  0.370000  0.387260  0.003856  -0.017260     -2.60 R
 213  0.360000  0.382260  0.003856  -0.022260     -3.36 R
 245  0.440000  0.422260  0.003856   0.017740      2.68 R
 295  0.387000  0.372499  0.003856   0.014501      2.19 R
 325  0.324000  0.309499  0.003856   0.014501      2.19 R
 326  0.345000  0.327999  0.003856   0.017001      2.56 R
 327  0.344000  0.329499  0.003856   0.014501      2.19 R
 328  0.369000  0.352249  0.003856   0.016751      2.53 R
 329  0.370000  0.355999  0.003856   0.014001      2.11 R
 330  0.370000  0.355499  0.003856   0.014501      2.19 R
 333  0.400000  0.386249  0.003856   0.013751      2.07 R
 337  0.300000  0.341249  0.003856  -0.041249     -6.22 R
 338  0.290000  0.331249  0.003856  -0.041249     -6.22 R
 339  0.280000  0.323749  0.003856  -0.043749     -6.60 R
 343  0.330000  0.316249  0.003856   0.013751      2.07 R
 344  0.330000  0.316249  0.003856   0.013751      2.07 R
 345  0.330000  0.316249  0.003856   0.013751      2.07 R
 360  0.360000  0.373749  0.003856  -0.013749     -2.07 R
 565  0.388000  0.369314  0.003856   0.018686      2.82 R
 600  0.334000  0.352314  0.003856  -0.018314     -2.76 R
 608  0.350000  0.328064  0.003856   0.021936      3.31 R
 609  0.340000  0.320564  0.003856   0.019436      2.93 R
 683  0.290000  0.275564  0.003856   0.014436      2.18 R
 700  0.350000  0.368064  0.003856  -0.018064     -2.72 R
 777  0.420000  0.405564  0.003856   0.014436      2.18 R
 835  0.389000  0.367177  0.003856   0.021823      3.29 R
 865  0.280000  0.304177  0.003856  -0.024177     -3.65 R
 866  0.295000  0.322677  0.003856  -0.027677     -4.17 R
 867  0.299000  0.324177  0.003856  -0.025177     -3.80 R
 868  0.330000  0.346927  0.003856  -0.016927     -2.55 R
 877  0.360000  0.335927  0.003856   0.024073      3.63 R
 878  0.350000  0.325927  0.003856   0.024073      3.63 R
 879  0.340000  0.318427  0.003856   0.021573      3.25 R
 933  0.370000  0.385927  0.003856  -0.015927     -2.40 R
 953  0.260000  0.273427  0.003856  -0.013427     -2.03 R
1035  0.360000  0.345927  0.003856   0.014073      2.12 R
1036  0.430000  0.443427  0.003856  -0.013427     -2.03 R

R denotes an observation with a large standardized residual.


Grouping Information Using Tukey Method and 95.0% Confidence

Drop    N    Mean  Grouping
2     270  0.3786  A
3     270  0.3751    B
4     270  0.3719      C
5     270  0.3698        D

Means that do not share a letter are significantly different.
```

```
Grouping Information Using Tukey Method and 95.0% Confidence

Device    N    Mean  Grouping
 1      120  0.4099  A
 6      120  0.4053    B
10      120  0.3961      C
 5      120  0.3860        D
 9      120  0.3710          E
 4      120  0.3623            F
 7      120  0.3522              G
 3      120  0.3434                H
 2      120  0.3381                  I

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Speed    N    Mean  Grouping
20     360  0.3776  A
40     360  0.3748    B
60     360  0.3691      C

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Section    N    Mean  Grouping
 6       108  0.4324  A
 1       108  0.4118    B
 7       108  0.4046      C
10       108  0.3959        D
 9       108  0.3817          E
 2       108  0.3739            F
 3       108  0.3730            F
 4       108  0.3553              G
 5       108  0.3476                H
 8       108  0.2622                  I

Means that do not share a letter are significantly different.
```

Results for: Worksheet 5 (results divided by section and speed)

Descriptive Statistics: DFT

Results for Section = 1

```
Variable  Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT       20     36   0  0.40956  0.00771  0.04628  0.35000  0.37375  0.39000
          40     36   0  0.41514  0.00721  0.04327  0.37000  0.38525  0.39150
          60     36   0  0.41078  0.00597  0.03579  0.36000  0.38075  0.39950

Variable  Speed       Q3  Maximum
DFT       20     0.43000  0.50500
          40     0.44000  0.51200
          60     0.45000  0.48800
```

Results for Section = 2

```
Variable   Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        20     36   0  0.39744  0.00807  0.04842  0.32000  0.36000  0.38000
           40     36   0  0.37225  0.00711  0.04266  0.29900  0.34200  0.36500
           60     36   0  0.35194  0.00530  0.03182  0.29400  0.33000  0.34650

Variable   Speed       Q3  Maximum
DFT        20     0.44750  0.47700
           40     0.41000  0.44000
           60     0.38000  0.39000
```

Results for Section = 3

```
Variable   Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        20     36   0  0.38994  0.00648  0.03888  0.30000  0.36000  0.39000
           40     36   0  0.37161  0.00535  0.03213  0.29000  0.35000  0.37000
           60     36   0  0.35736  0.00433  0.02598  0.28000  0.34000  0.35850

Variable   Speed       Q3  Maximum
DFT        20     0.41000  0.47600
           40     0.39000  0.43500
           60     0.37000  0.40000
```

Results for Section = 4

```
Variable   Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        20     36   0  0.34972  0.00464  0.02783  0.32000  0.33000  0.34000
           40     36   0  0.36014  0.00459  0.02752  0.31000  0.34325  0.36000
           60     36   0  0.35589  0.00368  0.02210  0.32000  0.33700  0.36000

Variable   Speed       Q3  Maximum
DFT        20     0.36450  0.41700
           40     0.37925  0.42000
           60     0.37225  0.39300
```

Results for Section = 5

```
Variable   Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        20     36   0  0.35411  0.00615  0.03689  0.29000  0.32000  0.35000
           40     36   0  0.34806  0.00577  0.03464  0.29000  0.32000  0.35000
           60     36   0  0.34069  0.00529  0.03172  0.29000  0.31250  0.34500

Variable   Speed       Q3  Maximum
DFT        20     0.39000  0.41000
           40     0.38000  0.41000
           60     0.36675  0.40000
```

Results for Section = 6

```
Variable   Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        20     36   0  0.44469  0.00607  0.03639  0.39000  0.42000  0.44000
           40     36   0  0.43447  0.00504  0.03023  0.38000  0.40775  0.43550
           60     36   0  0.41794  0.00480  0.02879  0.38000  0.40000  0.40950
```

```
Variable  Speed       Q3  Maximum
DFT       20     0.47050  0.51000
          40     0.45400  0.49000
          60     0.43750  0.48000
```

Results for Section = 7

```
Variable  Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT       20     36   0  0.40969  0.00542  0.03252  0.36000  0.38000  0.40500
          40     36   0  0.40242  0.00432  0.02591  0.36000  0.38125  0.40000
          60     36   0  0.40167  0.00388  0.02330  0.36000  0.39000  0.40550

Variable  Speed       Q3  Maximum
DFT       20     0.43925  0.47000
          40     0.42675  0.46000
          60     0.42000  0.44000
```

Results for Section = 8

```
Variable  Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT       20     36   0  0.26472  0.00272  0.01631  0.23200  0.26000  0.26000
          40     36   0  0.26372  0.00302  0.01814  0.22100  0.26000  0.26950
          60     36   0  0.25808  0.00249  0.01493  0.22000  0.25350  0.26000

Variable  Speed       Q3  Maximum
DFT       20     0.28000  0.29100
          40     0.28000  0.29000
          60     0.27000  0.28000
```

Results for Section = 9

```
Variable  Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT       20     36   0  0.36419  0.00711  0.04264  0.28000  0.33000  0.37000
          40     36   0  0.38311  0.00684  0.04105  0.29500  0.35000  0.39000
          60     36   0  0.39792  0.00700  0.04202  0.29900  0.35625  0.40800

