TTI: 5-6610-01

Evaluating Corrections to Improve Ride Quality Based on Surface Profiles

Implementation Report 5-6610-01-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
http://tti.tamu.edu/documents/5-6610-01-R1.pdf

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-17/5-6610-01-R1		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
EVALUATING CORRECTIONS TO IMPROVE RIDE QUALITY BASED ON SURFACE PROFILES	5. Report Date: Published: January 2019 6. Performing Organization Code
7. Author(s) Emmanuel Fernando, Sheng Hu, and Charles Gurganus	8. Performing Organization Report No. Report 5-6610-01-R1
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 5-6610-01
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	13. Type of Report and Period Covered Technical Report: June 2015–August 2017 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Implementation of Defect Correction Assessment Methodology on TxDOT Ride Quality Projects

URL: http://tti.tamu.edu/documents/5-6610-01-R1.pdf

16. Abstract

This project follows up on the original development of the defect correction index (DCI) in the Texas Department of Transportation project 0-6610. As part of implementing the DCI methodology for evaluating defect corrections using surface profile measurements, this implementation project conducted additional bump rating panels to verify the original DCI equation developed from project 0-6610. This verification led researchers to re-calibrate the original equation using the expanded bump rating panel database compiled in this implementation project. Researchers used the calibrated DCI equation in modifying the Grind Diagnostics program to automate the application of the DCI methodology for evaluating defect corrections on Item 585 projects or to identify treatments that can be made to an existing roadway during the project development and planning process to enhance the opportunity for ride quality improvement. In addition to automating the application of the DCI equation, researchers added a utility for estimating costs associated with correcting the defects identified from the DCI analysis and a utility for generating graphical output, through maps and charts, to help users communicate the results from this analysis.

17. Key Words	18. Distribution Statement
Ride Quality Measurement, Ride Quality Assurance Testing, Localized Roughness, Bump Rating Panel Surveys, Defect Correction Index	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia http://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	120	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EVALUATING CORRECTIONS TO IMPROVE RIDE QUALITY BASED ON SURFACE PROFILES

by

Emmanuel Fernando
Senior Research Engineer
Texas A&M Transportation Institute

Sheng Hu
Associate Research Engineer
Texas A&M Transportation Institute

and

Charles Gurganus
Associate Research Engineer
Texas A&M Transportation Institute

Report 5-6610-01-R1
Project 5-6610-01
Project Title: Implementation of Defect Correction Assessment Methodology on TxDOT Ride Quality Projects

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: January 2019

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

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, and is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Dr. Emmanuel Fernando, P.E. #69614.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors gratefully acknowledge Mr. Oscar Soliz, Alice area engineer, for his steadfast support and guidance throughout this project. In addition, the authors thank the members of the Project Monitoring Committee, particularly Mr. Charles Benavidez and Mr. Daniel Garcia, for organizing the bump rating panel surveys conducted in this project. The authors also acknowledge the technical support provided by Gerry Harrison of the Texas A&M Transportation Institute in setting up the test sites for these surveys. Finally, a special note of thanks is given to the raters who participated in these surveys and to the project manager, Joe Adams, of TxDOT's Research Technology and Implementation Office.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1. CONDUCT PILOT IMPLEMENTATION ON SELECTED TXDOT PROJECTS

INTRODUCTION

The Texas Department of Transportation (TxDOT) uses the Item 585 ride specification (*1*), which includes a provision to locate defects on the final surface based on measured surface profiles. However, some districts have used bump rating panels to determine the need for corrections based on the panel's opinion of defect severity from a ride quality point of view. Project 0-6610, "Impact of Changes in Profile Measurement Technology on QA Testing of Pavement Smoothness," developed a defect correction index (DCI) based on correlating defect characteristics to the need for corrections using data from bump rating panel surveys (*2*). In this implementation project, researchers conducted similar surveys to verify the DCI from Project 0-6610. This chapter documents the surveys conducted and summarizes the findings from analysis of the data collected.

BUMP RATING PANEL SURVEYS

Table 1 identifies the projects where the Texas A&M Transportation Institute (TTI) conducted bump rating panel surveys. The first four projects were recommended by the project monitoring committee. Of these four projects, US 281 and FM 88 include the Item 585 ride specification in the plans. On the other hand, SH 361 and US 77 are development projects that have been scheduled for rehabilitation by the Sinton Area Office. These two projects were included in the test plan to assess the application of the DCI for identifying corrective treatments on existing pavements to enhance smoothness improvement opportunities on scheduled rehabilitation projects. The last two projects, on US 190 and US 59, were identified from ride quality verifications conducted by TTI on an existing TxDOT interagency contract.

On all projects listed in Table 1, TTI collected profile data and conducted bump rating panel surveys. Table 2 identifies the raters who participated in these surveys. The rating panels included TxDOT and TTI personnel with experience in the following areas:

- Asphalt and concrete pavement design, maintenance, rehabilitation, and reconstruction.
- Assessment of pavement condition.
- Materials testing.
- Geotechnical investigations.

To identify defects for running the bump surveys, TTI analyzed the profile data using the current TxDOT methodology to evaluate localized roughness in the Item 585 ride specification, except that:

- Defects were identified by wheel path instead of using the average profile.
- The defect width was defined to be the distance between the intersections of the measured wheel path profile and its 25-ft moving average.

Prior to each survey, TTI marked the defect locations and conducted a panel briefing to discuss how the bump rating surveys would be conducted. As indicated in Figure 1, raters were asked to give their opinions on the need for correcting defects that they were driven on during each survey. Specifically, each rater checked *yes* if he or she felt that a defect group needed to be corrected based on his or her perception of the ride quality associated with the given defect group. Otherwise, the rater checked *no*. Note that in practice, an area of localized roughness may consist of several bumps and/or dips. Thus, road user perception can be an aggregate reaction to a group of defects as opposed to any single bump or dip. Consequently, the research team established defect groups along each test lane to define areas of localized roughness where each group could have one or more defects.

Table 1. Projects Where Bump Rating Panel Surveys Were Conducted.

Highway	Location	Project Limits		Length (lane miles)	Test Lanes
		Start	End		
US 281	Edinburg	N 26.385851° W 98.141893°	N 26.417360° W 98.136969°	2.187	Northbound outside frontage lane
FM 88	Elsa	N 26.298964° W 97.993396°	N 26.287878° W 97.993232°	3.080	Northbound/southbound outside and inside lanes
SH 361	Ingleside	N 27.915373° W 97.279013°	N 27.884369° W 97.215111°	9.077	Northbound/southbound outside lanes
US 77	Odem	N 27.942956° W 97.589164°	N 27.901851° W 97.631476°	7.676	Northbound/southbound outside lanes
US 190	North Zulch	N 30.914151° W 96.108996°	N 30.947136° W 95.918782°	24.627	Eastbound/westbound outside lanes
US 59	Leggett	N 30.806633° W 94.873636°	N 30.765271° W 94.903173°	3.364	Southbound outside lane
US 59	Leggett	N 30.653647° W 94.945876°	N 30.681487° W 94.950124°	1.896	Northbound outside lane

Table 2. Raters for the Task 1 Bump Rating Panel Surveys.

Project	Raters	Affiliation
US 281 Edinburg and FM 88 Elsa	Daniel Garcia	TxDOT Pharr District Lab
	Humberto Uresti	
	Rene Castro	
SH 361 Ingleside and US 77 Odem	Charles Benavidez	TxDOT Sinton Area Office
	Armando Bosquez	
	Connie Garcia	
	Ernest Longoria	
US 190 North Zulch	Tony Barbosa	TTI Materials & Pavements
	Charles Gurganus	
	Sang Ick Lee	
US 59 Leggett	Tony Barbosa	TTI Materials & Pavements
	Rick Canatella	
	Charles Gurganus	

FM 88 BUMP RATING PANEL SESSION

Rater: ______________________________

Lane: ____________________ Date: ______________

Defect Group	Correct Defect?			Defect Group	Correct Defect?	
	Yes	No			Yes	No

Figure 1. Example Bump Rating Panel Survey Form.

During the briefing, the research supervisor provided the following guidelines for conducting the bump rating panel survey:

- The driver of the test vehicle will alert the raters of an approaching defect group by saying, “Ready.” As the vehicle crosses the beginning station of the defect group, the driver will say, “Rate,” followed by “Stop” after the vehicle has passed the ending station. Each rater will check *yes* or *no* on the form based on his or her perception of the ride quality as the vehicle traverses the defect group from the time the driver said, “Rate,” to the time the driver said, “Stop.”
- Raters should focus on giving their opinions on the need for corrections during the drive through on the given test lane. During this time, raters were advised to focus on their rating sheets, and not look on the roadway or anywhere else.

- Raters were advised not to discuss their ratings to avoid influencing others. Each rater should focus on his or her rating sheet.
- Should it be needed, a rater may ask the driver to make another pass on the given test lane to decide what rating to give a particular defect group.

During the briefing, the research supervisor handed out the rating sheets and asked each rater to fill in the sheets with his or her name, the designations of the lanes to be tested, the test date, and the defect group IDs according to the sequence in which the defects were to be rated on each test lane. In this way, the raters could simply focus on rating the defect groups during the actual test run on the given lane.

After the briefing, TTI conducted a training exercise to provide an opportunity for the raters to familiarize themselves with the process of rating defects in a bump panel rating survey. This training exercise was conducted on a separate group of defects established along the test lanes of the project for the purpose of conducting a dress rehearsal for the raters participating in the surveys. Following this exercise, TTI conducted the bump rating panel surveys using a different set of defect groups on each of the projects listed in Table 1. Except on FM 88, these surveys were conducted at a test speed of 50 mph, just like the surveys done during the previous TxDOT project (0-6610). The FM 88 project is within the City of Elsa, where the posted speed limit is 35 mph. On this project, TTI conducted the rating surveys at 30 mph. All rating panel surveys were conducted using a 2015 Chevrolet Suburban owned and operated by TTI.

COMPARISON OF BUMP PANEL RATINGS WITH EXISTING DCI

To verify the DCI, the research team used the following equation developed from the earlier project to compute the DCI for each defect group rated during the surveys conducted in Task 1:

$$y = \frac{1}{1+e^{-(-2.1923+0.00597\,x_1\;-0.1317\,x_2\;+0.1497\,x_3)}} \qquad (1)$$

where,

y	=	defect correction index (DCI).
x_1	=	sum of defect amplitudes (mils).
x_2	=	sum of defect widths (ft).
x_3	=	maximum Type I contribution to section’s international roughness index (IRI) (in/mi).

The data from these surveys provide an independent verification of Equation (1), given that the data were not used in its original development. The comparisons indicated the need for further model calibration using the data from this current implementation project.

As developed in Project 0-6610, the DCI ranges from 0 to 1, with 0.5 used as the threshold to indicate the need for correcting a given defect (i.e., if the DCI is more than 0.5, then the defect or defects within the area of localized roughness should be corrected). The DCI is computed as a function of the profile-based characteristics x_1, x_2, and x_3, which are further defined as follows:

- x_1—Sum of defect amplitudes (mils): This variable is the sum of all defect amplitudes in a defect group.
- x_2—Sum of defect widths (ft): Similar to the sum of defect amplitudes, this variable is the sum of all defect widths in a group, where the width of a defect is as defined previously in this chapter.
- x_3—Maximum Type I IRI contribution (in/mi): The Type I IRI contribution is defined as the difference between the IRI computed from the existing wheel path profile and the IRI based on the simulated profile if only the given defect is corrected. Figure 2 illustrates this definition. The maximum Type I IRI contribution is the largest of the Type I IRIs calculated for the given defect group.

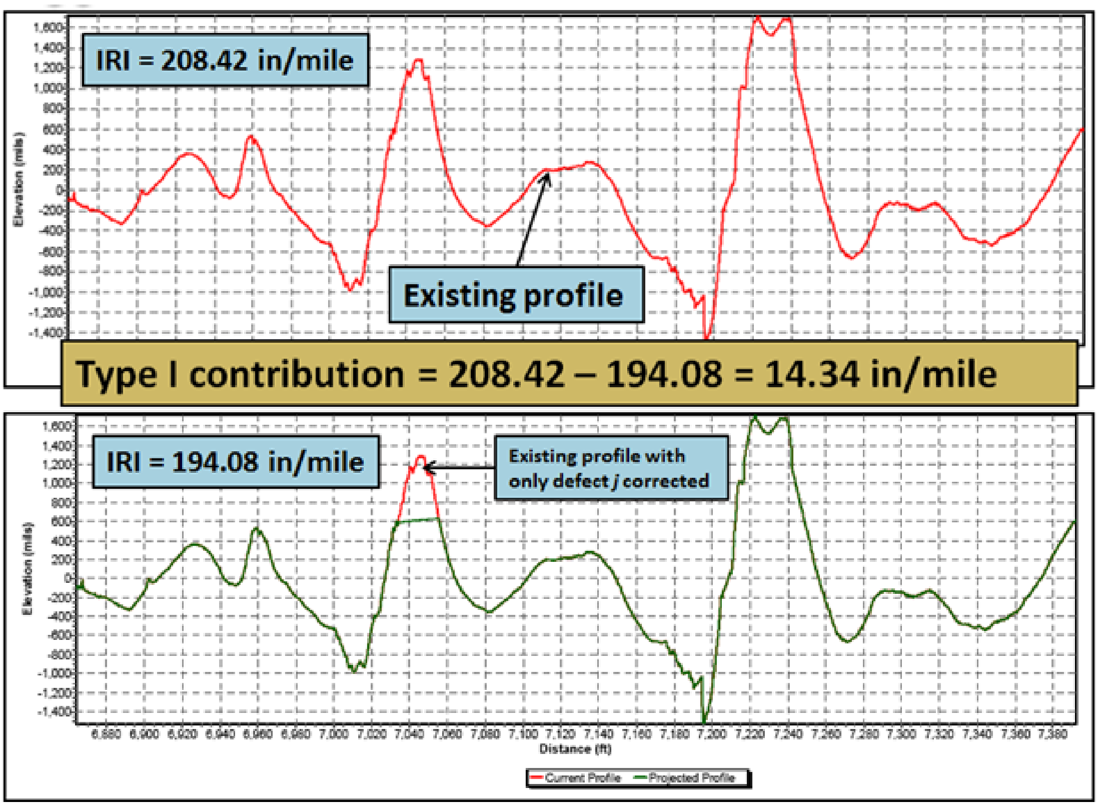


Figure 2. Type I IRI Contribution of a Given Defect.

Table 3 illustrates the calculation of the DCI from profile data. This calculation is explained as follows:

1. Evaluate the 25-ft moving average of the measured wheel path profile and determine the deviations between the moving average profile and the measured profile. Identify the locations where the deviations exceed 150 mils in magnitude.
2. Determine the locations where the moving average profile intersects the measured wheel path profile. This step establishes the beginning and ending locations of each defect shown in Table 3.
3. For each defect found in Step 2, find the maximum deviation between the measured profile and its 25-ft moving average. Report this deviation as the defect height. In Table

3, a positive deviation identifies a bump in the profile, while a negative deviation indicates a dip.

4. Determine the Type I IRI contribution of each defect. In this example, the computed Type I IRI contribution of each defect is given in Column 5 of Table 3. This variable is needed to compute the DCI using Equation (1).
5. Group defects along the measured wheel path located within an 80-ft interval of each other. The defect groups are color coded in Table 3, where defects belonging to the same group are identified by the same color. Defects that are not color coded (specifically those located within the interval from 3417.5 to 15,630.7 ft) are referred to as singular defects. Table 3 shows five of these defects and four distinct defect groups with more than one defect per group.
6. Take the absolute value of the defect height.
7. Compute the difference between the ending and starting locations to determine the width of each defect.
8. For each defect group, determine the sum of the amplitudes and the sum of the defects found within that group. In addition, determine the maximum of the Type I IRI contributions computed for the same defects. These calculations are given in Columns 8, 9, and 10 of Table 3.
9. Calculate the DCI with the input variables determined from Step 8.
10. Compare the DCI from Step 9 with the threshold of 0.5. If the DCI is greater than 0.5, then corrective action (*yes*) is indicated for the defect group. Otherwise, no corrective work is suggested. Of the nine defect groups found, Table 3 shows that five groups comprising 14 individual defects will need corrective work.

Table 3. Illustration of Method to Compute DCI.

<table>
<tr><th rowspan="2">Defect type</th><th colspan="2">Location (ft)</th><th rowspan="2">Defect ampl. (mils)</th><th rowspan="2">Type I IRI (in/mile)</th><th rowspan="2">Absolute defect ampl. (mils)</th><th rowspan="2">Defect width (ft)</th><th rowspan="2">Sum of ampl. (mils)</th><th rowspan="2">Sum of widths (ft)</th><th rowspan="2">Maximum Type I IRI (in/mile)</th><th rowspan="2">DCI</th><th rowspan="2">Correct defect?</th></tr>
<tr><th>From</th><th>To</th></tr>
<tr><td>Bump</td><td>1522.9</td><td>1538.4</td><td>173.60</td><td>0.65</td><td>173.60</td><td>15.5</td><td rowspan="4">720.53</td><td rowspan="4">33.6</td><td rowspan="4">4.21</td><td rowspan="4">0.16</td><td rowspan="4">No</td></tr>
<tr><td>Bump</td><td>1539.0</td><td>1547.0</td><td>192.78</td><td>2.69</td><td>192.78</td><td>8.0</td></tr>
<tr><td>Dip</td><td>1547.0</td><td>1553.6</td><td>-192.00</td><td>4.21</td><td>192.00</td><td>6.6</td></tr>
<tr><td>Dip</td><td>1583.8</td><td>1587.3</td><td>-162.15</td><td>2.08</td><td>162.15</td><td>3.5</td></tr>
<tr><td>Bump</td><td>1600.7</td><td>1610.0</td><td>293.43</td><td>6.78</td><td>293.43</td><td>9.3</td><td rowspan="5">1453.51</td><td rowspan="5">35.9</td><td rowspan="5">6.94</td><td rowspan="5">0.94</td><td rowspan="5">Yes</td></tr>
<tr><td>Dip</td><td>1610.0</td><td>1619.1</td><td>-220.73</td><td>4.24</td><td>220.73</td><td>9.1</td></tr>
<tr><td>Bump</td><td>1619.1</td><td>1625.8</td><td>162.55</td><td>3.37</td><td>162.55</td><td>6.7</td></tr>
<tr><td>Bump</td><td>1645.8</td><td>1649.2</td><td>396.81</td><td>6.94</td><td>396.81</td><td>3.4</td></tr>
<tr><td>Bump</td><td>1659.0</td><td>1666.4</td><td>379.99</td><td>0.00</td><td>379.99</td><td>7.4</td></tr>
<tr><td>Dip</td><td>1690.4</td><td>1696.4</td><td>-238.01</td><td>5.65</td><td>238.01</td><td>6.0</td><td rowspan="6">1364.76</td><td rowspan="6">41.7</td><td rowspan="6">6.51</td><td rowspan="6">0.81</td><td rowspan="6">Yes</td></tr>
<tr><td>Dip</td><td>1697.1</td><td>1702.6</td><td>-163.58</td><td>3.57</td><td>163.58</td><td>5.5</td></tr>
<tr><td>Bump</td><td>1702.6</td><td>1713.4</td><td>292.76</td><td>6.51</td><td>292.76</td><td>10.8</td></tr>
<tr><td>Bump</td><td>1719.3</td><td>1719.8</td><td>249.24</td><td>0.01</td><td>249.24</td><td>0.5</td></tr>
<tr><td>Bump</td><td>1730.1</td><td>1735.5</td><td>176.15</td><td>3.89</td><td>176.15</td><td>5.4</td></tr>
<tr><td>Dip</td><td>1752.5</td><td>1766.0</td><td>-245.02</td><td>4.96</td><td>245.02</td><td>13.5</td></tr>
<tr><td>Bump</td><td>3417.5</td><td>3418.1</td><td>917.80</td><td>4.06</td><td>917.80</td><td>0.6</td><td>917.80</td><td>0.6</td><td>4.06</td><td>0.98</td><td>Yes</td></tr>
<tr><td>Bump</td><td>3596.0</td><td>3596.6</td><td>379.55</td><td>1.63</td><td>379.55</td><td>0.6</td><td>379.55</td><td>0.6</td><td>1.63</td><td>0.56</td><td>Yes</td></tr>
<tr><td>Bump</td><td>8046.7</td><td>8047.6</td><td>429.33</td><td>1.56</td><td>429.33</td><td>0.9</td><td>429.33</td><td>0.9</td><td>1.56</td><td>0.62</td><td>Yes</td></tr>
<tr><td>Bump</td><td>15024.2</td><td>15024.9</td><td>327.48</td><td>1.68</td><td>327.48</td><td>0.7</td><td>327.48</td><td>0.7</td><td>1.68</td><td>0.48</td><td>No</td></tr>
<tr><td>Bump</td><td>15630.2</td><td>15630.7</td><td>151.02</td><td>0.19</td><td>151.02</td><td>0.5</td><td>151.02</td><td>0.5</td><td>0.19</td><td>0.21</td><td>No</td></tr>
<tr><td>Bump</td><td>15760.7</td><td>15779.3</td><td>179.20</td><td>5.77</td><td>179.20</td><td>18.6</td><td rowspan="2">378.88</td><td rowspan="2">30.8</td><td rowspan="2">5.77</td><td rowspan="2">0.04</td><td rowspan="2">No</td></tr>
<tr><td>Dip</td><td>15779.3</td><td>15791.5</td><td>-199.68</td><td>2.41</td><td>199.68</td><td>12.2</td></tr>
</table>

Following the above procedure using profile data collected from the projects surveyed, the research team calculated the DCIs for the defect groups identified in the measured profiles, and determined the need for corrections. This DCI assessment was then compared with corresponding ratings from the bump rating panels to perform an independent verification of Equation (1). In this comparison, the need to correct a given defect was based on the majority opinion of the panel members who rated the given defect. If the majority of the panel voted *yes*, then the defect or defect group was to be corrected based on the panel ratings.

Table 4 to Table 9 summarize the comparisons between the existing DCI equation and the panel ratings. For each project, the following goodness-of-fit statistics are reported:

1. Percent Correct—This statistic shows the percent of defect groups where the calculated DCIs and the majority panel ratings are in agreement. It is computed as the number of defect groups where both the panel and DCI voted *yes* on corrective work, plus the number of defect groups where both agree that no correction is necessary, divided by the number of defect groups rated. For perfect agreement, this number would be 100 percent.
2. Percent Error—This statistic shows the percent of defect groups where the calculated DCIs and the majority panel ratings are in disagreement. For perfect agreement, the percent error would be zero. The percent error is further broken down into Type A and Type B errors.

3. Type A error (percent)—This error is where the majority of raters indicated corrective action was needed (*yes*); however, the model indicated otherwise (*no*). Table 4 to Table 9 show the number of such cases as a percentage of the total number of defect groups rated.
4. Type B error (percent)—This error is where the majority of raters indicated no corrective action was needed; however, the model predicted just the opposite. The ideal case is where the level of agreement is 100 percent, for which the Type A and Type B errors are both zero.

To provide a baseline with which to evaluate the goodness-of-fit statistics given in Table 4 to Table 9, Table 10 shows the same statistics based on the original bump rating panel surveys conducted in Project 0-6610. As shown, Equation (1) provided an 84.4 percent level of agreement to the panel ratings collected in that earlier project. In contrast, the level of agreement in this project between the DCIs from this equation and the panel ratings varied from 33.8 to 81.8 percent. This finding indicates a need to investigate where the larger discrepancies are coming from and to re-calibrate the existing DCI model accordingly. Over all six projects, Table 11 shows that an overall level of agreement of 59.9 percent was achieved using the current DCI equation.

As observed from the results, the US 190 project shows the worst agreement. This rehabilitation project was completed in December 2015. However, another TxDOT project within the same limits began in January 2016. The contractor on this new project shifted the lane stripes to shift traffic away from the shoulder; so the profile data collected on the recent rehab project are not entirely consistent with the bump panel ratings, which were conducted after lane traffic was shifted. This change had to be considered in evaluating the original DCI equation.

Table 4. Comparison of DCI with Panel Ratings on US 281 Project in Edinburg.

Panel	**DCI**		**Total**
	Yes	No	
Yes	3	6	9
No	0	24	24
Total	3	30	33
	% Correct	81.82	
	% Error	18.18	
	Type A error (%)	18.18	
	Type B error (%)	0.00	

Table 5. Comparison of DCI with Panel Ratings on FM 88 Project in Elsa.

Panel	DCI		Total
	Yes	No	
Yes	0	10	10
No	0	14	14
Total	3	24	24
	% Correct	58.33	
	% Error	41.67	
	Type A error (%)	41.67	
	Type B error (%)	0.00	

Table 6. Comparison of DCI with Panel Ratings on SH 361 Project in Ingleside.

Panel	DCI		Total
	Yes	No	
Yes	8	3	11
No	10	42	52
Total	18	45	63
	% Correct	79.37	
	% Error	20.63	
	Type A error (%)	4.76	
	Type B error (%)	15.87	

Table 7. Comparison of DCI with Panel Ratings on US 77 Project in Odem.

Panel	DCI		Total
	Yes	No	
Yes	6	12	18
No	5	27	32
Total	11	39	50
	% Correct	66.00	
	% Error	34.00	
	Type A error (%)	24.00	
	Type B error (%)	10.00	

Table 8. Comparison of DCI with Panel Ratings on US 190 Project in North Zulch.

Panel	DCI		Total
	Yes	No	
Yes	4	46	50
No	3	21	24
Total	7	67	74
	% Correct	33.78	
	% Error	66.22	
	Type A error (%)	62.16	
	Type B error (%)	4.06	

Table 9. Comparison of DCI with Panel Ratings on US 59 Project in Leggett.

