Continuous Friction Measurement Equipment (CFME) Data Processing and Analysis Software

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ABSTRACT

Fixed slip devices collect friction data continuously constituting a big advantage and a practical alternative for network–level pavement friction data collection at highway speeds with low water consumption when compared to the locked wheel testers. These devices are highly maneuverable and especially adapted for investigating accident sites, supporting wet–weather accident reduction programs and identifying localized areas with reduced friction. Currently, these devices have not been implemented for use on highways in the United States to an extent that is commensurate with their potential benefits.

But the decision to implement this type of equipment will also be influenced by how easy it is to gather and present the information. Although it is inarguable that the quality of a continuous friction profile provides a wealth of information that is immeasurable with most locked wheel testers, the processing of vast amounts of information can be overwhelming for an operator or an analyst responsible for preparing reports.

This paper presents a software program that has been developed to allow users to view and analyze continuous pavement friction data automatically without further processing. This program allows users to perform averages, segmentations, and other desirable data analysis, while enabling the construction of user–defined plots that can be used in presentations and/or documents allowing an improved evaluation procedure to evaluate and schedule any maintenance work required.

INTRODUCTION

The recently updated Federal Highway Administration's (FHWA) pavement friction management policy mandates state highway agencies to design pavements to accommodate current and predicted traffic in a safe, durable and cost–effective manner. States are required to implement highway safety programs to reduce crashes on public roads that cause fatalities and serious injuries. These programs have to be "data driven", that is, based on the number of crashes and the crash potential that public roads have. In order to do this, most state highway agencies have implemented pavement friction management programs to collect pavement friction and friction–related data that are used to evaluate road design, construction, maintenance, and to identify locations with high accident rates that are then used to prioritize highway safety projects (*1*).

Because research has shown that wet–weather crashes increase with decreasing pavement friction, possible wet–weather crash locations are identified by implementing test methods that allow repeatable and reproducible friction testing under wet-weather conditions. There are four types of friction test equipment to do this: locked wheel, fixed slip, side force and variable slip. The locked wheel systems simulate braking without anti–lock (ABS) brakes whereas the fixed and variable slip devices simulate braking with ABS. Side force is used to measure brake control on curves. Currently, in the United States, highway agencies only use locked–wheel testers, except for the state of Arizona, who owns a fixed slip device. To the best knowledge of the authors, there is no variable slip or side force system currently being used in America.

Fixed slip devices collect data continuously over a test section, so they are also known as a Continuous Friction Measurement Equipment (CFME). This characteristic is a big advantage because it offers a practical alternative for network–level pavement friction data collection at highway speeds, because it can carry out substantial friction surveys with low water consumption when compared to the locked–wheel testers. These devices are also highly maneuverable and especially adapted for investigating accident sites, supporting wet–weather accident reduction programs and identifying localized areas with reduced friction. Currently, these devices have not been implemented for use on highways in the United States to an extent that is commensurate with their potential benefits.

However, decisions to implement this type of equipment will also be influenced by how easy it is to gather and present the information. Although it is inarguable that the quality of a CFME friction profile provides a wealth of information that is immeasurable with most locked wheel testers, the processing of this vast amount of information can be overwhelming for an operator or an analyst responsible for preparing reports. Data collected is useful only if it can be translated into useful information and effectively used by the decision makers. A simple 20 mile survey collected with a CFME can easily generate anywhere between 35 to 105 thousand friction data points that will also include distance, speed, flow, and other codes related to events like bridges, mileposts, change of pavement, etc.

PURPOSE AND SCOPE

This paper discusses the development of a software program that allows users to visualize and analyze continuous pavement friction data automatically without further processing. This program uploads friction measurements, distance, speed and other event markers. It allows users to perform averages, standard deviations, segmentations, and other desirable data analysis, while visually enabling the construction of user–defined plots that can be accessed to locate specific lengths of the road with similar and/or special friction characteristics and used in presentations.