Variable  Speed       Q3  Maximum
DFT       20     0.39000  0.45000
          40     0.41000  0.46000
          60     0.43000  0.46000
```

Results for Section = 10

```
Variable  Speed   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT       20     36   0  0.39147  0.00597  0.03581  0.33000  0.36000  0.38500
          40     36   0  0.39739  0.00602  0.03610  0.34000  0.37000  0.38000
          60     36   0  0.39883  0.00553  0.03315  0.33400  0.37000  0.38750

Variable  Speed       Q3  Maximum
DFT       20     0.41950  0.46000
          40     0.42150  0.47000
          60     0.43000  0.46000
```

Descriptive Statistics: DFT

Results for Speed = 20

```
Variable  Section   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        1       36   0  0.40956  0.00771  0.04628  0.35000  0.37375  0.39000
           2       36   0  0.39744  0.00807  0.04842  0.32000  0.36000  0.38000
           3       36   0  0.38994  0.00648  0.03888  0.30000  0.36000  0.39000
           4       36   0  0.34972  0.00464  0.02783  0.32000  0.33000  0.34000
           5       36   0  0.35411  0.00615  0.03689  0.29000  0.32000  0.35000
           6       36   0  0.44469  0.00607  0.03639  0.39000  0.42000  0.44000
           7       36   0  0.40969  0.00542  0.03252  0.36000  0.38000  0.40500
           8       36   0  0.26472  0.00272  0.01631  0.23200  0.26000  0.26000
           9       36   0  0.36419  0.00711  0.04264  0.28000  0.33000  0.37000
          10       36   0  0.39147  0.00597  0.03581  0.33000  0.36000  0.38500

Variable  Section       Q3  Maximum
DFT        1       0.43000  0.50500
           2       0.44750  0.47700
           3       0.41000  0.47600
           4       0.36450  0.41700
           5       0.39000  0.41000
           6       0.47050  0.51000
           7       0.43925  0.47000
           8       0.28000  0.29100
           9       0.39000  0.45000
          10       0.41950  0.46000
```

Results for Speed = 40

```
Variable  Section   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        1       36   0  0.41514  0.00721  0.04327  0.37000  0.38525  0.39150
           2       36   0  0.37225  0.00711  0.04266  0.29900  0.34200  0.36500
           3       36   0  0.37161  0.00535  0.03213  0.29000  0.35000  0.37000
           4       36   0  0.36014  0.00459  0.02752  0.31000  0.34325  0.36000
           5       36   0  0.34806  0.00577  0.03464  0.29000  0.32000  0.35000
           6       36   0  0.43447  0.00504  0.03023  0.38000  0.40775  0.43550
           7       36   0  0.40242  0.00432  0.02591  0.36000  0.38125  0.40000
           8       36   0  0.26372  0.00302  0.01814  0.22100  0.26000  0.26950
           9       36   0  0.38311  0.00684  0.04105  0.29500  0.35000  0.39000
          10       36   0  0.39739  0.00602  0.03610  0.34000  0.37000  0.38000

Variable  Section       Q3  Maximum
DFT        1       0.44000  0.51200
           2       0.41000  0.44000
           3       0.39000  0.43500
           4       0.37925  0.42000
           5       0.38000  0.41000
           6       0.45400  0.49000
           7       0.42675  0.46000
           8       0.28000  0.29000
           9       0.41000  0.46000
          10       0.42150  0.47000
```

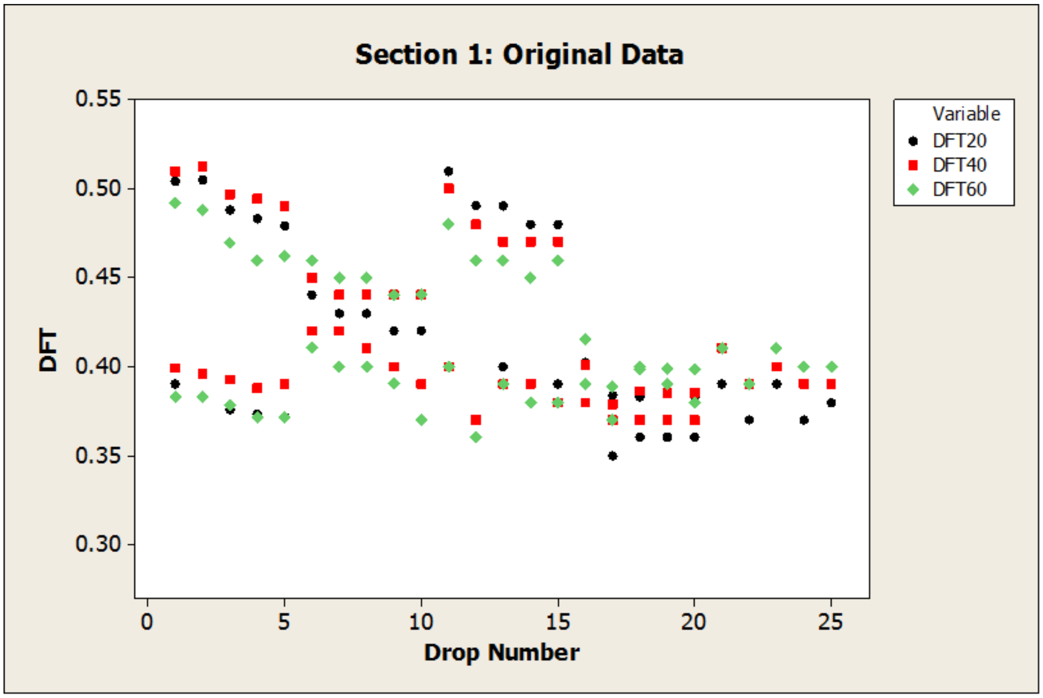
Results for Speed = 60

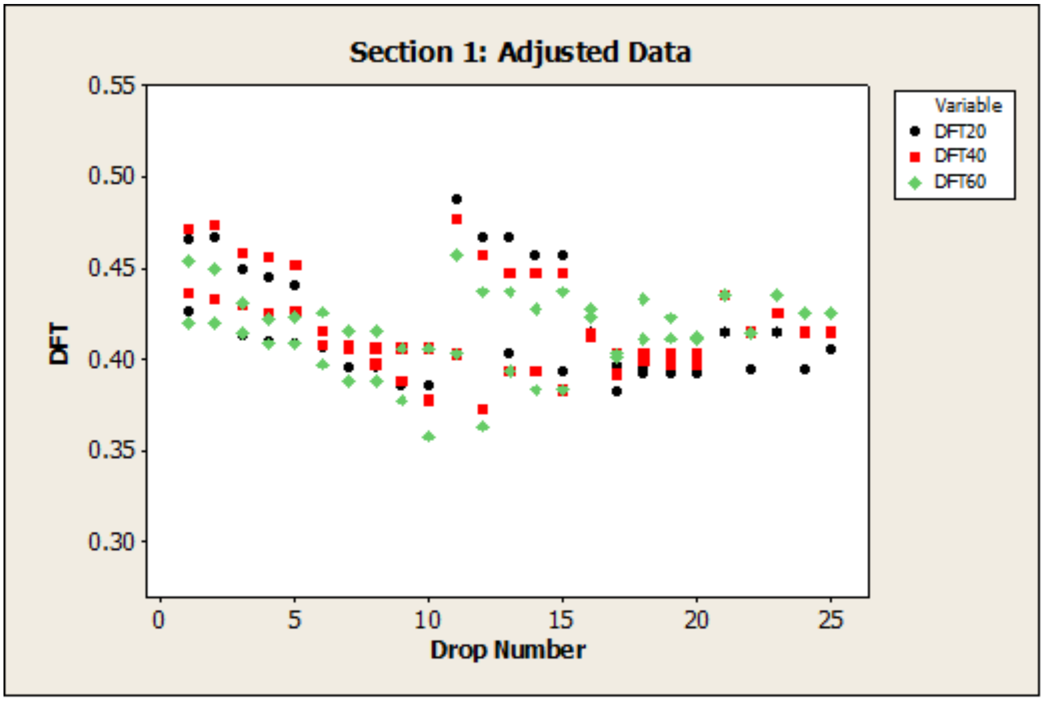
```
Variable  Section   N  N*     Mean  SE Mean    StDev  Minimum       Q1   Median
DFT        1       36   0  0.41078  0.00597  0.03579  0.36000  0.38075  0.39950
           2       36   0  0.35194  0.00530  0.03182  0.29400  0.33000  0.34650
```