Panel	DCI		Total
	Yes	No	
Yes	5	11	16
No	11	21	32
Total	16	32	48
	% Correct	54.17	
	% Error	45.83	
	Type A error (%)	22.92	
	Type B error (%)	22.92	

Table 10. Goodness-of-Fit Statistics of DCI Equation.

Panel	DCI		Total
	Yes	No	
Yes	27	12	39
No	5	65	70
Total	32	77	109
	% Correct	84.40	
	% Error	15.60	
	Type A error (%)	11.01	
	Type B error (%)	4.59	

Table 11. Overall Goodness-of-Fit Statistics of DCI Equation Based on Task 1 Data.

Panel	DCI		Total
	Yes	No	
Yes	26	88	114
No	29	149	178
Total	55	237	292
	% Correct	59.93	
	% Error	40.07	
	Type A error (%)	30.14	
	Type B error (%)	9.93	

CHAPTER 2. REFINE METHODOLOGY FOR DEFECT CORRECTION ASSESSMENT

INTRODUCTION

As noted in Chapter 1, TTI collected profile data and conducted bump rating panel surveys on all projects listed in Table 1. TTI used the profile data to calculate the DCI and to perform an independent verification of the DCI equation developed from TxDOT Project 0-6610. Specifically, the DCIs determined from the profile data were compared to the need for corrections as expressed by the panel of raters who rode the projects given in Table 1. This evaluation showed the need to re-calibrate the existing DCI model to improve the agreement with the bump rating panel data. This chapter presents the model recalibration.

LOGISTIC REGRESSION ANALYSIS OF BUMP RATING PANEL DATA

TTI researchers used the same logistic model from TxDOT Project 0-6610 to model the assessments made by the bump rating panels with respect to correcting defects identified from measured surface profiles. The logistic model is given by the following equation:

$$y = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_n x_n)}} \tag{2}$$

where,

y	=	predicted DCI ($0 \le y \le 1$).
x_i	=	i^{th} independent variable (i = 1 to n).
β_i	=	i^{th} model coefficient (i = 0 to n with β_0 being the intercept of the model).
n	=	number of independent variables.

Researchers used logistic regression since the decision to correct is binary. That is, does the defect or defect group need correction or not? In the above model, the dependent variable *y* is determined from the proportion of raters who voted *yes* on the need to correct a given defect group identified from the measured profiles of a given project. Specifically, if the proportion of *yes* votes meets the specified threshold, the dependent variable in the model is coded as 1 (meaning, the defect group needs correction). For example, using a threshold of 0.5 (representing a simple majority), the need for correction is coded as 1 (correct the defect group) if the proportion of *yes* votes exceeds this threshold. Otherwise, the need for correction is coded as 0 (do not correct).

Researchers used the same independent variables from Project 0-6610 to re-calibrate the DCI equation developed from that earlier research project. This calibration included the bump rating panel data collected in this implementation project and data from the bump rating surveys conducted in Project 0-6610 and from a TxDOT project along US 281 in Alice. This latter project, which was completed in 2014, provided the first opportunity to use the DCI equation to identify where corrective work is needed to improve the as-built ride quality on the project. TTI researchers used the following independent variables to calibrate the DCI model:

1. Pavement type—continuously reinforced concrete pavement (CRCP) or hot-mix asphalt (HMA). Project 0-6610 included bump panel ratings on CRCP and HMA sections. This independent variable was used as a blocking factor to determine if the panel ratings are significantly influenced by pavement type.
2. Maximum defect amplitude (mils)—Each defect group has one or more defects. The bump or dip amplitude is defined as the maximum absolute value of deviations greater than 150 mils from a 25-ft moving average. A positive deviation indicates a bump and a negative deviation indicates a dip. Note that this is the same definition used in TxDOT's existing Ride Quality program.
3. Average defect width (ft)—The bump or defect width is defined as the distance between the two points where the profile crosses the 25-ft running average. For multiple defects in a defect group, this statistic is the average of those widths.
4. Sum of defect amplitudes (mils)—Similar to the maximum defect amplitude, this variable is the sum of all defect amplitudes in a group.
5. Sum of defect widths (ft)—Similar to the sum of defect amplitudes, this is the sum of all defect widths in a defect group.
6. Amplitude-to-width ratio—The ratio of the sum of defect amplitudes to the sum of defect widths.
7. Sum of Type I IRIs (in/mi)—Researchers evaluated the contribution of a given defect to the IRI of a 528-ft section in two ways. The first method is based on the difference between the IRI computed from the existing wheel path profile and the IRI based on the simulated profile after correcting only Defect *j*. This difference is referred to as the Type I IRI contribution for Defect *j*, as illustrated earlier in Figure 2. The sum of the Type I IRIs is the sum of the computed Type I IRI contributions for the defects within a given group.
8. Sum of Type II IRIs (in/mi)—Figure 3 illustrates the second method for evaluating the contribution of a given defect to the section IRI. This method, referred to as the Type II IRI contribution, is based on the difference between the IRI computed from the simulated wheel path profile after correcting all defects except Defect *j* and the IRI computed from the simulated profile with all defects fixed. The sum of the Type II IRIs is the sum of the computed Type II IRI contributions for the defects within a given group.
9. Maximum Type I IRI (in/mi)—This is the maximum of the Type I IRIs in a defect group.
10. Maximum Type II IRI (in/mi)—This is the maximum of the Type II IRIs in a defect group.
11. Average Type I IRI (in/mi)—Average of Type I IRI contributions within a defect group.
12. Average Type II IRI (in/mi)—Average of Type II IRI contributions within a defect group.
13. Weighted average amplitude—Average of the defect amplitudes weighted by the widths of the defects in the group.
14. Test speed—Except on FM 88, bump rating panel surveys were conducted at a test speed of 50 mph, just like the surveys done on TxDOT Project 0-6610. The FM 88 project is within the City of Elsa, where the posted speed limit is 35 mph. On this project, TTI conducted the bump rating surveys at 30 mph, so researchers included test speed as an independent variable to calibrate the DCI model in Task 2.

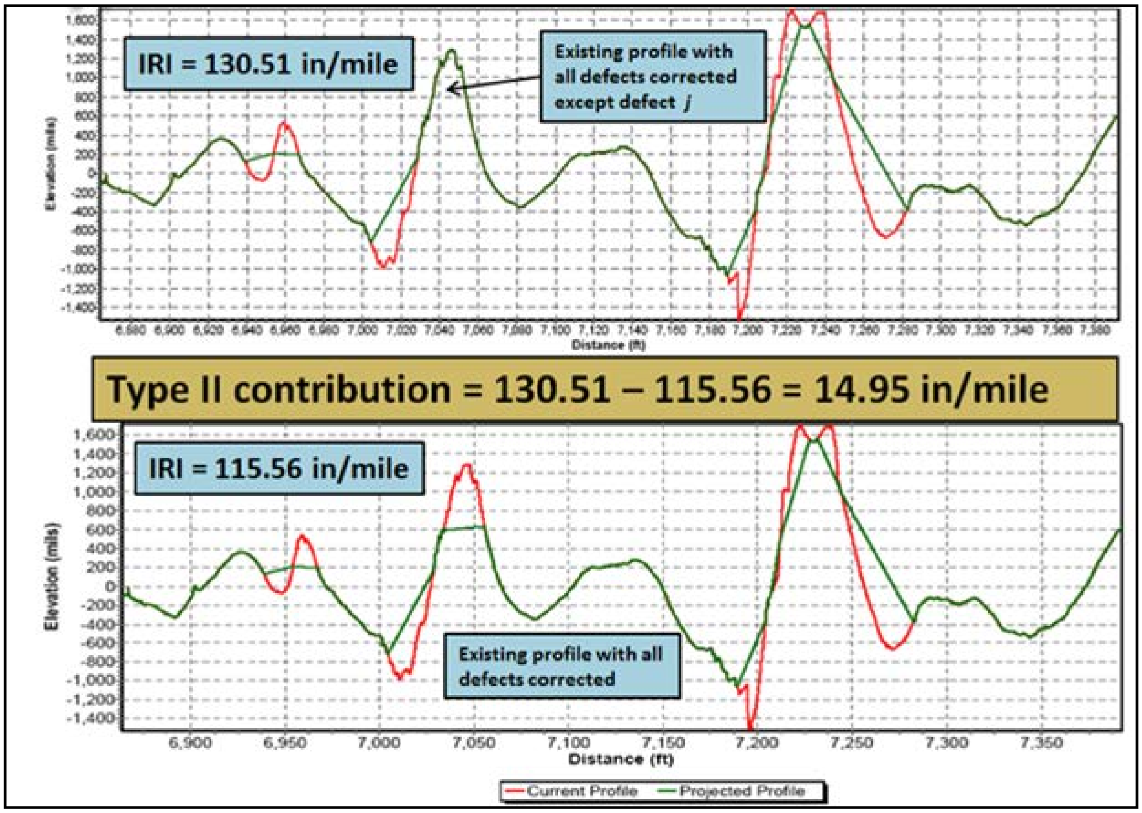


Figure 3. Type II IRI Contribution of a Given Defect.

VERIFICATION OF DCI EQUATION FROM PROJECT 0-6610

To recap, the existing DCI equation is given by the following expression:

$$y = \frac{1}{1 + e^{-(-2.1923 + 0.00597\,x_1 - 0.1317\,x_2 + 0.1497\,x_3)}}$$

where,

y	=	DCI.
x_1	=	sum of defect amplitudes (mils).
x_2	=	sum of defect widths (ft).
x_3	=	maximum Type I contribution to section IRI (in/mi).

As reported in Chapter 1, TTI researchers initially used the data from the bump rating surveys to verify the above equation from Project 0-6610. Since the survey data were not used in the original development of the DCI, the findings from this verification indicated the need to calibrate the existing model using the data from follow-up surveys.

Table 12 summarizes the results from verification of the DCI using the above equation with bump rating panel data collected from surveys done on the projects identified in Table 1 and from the US 281 project in Alice. The DCI ranges from 0 to 1, with 0.5 used as the threshold to indicate the need for correcting a given defect. If the DCI based on profile measurements is more than 0.5, the defect or defects within the area of localized roughness is considered to need correction based on the DCI. Researchers compared the outcomes based on the computed DCIs with the corresponding ratings from the bump rating panels to verify Equation (1). In this comparison, if the majority of the panel voted *yes* to correct a given defect, then the defect or defect group is considered to need corrective work based on the panel ratings.

Table 12 summarizes the comparisons between the existing DCI equation and the panel ratings. For each project, the following goodness-of-fit statistics are reported:

1. Percent Correct—This statistic shows the percent of defect groups where the calculated DCIs and the majority panel ratings are in agreement. This concordance statistic is computed as the number of defect groups where both the panel and DCI voted *yes* on corrective work, plus the number of defect groups where both agree that no correction is necessary, divided by the number of defect groups rated. For perfect agreement, this number would be 100 percent.
2. Percent Error—This statistic shows the percent of defect groups where the calculated DCIs and the majority panel ratings are in disagreement. For perfect agreement, the percent error would be zero.

Table 12. Results from Verification of Equation (1) Using Data from Other Projects.

Project	% Correct	% Error	Number of Defect Groups
US 281—Edinburg	81.82	18.18	33
FM 88—Elsa	58.33	41.67	24
SH 361—Ingleside	74.60	25.40	63
US 77—Odem	64.00	36.00	50
US 190—North Zulch	39.19	60.81	74
US 59—Leggett	54.17	45.83	48
US 281—Alice	82.28	17.72	79
Overall seven projects above	64.69	35.31	371
Project 0-6610 data	84.40	15.60	109

To provide a baseline with which to evaluate the goodness-of-fit statistics given in Table 12, the DCI equation based on the original bump rating panel surveys provided an 84.4 percent level of agreement to the panel ratings collected in that earlier project. In contrast, the level of agreement between the DCIs from this equation and the panel ratings collected from the follow-up surveys identified in Table 1 varied from about 39 to 82 percent, with an overall level of agreement of about 65 percent based on data from all seven follow-up surveys. These results indicated a need to recalibrate the original DCI equation using data from the additional surveys conducted since project 0-6610 was completed. The next section presents the DCI model calibration.

CALIBRATION OF DCI EQUATION FROM PROJECT 0-6610

Table 12 shows that a total of 480 defect groups (371 + 109) were rated during the original bump surveys, the follow-up surveys, and the US 281 project in Alice. Given the large database compiled from all surveys, researchers decided to divide this database into two data sets—one set to be used for model calibration and the other set to be used for model verification. Researchers adopted this approach since it provides data with which to independently verify the DCI model after calibration. The findings from this exploratory analysis were later used to decide the final form of the DCI model and to perform a final calibration using data from all bump rating panel surveys.

Figure 4 shows the distribution of the proportion of *yes* votes from all bump rating panel surveys. To divide the bump rating panel data into a data set for model calibration and a data set for model verification, researchers sampled the data from all surveys to form two data sets with distributions of the proportion of *yes* votes comparable to the overall distribution shown in Figure 4. Figure 5 and Figure 6 show the distributions of the resulting data sets for model calibration and model verification, respectively. The similarity between the distributions is fairly evident from comparing Figure 4, Figure 5, and Figure 6.

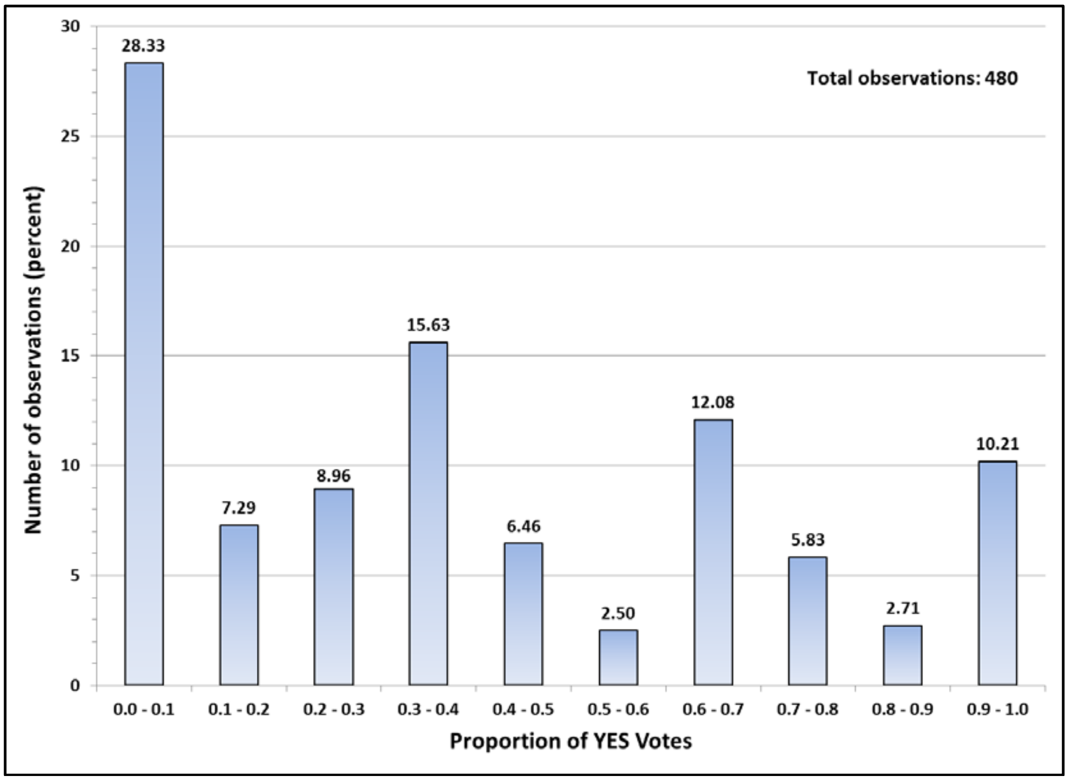


Figure 4. Distribution of the Proportion of Yes Votes from All Bump Rating Panel Surveys.

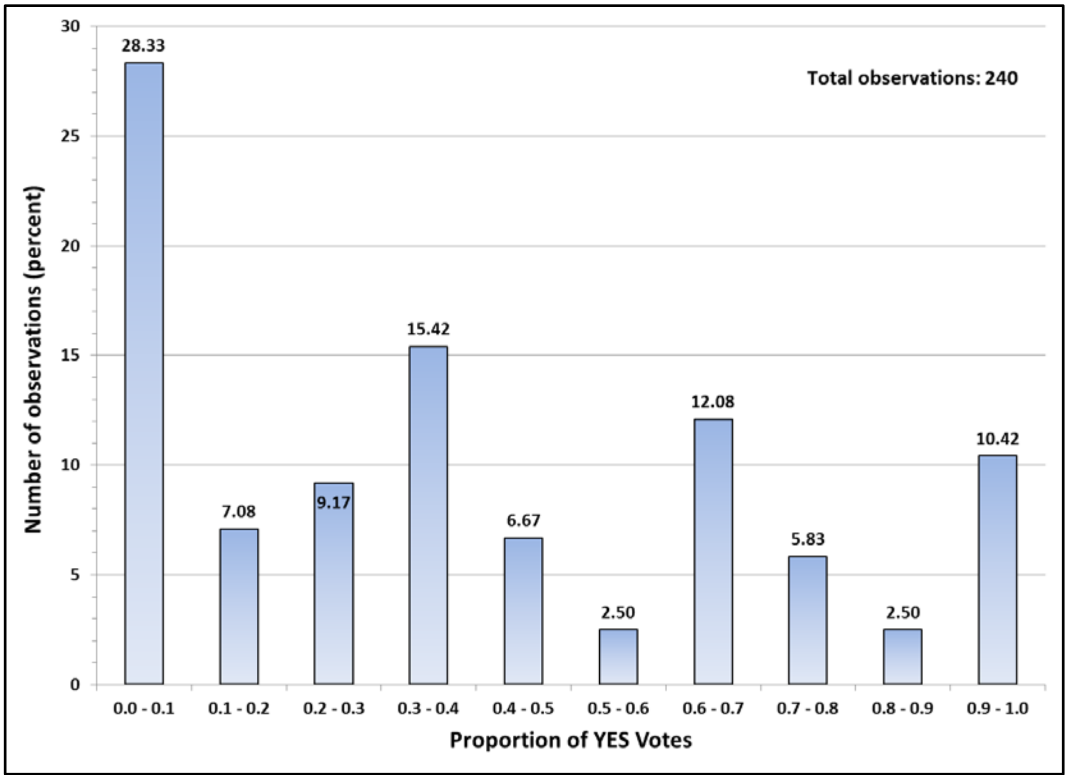


Figure 5. Distribution of Proportion of Yes Votes for the Model Calibration Data Set.

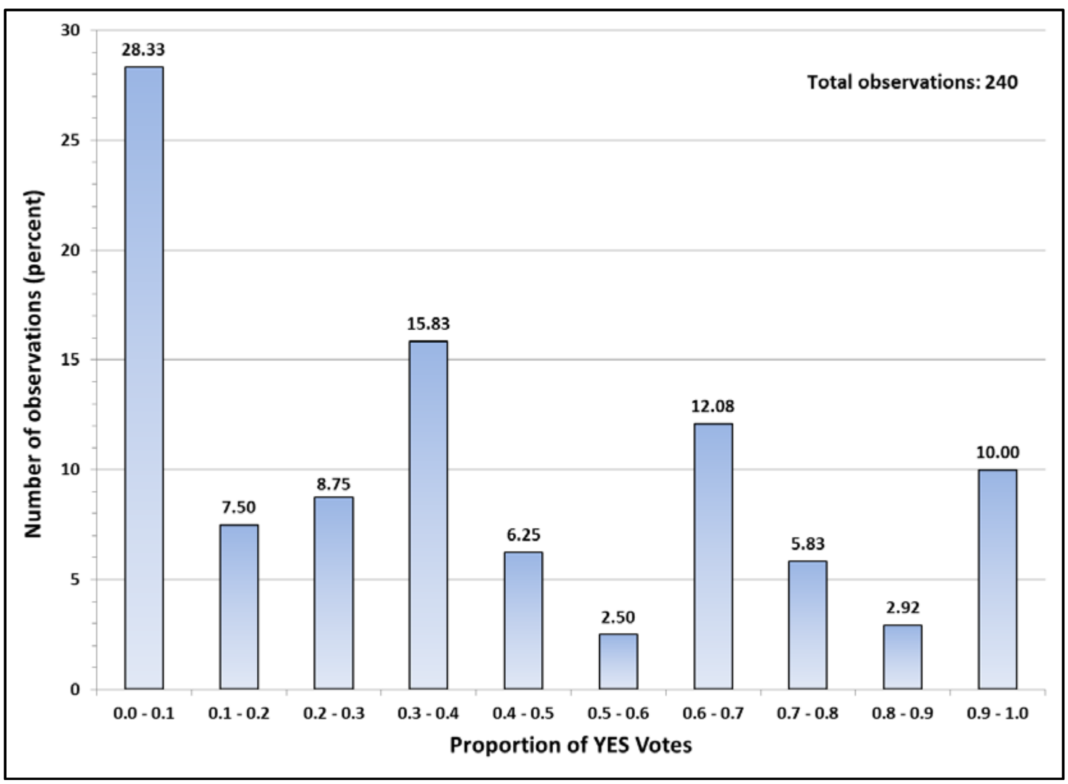


Figure 6. Distribution of Proportion of Yes Votes for the Model Verification Data Set.

Researchers used the independent variables identified previously in a stepwise logistic regression analysis to determine an equation that relates profile physical characteristics to the need for correcting a given defect. This analysis used the model calibration data set and was conducted over a range of thresholds from 0.30 to 0.70. From this analysis, the following equation was determined that gave the best agreement with the bump panel ratings at a DCI threshold of 0.70:

$$y = \frac{1}{1 + e^{-(-3.3361 + 0.00213 x_1 + 0.1426 x_2)}} \tag{3}$$

where,

y	=	DCI.
x_1	=	sum of defect amplitudes (mils).
x_2	=	average Type I IRI contribution (in/mi).

Table 13 provides summary statistics from the stepwise logistic regression analysis that led to the above DCI equation. As shown in this table, all model coefficients are statistically significant at greater than the 99.99 percent level, as indicated by the small *p*-values for these coefficients.

Table 13. Parameter Estimates and Statistical Significance of Coefficients of Equation (3).

Parameter	Estimate	Wald chi-square	Pr > chi-square
Intercept	−3.3361	69.9343	< 0.0001
Sum of defect amplitudes	0.00213	20.3346	< 0.0001
Average Type I IRI	0.1426	7.8918	0.0050

In practice, one would use Equation (3) along with the applicable values of the independent variables to compute the DCI. If the computed DCI is more than 0.7, then corrective work is needed for the given defect or defect group. Researchers evaluated the level of agreement between the DCIs determined from Equation (3) and the bump panel ratings. Table 14 summarizes the results from this evaluation using the model calibration and model verification data sets. Comparing the results given in Table 12 with those from Table 14, it is evident that the DCI equation after recalibration gives a better overall level of agreement with the bump panel ratings than the original DCI equation. In addition, Table 14 indicates that Equation (3) is fairly robust, giving reasonable levels of agreement with the panel ratings belonging to the model verification data set, which was not used in determining the equation. However, there are two projects, FM 88 and US 77, where the concordance between the calibrated DCI equation and the panel ratings are below 70 percent when the equation is used with the verification data set. Given this result, researchers decided to run another logistic regression analysis, this time using both data sets (all bump rating survey data) with the same form of the model (independent variables) used in determining Equation (3). Equation (4) shows the result from this analysis.

$$y = \frac{1}{1+e^{-(-3.0979+0.00172x_1 + 0.1409x_2)}} \tag{4}$$

where the variables y, x_1, and x_2 are as defined in Equation (3).

Table 15 provides summary statistics from the stepwise logistic regression analysis that led to the above DCI equation. As shown in this table, all model coefficients are statistically significant at greater than the 99.999 percent level, as indicated by the small p-values (< 0.0001) for these coefficients.

Researchers evaluated the level of agreement between the DCIs determined from Equation (4) and the bump panel ratings. Table 16 shows the results from this evaluation. The percent of cases where Equation (4) concurred with the bump panel ratings (percent correct) ranges from about 71 to 92 percent. The lowest concordance statistics of about 71 percent and 74 percent, respectively, on the FM 88 and US 77 projects are comparable to the statistics obtained on the same projects (73 percent and 76 percent, respectively) using Equation (3) with the model calibration data set. On all other projects, the concordance statistics are above 80 percent, and over all the bump rating survey data, the concordance statistic is 84.17 percent. Given these results, researchers recommend using the DCI given in Equation (4) to assess the need for corrections based on measured wheel path profile characteristics.

Table 14. Results from Verification of Equation (3).

Project	Model Calibration Data Set		Model Verification Data Set		Number of Defect Groups	
	% Correct	% Error	% Correct	% Error	Model Calibration Data Set	Model Verification Data Set
US 281—Edinburg	88.24	11.76	93.75	6.25	17	16
FM 88—Elsa	72.73	27.27	61.54	38.46	11	13
SH 361—Ingleside	87.50	12.50	90.32	9.68	32	31
US 77—Odem	76.00	24.00	68.00	32.00	25	25
US 190—North Zulch	84.21	15.79	83.33	16.67	38	36
US 59—Leggett	91.67	8.33	91.67	8.33	24	24
US 281—Alice	92.31	7.69	85.00	15.00	39	40
Project 0-6610 data	83.33	16.67	78.18	21.82	54	55
All project data	85.42	14.58	82.08	17.92	240	240

Table 15. Parameter Estimates and Statistical Significance of Coefficients of Equation (4).