RESEARCH METHODS

CFME Loan Program

The FHWA has developed a CFME loan program to allow state agencies, practitioners and/or researchers the opportunity to evaluate two types of fixed slip CFME devices without the significant financial commitment this would otherwise represent, and to make an informed decision concerning possible procurement. The program is managed by the Pavement Surface Characteristics Consortium. The Consortium is a joint effort between the Federal Highway Administration (FHWA) and six DOTs (Connecticut, Georgia, Mississippi, Pennsylvania, South Carolina, and Virginia). The consortium is part of the activities of Virginia's Sustainable Pavement Research Consortium (VA–SPRC) managed by Virginia Transportation Research Council (VTRC) and run by the Center for Sustainable Transportation Infrastructure at the Virginia Tech Transportation Institute (VTTI).

The Center for Sustainable Transportation Infrastructure (CSTI) at VTTI has run the CFME equipment loan program since 2007 and provides the on-site training and technical support. CSTI has developed individual containers to carry one type of these units (GripTester) and all its components for easy deployment. Another type is mounted on a dedicated vehicle (Dynatest), as shown in Figure 1.

a) GripTester CFME **b) Dynatest Highway Friction Tester CFME**

FIGURE 1 Loan Program CFME fixed slip units

As part of the on–site training and technical support given to the state agencies since the inception of the loan program, it became evident that, although CFME friction profiles provide more information than what presently is being obtained by most locked wheel testers, its processing becomes overwhelming. Simple surveys collected with a CFME can rapidly generate thousands of friction data points associated with distance, speed, flow, and other events like bridges, mileposts, change of pavement, etc.

It was deemed necessary for the success of the program, to develop a software program that would allow users to visualize, immediately after the data collection phase, the data collected and also to elaborate friction profiles, friction-distance plots, and any other plots or analysis that could later be exported into documents and/or presentations. The process needed to be considerably easier (and quicker) than the processing that is normally needed to divide, characterize, average and plot all of the data with normally available commercial spreadsheets.

As the contractor in charge of the CFME Loan Program, CSTI partnered with the University of Hawaii at Manoa to develop a software program to allow the users to view and analyze the pavement friction profile of any road automatically without further processing. This program works very much like another FHWA product, ProVAL, which is used to view and analyze pavement profile data (*2*). The software was initially called GripVal, but it will be re-named to reflect the universality of its application in a later phase.

The program uploads friction measurements as well as distance and other event markers. It allows users to perform averages and other statistical analyses, segment sections of equal average friction, user-configure plots to be used in documents or presentations, and other desirable data processes while zooming–in or out of specific segments of the road with similar and/or special friction characteristics.

Analysis Options

Most of the functions of the software basically carry out different visualization options for the data collected by the CFME devices. The software also allows friction profiles to be shifted to make direct comparisons between different runs of the same road segments and it offers other functions useful for researchers doing friction profile comparisons.

However, the most useful function introduced by this software as part of the analysis options is the one included to create segmentations of the CFME friction series. Typically, when assessing continuous road measurement information contained in series, it is useful to separate it into segments of similar characteristics such as roughness, rutting, friction, etc., that will allow the proper evaluation of the maintenance work required as evidenced by the individual condition of each segment.

For this purpose, the algorithm used combines a Bayesian identification of transitions between two homogeneous road sections with a heuristic approach to find multiple homogeneous sections, as developed by Dr. Fridtjof Thomas (*3, 4, and 5*). The segmentation algorithm identifies changes in the level, in the variance, or in the autocorrelation of the series of measurements. Therefore, the homogenous segments identified need not have a constant level of friction. In fact, most of the series analyzed so far show gradual changes in the friction level, which would make more difficult the identification of segments with constant friction.

Although another version of the algorithm which produces homogeneous sections based only on the level and variance is available, when tested with the available experimental data it produced too many small segments due to the increasing or decreasing patterns in the data. Therefore, only the algorithm based on the level, variance, and autocorrelation is implemented at this stage. The default threshold probability level currently used for detecting change–points is 0.99, which is quite high.