```
           3       36   0  0.35736  0.00433  0.02598  0.28000  0.34000  0.35850
           4       36   0  0.35589  0.00368  0.02210  0.32000  0.33700  0.36000
           5       36   0  0.34069  0.00529  0.03172  0.29000  0.31250  0.34500
           6       36   0  0.41794  0.00480  0.02879  0.38000  0.40000  0.40950
           7       36   0  0.40167  0.00388  0.02330  0.36000  0.39000  0.40550
           8       36   0  0.25808  0.00249  0.01493  0.22000  0.25350  0.26000
           9       36   0  0.39792  0.00700  0.04202  0.29900  0.35625  0.40800
          10       36   0  0.39883  0.00553  0.03315  0.33400  0.37000  0.38750

Variable  Section       Q3  Maximum
DFT        1       0.45000  0.48800
           2       0.38000  0.39000
           3       0.37000  0.40000
           4       0.37225  0.39300
           5       0.36675  0.40000
           6       0.43750  0.48000
           7       0.42000  0.44000
           8       0.27000  0.28000
           9       0.43000  0.46000
          10       0.43000  0.46000
```

Appendix B
Number of Drops Analysis

This appendix provides the graphic presentation of the 25-drop sequence for each pavement test section. For each pavement section, the top graph is the raw data and the bottom graph is the adjusted data.


Section 1: Original Data
DFT
0.55
0.50
0.45
0.40
0.35
0.30
0
5
10
15
20
25
Drop Number
Variable
● DFT20
■ DFT40
◆ DFT60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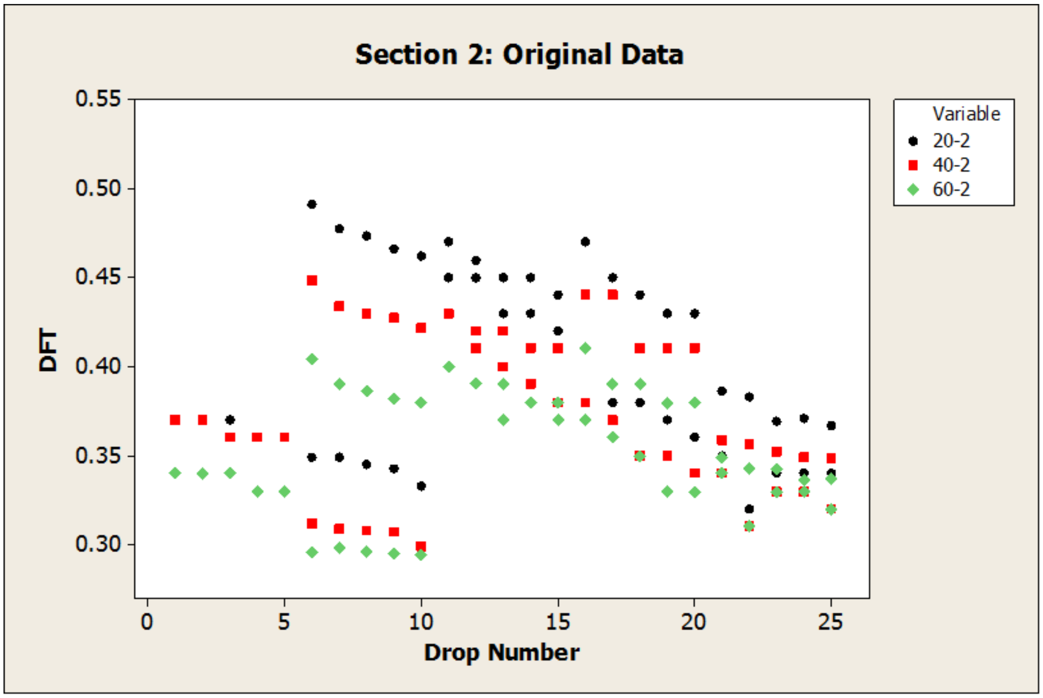
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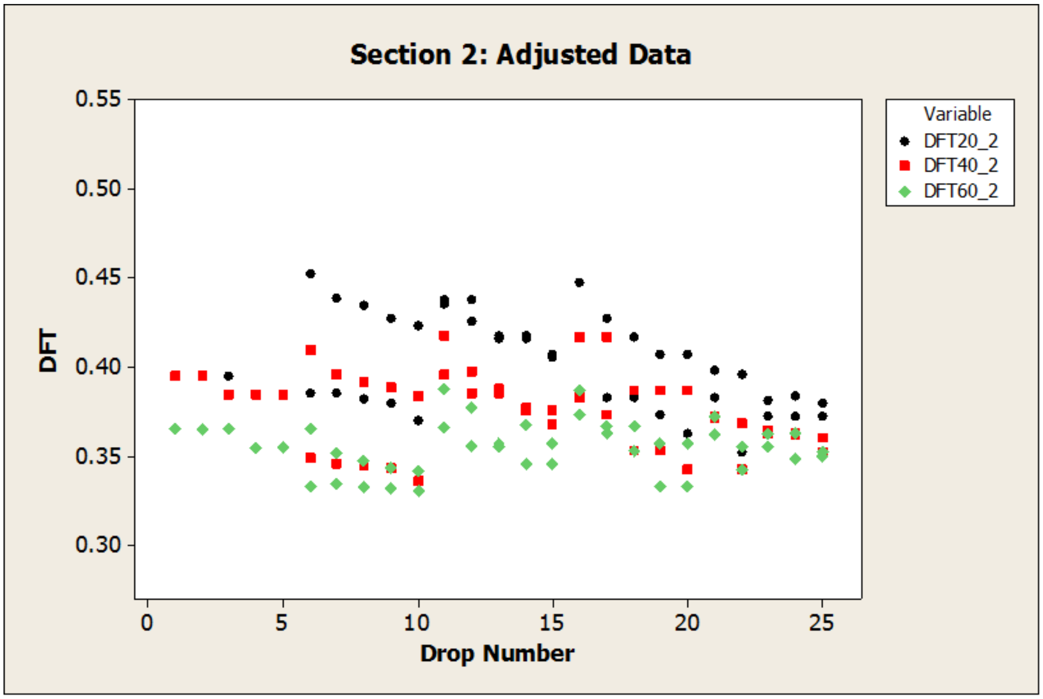
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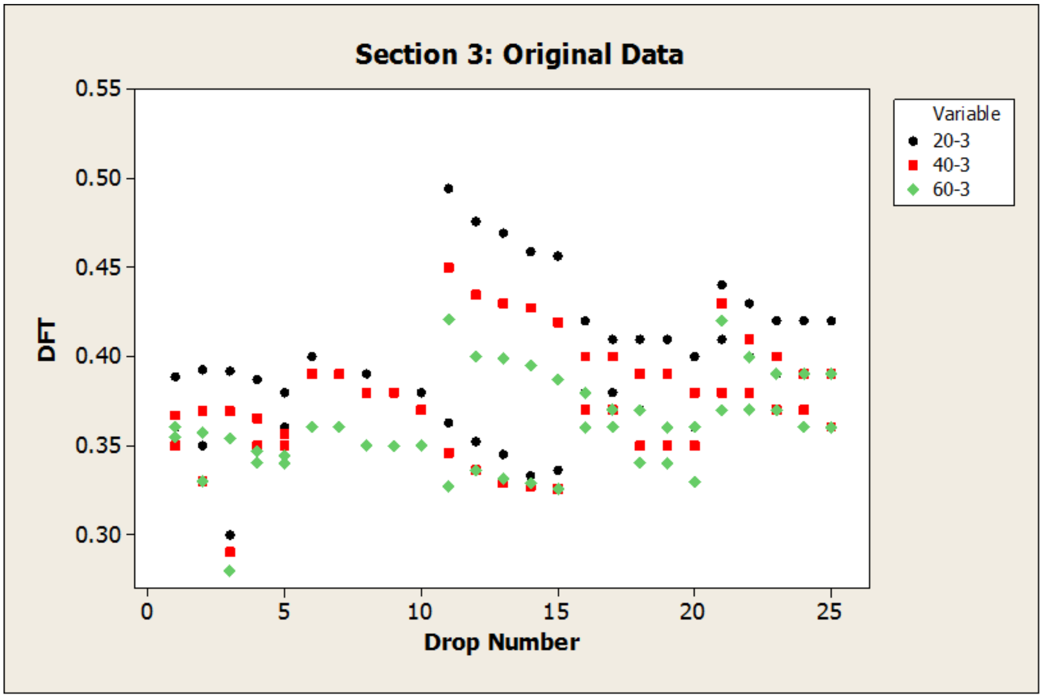
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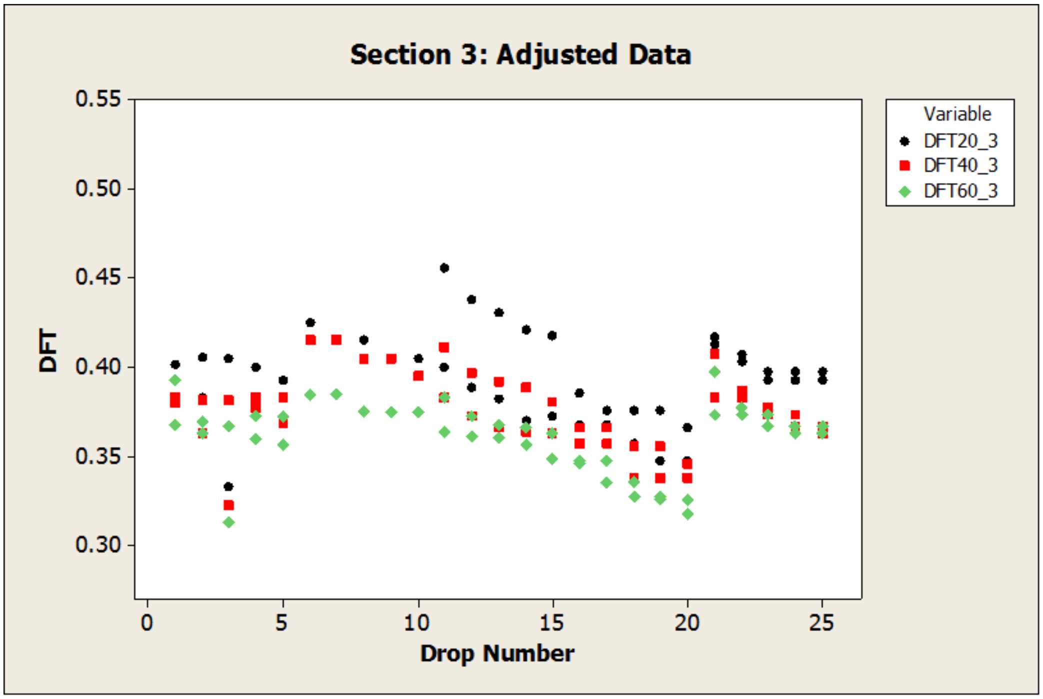
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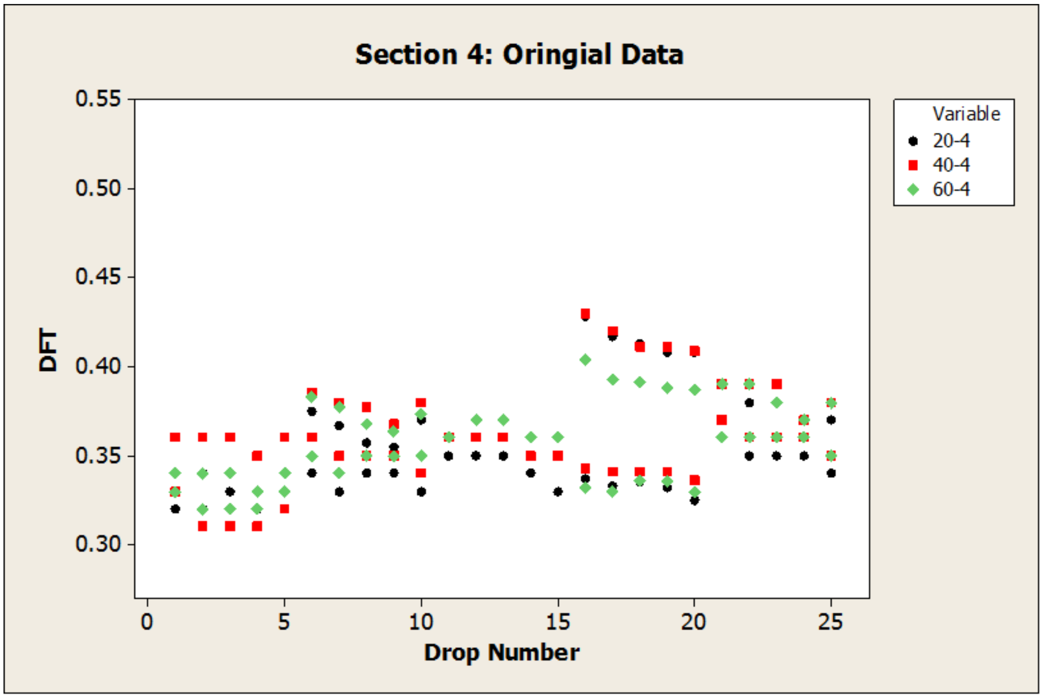