Parameter	Estimate	Wald chi-square	Pr > chi-square
Intercept	−3.0970	137.8605	< 0.0001
Sum of defect amplitudes	0.00172	34.0621	< 0.0001
Average Type I IRI	0.1409	16.0382	< 0.0001

Table 16. Results from Verification of Equation (4).

Project	% Correct	% Error	Number of Defect Groups
US 281—Edinburg	90.91	9.09	33
FM 88—Elsa	70.83	29.17	24
SH 361—Ingleside	88.89	11.11	63
US 77—Odem	74.00	26.00	50
US 190—North Zulch	83.78	16.22	74
US 59—Leggett	91.67	8.33	48
US 281—Alice	88.61	11.39	79
Project 0-6610 data	80.73	19.27	109
All project data	84.17	15.83	480

CHAPTER 3. AUTOMATE THE METHODOLOGY FOR ASSESSING DEFECT CORRECTIONS

INTRODUCTION

TTI researchers verified and recalibrated the original DCI equation using data collected from follow-up bump rating panel surveys. This effort resulted in a more robust DCI equation given by the following relationship:

$$y = \frac{1}{1 + e^{-(-3.0979 + 0.00172 x_1 + 0.1409 x_2)}}$$

where,

y	=	DCI ($0 \le y \le 1$).
x_1	=	sum of defect amplitudes (mils).
x_2	=	average Type I IRI contribution (in/mi).

This chapter documents the efforts made to implement the revised DCI equation in the existing Grind Diagnostics program developed by TTI from an earlier TxDOT interagency contract.

GRIND DIAGNOSTICS PROGRAM

As originally developed, the Grind Diagnostics program uses the same methodology for evaluating localized roughness in the current Item 585 ride specification, except that:

1. The defect width is taken to be the interval within which the measured profile deviates from its 25-ft moving average as opposed to the width of the interval within which the deviation exceeds 150 mils.
2. Defects have always been identified by wheel path instead of the average profile, which was used in TxDOT's 2004 Item 585 specification but which has since been changed to report the defects by wheel path in the 2014 specification.

However, the original DCI equation was never added to the Grind Diagnostics program since this task was not included in the original project work plan. This implementation project provided the opportunity to verify and re-calibrate the original DCI model and to add the revised DCI equation to the existing Grind Diagnostics program. In this way, the application of the DCI can be done via software.

AUTOMATED DCI ANALYSIS

TTI researchers modified the existing Grind Diagnostics program to include a *DCI Analysis* function in the *Tool* menu (Figure 7). Prior to running the DCI analysis, the user must first run a defect analysis for each wheel path using the *Analyzer* function in the *Tool* menu and export the results from each analysis using the *Export* button of the Grind Diagnostics program. For each wheel path, the program writes the results of the defect analysis in a comma-separated-value (CSV) file specified by the user. The resulting CSV files are then used as inputs in the DCI analysis. For instructions on running the defect analysis and exporting the results, refer to the Grind Diagnostics User's Guide included in Appendix I. This chapter focuses on describing the *DCI Analysis* function, which TTI researchers added to the existing program.

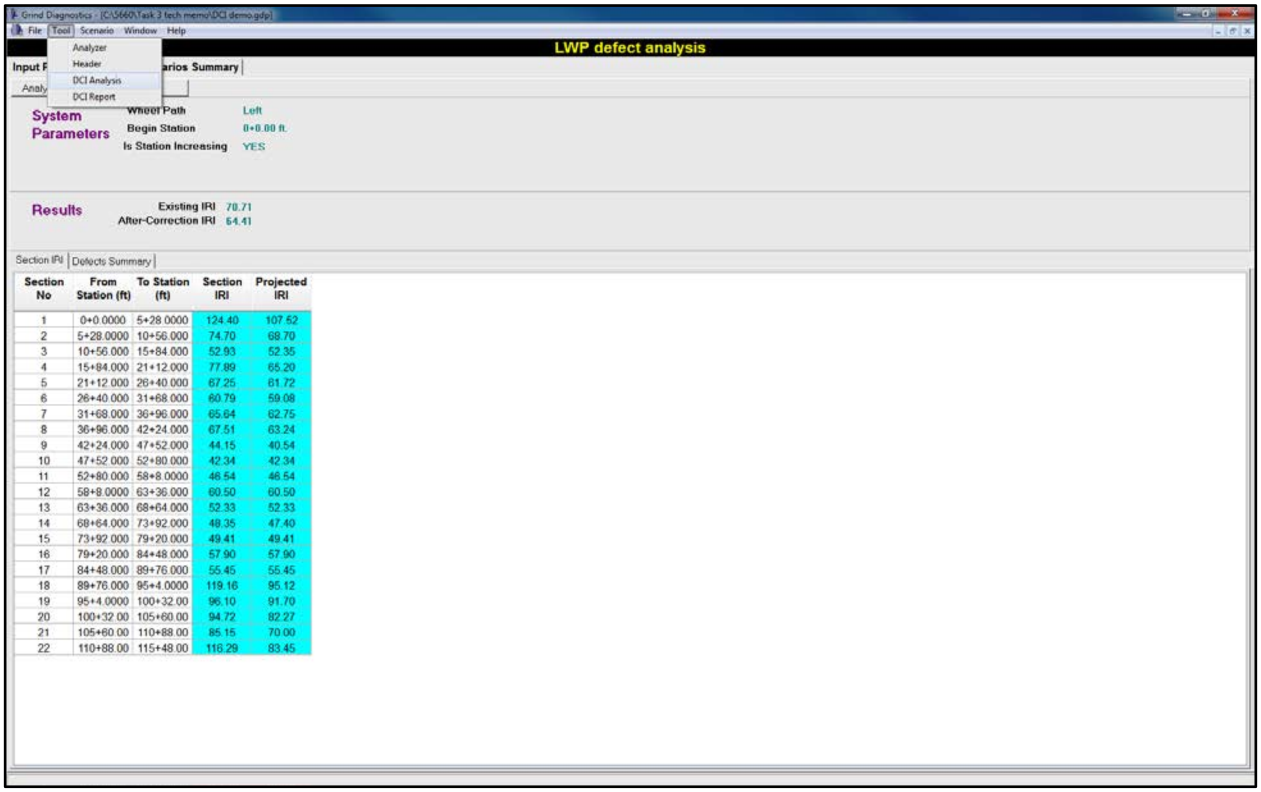


Figure 7. DCI Analysis Function in Grind Diagnostics Tool Menu.

To run the DCI analysis in the modified Grind Diagnostics program, click on this function in the *Tool* menu illustrated in Figure 7. The program then displays the *DCI Analysis* input screen illustrated in Figure 8. As shown, the user specifies the CSV file from the defect analysis done on each wheel path and the TxDOT PRO file used in this analysis. The *Select* buttons permit the user to browse the computer's directories to find and select the relevant input files needed in the DCI analysis. Also shown on this screen are two other parameters for running the DCI analysis:

1. The grouping interval specifies the length with which to group the defects found along a given wheel path. By default, the modified Grind Diagnostics program uses an 80-ft interval since this was the length by which defects were grouped and rated in the bump rating panels. Note that the default defect group size of 80 ft is about the length traveled in 1 second at a speed of 55 mph.
2. The DCI threshold is the limit above which a given group of defects needs to be corrected. The threshold of 0.70 was established from analysis of the bump rating panel data. For each defect group, the DCI is calculated using Equation (4).

To group defects for the DCI analysis, the modified program permits the user to select either a strict application of the specified grouping interval or an approximate application of that interval. By default, the *Approximate Match* is used to permit a defect to be included within the current group based on decision rules included in the revised program.

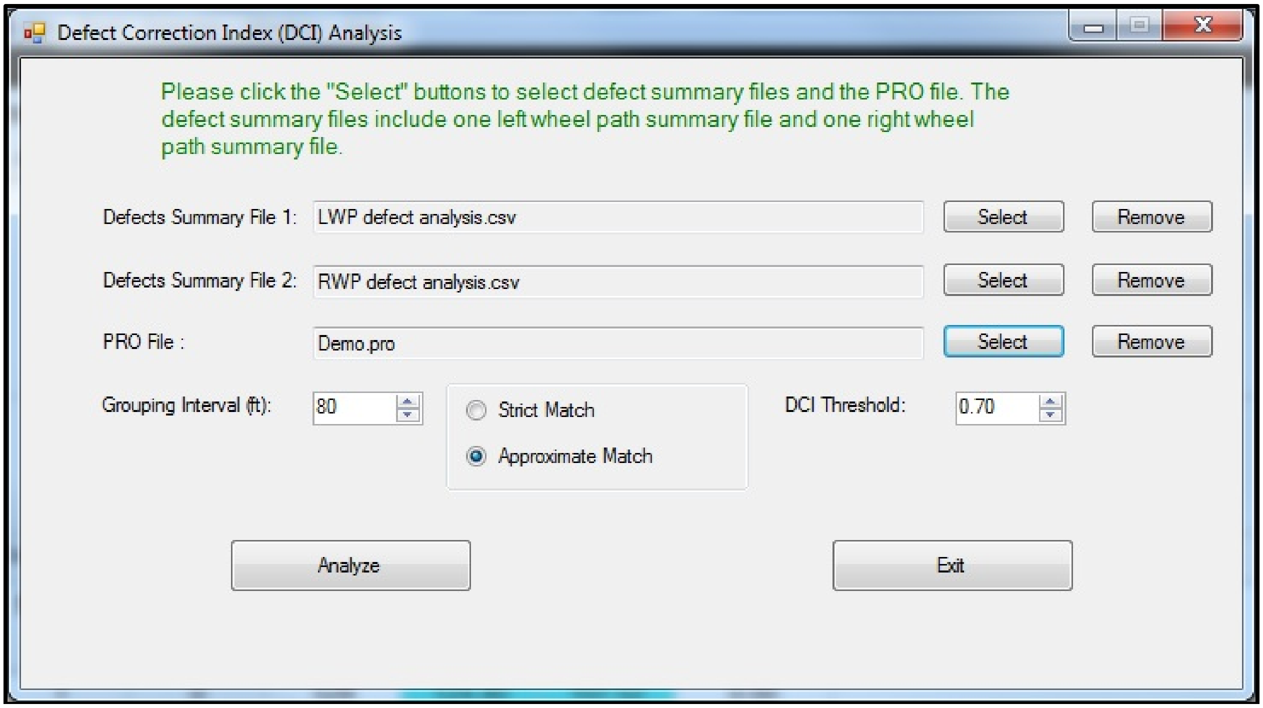


Figure 8. DCI Analysis Input Screen.

After specifying the DCI analysis inputs, click on the *Analyze* button of the input screen to run the analysis. The modified Grind Diagnostics program outputs the results in an Excel spreadsheet and displays this spreadsheet, as illustrated in Figure 9. As shown, the output includes the variables determined from the analysis steps given previously. The output is also color coded to more readily identify the defect groups established from the DCI analysis.

For each defect group, the *Result* worksheet shows the computed DCI under Column O. If this value is greater than 0.7, then corrective work is needed, as indicated by *yes* in Column P. Note that Figure 9 shows only a partial listing of the defects determined from the analysis. The *Result* worksheet will have as many rows as there are defects identified in the input profile data plus the rows of header information. In addition to the *Result* worksheet, the modified Grind Diagnostics program writes the defect groups needing correction in a separate worksheet (aptly labeled *DefectsNeedCorrection)*. In this way, the engineer can readily identify these defect groups by opening that worksheet in Excel (see Figure 10 for an example).

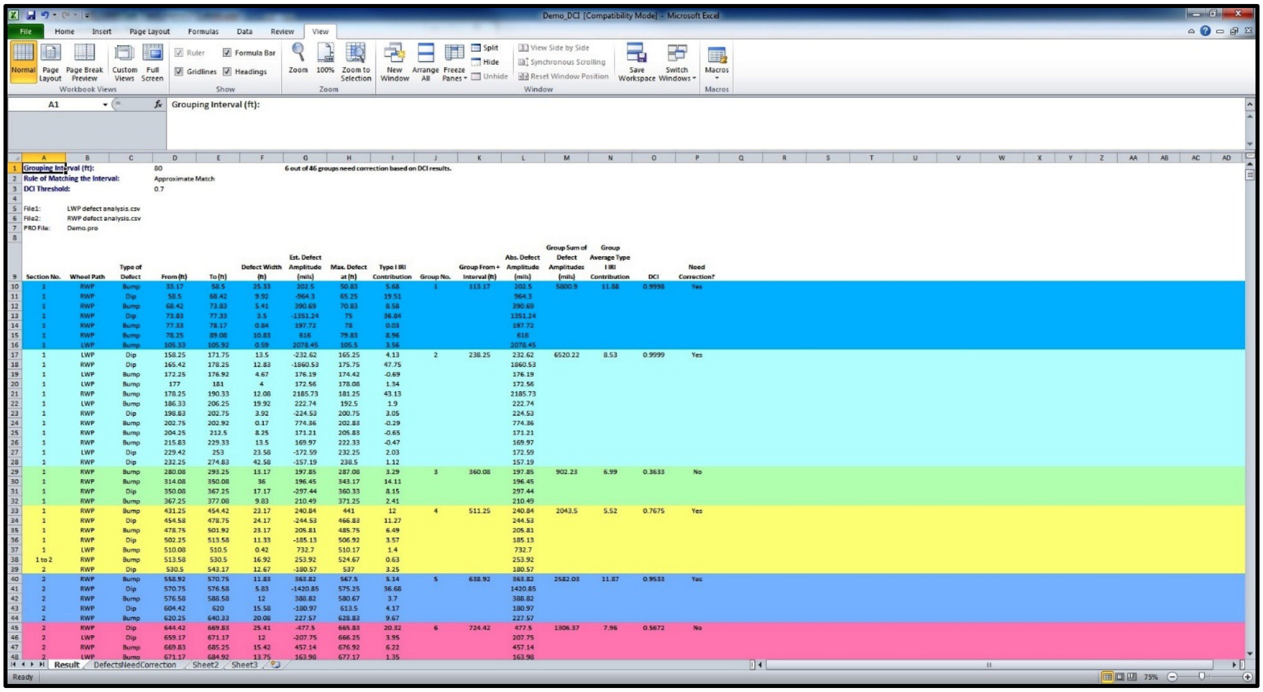


Figure 9. DCI Analysis Results Displayed in Excel Spreadsheet.

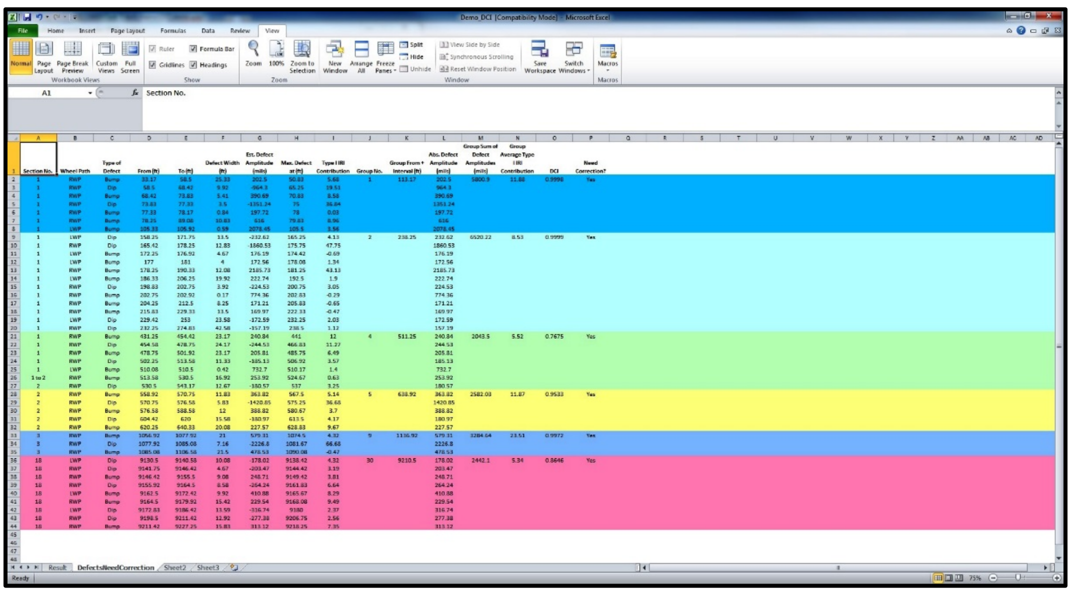


Figure 10. Excel Worksheet Identifying Defects Needing Correction.

MAP DISPLAY OF ANALYSIS RESULTS

To provide a visual display of the defects determined from the DCI analysis, TTI researchers added a mapping function to the Grind Diagnostics program. In this way, the user can view the locations of defects from a map to better communicate where corrections need to be made to improve ride quality. After the DCI analysis ends, the modified program displays the *Show Map* button in the *DCI Analysis* input screen, as illustrated in Figure 11. Clicking this button shows a map with markers identifying defects found from the analysis. An Internet connection must be available and the computer's Wi-Fi turned on to use the map function.

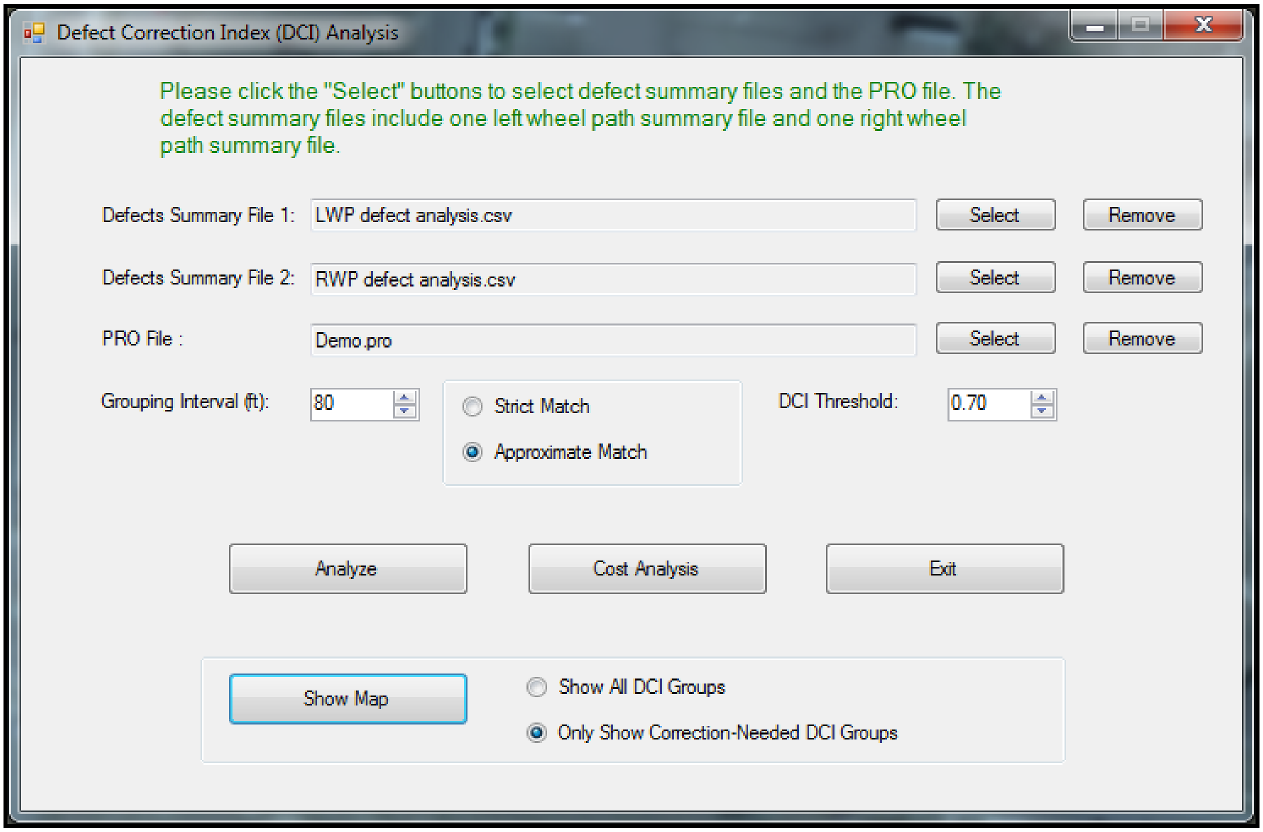


Figure 11. Show Map Button to Generate Map of Defects after DCI Analysis.

Figure 12 illustrates an example map generated by the modified Grind Diagnostics program. This figure shows a satellite view of the roadway. To change from a satellite to a map view, right-click on the display and select *Map*. To view other defects found along the project, drag the map with the mouse up or down and side-to-side, as needed. Use the mouse to zoom in and view more details, or to zoom out and view a wider area. The map function uses the GPS data in the input PRO file to determine the approximate locations of defects found from the analysis.

Embedded within the map are data on each defect. To view the embedded data, zoom in as needed on the defects of interest and position the mouse on a given defect marker to view the data associated with that defect. Figure 13 illustrates an example. For any selected defect, the modified Grind Diagnostics program provides the following information:

1. Wheel path and section where the defect is found.
2. Defect limits relative to the start of the profile.
3. Defect width.
4. Location of the defect peak relative to the start of the profile.
5. Defect magnitude.
6. Type I IRI contribution associated with the defect.

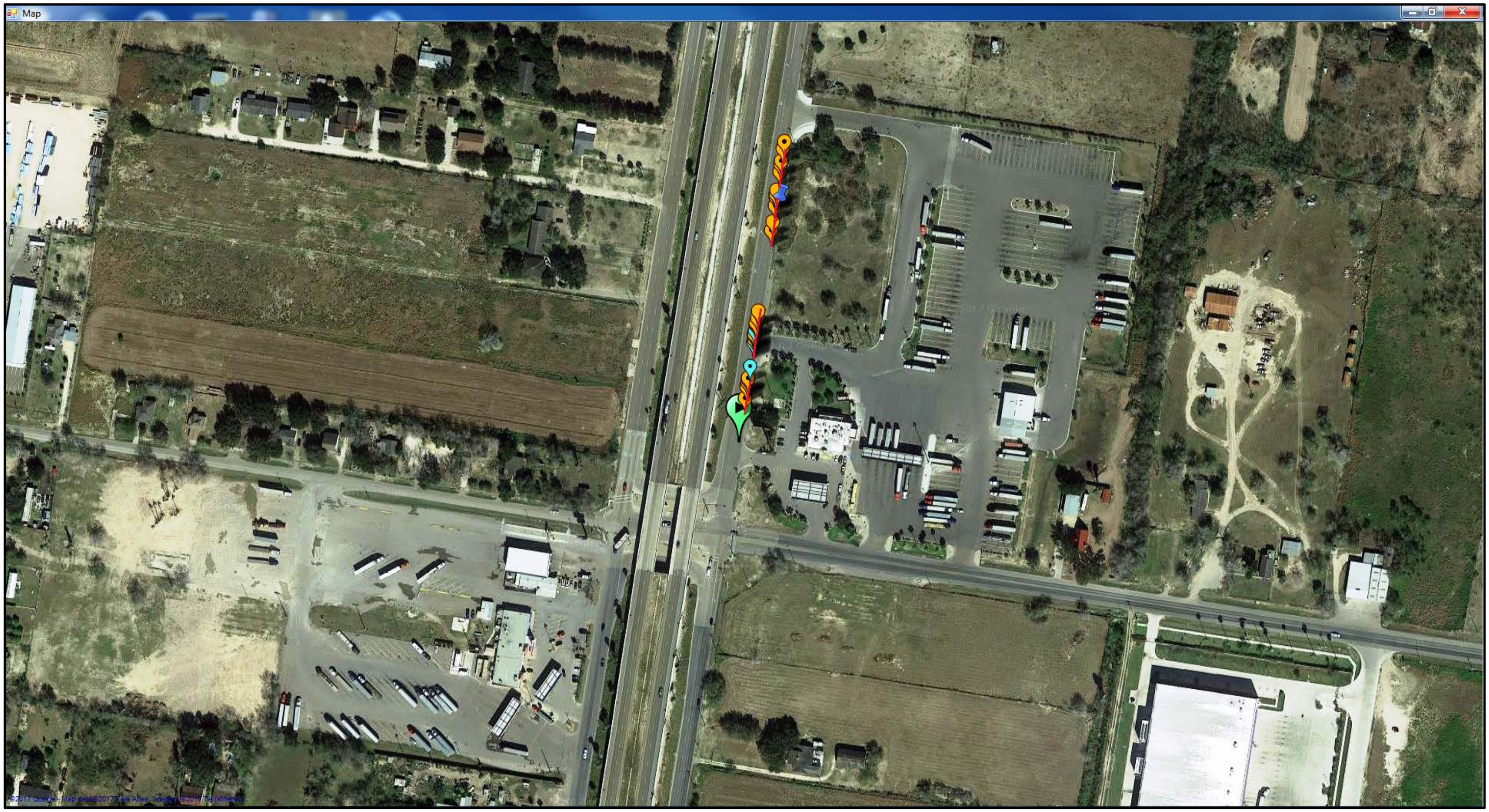


Figure 12. Example Illustration of Map Identifying Defects Found.

Figure 13. Illustration of Defect Data Embedded in Map.

In addition to the preceding information, the program also shows the defect group at the mouse position, the calculated DCI for that group, the DCI threshold, and whether the defect group needs to be corrected or not. In the example illustrated in Figure 13, the DCI is close to 1, which exceeds the specified DCI threshold of 0.70. The group of defects joined by the red line in the figure need to be corrected based on the DCI. The program uses a red line to identify a group of defects that need corrective work and a green line to identify a group where corrective work can be waived based on the DCI. The example given in Figure 13 shows a defect group immediately upstream of Group 2, where corrective work is also indicated according to the calculated DCI for that group.