RESULTS AND DISCUSSION

The data measurements used to showcase this software include data from two sources. The first source is from experimental measurements performed at the Virginia Smart Road in 2008 and the second one is from actual measurements performed in the public roads of Costa Rica in 2010 and previous years as part of the Friction Measurement Program carried on by the Materials and Structural Models Laboratory of the University of Costa Rica (LanammeUCR).

Smart Road Comparisons

Since it was formed three years ago, consortium representatives have met for one week in May at the Virginia Smart Road at VTTI with the goal of comparing and verifying surface property measurements on the surfaces available at the facility. This event has been called the "Surface Properties Rodeo". Tire friction data with a GripTester collected in the 2008 Rodeo was used to develop a user's manual for the software. [The reader is referred to two references for those interested in the operational characteristics of the GripTester and its use in obtaining and comparing friction measurements (*6*, *7*).] The following pages show some screen shots to demonstrate the versatility, user–friendliness and some capabilities of GripVal.

Getting started (data views of one imported file)

As soon as the information of a raw data file is uploaded into the software, the user can see the result of the CFME measurements in a plot of distance vs. friction number, presently called GN for Grip Number, as shown in Figure 2. These measurements represent the coefficient of friction, mu (μ) collected by the CFME, on a decimal scale from zero to one. Distance along the road is represented in the horizontal axis. Notice that depending on the user defined options available, these units can be either in the International (SI) System or as shown here in the English system. In the bottom of the friction plots the corresponding speed plot of the friction measurements is shown.

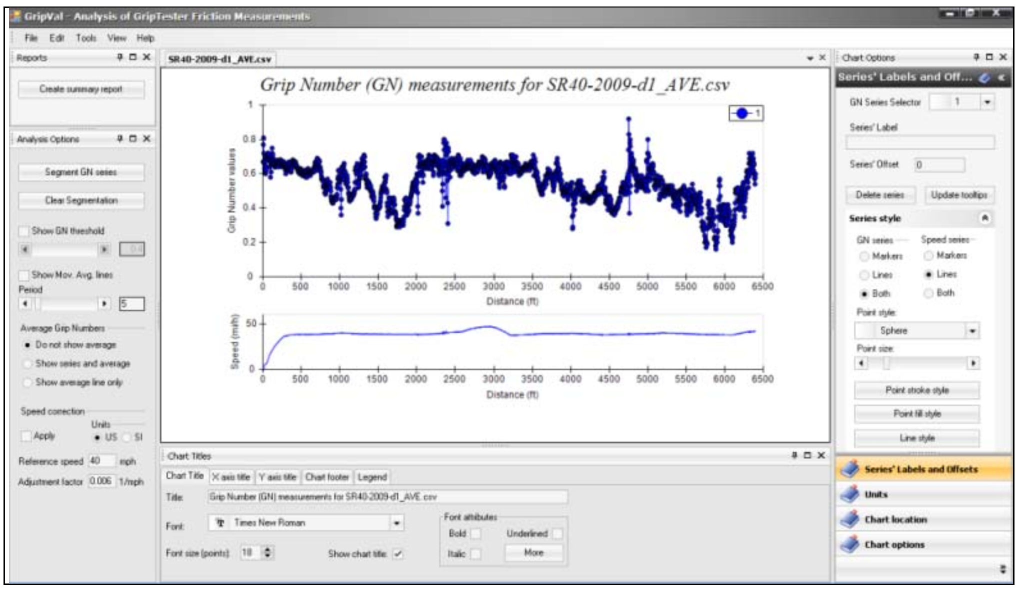


FIGURE 2 Initial screen shot of imported data, 1 series

The plots shown can be customized to include markers, lines or both. The user has the options also of choosing the colors for the points and the lines, and the point style, size and stroke. Fonts colors and sizes of all text included can also be modified to suit any presentation or document requirements that the users might require. The chart will place the name of the imported file as the title of the plot, but both the title and the vertical and horizontal axis names can be modified by the user using the chart titles labels options. Furthermore, for presentation purposes, the user can remove the speed plot increasing the size of the friction measurements plots to be copied into the clipboard so that it can be pasted into any presentations and/or documents. Speed correction factors can also be applied to the friction measurements when these are known, or if they can be obtained from similar work elsewhere.