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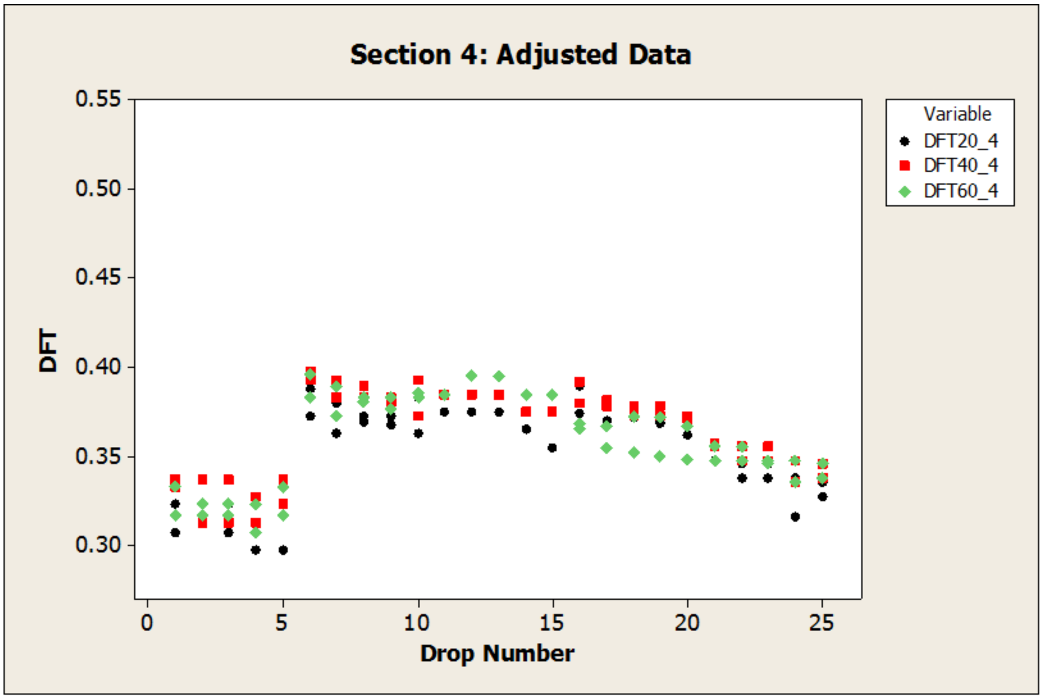
◆ 60-4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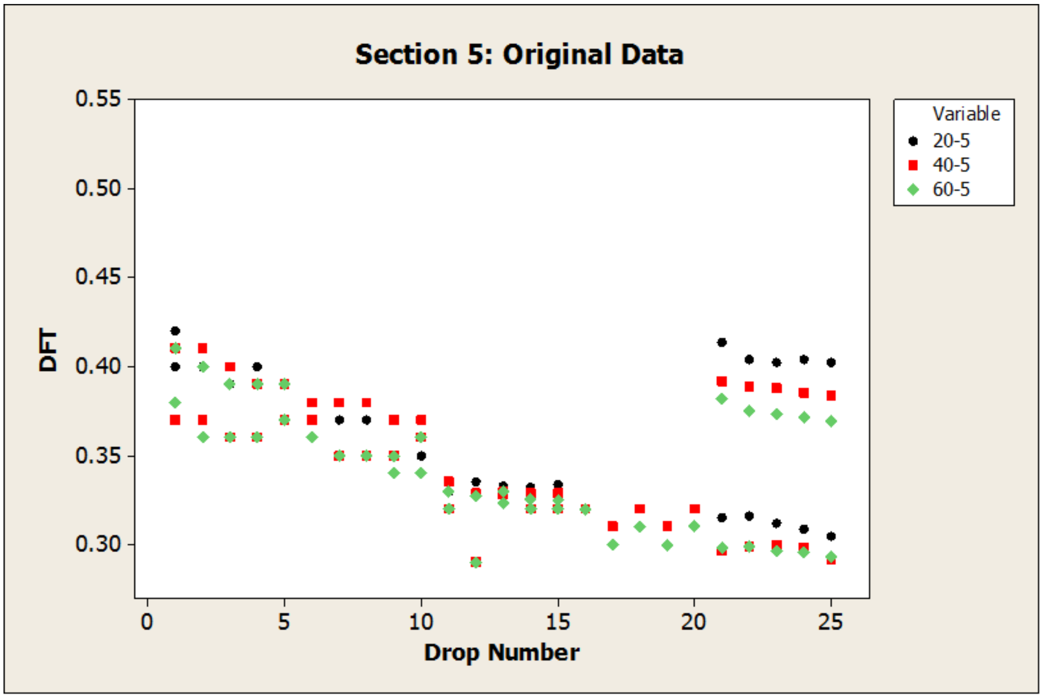
■ DFT40_4
◆ DFT60_4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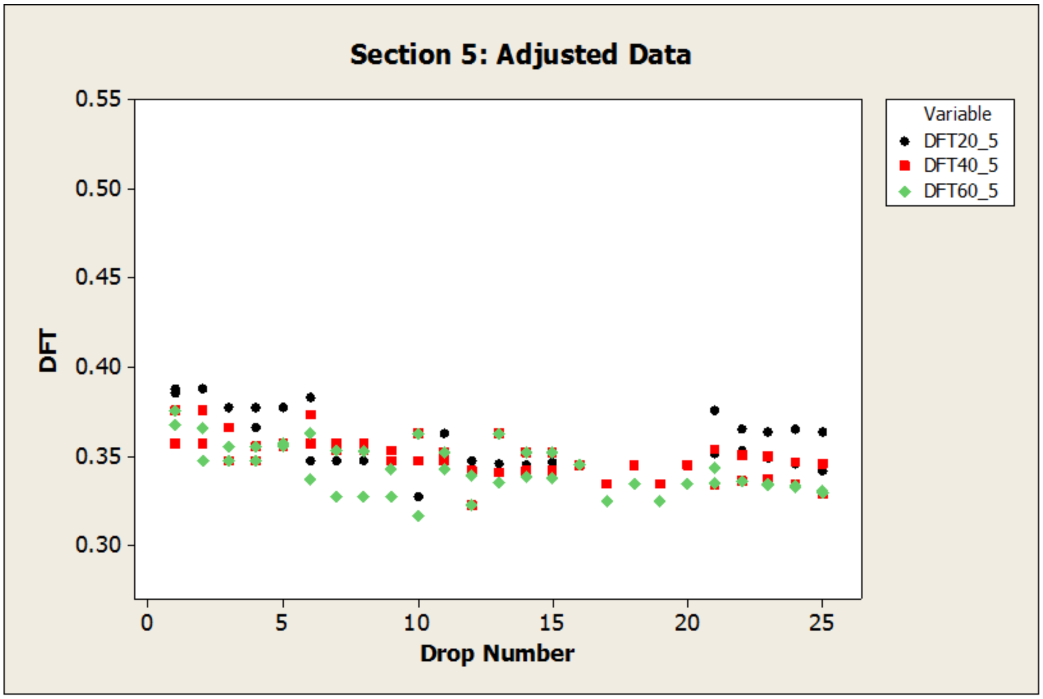
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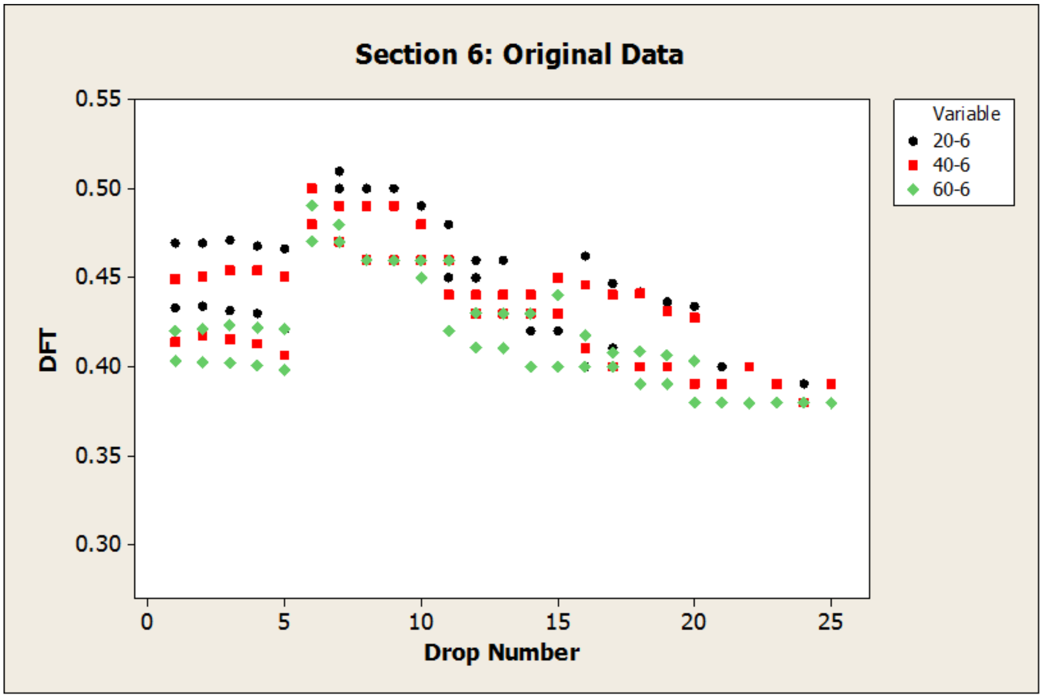
DFT40_5
DFT60_5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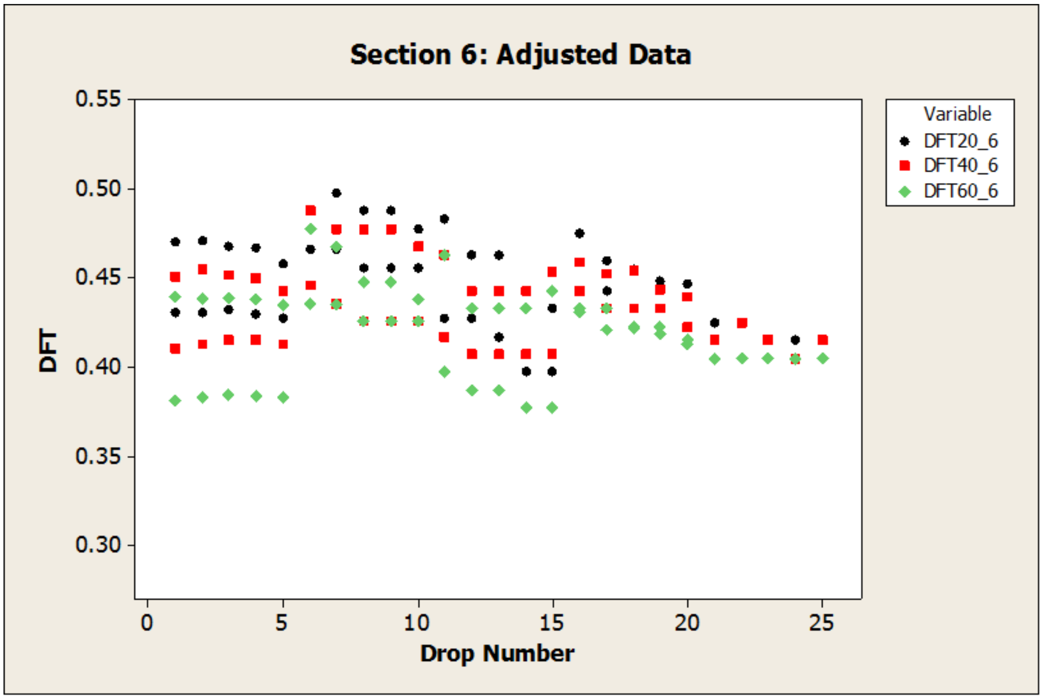
■ 40-6
◆ 60-6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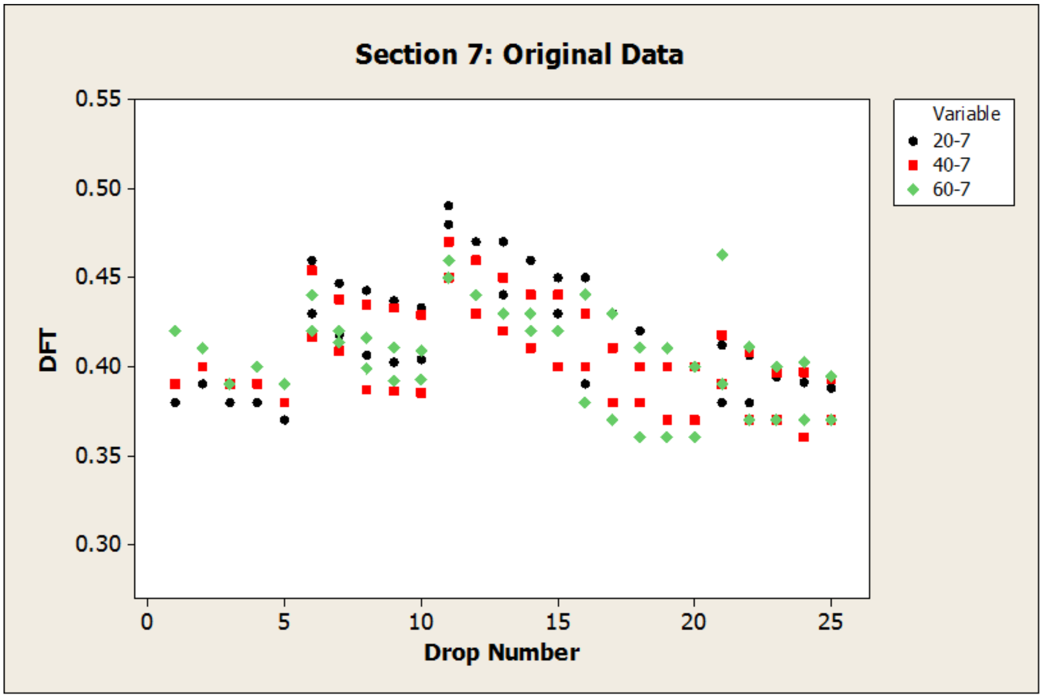
■ DFT40_6
◆ DFT60_6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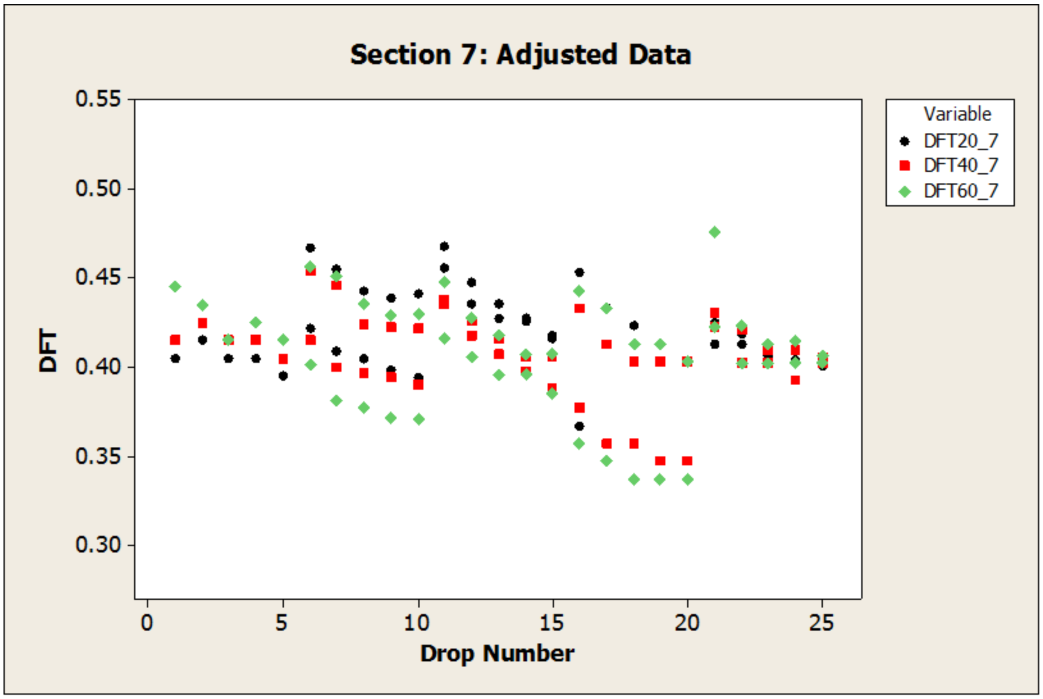
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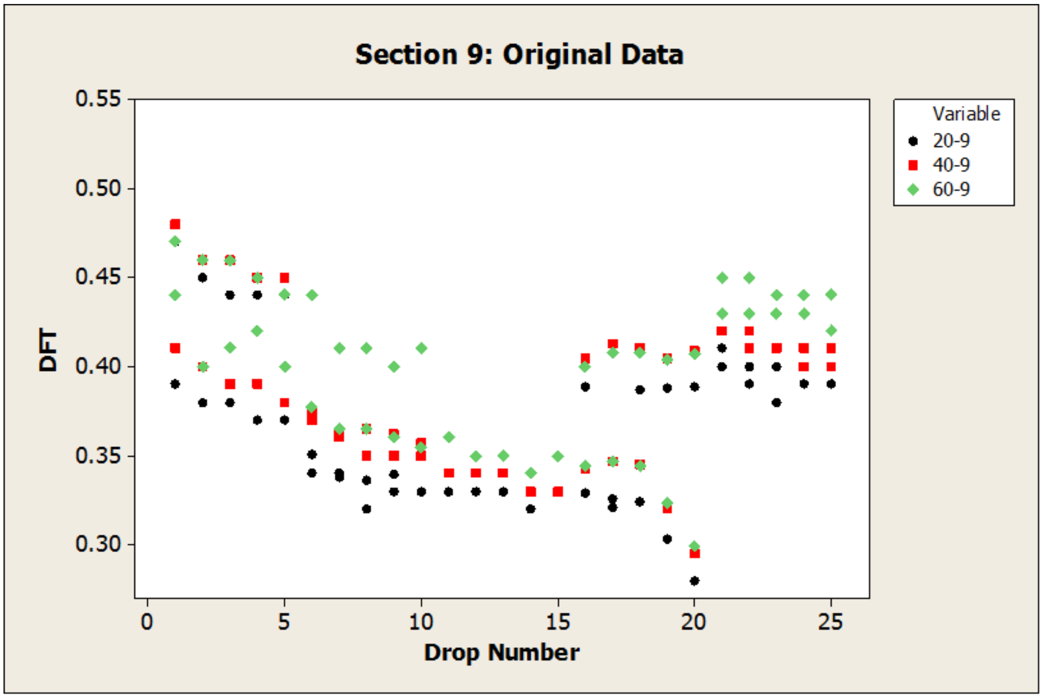
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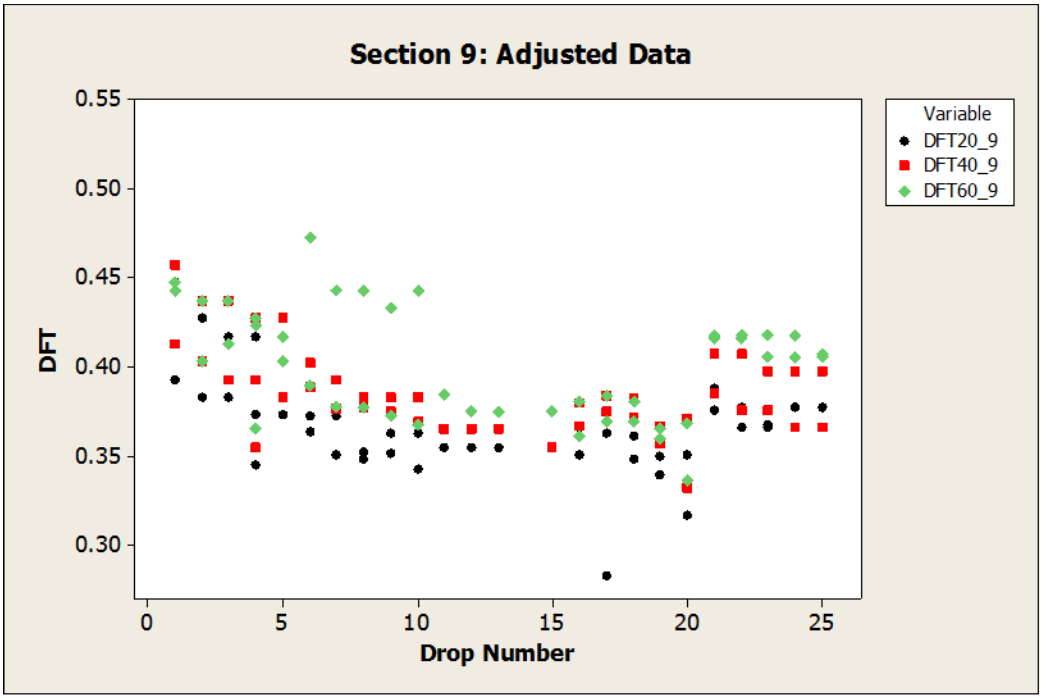
◆ 60-9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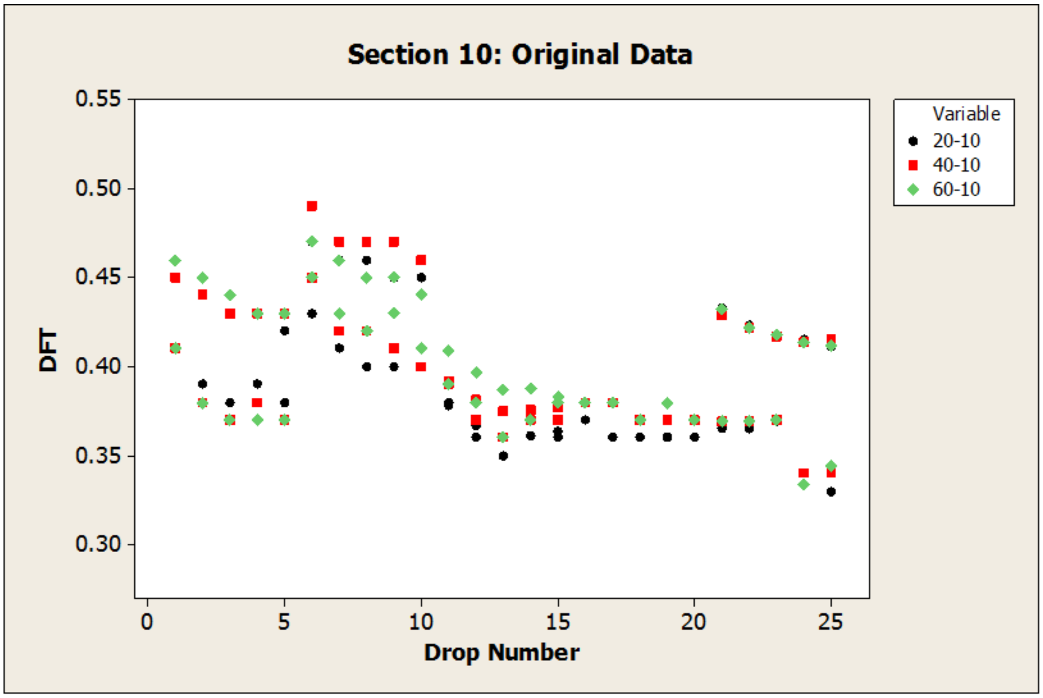
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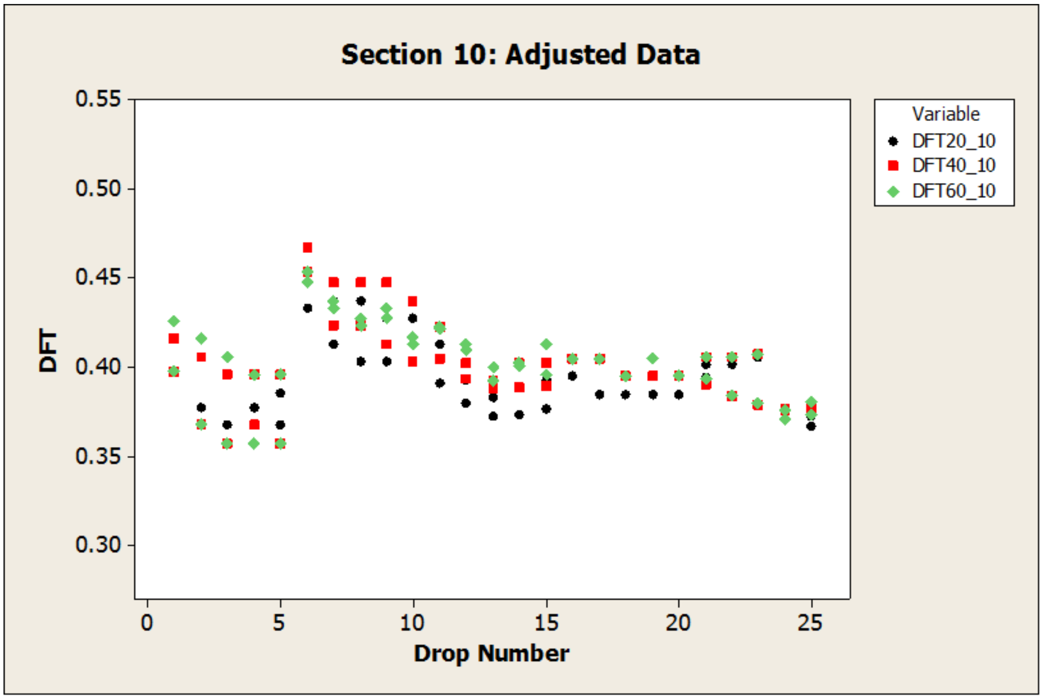
◆ 60-10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● DFT20_10
■ DFT40_10
◆ DFT60_10

Appendix C
DFT User Guide

This user guide is intended to assist users, particularly new users, obtain more accurate and consistent test results from the DFT. It is based on the collective knowledge of experienced users who are predominantly using the DFT model prior to 2010. This guide is not intended to be a full discussion of each topic. It is a guide of best practices, not a replacement to the ASTM E 1911 standard.

Critical Components