COST ANALYSIS

In addition to the map display of analysis results, TTI researchers added a cost analysis function to the Grind Diagnostics program that covers the following options for correcting defects identified from the DCI analysis:

1. Grind Only.
2. Mill and Fill.
3. Overlay.
4. Spot Overlay.

These four options were selected for their applicability to ride quality corrections on construction projects with Item 585 and to project development. Grind Diagnostics generates an estimate for each work action after completing the DCI analysis. The cost analysis only applies to roughness areas identified by the DCI as needing correction.

A TxDOT cost perspective and contractor cost perspective are generated during each cost analysis. The two estimates provide engineers with different types of information depending on the application of the DCI analysis. When applying the DCI to a construction project with Item 585 requirements, the two estimates present a financial tool that helps TxDOT engineers understand the financial impacts of corrective work. With an understanding of these financial impacts, TxDOT engineers can better determine how to apply the ride quality specification. With the power of the DCI analysis to identify defects and groups of defects requiring correction, including a cost estimate for those corrections allows engineers to better weigh the application of a financial penalty or require corrective work.

The scale associated with corrective action on a construction project usually eliminates economies of scale. The TxDOT perspective within Grind Diagnostics uses average unit bid prices. Because average unit bid prices capture district or statewide economies of scale, the financial impact to the contractor to perform corrective work is much higher. Therefore, the contractor cost perspective includes labor, equipment, material, mobilization, and other real costs that the contractor experiences to perform the work. When quantities of work are relatively small, such as those required at the end of construction projects, the TxDOT perspective is markedly lower than the contractor perspective. However, for project development with large quantities of work required, the TxDOT and contractor perspectives begin to converge as economies of scale are realized.

Within the TxDOT cost perspective, 12-month average unit bid prices provide the foundational input. Presently, generic items rather than contract specific items generate the TxDOT estimate. In future iterations of Grind Diagnostics, overwriting options should be made available to allow engineers to use the unit bid price associated with a particular contract. For project development purposes, future iterations should include the ability to specify various types of mix so that the program can use the average unit bid price for a particular mix rather than the current default. Current defaults for average unit bid prices are:

- Item No. 3004-6006—SPOT DIAMOND GRINDING ASPH PVMT.
- Item No. 315-6006—FOG SEAL (SS-1H OR CSS-1H)—State Maintenance.
- Item No. 344-6103—SUPERPAVE MIXTURES SP-D SAC-A PG64-22.
- Item No. 354-6002—PLAN & TEXT ASPH CONC PAV (0 in. TO 2 in.).

Item No. 3004-6006, used for the grind-only option, exists within only the San Angelo District. For construction projects, repairing localized roughness is the responsibility of the contractor; therefore, items of work and associated costs for corrective actions are not always widely available. For the grind-only option, the contractor perspective likely presents a more accurate estimate.

The estimate package created for the contractor perspective includes labor, equipment, and material costs. Rates for labor and equipment are pulled from TxDOT-available resources. For labor, hourly rates required within each county as dictated by project proposals are used. For equipment, hourly rates established within the *Rental Rate Blue Book* are used. The *Rental Rate Blue Book* does not include a rate for grinders used to grind bumps. A typical industry rate was used for the hourly cost of a grinder that includes the use of the equipment and its operator.

A generic material cost for HMA is used within the Grind Diagnostics estimation tool. Presently, $60/ton freight-on-board (FOB) to the paver is used. Future iterations of the program should include an overwrite cell to change this value when engineers have better local knowledge of the market. The use of an FOB price to the paver is highly encouraged to avoid the need to estimate freight costs from the plant to the project.

In addition to labor, equipment, and materials, the bid sheets provide a space to estimate other costs such as mobilization. After all costs are included in the bid sheets, the daily production rate for each type of work is applied to each hourly rate, generating a total cost. The estimate package then applies a 25 percent labor markup, 15 percent equipment markup, 25 percent material markup, 55 percent insurance and taxes to the labor subtotal, and 1 percent bond. These values come from the TxDOT standard specifications associated with force account work. These markups likely inflate estimates when applied at the project development level, but this inflation should be vetted during follow-on projects while working directly with districts. Daily production rates and other work action defaults are discussed below.

The following daily rates are used within the grind-only option:

- < 20 bumps = 1 day of work.
- 20 to 50 bumps = 2 days of work.
- 50 to 100 bumps = 3 days of work.

- 100 to 150 bumps = 4 days of work.
- 150 to 200 bumps = 5 days of work.
- > 200 bumps, grinding is not a recommended option.

If a bump's height exceeds 1 in., it is counted twice based on the assumption that multiple passes are required to eliminate the defect. While grinding machines typically grind as narrow as 2 or 3 ft, a minimum 10-ft width and length are used. The 10-ft minimum provides "daylighting" passes to ensure positive drainage and eliminate drop-offs. Limiting the width to 10 ft enables maintaining final striping on most lanes. A minimum length allows grinding equipment to drive in and out of bumps, which assists in creating a smoother ride.

The mill and fill corrective action address both bumps and dips. A minimum width of 10 ft permits the use of a paving machine inside of the milled area. The minimum patch length is 100 ft, thus providing 50 ft on each side of the defect to create a patch length long enough to improve ride quality. Currently, the mill and fill option includes a 1.5-in. mat thickness, which can be changed on the cost estimate summary tab. If permanent striping has been placed, a patch width of 10 ft should stay within the permanent striping. The daily production rate for mill and fill is based on the amount of HMA that can be laid within a day. Presently, 1000 tons/day is used. Future iterations of Grind Diagnostics should include a provision for engineers to accept or overwrite this daily rate. Overwriting this daily rate is necessary if the DCI is applied during project development. Project development is performed on roadways requiring significant work, not spot repairs, as is the case on construction projects. With extensive work, economies of scale and higher production rates are realized.

The overlay option requires the most extensive amount of work of all of the correction actions. This work action addresses both bumps and dips. Areas requiring overlay span the entire 0.1-mile section where the DCI flags a location in need of repair. The contractor perspective within this work action includes a complete quality control/quality assessment QC/QA paving crew with multiple rollers. The overlay depth currently defaults to 1.5 in. While corrective work might only be required in a single lane, an overlay must be placed over all travel lanes to avoid uneven lanes. The number of travel lanes can be changed on the summary tab within the cost estimate. The number of lanes input should represent the number of lanes adjacent to each other where eliminating an edge condition is required. The daily rate for overlay is 1000 tons of HMA per day. As with the mill and fill option, during project development, this rate should change to reflect construction activities experienced for extensive construction work rather than corrective action.

Finally, the spot overlay option only addresses dips. Spot overlay functions more like a pure maintenance action than the mill and fill or overlay option. The crew used to generate the estimate is a smaller paving crew, incapable of laying extensive amounts of mix under QC/QA specifications. The daily rate is also reduced to 600 tons/day and it is assumed that the mix can be burned to zero in the transverse and longitudinal direction. This avoids the need to overlay adjacent lanes. The minimum patch length is 100 ft, the same as the mill and fill option. It is unlikely this type of work will be performed as corrective action on a recently completed construction project; however this work action might prove helpful in project development. For example, using pre-project profiles, an area engineer can work with a maintenance supervisor to identify dips that need to be leveled-up with blade lay operations. This type of work could be performed prior to district seal coat operations. By using the DCI to identify bumps in need of correction, an estimate can be generated to perform the work.

The remainder of this section describes how to use the *Cost Analysis* tool. Click on the *Cost Analysis* button of the menu shown in Figure 11 to have the program estimate the costs associated with each of the above repair options. By default, repairs are done on the defects identified as needing corrections from the DCI analysis. The program outputs the results in an Excel spreadsheet, as illustrated in Figure 14. By default, the program names this spreadsheet using the input PRO file name followed by *_DCICostAnalysis*.

As shown in Figure 14, the cost analysis spreadsheet includes a *Summary Sheet* that identifies the district and county where the project is located and a table that shows the cost of each repair option included in the program. The district and county are pulled from the first header card of the input PRO file. The user can also click on the *County* field to access a pull-down menu of Texas counties. Once a county is selected from this menu, the program fills in the TxDOT district where the specified county is located. The county dictates the labor hourly rate as set forth in project proposals.

The *Summary Sheet* includes a cost table and a listing of locations where corrections are to be made for each repair alternative. The cost table shows two groups of cost estimates. The first group, labeled *TxDOT Perspective*, gives estimates calculated using historical bid prices. The other group, labeled *Contractor Perspective*, uses estimates of labor, material, and equipment requirements along with corresponding unit costs for these items to evaluate the cost for each alternative. The cost information given under this group reflects what the contractor's actual cost could be for each repair option. These estimates use hourly rates for labor based on federal requirements and *Rental Rate Blue Book* rates for equipment use.

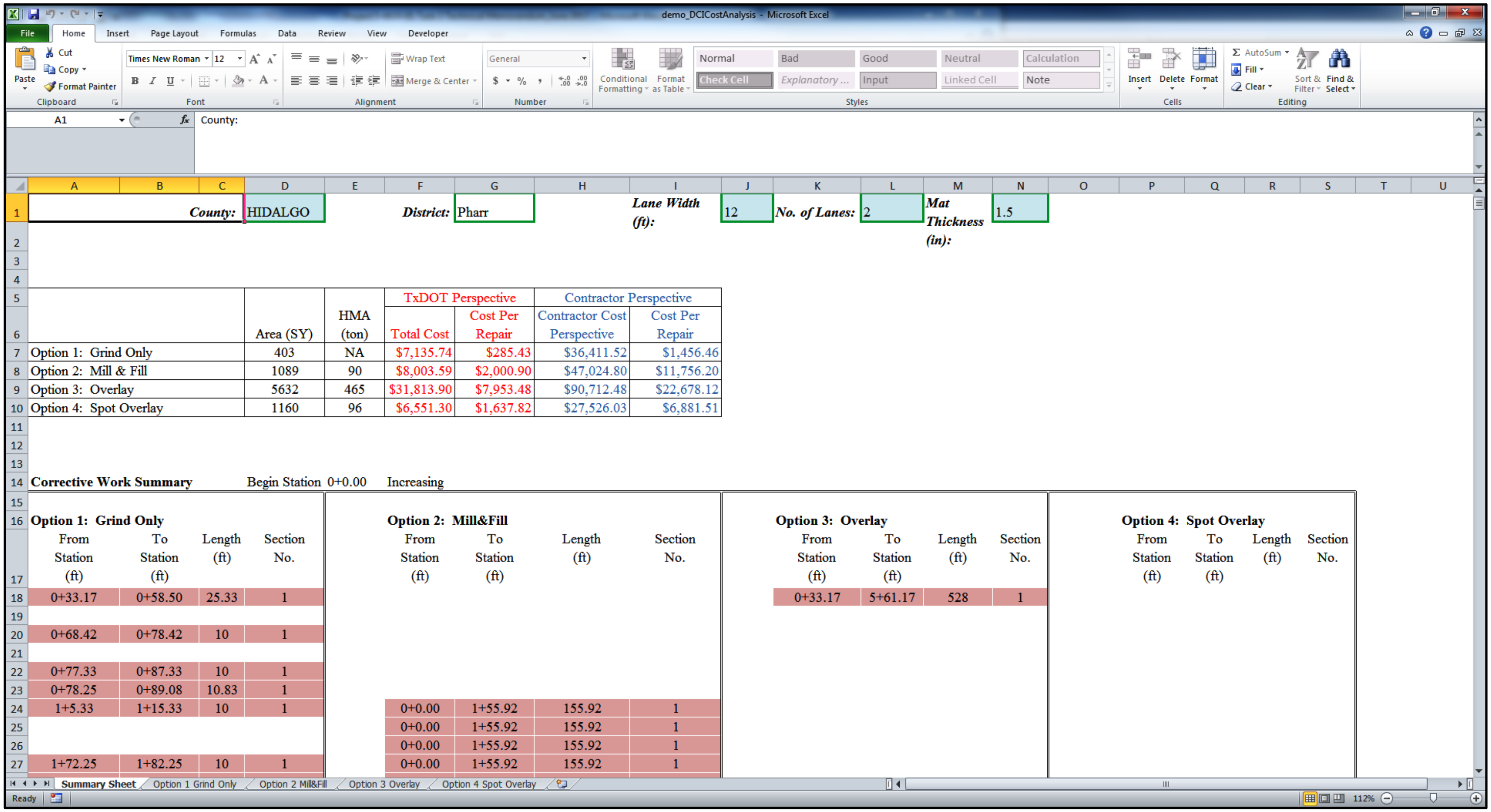


Figure 14. Cost Analysis Spreadsheet.

To view detailed information on the cost rates along with the labor, material, and equipment estimates used to evaluate the cost for each option, click on the corresponding tab for the repair alternative at the bottom of the spreadsheet. For example, click on *Option 1 Grind Only* to view the data used to estimate the cost of this option. This action brings up the worksheet illustrated in Figure 15. The top of the worksheet shows the assumed makeup of the grinding crew and equipment. To the right of this table, the worksheet shows additional information, which includes the number of repair locations and the estimated area to be ground in square yards. These estimates are based on the DCI analysis results.

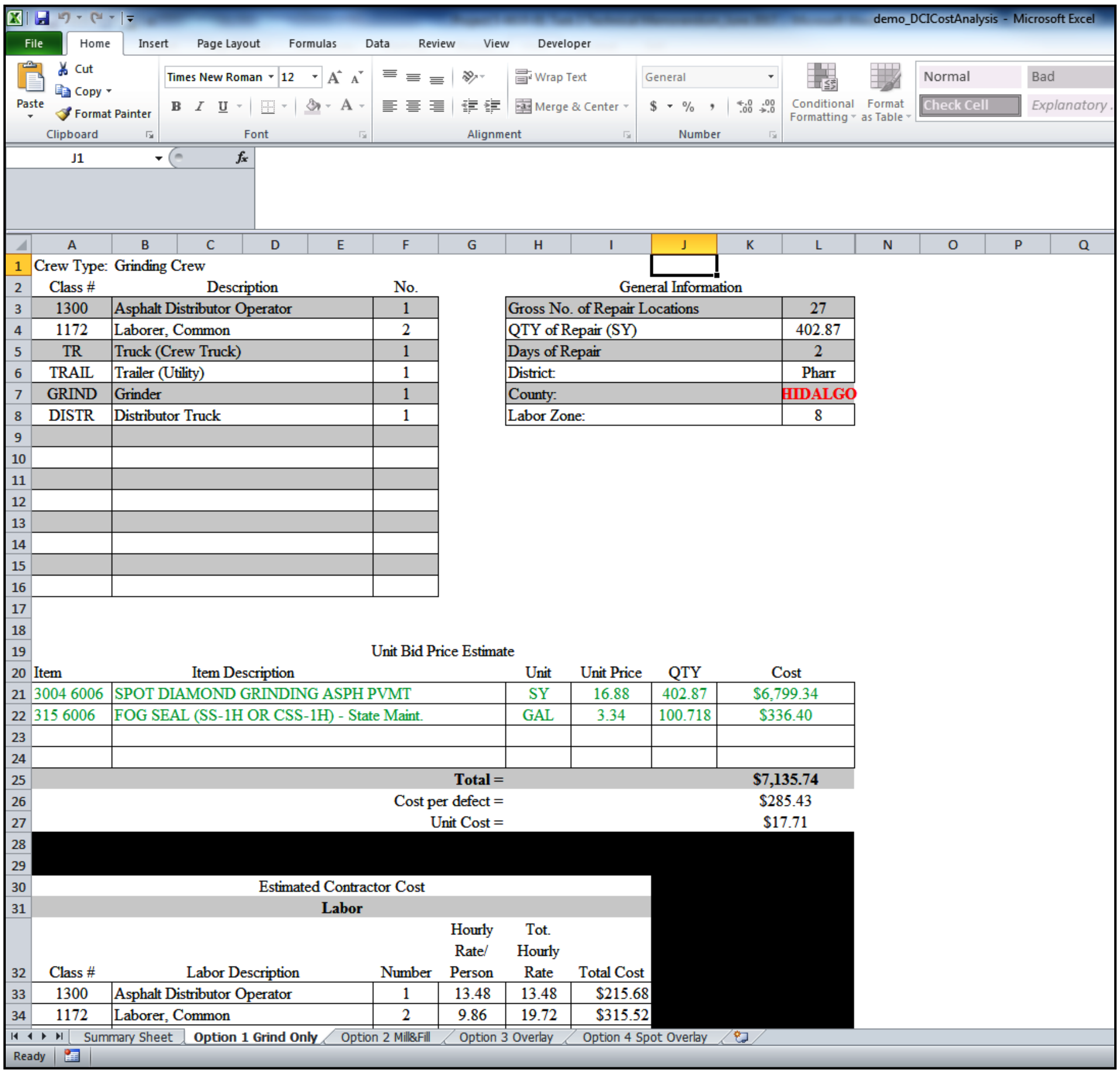
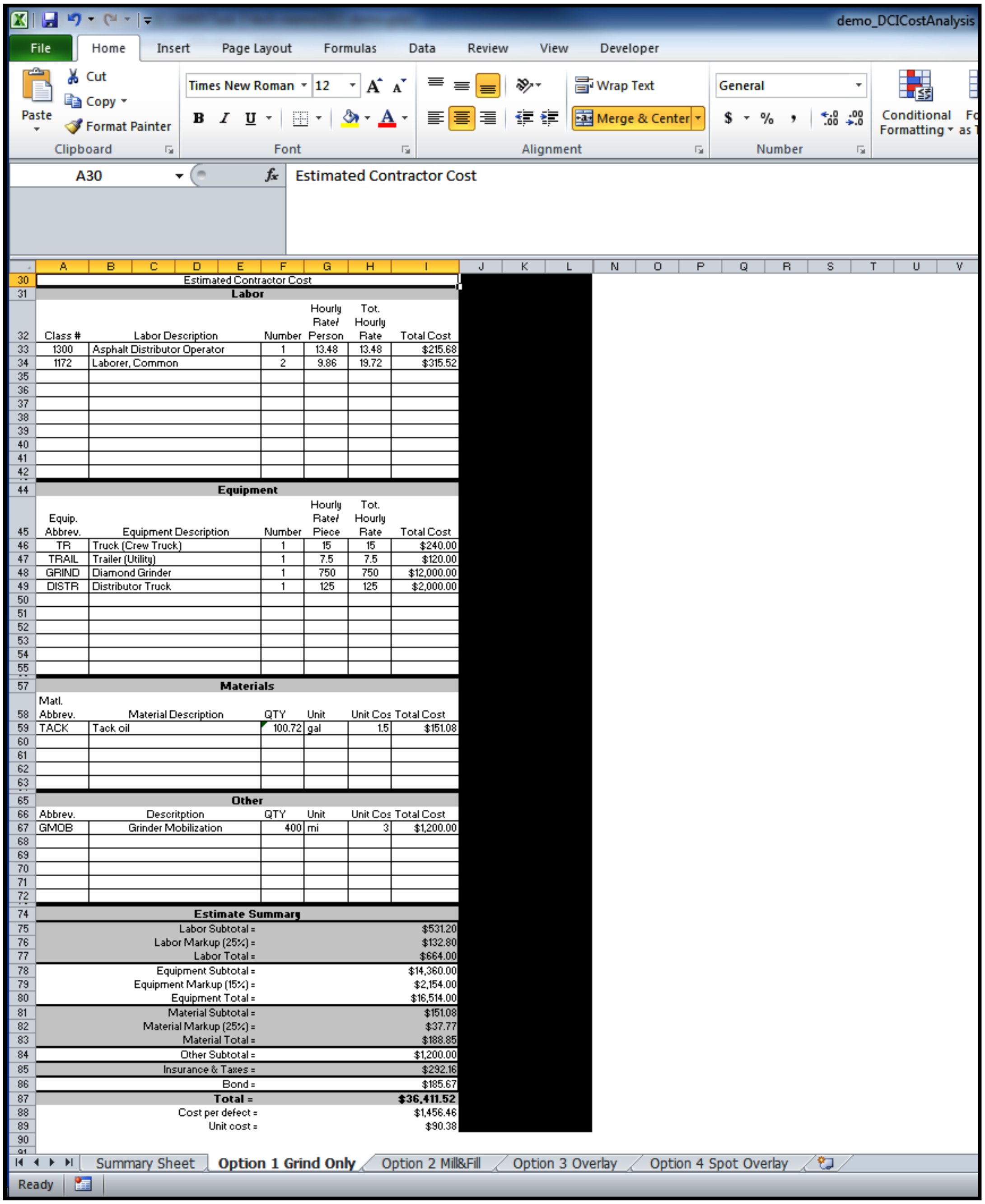


Figure 15. Worksheet to Estimate Cost of Grind-Only Alternative.

Following the *Grinding Crew* and *General Information* tables are the unit bid price estimates used to calculate the cost of the *Grind-Only* alternative under the *TxDOT Perspective*. Below this information, the worksheet shows the rates for calculating the contractor's cost. Scroll down the worksheet to view the rates for different cost categories that include labor, equipment, materials, and other. For this example, Figure 16 shows the information used by the program to estimate the contractor's cost for the *Grind-Only* alternative. To view similar cost information for another repair option, click on its tab.



	A	B–E	F	G	H	I
30	Estimated Contractor Cost					
31	**Labor**					
32	Class #	Labor Description	Number	Hourly Rate/ Person	Tot. Hourly Rate	Total Cost
33	1300	Asphalt Distributor Operator	1	13.48	13.48	$215.68
34	1172	Laborer, Common	2	9.86	19.72	$315.52
44	**Equipment**					
45	Equip. Abbrev.	Equipment Description	Number	Hourly Rate/ Piece	Tot. Hourly Rate	Total Cost
46	TR	Truck (Crew Truck)	1	15	15	$240.00
47	TRAIL	Trailer (Utility)	1	7.5	7.5	$120.00
48	GRIND	Diamond Grinder	1	750	750	$12,000.00
49	DISTR	Distributor Truck	1	125	125	$2,000.00
57	**Materials**					
58	Matl. Abbrev.	Material Description	QTY	Unit	Unit Cos	Total Cost
59	TACK	Tack oil	100.72	gal	1.5	$151.08
65	**Other**					
66	Abbrev.	Descritption	QTY	Unit	Unit Cos	Total Cost
67	GMOB	Grinder Mobilization	400	mi	3	$1,200.00
74	**Estimate Summary**					
75		Labor Subtotal =				$531.20
76		Labor Markup (25%) =				$132.80
77		Labor Total =				$664.00
78		Equipment Subtotal =				$14,360.00
79		Equipment Markup (15%) =				$2,154.00
80		Equipment Total =				$16,514.00
81		Material Subtotal =				$151.08
82		Material Markup (25%) =				$37.77
83		Material Total =				$188.85
84		Other Subtotal =				$1,200.00
85		Insurance & Taxes =				$292.16
86		Bond =				$185.67
87		**Total =**				**$36,411.52**
88		Cost per defect =				$1,456.46
89		Unit cost =				$90.38

Figure 16. Rates for Estimating Contractor's Cost under Grind-Only Alternative.

GRAPHICAL OUTPUT

To help users communicate results from the evaluation of corrective measures to improve existing ride quality, TTI researchers added a graphical function to the Grind Diagnostics program to generate charts showing the defects to be corrected. Note that the DCI analysis must first be performed before this graphical function can be used. To use this function, go to the *Tool* menu and click on *DCI Report*. The program then displays the input menu shown in Figure 17.

The graphical function requires a scenario file for each wheel path and the *DCI Analysis* result file. For convenience, the program remembers the files generated from the most recent DCI analysis and displays the names of these files in the input menu given in Figure 17. Alternatively, one can use the *Select* buttons to specify the files for generating the defect charts. After specifying the input files, click on *Generate DCI Report* to plot the charts. Grind Diagnostics draws the charts by defect groups and gives users the option to plot only the defects that need corrections according to the DCI analysis or to plot all the defect groups. The program outputs the defect charts into an Excel spreadsheet (Figure 18). Each worksheet is labeled with the defect group number. For the example shown, the DCI analysis identified six defect groups where corrections need to be made (Group 1, Group 2, Group 4, Group 5, Group 9, and Group 30). To view the charts for a given defect group, click on its tab in the Excel spreadsheet illustrated in Figure 18. This particular example shows the charts of the defects found in DCI Group 30. The user can print charts from this spreadsheet or put them into a document or presentation file to help communicate the results from the analysis.