Comparisons of two or more friction profiles

Simply selecting the import command again creates a new document with another chart showing the new series. However, if the user wishes to compare different runs of measurements on the same section of road in the same chart, GripVal provides an import series command that displays the additional measurement series in the same chart, as shown in Figure 3 below.

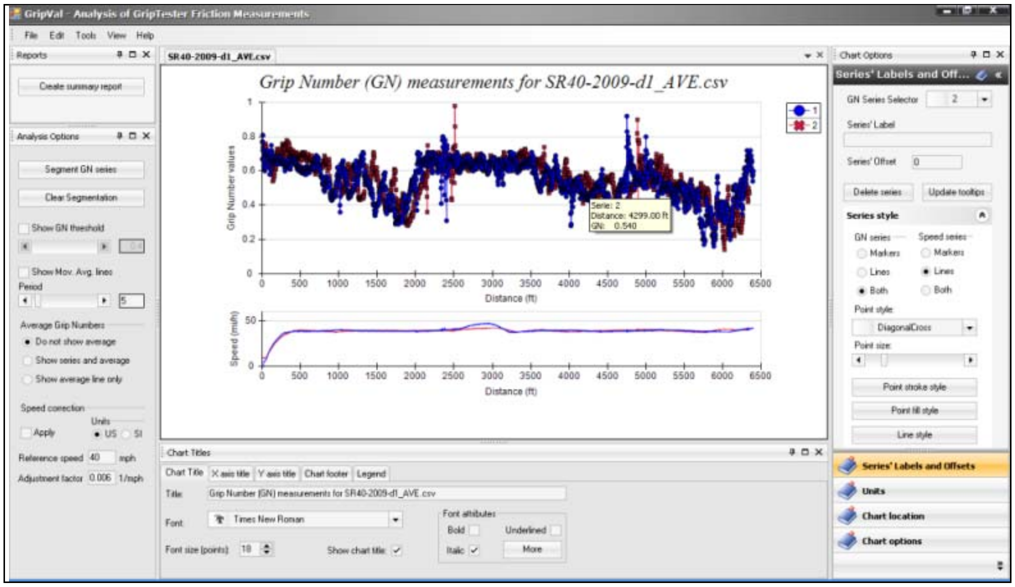


FIGURE 3 Initial screen shot of imported data, 2 or more series

As shown in this figure, a second series of measurements has been added to the friction chart as well as to the speed chart. The document is identified in the tab with the name of the first file that was opened. Subsequent additions (up to ten data files per plot) do not change the tab or the title of the plot. Nevertheless, as mentioned above, the user has the capability of changing the chart title to something more meaningful, including the font attributes of the chart.

Finally, notice a possible common situation when analyzing multiple series of the same road. Although the trends are the same in the two series, there appears to be a displacement between them. This is a very common occurrence when making several runs of the same segment. Thus, it is convenient to have a mechanism for offsetting one or more series. GripVal provides this mechanism. When the user enters a numeric value in the Series Offset textbox, both the grip number and speed series of the measurements selected are shifted by the amount of the offset. The effect of this operation is illustrated in Figure 4 below, where the second series has been offset by +138 ft.