Rubber Sliders – The set of rubber sliders must be replaced when they begin to wear. The level of allowable wear should be monitored by the use of a validation plate, visual inspection of the sliders, or drop count (number of tests). The ASTM E 1911 standard is based on replacement after 12 drops. Common practice has shown that the rubber sliders will wear before 12 drops on high friction surfaces (friction above 0.60) and can be used for 30 or more drops on common pavement surfaces (friction less than 0.50).

The steel plate the rubber slider is mounted to should fit the mounting bracket exactly. If the plate is too wide and becomes wedged against the bracket wall, DO NOT force the plate in with the mounting screw. You can narrow the plate with a file or return it for a replacement.

Balance Spring – The balance spring is located between the steel fly wheel plate and lower disc. It cannot be seen. The balance spring works with the displacement meter to measure friction load. When the spring breaks, the friction measurements will be irregular and the lower plate will easily move a small amount by hand. The spring must be replaced and the displacement meter recalibrated before further use of the DFT.

Vertical Load Springs – The load springs are visible on the older model and support the spinning plate assembly. These springs will relax (stretch) over time and must be adjusted to insure the vertical load placed on the rubber sliders is correct. Each spring must carry the same amount of load. If one spring breaks, both springs should be replaced.

Damper and Damper Screw – The damper has two functions. First, the damper holds the spinning plate assembly until it reaches test speed and, second, it lowers the plate assembly to the test surface. The proper lowering of the plate assembly requires that the steel rod in the center of the damper is clean and free to move. This should be checked and cleaned as needed. The damper screw controls the rate at which the spinning