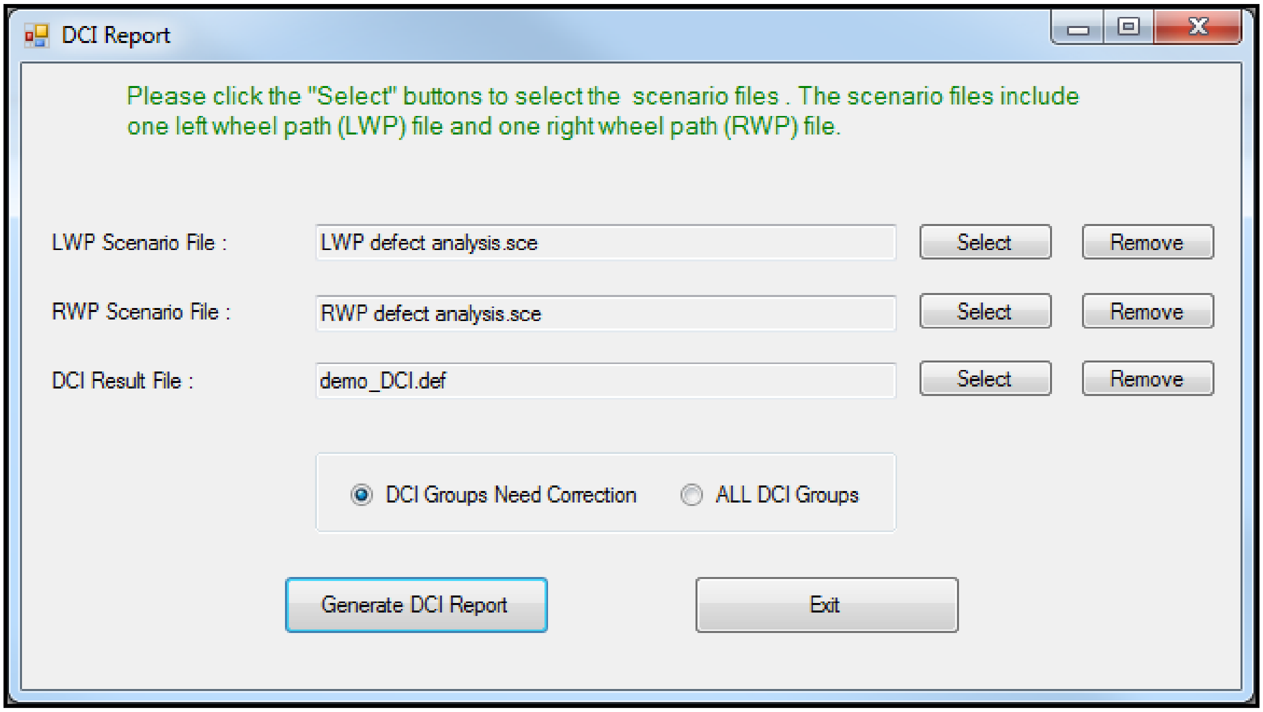


Figure 17. DCI Report Input Screen.

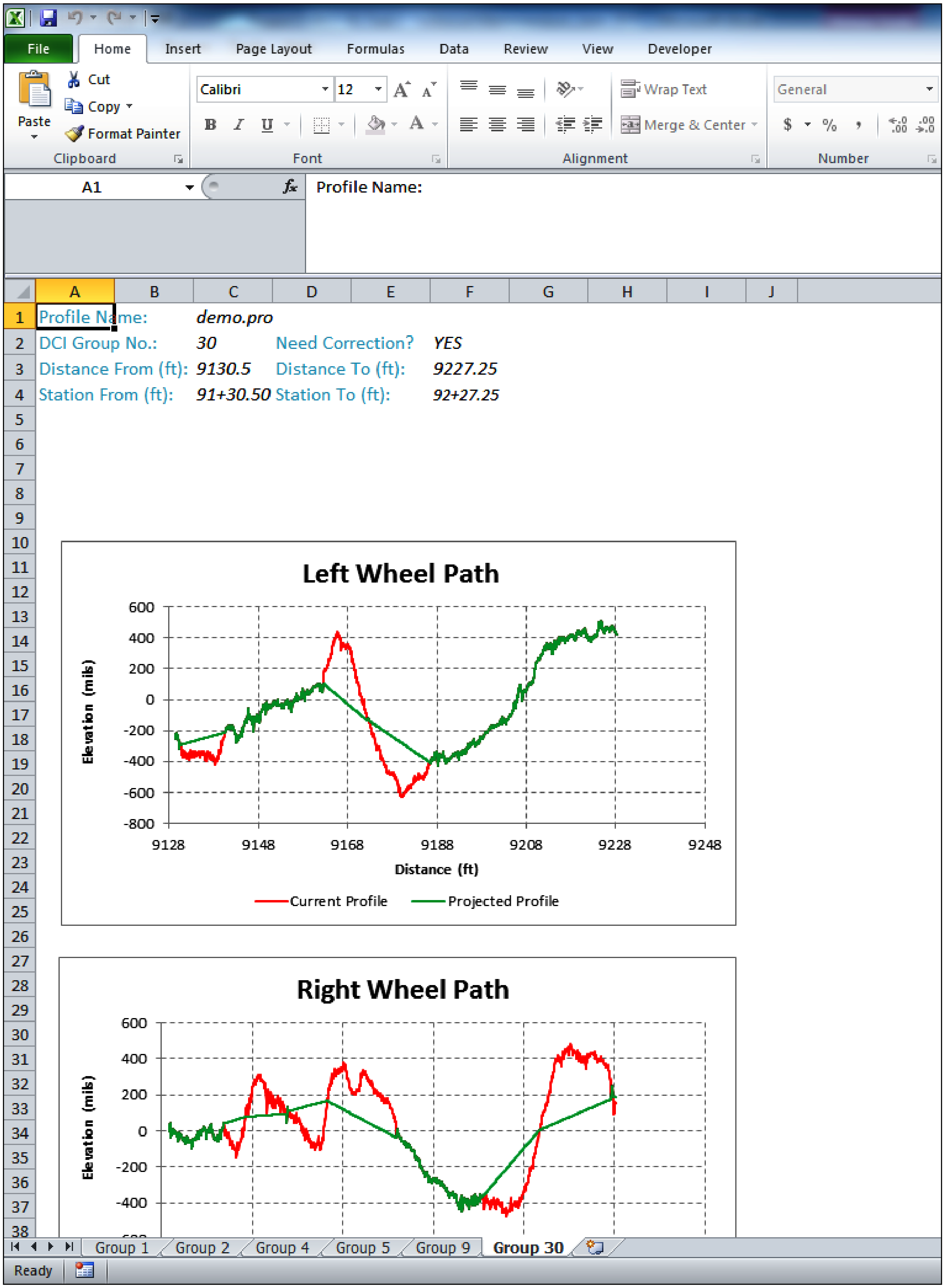


Figure 18. Excel Spreadsheet of Defect Charts Determined from DCI Analysis.

CHAPTER 4. CONDUCTING TRAINING CLASSES

INTRODUCTION

TTI researchers scheduled three training classes to introduce the application of the modified Grind Diagnostics program from this implementation project. The training classes were held in the Corpus Christi, Tyler, and Bryan Districts. Class participants included directors of construction, area engineers, assistant area engineers, pavement design engineers, transportation engineers, and project engineers. Each district provided the venue for the training class.

In preparation for this class, researchers consulted with the head of the project advisory panel to prepare the course outline and questionnaire shown, respectively, in Figure 19 and Figure 20. The questionnaire solicited comments from the class participants for the purpose of evaluating the class and identifying areas where future improvements, such as in the course content and software, could be made. The head of the project advisory panel concurred with the agenda and questionnaire prepared by the researchers. Both documents were subsequently submitted to the project manager at TxDOT's Research and Technology Implementation Office. This chapter presents the feedback received from the training classes.

A. BACKGROUND (45 minutes)
   1. Introductions
   2. Class objectives
   3. Basic concepts
      a. TxDOT bump template
      b. Defect correction index (DCI)

Break (15 minutes)

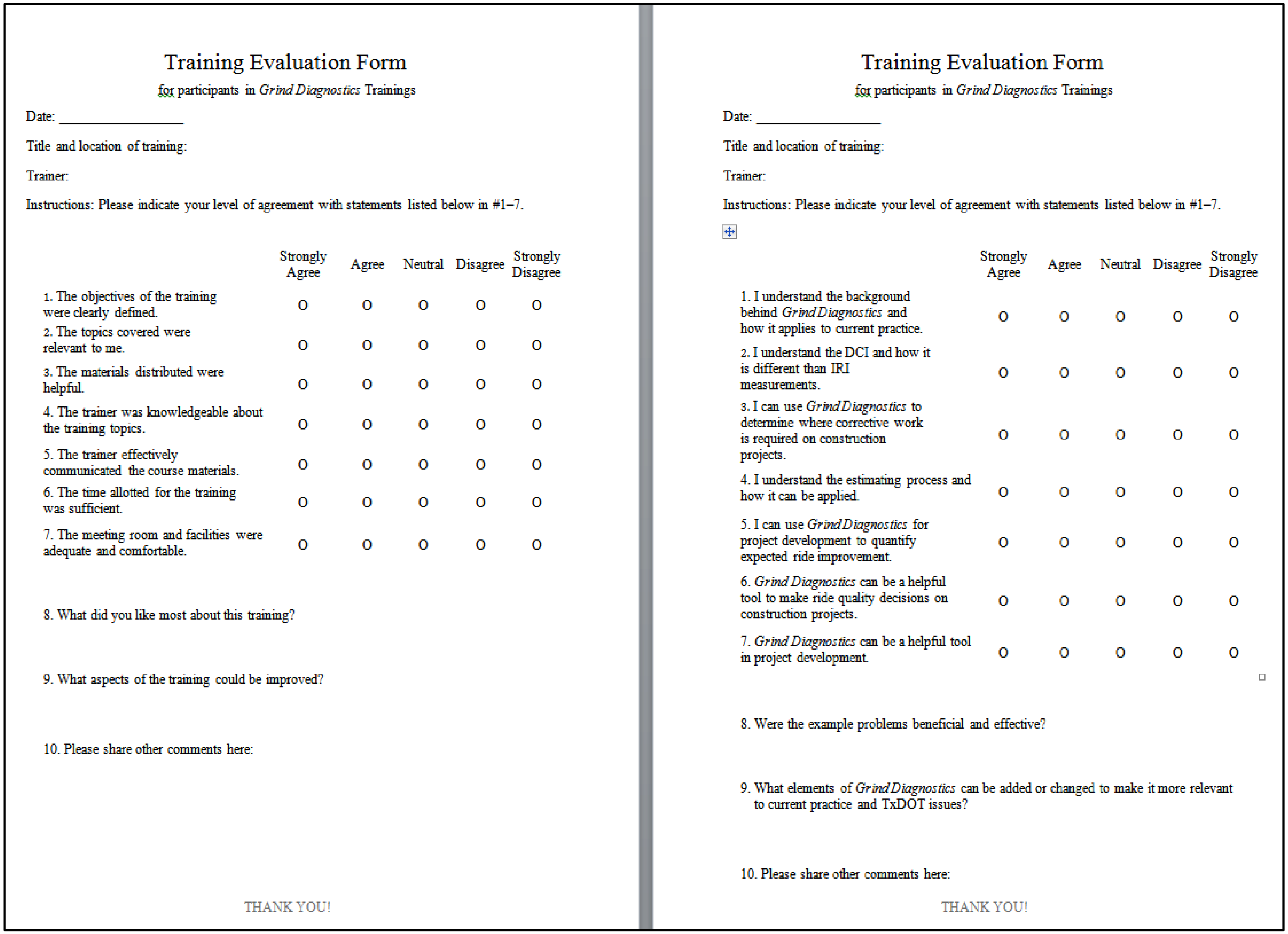
B. USING GRIND DIAGNOSTICS (60 minutes)
   1. Program installation
   2. Running the program to:
      a. Determine where corrections are needed
      b. Estimate costs of alternative treatments

Break (15 minutes)

C. EXAMPLE PROBLEMS (75 minutes)
   1. Project development application
   2. Establishing scope of corrections on Item 585 projects

D. CLASS CONCLUSION (30 minutes)
   1. Final Q&A
   2. Completion of feedback document

Figure 19. Grind Diagnostics Training Class Outline.



Training Evaluation Form

for participants in *Grind Diagnostics* Trainings

Date: ______________

Title and location of training:

Trainer:

Instructions: Please indicate your level of agreement with statements listed below in #1–7.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. The objectives of the training were clearly defined.	O	O	O	O	O
2. The topics covered were relevant to me.	O	O	O	O	O
3. The materials distributed were helpful.	O	O	O	O	O
4. The trainer was knowledgeable about the training topics.	O	O	O	O	O
5. The trainer effectively communicated the course materials.	O	O	O	O	O
6. The time allotted for the training was sufficient.	O	O	O	O	O
7. The meeting room and facilities were adequate and comfortable.	O	O	O	O	O

8. What did you like most about this training?

9. What aspects of the training could be improved?

10. Please share other comments here:

THANK YOU!

Training Evaluation Form

for participants in *Grind Diagnostics* Trainings

Date: ______________

Title and location of training:

Trainer:

Instructions: Please indicate your level of agreement with statements listed below in #1–7.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I understand the background behind *Grind Diagnostics* and how it applies to current practice.	O	O	O	O	O
2. I understand the DCI and how it is different than IRI measurements.	O	O	O	O	O
3. I can use *Grind Diagnostics* to determine where corrective work is required on construction projects.	O	O	O	O	O
4. I understand the estimating process and how it can be applied.	O	O	O	O	O
5. I can use *Grind Diagnostics* for project development to quantify expected ride improvement.	O	O	O	O	O
6. *Grind Diagnostics* can be a helpful tool to make ride quality decisions on construction projects.	O	O	O	O	O
7. *Grind Diagnostics* can be a helpful tool in project development.	O	O	O	O	O

8. Were the example problems beneficial and effective?

9. What elements of *Grind Diagnostics* can be added or changed to make it more relevant to current practice and TxDOT issues?

10. Please share other comments here:

THANK YOU!

Figure 20. Questionnaire for Evaluating Grind Diagnostics Training Class.

FEEDBACK FROM CLASS EVALUATIONS

Part 1 of the class evaluation aimed to assess the course content, the quality of instruction, and the class venue, as well as to solicit suggestions on how the training course could be improved. On the other hand, Part 2 aimed to assess the effectiveness of the course in teaching the Grind Diagnostics program to first-time users based on the following factors:

1. Developing a basic understanding of the principles behind the DCI and cost analysis functions built into the program.
2. Developing a working knowledge of program applications through hands-on training using actual project data.
3. Recognizing the applicability of the program as a tool for making decisions affecting ride quality on construction projects and for project development and planning.

In addition, Part 2 aimed to solicit suggestions on how Grind Diagnostics could be improved to make it more useful to current practice and to resolving TxDOT issues.

Overall, the training course received very positive feedback from the class participants. This assessment is evident from the responses received, as summarized in Table 17 and Table 18. The course evaluation ratings given in Table 17 give an indication of a need to increase the time allocated for the course, which covered 4 hours and included two 15-minute breaks. Examination of the feedback provided in Part 1 of the evaluation form revealed a number of participants who wanted to go through more examples of program applications. Thus, for future training classes, there is a need to revisit the course outline to decide where changes can be made to optimize the course content with the time available for training.

The ratings given in Table 17 also show three respondents who had issues with the training facility. In one district, there was an issue with the air conditioner in the meeting room, which was later resolved during the course of the training. In another district, the projection boards in the training facility were fixed to the walls. This setup made it hard to see what was being projected on the boards depending on where one was seated. The projection boards need to be angled or moved to the center, according to comments provided by two class participants.

With respect to the program itself, Table 18 shows that the feedback on Grind Diagnostics is highly positive. In particular, all class participants who were surveyed either agreed or strongly agreed that Grind Diagnostics can be a helpful tool for making ride quality decisions on construction projects and for project development. Nevertheless, participants suggested a number of program enhancements that are summarized below:

1. Permit input of specific project data and costs, including cost of traffic control.
2. Provide option to run defect analysis on both wheel paths automatically.
3. Provide option to generate a keyhole markup language (KML) file to show map of defects using Google Earth. This KML file can be compressed or zipped to create the KMZ file.
4. Include bonus/penalty information from ride QA testing with cost estimates determined using the program.
5. Expand program application to flexible base projects.

Based on the feedback received from the training classes, the next chapter provides recommendations on how TxDOT should proceed with further implementation of the application developed from this project.

Table 17. Summary of Ratings (Part 1 of Evaluation).

Statement	Number of Responses at the Given Rating					Number of Agree/Strongly Agree Ratings	% of Agree/Strongly Agree Ratings
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree		
The objectives of the training were clearly defined.	6	16	2	0	0	22	91.7
The topics covered were relevant to me.	10	12	2	0	0	22	91.7
The materials distributed were helpful.	6	18	0	0	0	24	100.0
The trainer was knowledgeable about the training topics.	19	5	0	0	0	24	100.0
The trainer effectively communicated the course materials.	6	17	0	1	0	23	95.8
The time allotted for the training was sufficient.	6	13	4	1	0	19	79.2
The meeting room and facilities were adequate and comfortable.	7	14	1	2	0	21	87.5

Table 18. Summary of Ratings (Part 2 of Evaluation).

Statement	Number of Responses at the Given Rating					Number of Agree/Strongly Agree Ratings	% of Agree/Strongly Agree Ratings
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree		
I understand the background behind Grind Diagnostics and how it applies to current practice.	6	16	2	0	0	22	91.7
I understand the DCI and how it is different than IRI measurements.	5	18	1	0	0	23	95.8
I can use Grind Diagnostics to determine where corrective work is required on construction projects.	5	18	1	0	0	23	95.8
I understand the estimating process and how it can be applied.	2	21	1	0	0	23	95.8
I can use Grind Diagnostics for project development to quantify expected ride improvement.	6	16	2	1	0	22	91.7
Grind Diagnostics can be a helpful tool to make ride quality decisions on construction projects.	14	10	0	0	0	24	100.0
Grind Diagnostics can be a helpful tool in project development.	14	10	0	0	0	24	100.0

CHAPTER 5. SUMMARY AND RECOMMENDATIONS

This project followed up on the original development of the DCI in TxDOT Project 0-6610. As part of implementing the DCI methodology for evaluating defect corrections using surface profile measurements, researchers conducted additional bump rating panels to verify the original DCI equation. This verification led researchers to recalibrate the original equation using the expanded bump rating panel database.

TTI researchers used the recalibrated DCI equation to modify the Grind Diagnostics program to assess the need for corrections based on measured wheel path profile characteristics. This modification automated the application of the DCI methodology for evaluating defect corrections on Item 585 projects or to identify treatments that can be made to an existing roadway during the project development and planning process to enhance the opportunity for ride quality improvement. In addition to automating the application of the DCI equation, researchers added a utility for estimating costs associated with correcting the defects identified from the DCI analysis and a utility for generating graphical output, through maps, and charts to help users communicate the results from this analysis.

To provide for implementing the modified Grind Diagnostics program on TxDOT projects, researchers reviewed TxDOT's Test Method Tex-1001-S on *Operating Inertial Profilers and Evaluating Pavement Profiles* (*3*). Researchers conducted this review in consultation with the TxDOT engineer responsible for this test method. The main revision suggested from this review was to add a note updating the section on "Detecting Localized Roughness" to allow use of the DCI as a method to establish corrective actions to fix defects and improve ride quality. In addition, a clarification was added to state that Grind Diagnostics does not override pay adjustments determined by TxDOT's Ride Quality program. Appendix II presents a marked-up version of the existing Test Method Tex-1001-S identifying the proposed revisions. Researchers recommend that this version be included in the next TxDOT specification review cycle.

Researchers strongly recommend a follow-up project to provide for the recommended software improvements identified from the training classes and to continue the implementation effort. The next stage of this implementation should include demonstration projects where the researchers work with area engineers on actual construction and development projects. Researchers recommend that these demonstrations include flexible base projects to provide an initial evaluation of how the program can be used on these projects. The experience from this collaborative engagement will further identify specific program changes to better tailor the program to the applications for which it is used. This experience will also provide better examples to go over program applications in additional training courses to be conducted in the recommended follow-up project.

REFERENCES

1. *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. Texas Department of Transportation, Austin, Tex., 2004.

2. Fernando, E. G., and R. S. Walker. *Evaluate Methodology to Determine Localized Roughness*. Report 0-6610-2, Texas A&M Transportation Institute, Texas A&M University System, College Station, Tex., 2013.

3. *Operating Inertial Profilers and Evaluating Pavement Profiles*. TxDOT Designation Tex-1001-S, Texas Department of Transportation, Austin, Tex., January 2017.

APPENDIX I. GRIND DIAGNOSTICS USER'S GUIDE

PROGRAM INSTALLATION

To install Grind Diagnostics, insert the installation CD, and the installation process will be executed automatically. If the installation process does not begin, run the "setup.exe" file from the installation CD. Once the installation process begins, follow the instructions in the setup program to install Grind Diagnostics. The final installation screen will indicate the install is complete and ask if the user would like to launch Grind Diagnostics.

QUICK GUIDE TO GRIND DIAGNOSTICS

Grind Diagnostics is a tool for identifying defects using TxDOT's bump template on profile measurements collected along the left and right wheel paths of the given test lane. With the defects determined in both wheel paths, the program groups the defects and calculates the corresponding DCI value for each group to determine if the defect group needs correction or not. The steps below provide a quick guide to the analysis process. For additional details, read through this user's guide.

Step 1: Choose *Open File* under *File* menu to load a TxDOT PRO file.

Step 2: On the pop-up window after Step 1, choose *Left Profile*, *Right Profile,* or *Average* to show a plot of the selected profile. This step permits the user to view the selected profile before any analysis is done. Whatever the user selects, Grind Diagnostics loads the left and right wheel path profiles in the specified PRO file.

Step 3: Select *Analyzer* under the *Tool* menu to perform a defect analysis.

Step 4: On the pop-up window after Step 3, choose the wheel path profile to analyze. By default, the left wheel path is first selected.

Step 5: A message box pops up after Step 4 prompting the user to save the project before running the analysis. Provide a file name for the project in this step.

Step 6: After the analysis is completed, Grind Diagnostics shows a *Result* screen with tab controls, sub-menus, and result tables. Click on the *Export* tab and choose *Section IRI and Defects Summary* to export the results from the analysis to a *CSV* file.

Step 7: Repeat Steps 3, 4, and 6 to perform a defect analysis on the other wheel path.

Step 8: Select *DCI Analysis* under the *Tool* menu. Grind Diagnostics displays the *DCI Analysis* dialog box. By default, the program uses the most recent *CSV* files generated during the previous steps, and the current PRO file for the DCI analysis. Click the *Analyze* button in the dialog box to run the DCI analysis.

Step 9: When the DCI analysis is completed, the program displays the results in an Excel file. In addition, the *DCI Analysis* dialog box activates two buttons—*Cost Analysis* and *Show Map*.

Step 10: Click *Show Map* to show the DCI analysis results in a Google map. Users can zoom in, zoom out, and drag the map to view detailed information.

Step 11: Click *Cost Analysis* to perform a cost analysis based on the four repair options built into the program. Grind Diagnostics displays the results of this analysis in an Excel file.

Step 12: Select *DCI Report* under the *Tool* menu to generate an Excel report with plots of the left and right wheel path profiles for each DCI defect group.

IDENTIFYING DEFECTS USING GRIND DIAGNOSTICS

To launch Grind Diagnostics, use the shortcut on the system's *Start* menu or on the user's desktop. When Grind Diagnostics starts, you will see a window similar to the one shown in Figure 21.

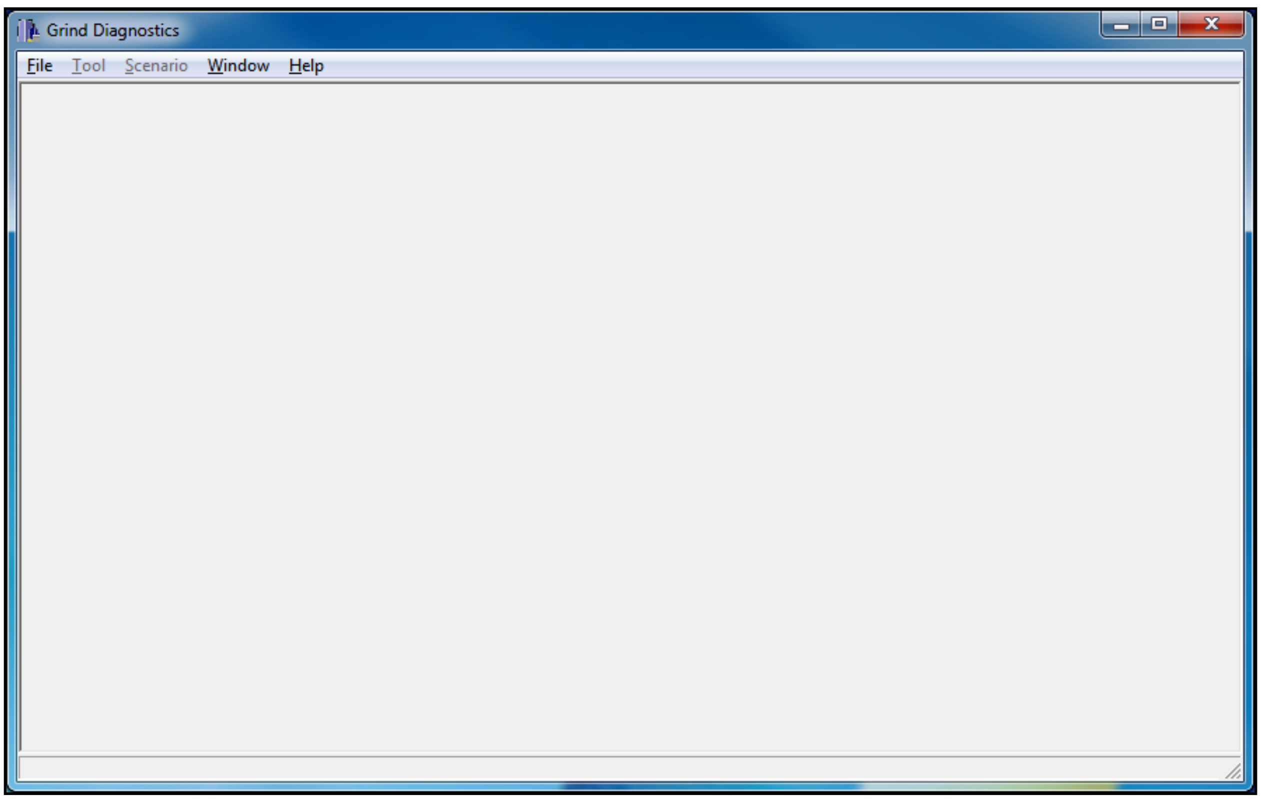


Figure 21. Grind Diagnostics Start Screen.