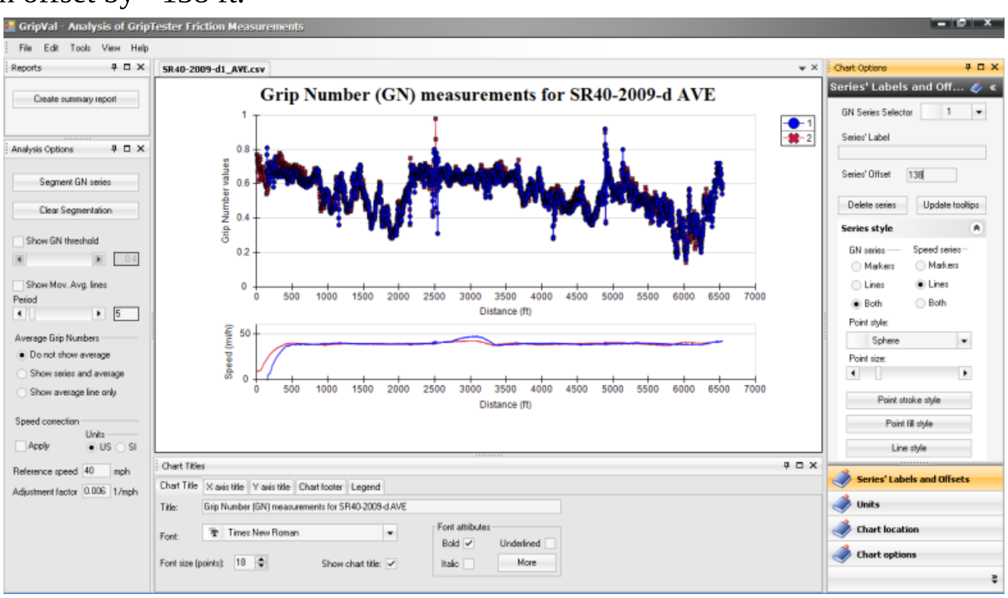


FIGURE 4 Screen shot of imported data, 2 or more series with offset correction applied

Notice how now there appears to be a much better correspondence between the two series. This option has proven to be very convenient in equipment comparisons performed basically in research applications such as the Consortium Rodeo but its usefulness could also be appreciated by any highway agencies that want to study how road segments are performing over time.

A series of different screen configurations and other options are also available, such as the zooming and scrolling capability of the program for particular segments of interest the user could have and would want to emphasize with customized plots for presentations and/or documents. One of these options is the ability to automatically perform corrections to the friction measurements based on different speed relationships when the measurements are taken in the roads. This is not an uncommon occurrence under real world traffic conditions which are affected by traffic, slope and other disturbances which might force the test vehicle to alter the speed at which it is traveling. For this, GripVal allows the application of a speed correction factor that can be applied to all of the friction measurements that deviate from the standard speed, which is also an input for this option.

Specific speed correction factors usually depend on the type of pavement and other factors that can influence the measurements being tested (*8*). This speed correction option will be shown later. However, the most important utility for decision making, and for the objectives of this paper, is considered to be the segmentation methods which will be also shown in the next section with actual data obtained from actual road measurements performed in Costa Rica. These include the averaging options and the summary report created for the corresponding segments generated, as well as some advanced statistical plots that can be also generated.

Costa Rica GripVal Experience

Costa Rica is located in Central America and has a national paved road network of about 2500 miles (4,100 km). LanammeUCR owns a GripTester that is used to measure the friction condition of the network in a two–year cycle to provide the national Pavement Management Office the frictional condition information to help allocate the annual funds required for its maintenance.

In 2008, 1,446 miles (2,328 km), or about 50.2% of the paved road network, were evaluated with this GripTester. The segments of the road network measured have been previously pre-screened with a high speed profiler to include only those segments with an International Roughness Index (IRI) less than 250 in/mi (4.0 m/km); this is done to avoid rougher segments that could cause possible calibration issues with the GripTester. All of the measurements were done at a target speed of 31 mph (50 kph).

Because of the large amount of data generated to evaluate more than 1,200 miles (2,000 km), it is necessary to use computers to analyze it efficiently. Recently, GripVal was shared with LanammeUCR for the creation of homogenous friction segments of data. It is envisioned as a more agile data analysis process that will allow reports and plots to be quickly generated to identify low friction spots among the various road segments. This will allow, for example, the evaluation of low friction spots with accident data from the road network that could require resurfacing of the pavement segments.