plate assembly drops. The plate should not bounce, but should drop freely. There is no documented procedure for setting this screw. A suggested procedure is closing the screw and running a test. The friction trace will initiate with a rounded shape reflecting the gradual lowering of the plate. Open the screw in one-quarter turn increments until the friction trace begins with a wavy shape that reflects the plate bouncing. Return the screw to the last setting and tighten the locking nut.

Water Supply – Maintaining the proper water flow is important. Use a sufficient length of hose (up to 3 meters) for easy movement of the DFT to and from the test surface. Maintain the water bucket at least 0.6 meters above the test surface. Check the spray bar mounted in the DFT for debris or mineral buildup that could restrict the water flow. There is no specific target water film depth. Test surface conditions, like surface macro texture and rutting, will influence the uniformity of water. Some testing has shown the high macro-texture surface should be pre-wetted with a hose before testing.

Calibration Frequency

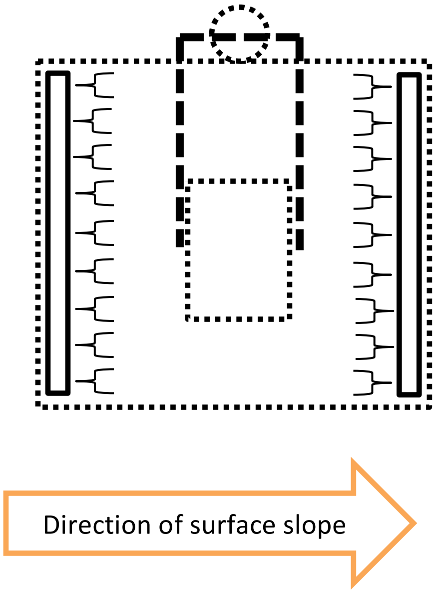
The DFT is a dynamic, mechanically demanding test that should be checked for testing accuracy on a frequent basis. The frequency of a full calibration check by a trained technician will depend on the amount and type of use. For routine (monthly) use on common pavement surfaces, the device should be calibrated every one to two years. Factors that influence the frequency of calibration are age of the unit, amount of use, use of commercial shipping, and test (drop) speed.

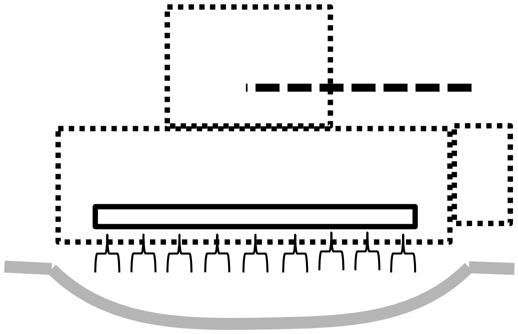