Next, choose *Open File* under *File* menu to load a profile (PRO) file. If the PRO file contains the profiles of both the left and right wheel paths, you will be asked to choose the profile to be analyzed (Figure 22). After choosing the desired profile, click the *Select* button and the program will load and plot the profile, as shown in Figure 23.

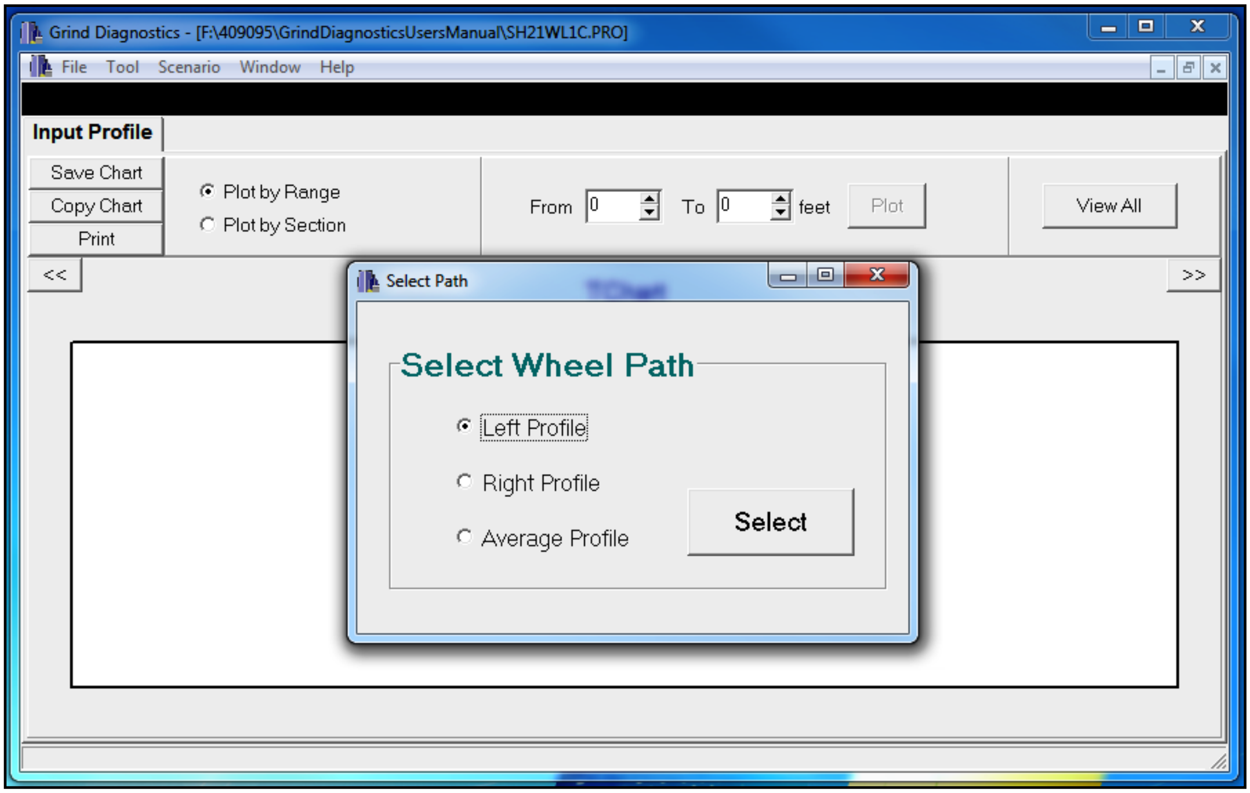


Figure 22. Wheel Path Selection Window.

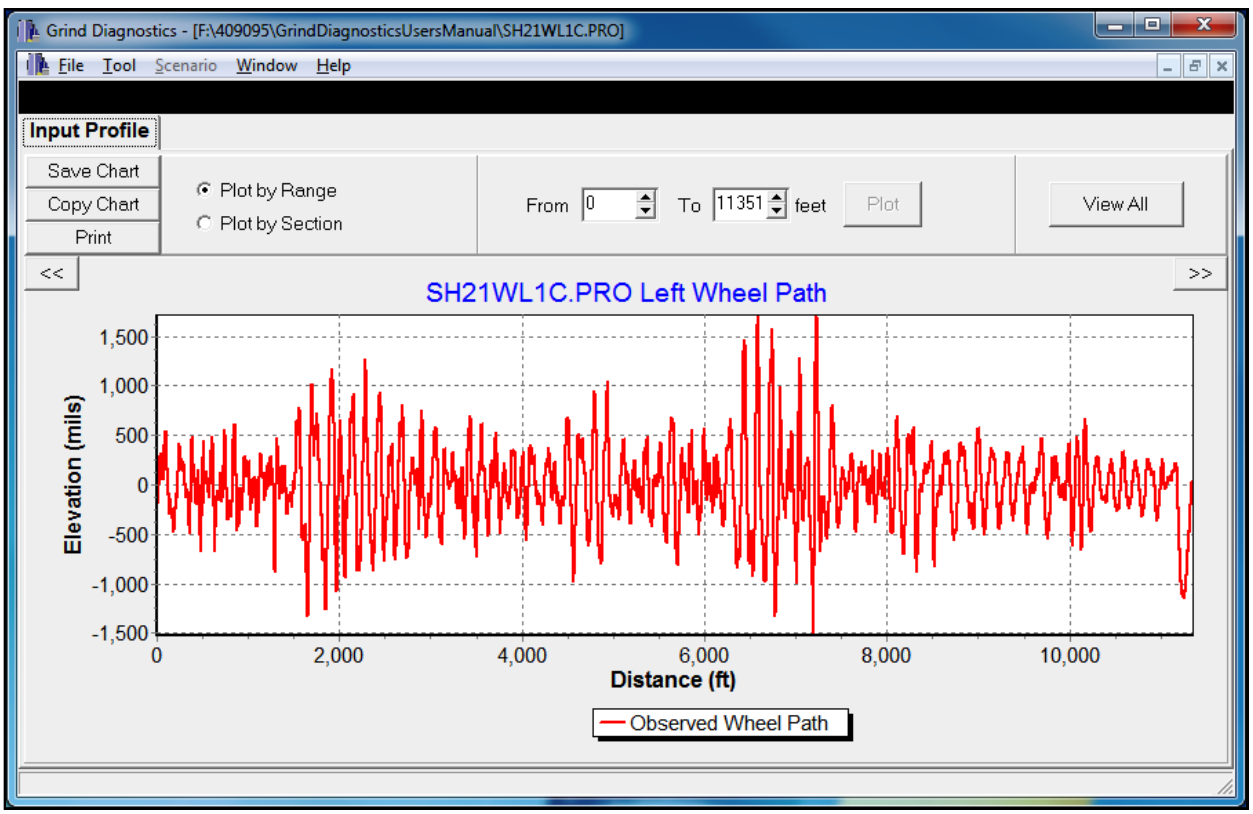


Figure 23. Input Profile Plot.

Once the profile is loaded, the program will activate the *Tool* menu on the menu bar (Figure 23). To analyze the profile, select *Analyzer* under *Tool* menu and a window for parameter settings will be displayed as shown in Figure 24. Here, you have the option to choose the profile of another wheel path for analysis. By default, the loaded profile is selected.

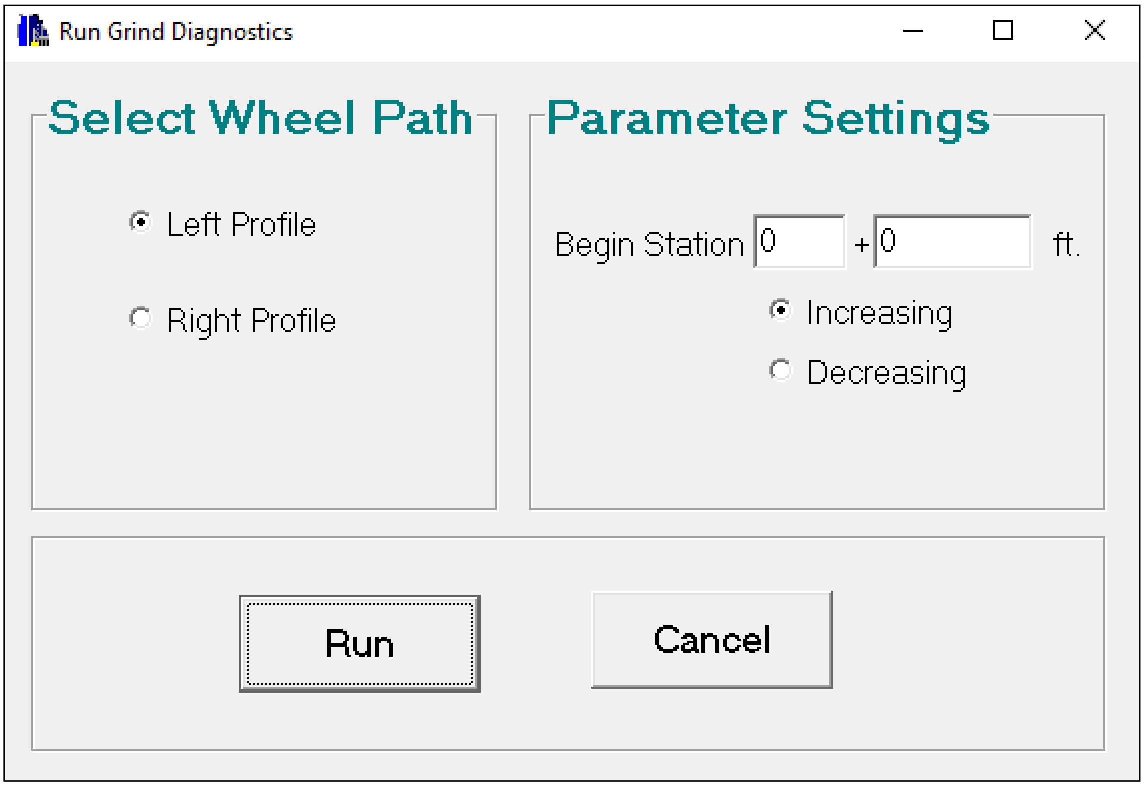
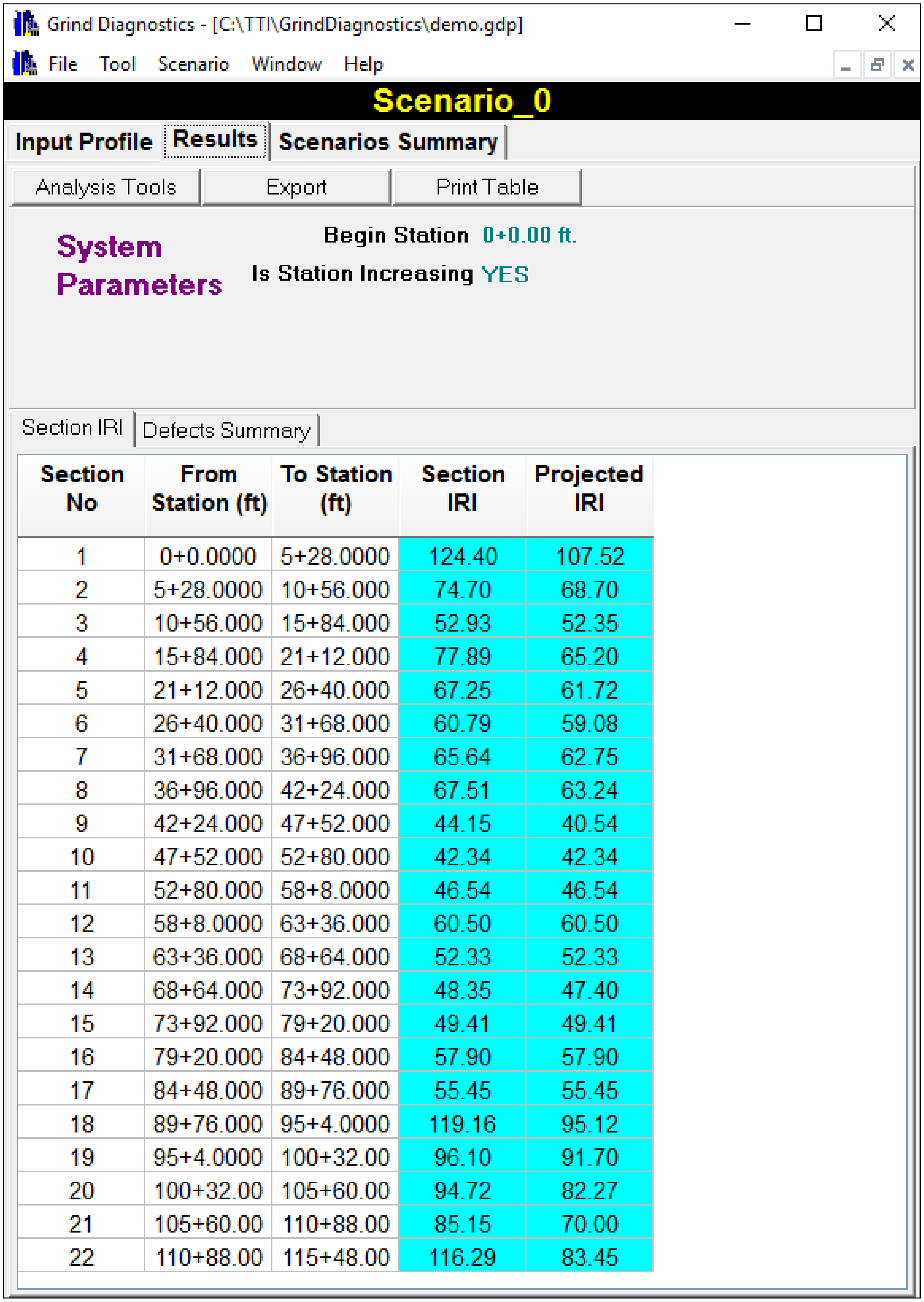


Figure 24. Parameter Settings Window.

After setting the parameters, click *Run* to analyze the selected profile. A description of the input parameters is given later in this guide. If this run is the first time the specified profile is analyzed, you will be prompted to create a project. Click *OK* to create a project. After specifying the project file name, the analysis will start. When the analysis is done, the program will create a new *scenario* associated with the selected profile and the corresponding results for further reference. The program will assign a name to the scenario, which you can rename later. In addition, the program will display two more tab pages, namely *Results* and *Scenarios Summary*.

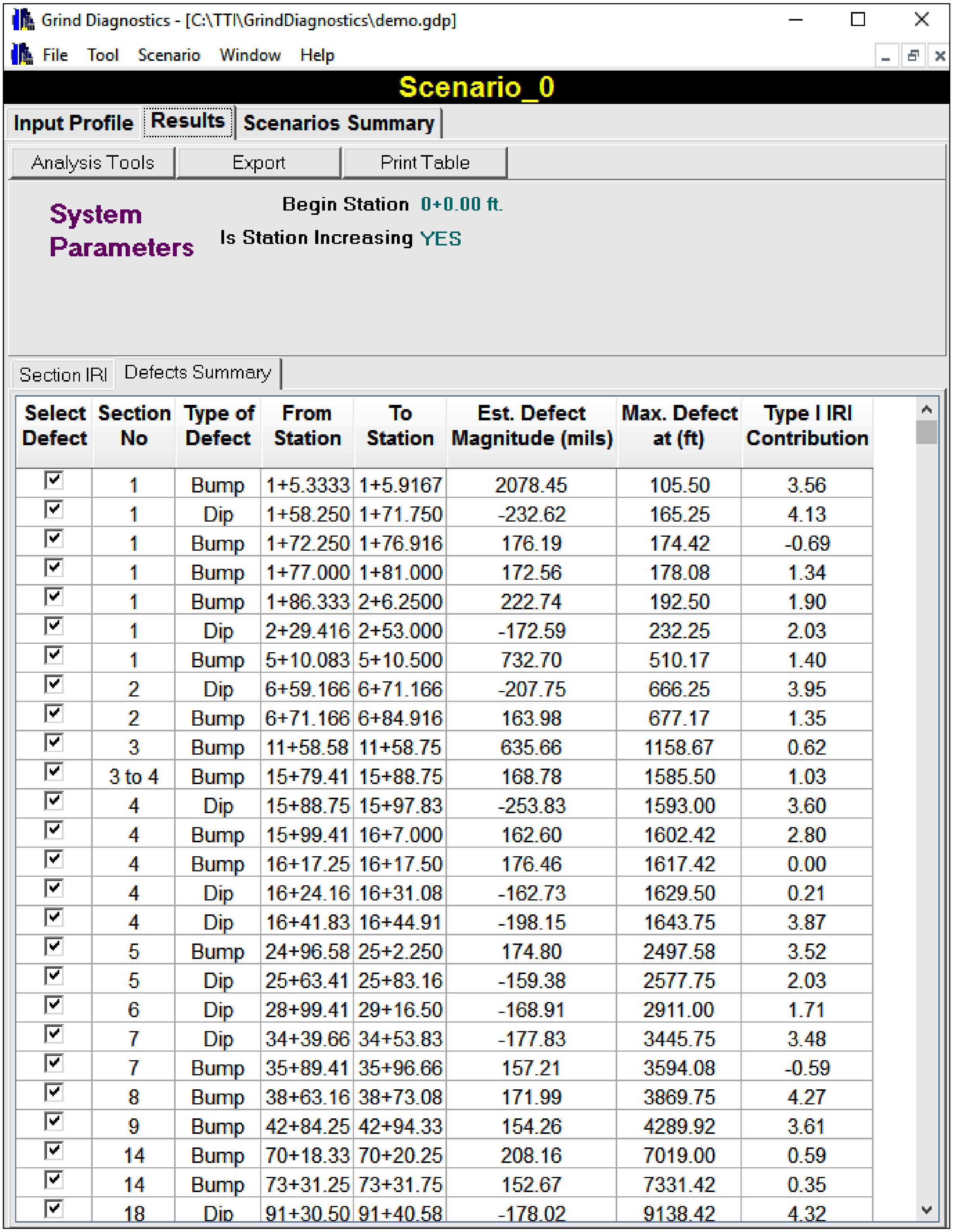
The *Results* page presents the results from the profile analysis. It also summarizes the results by section (Figure 25) and by defect (Figure 26). Moreover, you can create a new scenario for evaluation by selecting a subset of defects to be fixed in the *Defects Summary* tab. The details will be described in the **Features of Grind Diagnostics** section.

The *Scenarios Summary* page reports the results of each scenario analysis associated with the current project. Figure 27 illustrates a case where only a single scenario is identified corresponding to the single analysis the user ran. The summary page will list all the scenarios generated from the analyses done by the user. Further information on this page will be provided in the **Features of Grind Diagnostics** section.



Section No	From Station (ft)	To Station (ft)	Section IRI	Projected IRI
1	0+0.0000	5+28.0000	124.40	107.52
2	5+28.0000	10+56.000	74.70	68.70
3	10+56.000	15+84.000	52.93	52.35
4	15+84.000	21+12.000	77.89	65.20
5	21+12.000	26+40.000	67.25	61.72
6	26+40.000	31+68.000	60.79	59.08
7	31+68.000	36+96.000	65.64	62.75
8	36+96.000	42+24.000	67.51	63.24
9	42+24.000	47+52.000	44.15	40.54
10	47+52.000	52+80.000	42.34	42.34
11	52+80.000	58+8.0000	46.54	46.54
12	58+8.0000	63+36.000	60.50	60.50
13	63+36.000	68+64.000	52.33	52.33
14	68+64.000	73+92.000	48.35	47.40
15	73+92.000	79+20.000	49.41	49.41
16	79+20.000	84+48.000	57.90	57.90
17	84+48.000	89+76.000	55.45	55.45
18	89+76.000	95+4.0000	119.16	95.12
19	95+4.0000	100+32.00	96.10	91.70
20	100+32.00	105+60.00	94.72	82.27
21	105+60.00	110+88.00	85.15	70.00
22	110+88.00	115+48.00	116.29	83.45

Figure 25. Section IRI Tab of Results Page.



Select Defect	Section No	Type of Defect	From Station	To Station	Est. Defect Magnitude (mils)	Max. Defect at (ft)	Type I IRI Contribution
☑	1	Bump	1+5.3333	1+5.9167	2078.45	105.50	3.56
☑	1	Dip	1+58.250	1+71.750	-232.62	165.25	4.13
☑	1	Bump	1+72.250	1+76.916	176.19	174.42	-0.69
☑	1	Bump	1+77.000	1+81.000	172.56	178.08	1.34
☑	1	Bump	1+86.333	2+6.2500	222.74	192.50	1.90
☑	1	Dip	2+29.416	2+53.000	-172.59	232.25	2.03
☑	1	Bump	5+10.083	5+10.500	732.70	510.17	1.40
☑	2	Dip	6+59.166	6+71.166	-207.75	666.25	3.95
☑	2	Bump	6+71.166	6+84.916	163.98	677.17	1.35
☑	3	Bump	11+58.58	11+58.75	635.66	1158.67	0.62
☑	3 to 4	Bump	15+79.41	15+88.75	168.78	1585.50	1.03
☑	4	Dip	15+88.75	15+97.83	-253.83	1593.00	3.60
☑	4	Bump	15+99.41	16+7.000	162.60	1602.42	2.80
☑	4	Bump	16+17.25	16+17.50	176.46	1617.42	0.00
☑	4	Dip	16+24.16	16+31.08	-162.73	1629.50	0.21
☑	4	Dip	16+41.83	16+44.91	-198.15	1643.75	3.87
☑	5	Bump	24+96.58	25+2.250	174.80	2497.58	3.52
☑	5	Dip	25+63.41	25+83.16	-159.38	2577.75	2.03
☑	6	Dip	28+99.41	29+16.50	-168.91	2911.00	1.71
☑	7	Dip	34+39.66	34+53.83	-177.83	3445.75	3.48
☑	7	Bump	35+89.41	35+96.66	157.21	3594.08	-0.59
☑	8	Bump	38+63.16	38+73.08	171.99	3869.75	4.27
☑	9	Bump	42+84.25	42+94.33	154.26	4289.92	3.61
☑	14	Bump	70+18.33	70+20.25	208.16	7019.00	0.59
☑	14	Bump	73+31.25	73+31.75	152.67	7331.42	0.35
☑	18	Dip	91+30.50	91+40.58	-178.02	9138.42	4.32

Figure 26. Defects Summary Tab of Results Page.

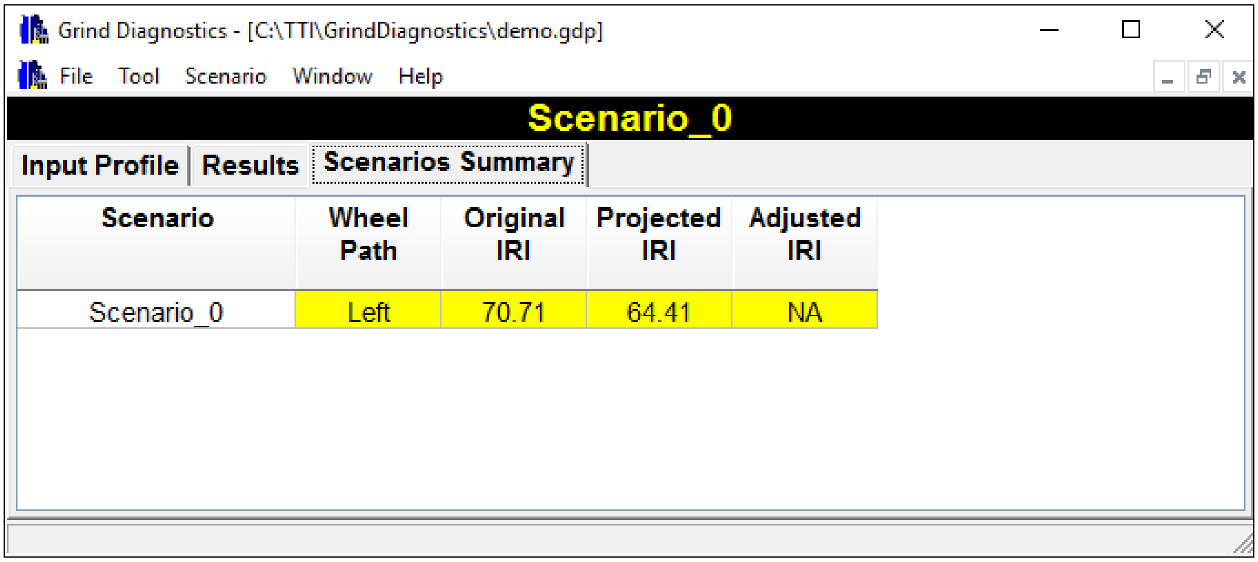


Figure 27. Scenarios Summary Page.

Before closing the application, you may want to save the results of all the analyses you have performed. To do so, click *Save Project* under *File* menu. Then close the project by choosing *Close* under *File* menu. If you want to review the results again, click *Open Grind Project* under *File* menu to open the corresponding project. Once the project data are loaded, you will see a screen similar to that shown in Figure 28. You can review the results by navigating to different tab pages and perform further analyses.