Figure 5 below shows an example of the screenshot obtained from GripVal from a raw data file of a segment from Route 155 in Costa Rica. Notice on the bottom left corner of the Analysis Options panel that when the file is first uploaded the speed correction option is not selected.

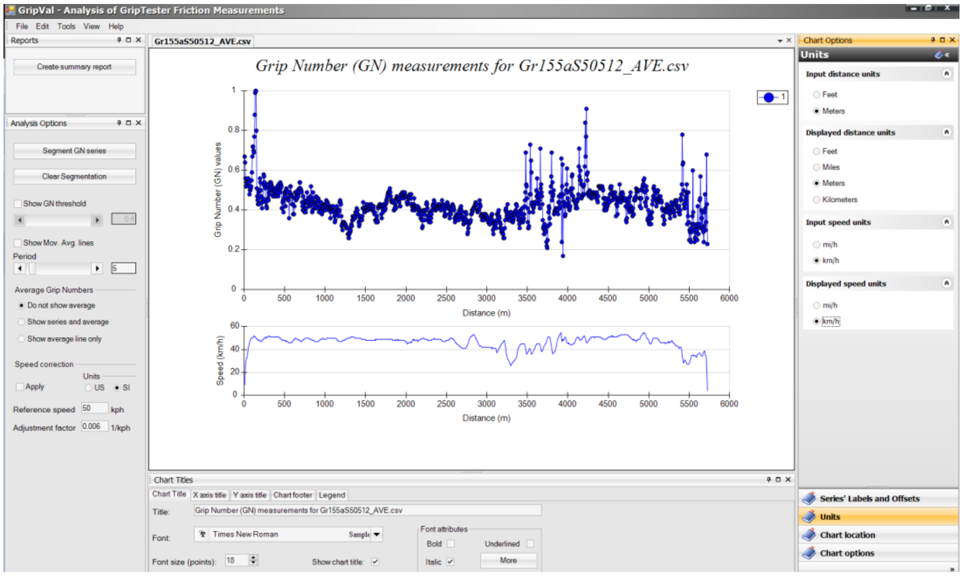


FIGURE 5 GripVal screenshot of raw data file, Route 155 from Costa Rica

Friction Measurements Speed Correction

Being able to view the results shown on the speed plot, we can quickly see that several measurements have been made below the intended speed of 31 mph (50 kph). By clicking on the speed correction option, as shown in Figure 6 below, the appropriate corrections are immediately made by the software resulting in lower friction results in the areas of the plot were the speed was below the desired intended speed. This is especially noticeable between measurements 3,000 and 4,000 were the speed plot shows that the speed was not maintained as intended.