A good practice for monitoring the accuracy of the DFT measurement is to use a validation plate (surface). Immediately after the unit is properly calibrated, perform a test on the validation plate to establish a target friction value. During regular use, retest on the validation plate and compare the current measurement to the target value. Chart the values and look for trends when the test results do not randomly fall between +/- one standard deviation. Based on the workshop test results for ten devices testing ten pavement surfaces, an appropriate standard deviation is 0.015 for five replicate tests.

Placement on a Test Surface

The ASTM test standard does not give guidance on the best orientation of the device to the test surface. Users can follow the following bullets and figures to best fit the device to the testing surface. This orientation guidance is less critical for the new DFT device because it is built with a spray bar on all four sides

- Orientation to the slope of the test surface – place the spray bar perpendicular to the direction of the slope.
- Orientation to the rutting of the test surface – place the spray bar perpendicular to the direction of the rut.




Rutting

Testing Plan

The ASTM test standard does not give guidance on setting up a testing plan. The plan will be controlled by the degree of accuracy required, the time allotted for traffic control lane closure, the level of surface friction, and use for material/surface specification compliance. A higher degree of accuracy requires more test locations and more replicate measurements per location. The time allotted for lane closure dictates the number of tests that can be performed in a period of time. The use of the test for specification compliance restricts the number of tests per set of rubber sliders.

- Testing Pattern – The most appropriate testing pattern for pavement testing is a stratified random pattern with a minimum of three sublots, but no more than 500 feet lineal per sublot. A test location is the random point in each sublot where the friction is measured.