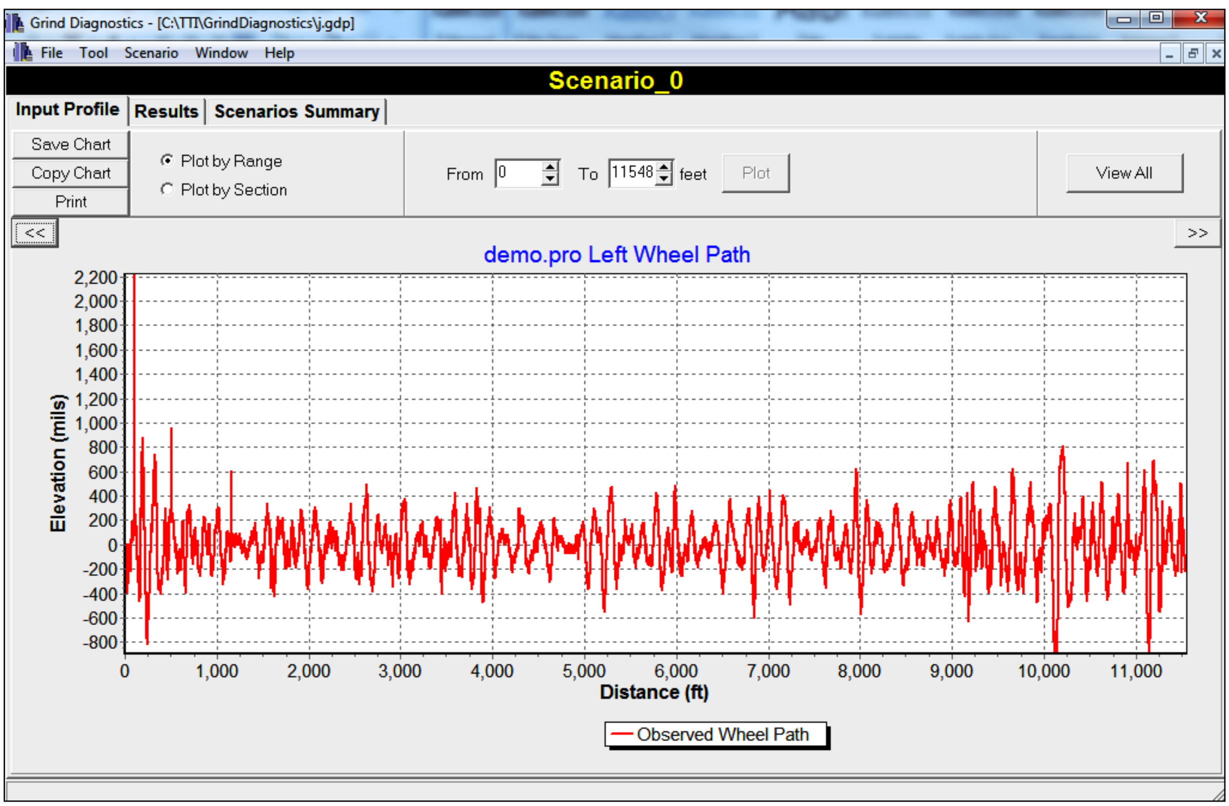


Figure 28. Screen Displayed when Opening a Project File.

FEATURES OF GRIND DIAGNOSTICS

Menu Bar

The menu bar is composed of five menus: *File*, *Tool*, *Scenario*, *Window*, and *Help*.

File Menu

This menu provides the options to open, save, and close both the profile file (*.pro) and the Grind Diagnostics Project file (*.gdp). In addition, this menu maintains a list of up to the five most recent files that you can open by a simple click. Figure 29 shows the items under *File* menu.

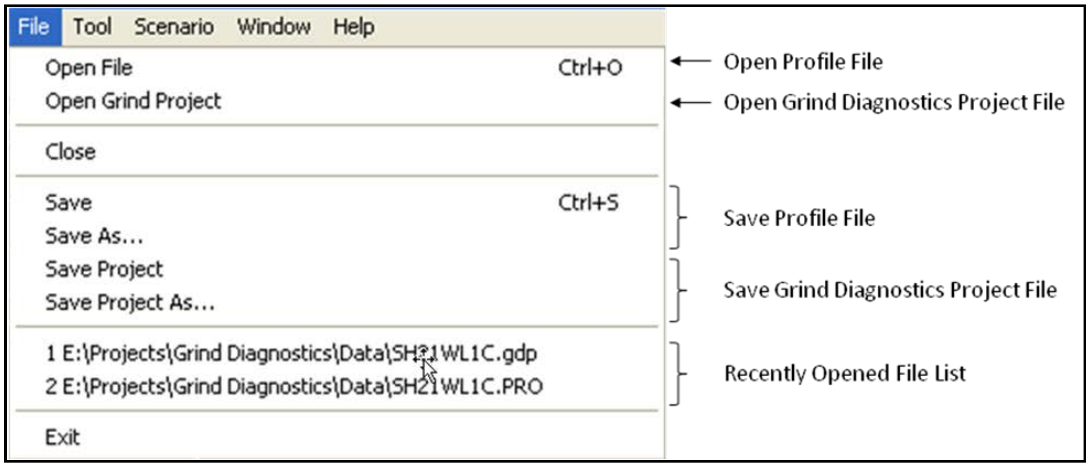
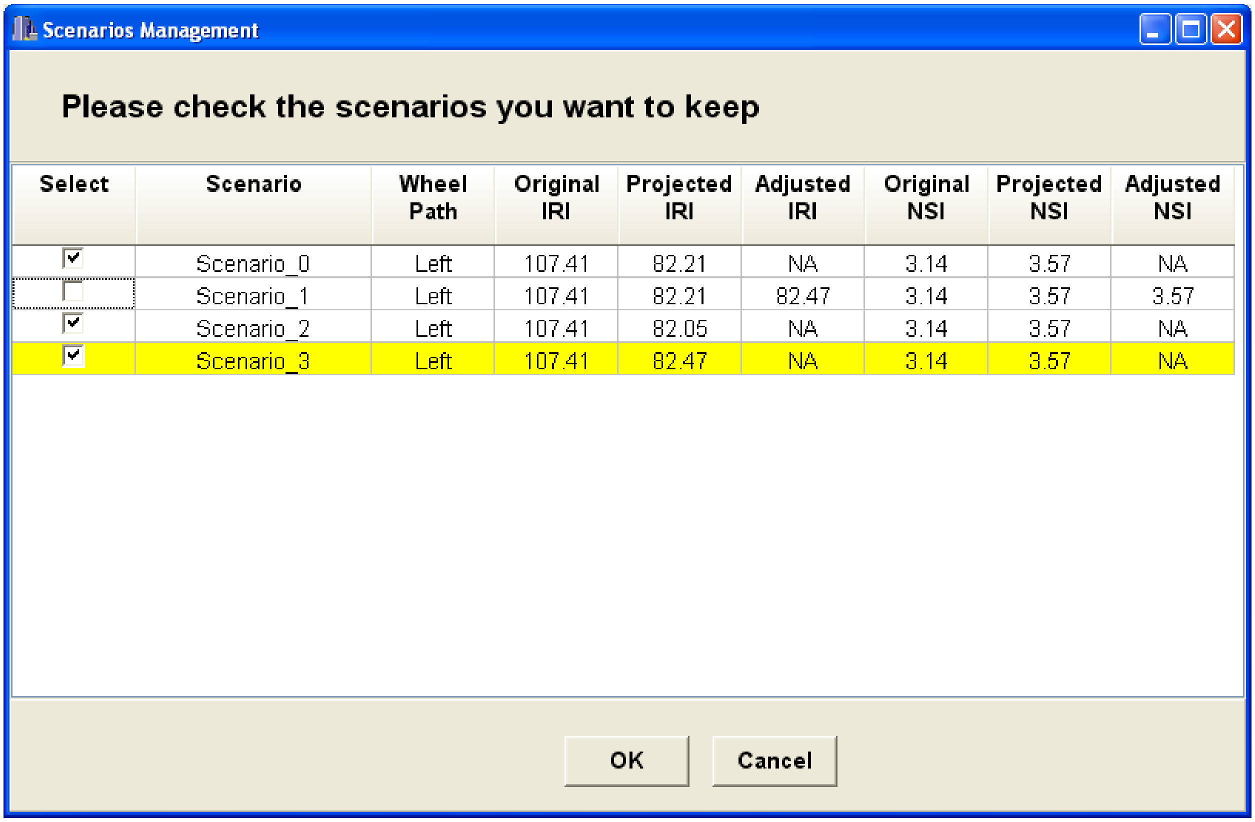


Figure 29. File Menu.

If you have done only one analysis (i.e., there is only one scenario), the program will save the corresponding results of that scenario automatically when you click *Save Project* or *Save Project As*. However, if there is more than one scenario associated with the current project, choosing *Save Project* or *Save Project As* will activate the window shown in Figure 30. This window allows you to choose which scenarios to save. For example, if you uncheck the checkbox for Scenario_1 (as illustrated in Figure 30) and click the *OK* button, the program will save the results of Scenario_0, Scenario_2, and Scenario_3 to the project. The results corresponding to Scenario_1 will be discarded.



Select	Scenario	Wheel Path	Original IRI	Projected IRI	Adjusted IRI	Original NSI	Projected NSI	Adjusted NSI
☑	Scenario_0	Left	107.41	82.21	NA	3.14	3.57	NA
☐	Scenario_1	Left	107.41	82.21	82.47	3.14	3.57	3.57
☑	Scenario_2	Left	107.41	82.05	NA	3.14	3.57	NA
☑	Scenario_3	Left	107.41	82.47	NA	3.14	3.57	NA

Figure 30. Window for Selecting Scenarios to Save.

Tool Menu

This menu consists of two useful tools, *Analyzer* and *Header*. *Analyzer* allows you to perform Grind Diagnostics on the selected profile. When you click on *Analyzer*, the program activates the window shown in Figure 31. This window allows you to specify which wheel path to analyze. In addition, the window allows users to input the beginning station of the profile to be analyzed and to specify whether the station numbers increase or decrease from the beginning of the profile.

In addition to the *Analyzer* function in the Tool menu, the *Header* function activates a window that displays the header card information in the active PRO file. You can update the header information in this window and replace the existing PRO file or save to a new PRO data file via the *File* menu. Figure 32 shows an example of the *Header* window.

Scenario Menu

When an analysis is executed, the program will create a new scenario that is associated with the analysis results. This menu provides three useful scenario management options that allow you to load, delete, or rename a scenario. If you run more than one analysis corresponding to the current profile, you can view the results of each analysis by using the *Load* option. When *Load* is highlighted, the program displays a submenu that contains a list of available scenarios. Simply click on the desired scenario on the submenu, and the program will load and display the corresponding results for your review. Figure 33 illustrates an example where one of three scenarios may be selected for viewing using the *Load* option.

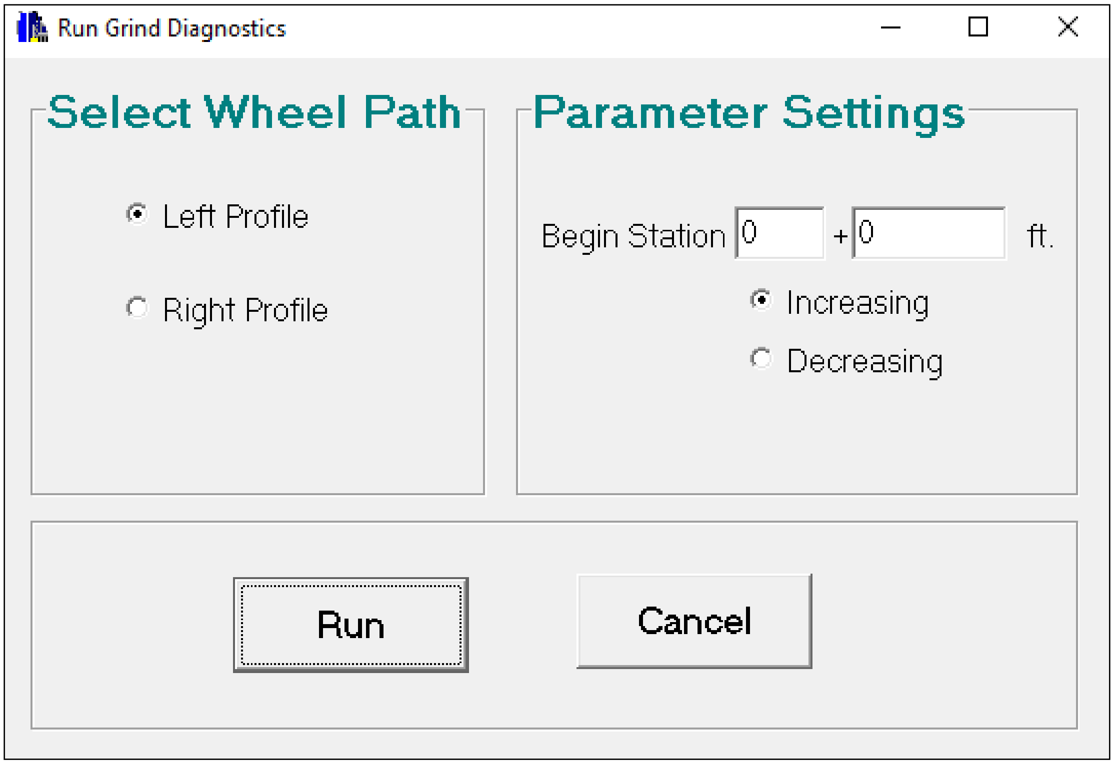


Figure 31. Grind Diagnostics Analyzer Window.

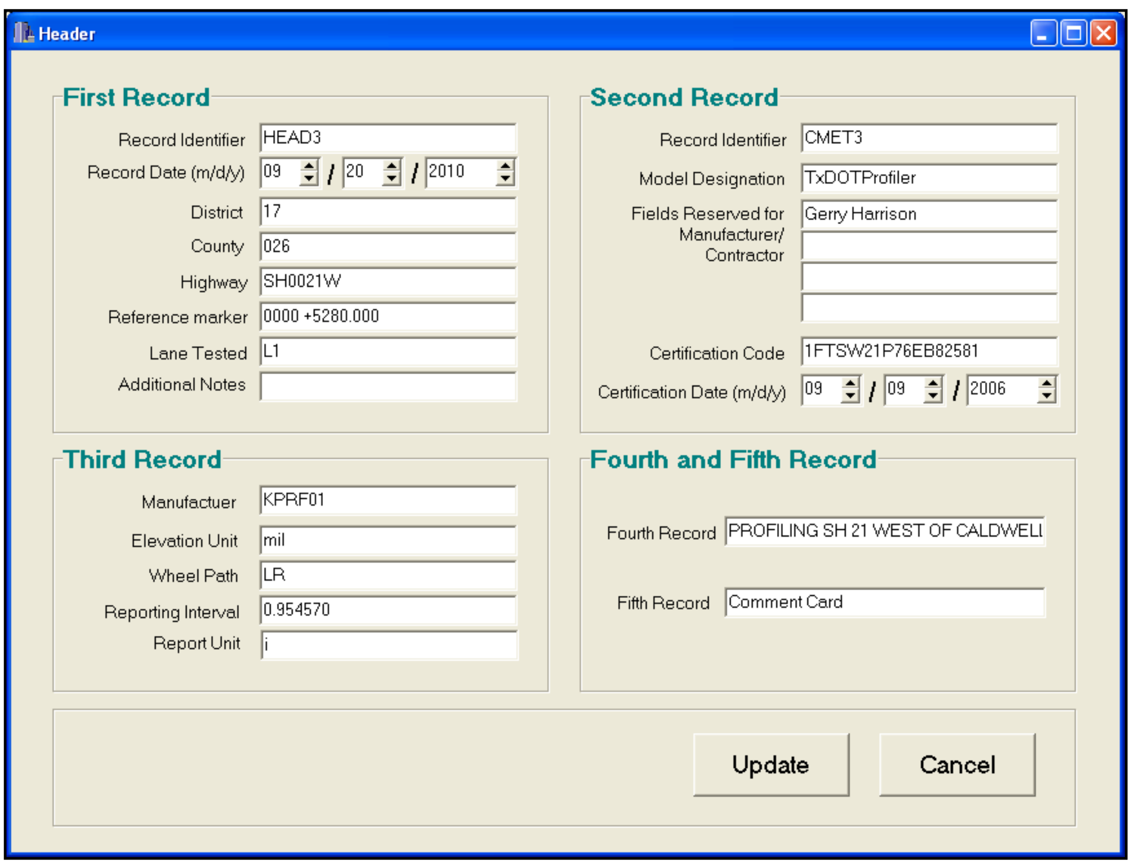


Figure 32. Header Window.

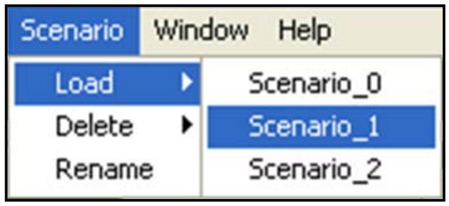


Figure 33. Illustration of the Scenario Load Menu.

After reviewing the results of an analysis, you may decide not to keep that scenario. The procedure of removing a scenario is similar to that of loading one. To remove a scenario, click *Delete* under the *Scenario* menu and a submenu with a list of available scenarios will appear. Click on the scenario name from the list, and the program will delete that scenario and the corresponding results. Figure 34 shows an example where one of three scenarios may be selected for removal using the *Delete* option.

Figure 34. Illustration of Scenario Delete Menu.

As mentioned previously, when a new scenario is created, the program will assign a default name to the scenario. However, you may want to use a meaningful name for easy reference. *Rename* allows you to change the name of the currently loaded scenario. If you want to rename another scenario, load that scenario first. After the scenario is loaded, you can rename the scenario by clicking *Rename* under the *Scenario* menu.

Window Menu

This menu provides alternatives for organizing the screen if multiple documents are opened. *Cascade* stacks windows for all data files currently open. *Tile Horizontally* sizes the windows equally and displays them one above the other, while *Tile Vertically* sizes the windows equally and displays them side by side on the screen. Also, this menu displays a list of currently opened data files that allows you to switch between data sets as you wish. Figure 35 illustrates the *Window* menu.

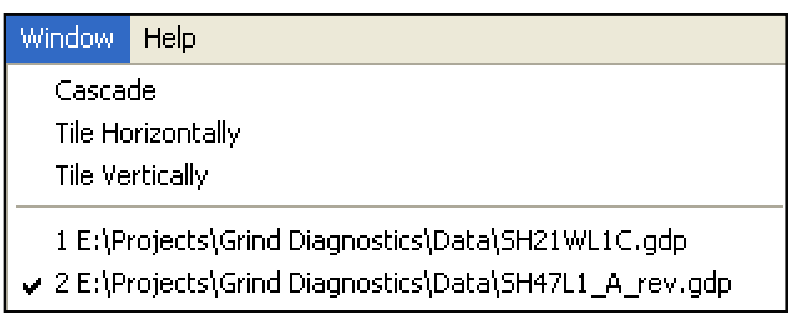


Figure 35. Window Menu.

Help Menu

As shown in Figure 36, this menu allows you to access the user's guide and view the information about Grind Diagnostics. To consult the user's guide, click on *User's Guide* to view the document in PDF format. Major topics of the user's guide are bookmarked in the PDF file to facilitate navigation of the document. The bookmarks can be viewed by clicking the bookmark tab in Acrobat Reader.

Figure 36. Help Menu.

When choosing the *About…* option under the *Help* menu, the program will activate a window with the version and copyright information about Grind Diagnostics, as shown in Figure 37.

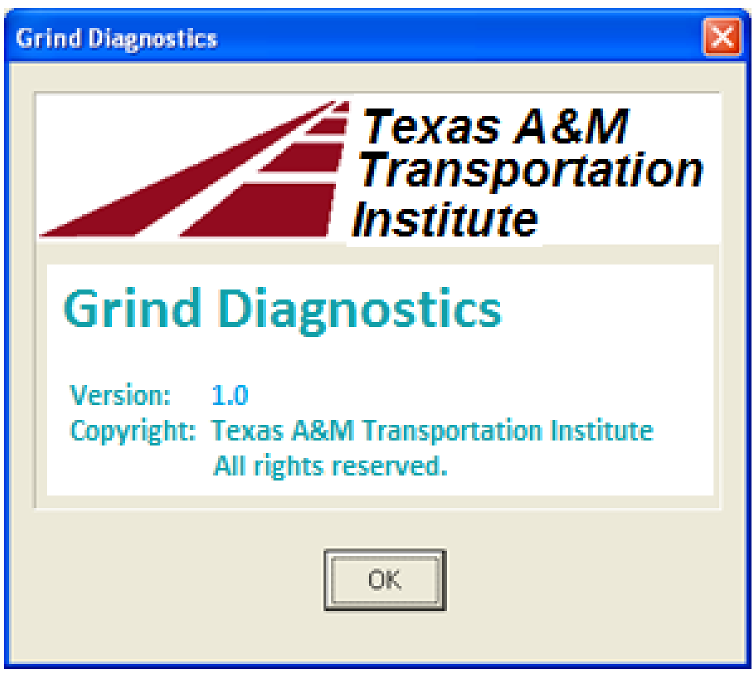


Figure 37. Program Information Window.

Tab Pages

Input Profile Tab Page

This tab page displays a chart of the selected wheel path profile. In addition, Grind Diagnostics provides different features related to the chart to help you analyze the profile. Figure 38 shows a screenshot of this tab page.

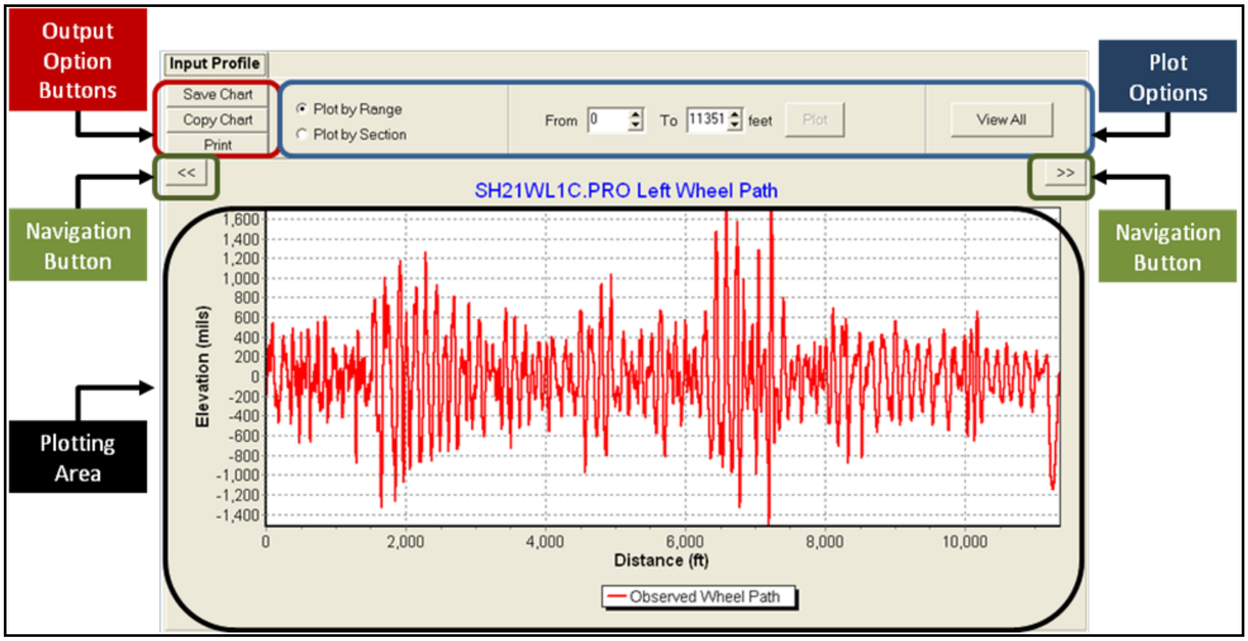


Figure 38. Input Profile Tab Page.

To have a closer look at the wheel path profile, you can review the chart using the plot options and navigation buttons. For example, if you want to review the chart every 1000 ft, choose *Plot by Range*, specify the viewing range on the top panel, and click *Plot*. Then, you will see a chart similar to the one shown in Figure 39. You can use the navigation buttons to review the wheel path profile of the previous/next 1000 ft. Similarly, following the same procedure, you can review the chart using the standard 582-ft section length of the TxDOT ride specifications. After reviewing the wheel path profile by range/section, you can view the complete wheel path profile again by clicking the *View All* button.

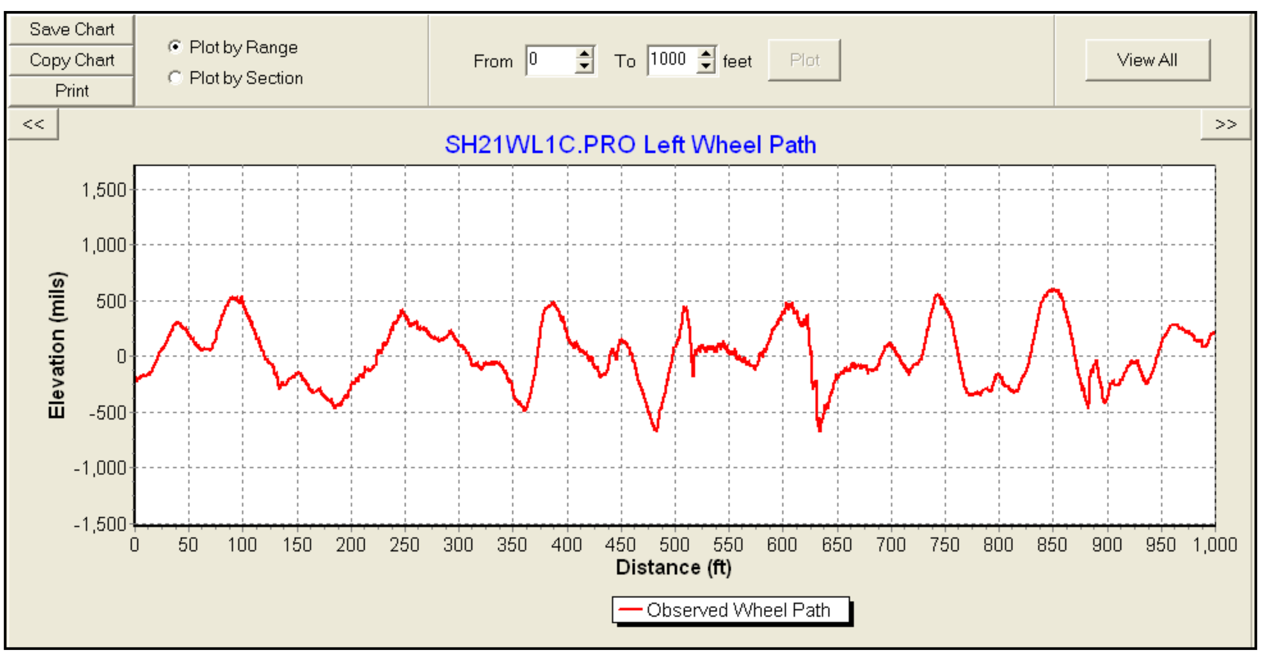


Figure 39. Illustration of Plot by Range.