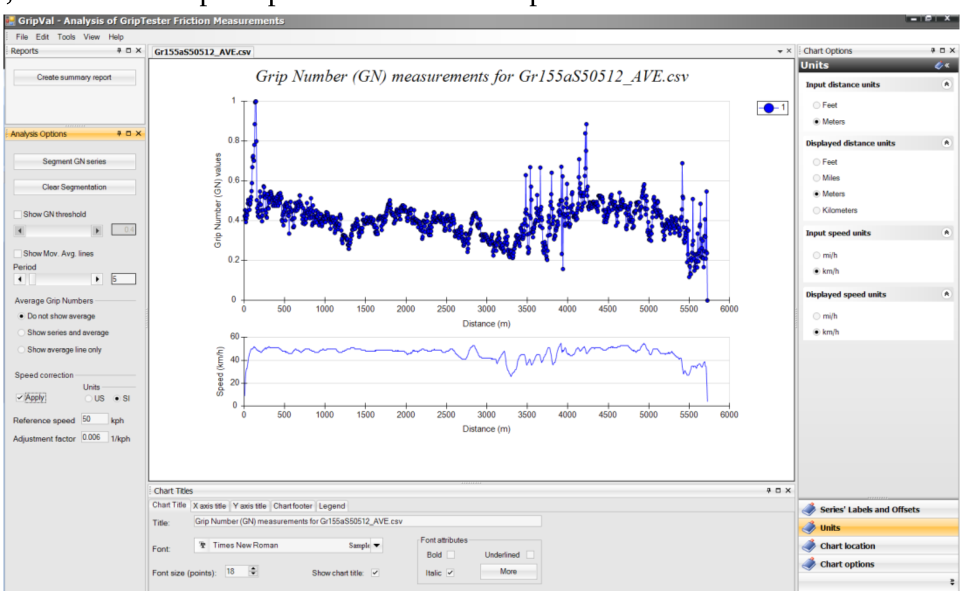


FIGURE 6 GripVal screenshot of corrected speed data file, Route 155 from Costa Rica

Friction Measurement Segmentation

Last, the segmentation option for the friction (GN) option is selected resulting in the data segmentation plot shown in Figure 7. Notice how 20 different segments with different shades separate the friction plot especially separating the unusual high and low peaks segments, even of different length, found in the friction profile segment plot. These represent uniform homogenous friction segments that are as short as 15 meters and as long as 1,490. It is very important to note that sound engineering judgment, along with good local knowledge of the road is very important to assess a correct evaluation of the conditions in each road. Short segments could represent much localized areas that need to be treated separately and not be generalized for maintenance purposes of larger road segments. This is made evident in this case when analyzing the GripTester data file where it is has been documented that from stations 3,500 to 4,100 there was a steep grade of more than 10% and that between stations 4,100 to 4,330 the grade was between 5 and 10%, which explains the variations in the speed at the time of the survey.

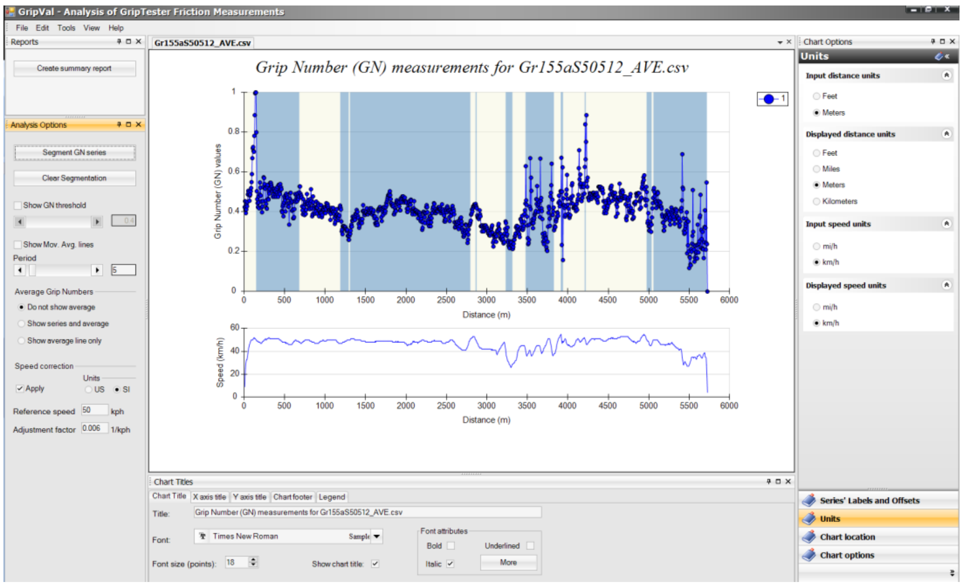
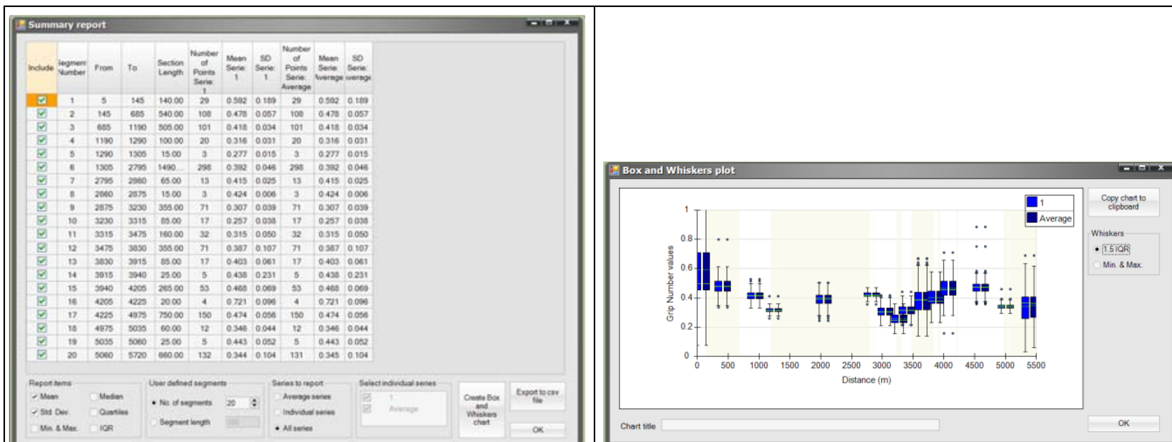