- Number of Drops per Test Location – Some commonly used testing plans are given below. Testing plans that use one drop per location cannot directly evaluate testing precision. The variation between tests is a combination of testing variability and test surface variability.
    - 1 drop at each of three locations (total of 3 drops) for field testing
    - 1 drop at each of five locations (total of 5 drops) for field testing
    - 3 drops at each of three locations (total of 9 drops) for field testing
    - 5 drops, discard first drop at one location (total of 5 drops) for lab testing
- Evaluating Test Precision – Users must consider the source of data used for the precision statement and the degree of risk associated with the number of replicates. The

precision can be based on standard deviation if there are sufficient replicates (more than four) or based on replicate range.

- Number of Drops per Set of Rubber Sliders – Users taking friction measurements for material or pavement surface compliance with specification criteria must follow the current test standard. Less than 12 drops should be used when testing high friction surfaces. For other testing, a set of rubber slider pads have been found to be appropriate for as many as 45 drops.
- Selection of Initial Test Speed – The more common friction values used from the test are the measurements at 60, 40 or 20 kph. The spinning plate assembly can be released at a number of tangential speeds. The ASTM specification implies the use of 90 kph. If there is no specific interest in friction values at 80 kph, the device should be released at a lower speed to reduce wear on the equipment and reduce testing time. The release speed should be at least 10 kph higher than the measured friction speed.