FIGURE 7 GripVal screenshot of segmented and corrected speed data file, Route 155 from Costa Rica

The result of the segmentation can furthermore be exported into a summary report data file that contains a summary of the characteristics of each segment, such as from, to, the section length, number of points in this section, the mean friction of the section, the mean standard deviation, etc. These results can be exported to a file for further analysis. A box and whiskers plot of the segmentation is also available by simply choosing this option for creating this plot to be used in presentations or documents, if so desired, either using a 1.5 Interquartile or a minimun and maximun range. Both of these options can be seen in Figure 8.



a) Data summary report **b) Box and whiskers plot option**

FIGURE 8 GripVal screenshots of segmented data and plots, Route 155 from Costa Rica

CONCLUSIONS

This paper presented examples of applications of CFME and a software program that has been developed to allow users to visualize and analyze continuous pavement friction data automatically without further processing. The following points summarize the main conclusions:

- Fixed slip devices that collect data continuously offer a practical alternative for network–level pavement friction data collection at highway speeds. However, effective implementation of this type of equipment requires a means to process the vast amount of information obtained. The software program presented in this paper is an example of this type of tool, which allows users to visualize and analyze continuous pavement friction data automatically without further processing.
- The program presented here uploads friction measurements, distance, speed and other event markers automatically form the raw data files collected by the CFME. It allows users to perform averages, standard deviations, segmentations, and other desirable data analysis, while visually enabling the construction of user–defined plots that can be further accessed to locate specific lengths of the road with similar and/or special friction characteristics.
- A summary report with a data grid that displays the information of all the series available and their average contains averages and standard deviations for all the segments, and is also available with or without speed corrections, if this option is selected before generating the report. Proper speed correction factors need to be obtained by the corresponding agencies on their roads before this option is used.
- One of the useful functions introduced by the software is the one included to create segmentations of the CFME friction series to assess and separate the road measurement information into segments of similar frictional characteristics. The algorithm used combines Bayesian identification with a heuristic approach to find multiple homogeneous sections and has been applied before to evaluate road profile series measurements. This type of analysis allows the identification of sections with low friction, which may represent safety hazards and require maintenance work.

It is expected that this software will be made available soon to all interested scientific and practicing pavement friction measurement users and that this will allow a more effective use of all CFME equipment to help improve safety conditions of pavements everywhere.

ACKNOWLEDGMENTS

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The other part of the data used was collected by the LanammeUCR friction collection program for the government of Costa Rica and is gratefully appreciated. It is used here only for illustration purposes and does not represent or intends to convey any meaningful analysis of the road segments portrayed in the screenshots used to illustrate the use of the software presented in this paper.

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