An alternative for taking a closer look at the wheel path profile is via zoom-in. Left-click in the plotting area and move the mouse while holding the mouse's left-button. You will then see a black rectangular box identifying the area that the program will zoom in on (Figure 40). Release the button, and the program will enlarge that area and update the range on the top panel (Figure 41).

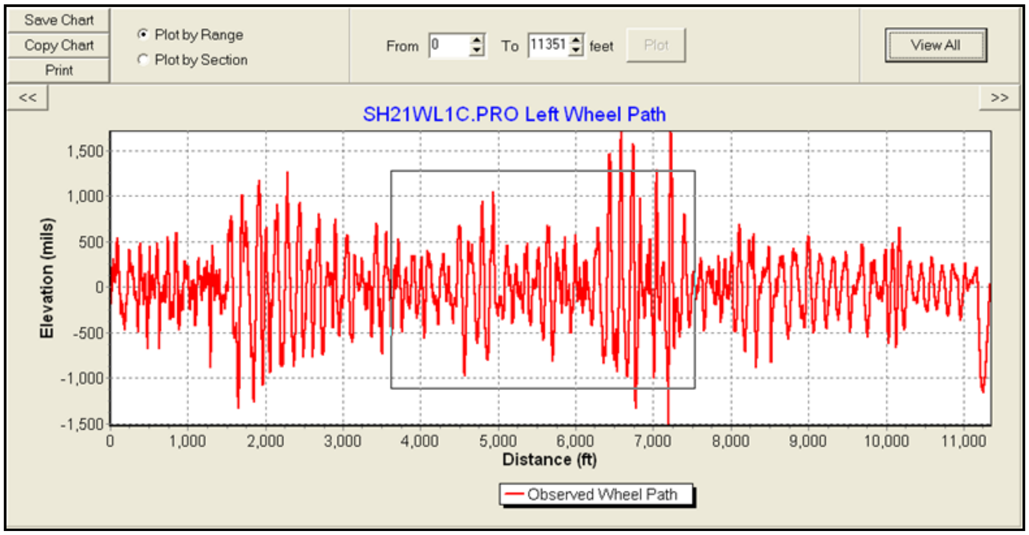


Figure 40. Illustration of Program Zoom-In Function.

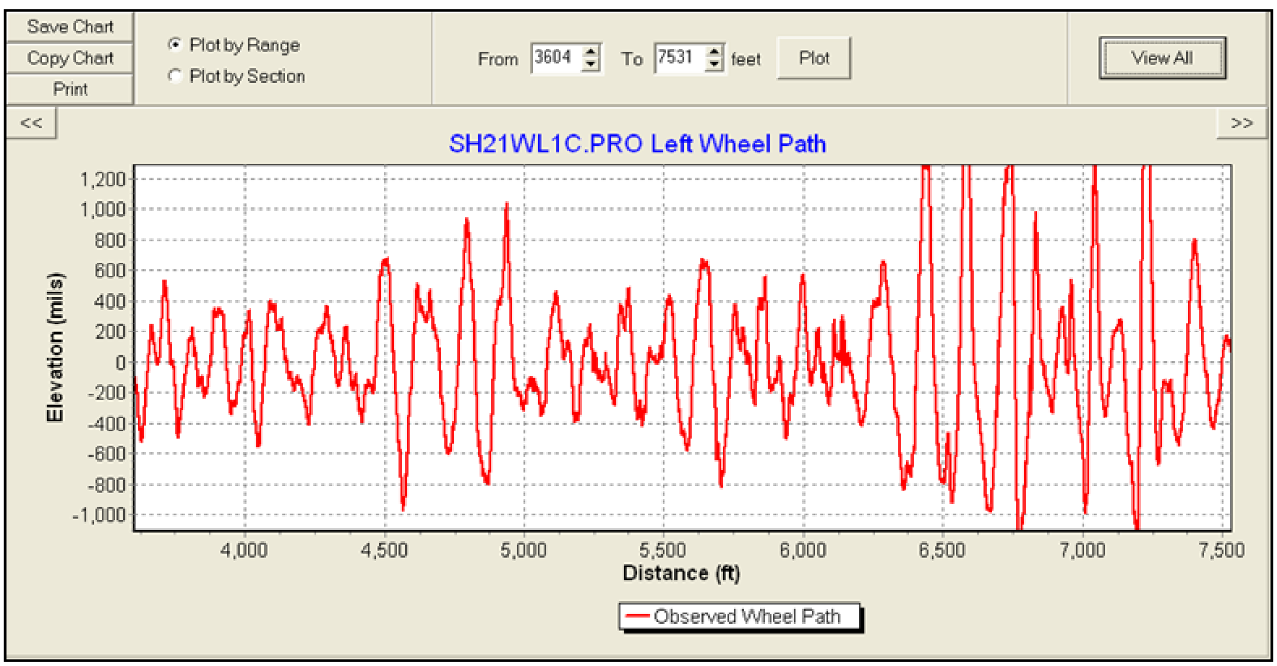


Figure 41. Result of Zoom-In Operation.

Alternatively, you can zoom in by right-clicking on the plotting area. Right-clicking on the plotting area will activate a menu, as shown in Figure 42. Three options are available in this menu (*Zoom In*, *Zoom Out*, and *View All*). *Zoom In* reduces the displayed distance range by 10 percent to show an enlarged chart that covers a smaller data range over the same screen area.

Zoom Out has the opposite effect. The *View All* option has the same function as the *View All* button and displays the complete wheel path profile.

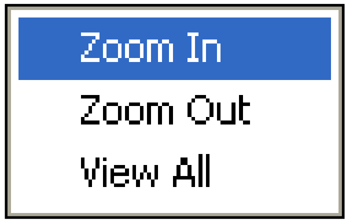


Figure 42. Zoom Menu.

Another feature associated with the plotting area is the pop-up information on the wheel path profile displayed on the screen. When the cursor rests on any point of the profile in the plotting area, the program will display a pop-up yellow box with the location and elevation coordinates at that point, as illustrated in Figure 43.

Finally, you can output the chart using one of the output option buttons located in the top left corner. *Save Chart* and *Copy Chart*, respectively, save and copy the chart using bitmap or metafile format. *Print* outputs the chart to a printer to provide you a hard copy for future reference.

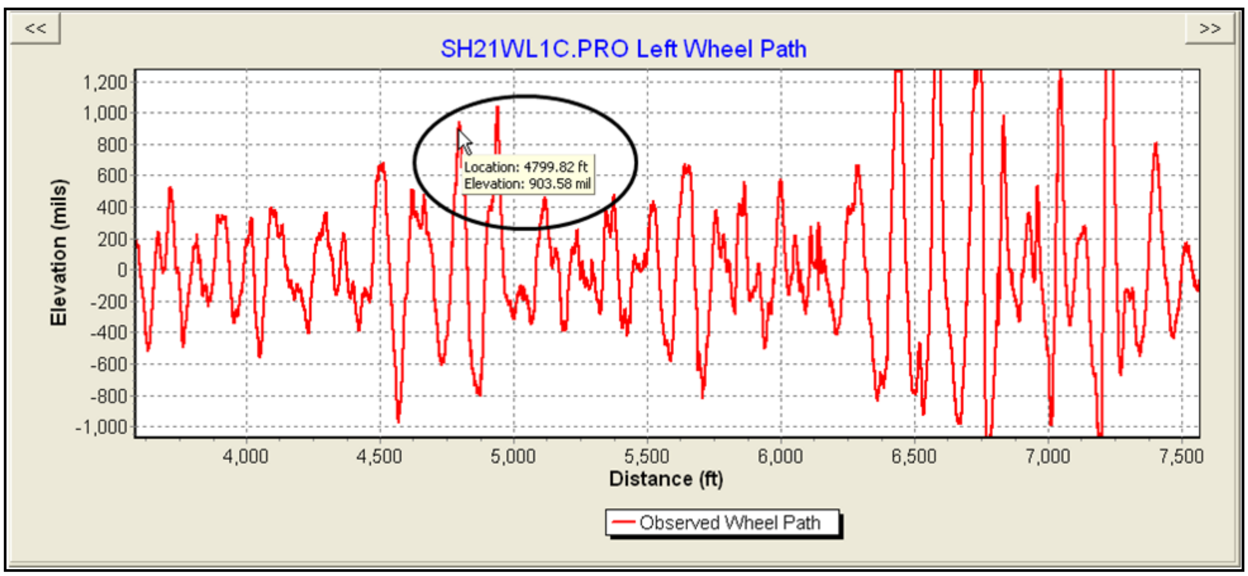


Figure 43. Pop-Up Wheel Path Information.

Results Tab Page

This tab page reports the results of the analysis on the chosen wheel path profile. It consists of three main sections: tools options, system parameters, and detailed report (Figure 44). The tools options section allows you to analyze the effect of fixing only a subset of defects and provides the options of exporting and printing the results. The details of the tools options section will be discussed later.

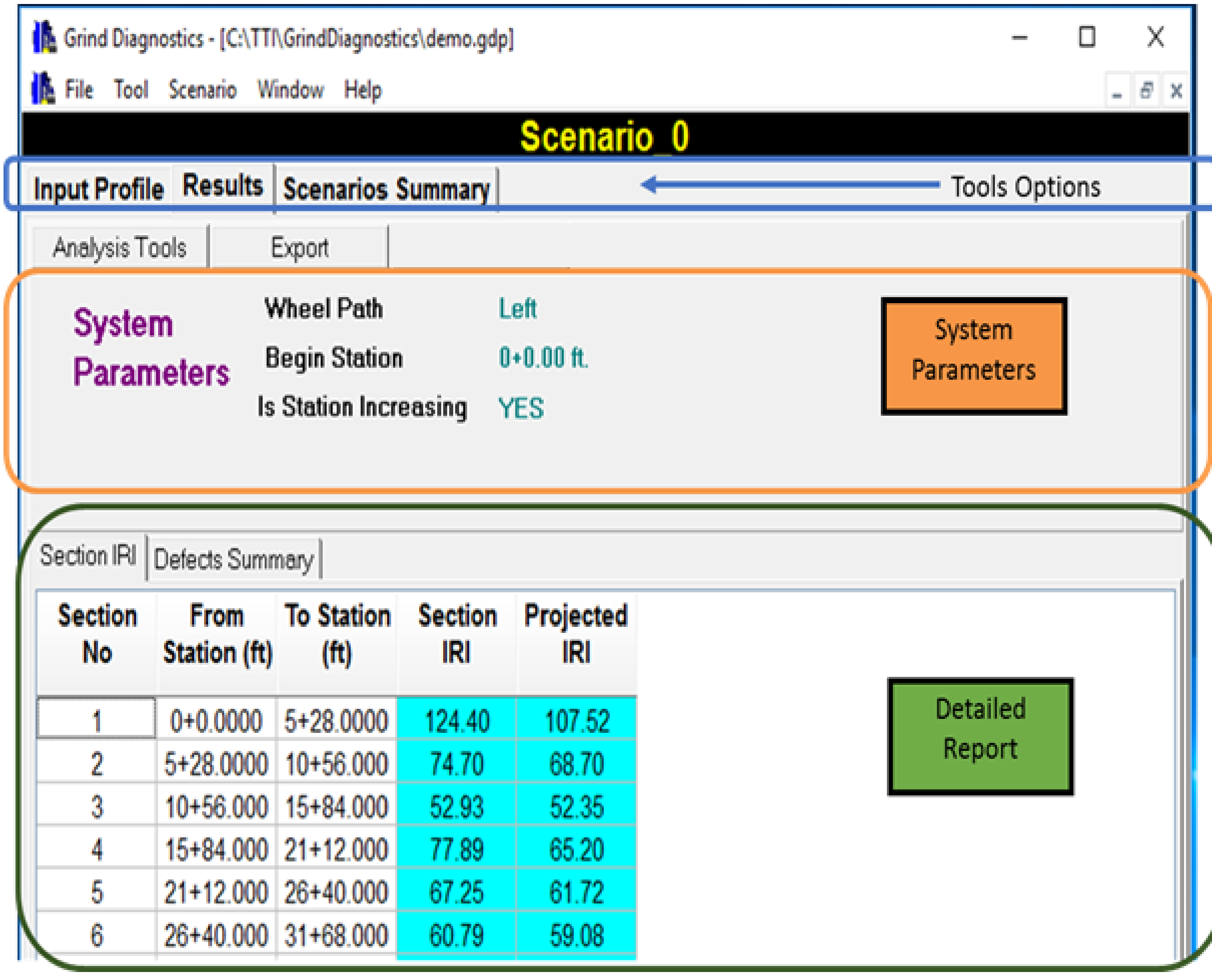


Figure 44. Results Tab Page.

The detailed report section provides two summary reports, the *Section IRI* report and the *Defects Summary* report. The *Section IRI* report summarizes the results of the analysis for each 528-ft section. As shown in Figure 45, this report presents information on the start and end points of each section and on the corresponding IRIs for both the existing profile and the simulated profile after corrections.

Section IRI | Defects Summary

Section No	From Station (ft)	To Station (ft)	Section IRI	Projected IRI
1	0+0.0000	5+28.0000	124.40	107.52
2	5+28.0000	10+56.000	74.70	68.70
3	10+56.000	15+84.000	52.93	52.35
4	15+84.000	21+12.000	77.89	65.20
5	21+12.000	26+40.000	67.25	61.72
6	26+40.000	31+68.000	60.79	59.08

Figure 45. Section IRI Report.

If you want to visually examine the actual and simulated profiles for a particular section, double-click on any cell corresponding to that section and the program will activate a pop-up chart, as shown in Figure 46. This chart has all the features described in the *Input Profile Tab Page* section. In addition, the chart provides an option for plotting the defect magnitude, which is defined as the difference between the elevation of the actual profile at a given location and the corresponding elevation based on the moving average profile. If this option is selected, the program will plot three additional line series—the defect magnitude profile and the upper and lower tolerance limits corresponding to the 150-mil threshold used in TxDOT's Item 585 ride specification. The corresponding y-axis for these line series is on the right-hand side of the plot, as illustrated in Figure 47.

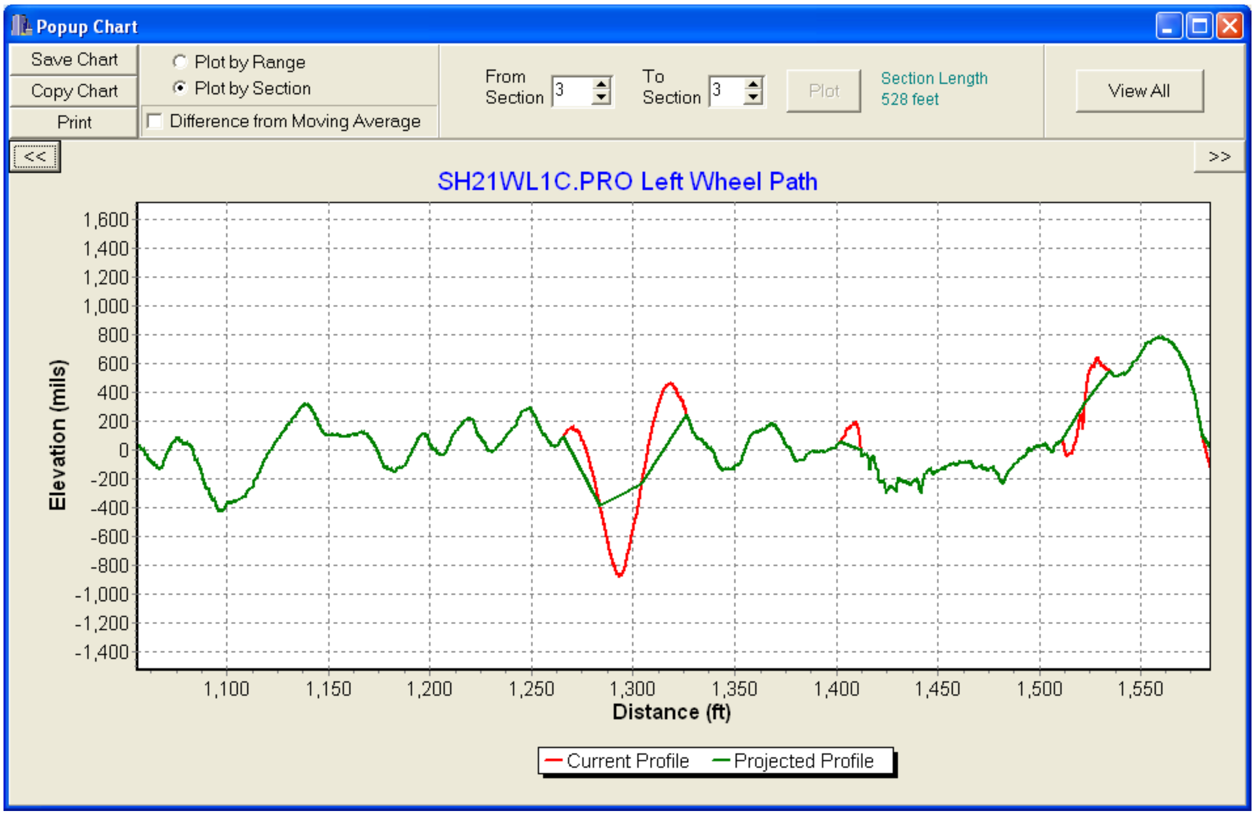


Figure 46. Profile Chart of a Section.

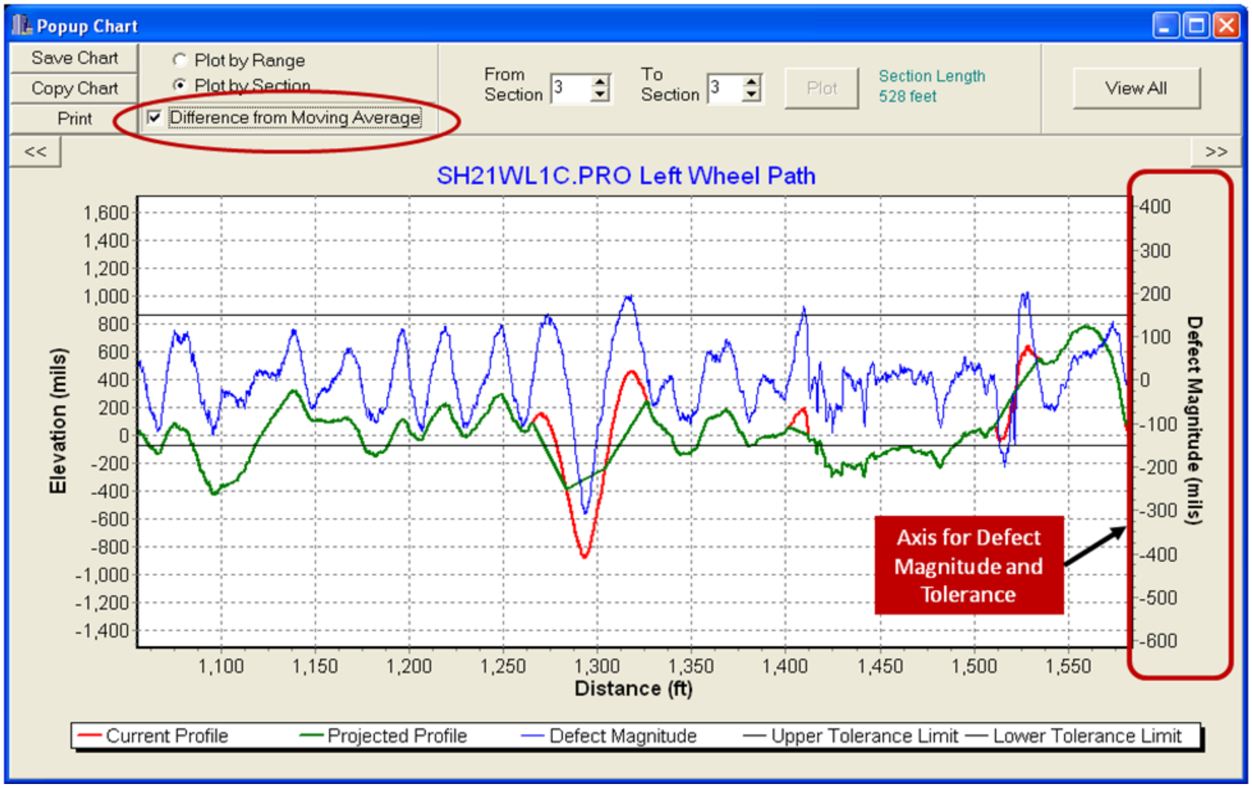


Figure 47. Profile Chart with Defect Magnitude Information.

The *Defects Summary* report presents the information on each defect identified by the program (Figure 48). The *Select Defect* column allows you to specify a subset of defects by checking/unchecking the related checkboxes for analyzing the effects of fixing only the selected defects. Columns 2 to 5 identify the location and type of the defect. The *Est. Defect Magnitude* and *Max. Defect at* columns report the estimated maximum defect magnitude and its corresponding location, respectively. The estimated defect magnitude is calculated as the maximum difference between the moving average profile obtained using the standard 25-ft moving average base length and the measured profile.

Figure 49 explains the Type I IRI contributions shown under the rightmost column of the *Defects Summary* report. As shown in this figure, the Type I IRI contribution is determined as the change in IRI caused by fixing a particular defect relative to the IRI determined from the existing section profile (with all of its defects). In this example, the IRI associated with the existing section profile (plotted at the top of Figure 49) is 208.42 in/mi. Also, note the bump illustrated at the bottom plot of the figure, located 7048 ft from the start of the profile. The projected profile if this bump is corrected gives an IRI of 194.08 in/mi. Given this information, the Type I contribution of the bump to the section IRI is calculated as the difference between the IRI of the existing profile and the estimated IRI after correcting the bump. In this particular example, this difference amounts to 14.34 in/mi. The Type I contribution is then seen as the potential reduction in IRI if only the given bump is corrected among the defects identified within the section.

Section IRI | Defects Summary

Select Defect	Section No	Type of Defect	From Station	To Station	Est. Defect Magnitude (mils)	Max. Defect at (ft)	Type I IRI Contribution
☑	1	Bump	1+5.3333	1+5.9167	2078.45	105.50	3.56
☑	1	Dip	1+58.250	1+71.750	-232.62	165.25	4.13
☑	1	Bump	1+72.250	1+76.916	176.19	174.42	-0.69
☑	1	Bump	1+77.000	1+81.000	172.56	178.08	1.34
☑	1	Bump	1+86.333	2+6.2500	222.74	192.50	1.90
☑	1	Dip	2+29.416	2+53.000	-172.59	232.25	2.03
☑	1	Bump	5+10.083	5+10.500	732.70	510.17	1.40
☑	2	Dip	6+59.166	6+71.166	-207.75	666.25	3.95
☑	2	Bump	6+71.166	6+84.916	163.98	677.17	1.35
☑	3	Bump	11+58.58	11+58.75	635.66	1158.67	0.62
☑	3 to 4	Bump	15+79.41	15+88.75	168.78	1585.50	1.03
☑	4	Dip	15+88.75	15+97.83	-253.83	1593.00	3.60
☑	4	Bump	15+99.41	16+7.000	162.60	1602.42	2.80
☑	4	Bump	16+17.25	16+17.50	176.46	1617.42	0.00
☑	4	Dip	16+24.16	16+31.08	-162.73	1629.50	0.21
☑	4	Dip	16+41.83	16+44.91	-198.15	1643.75	3.87
☑	5	Bump	24+96.58	25+2.250	174.80	2497.58	3.52
☑	5	Dip	25+63.41	25+83.16	-159.38	2577.75	2.03
☑	6	Dip	28+99.41	29+16.50	-168.91	2911.00	1.71
☑	7	Dip	34+39.66	34+53.83	-177.83	3445.75	3.48
☑	7	Bump	35+89.41	35+96.66	157.21	3594.08	-0.59
☑	8	Bump	38+63.16	38+73.08	171.99	3869.75	4.27
☑	9	Bump	42+84.25	42+94.33	154.26	4289.92	3.61
☑	14	Bump	70+18.33	70+20.25	208.16	7019.00	0.59
☑	14	Bump	73+31.25	73+31.75	152.67	7331.42	0.35
☑	18	Dip	91+30.50	91+40.58	-178.02	9138.42	4.32
☑	18	Bump	91+62.50	91+72.41	410.88	9165.67	8.29
☑	18	Dip	91+72.83	91+86.41	-316.74	9180.00	2.37
☑	18	Bump	92+31.16	92+31.58	152.97	9231.50	-0.03
☑	18	Dip	92+57.16	92+65.08	-154.66	9260.67	1.29
☑	18	Dip	94+24.75	94+38.25	-220.28	9430.58	5.42
☑	19	Dip	96+87.58	97+0.500	-242.01	9694.33	2.25

Figure 48. Defects Summary Report.

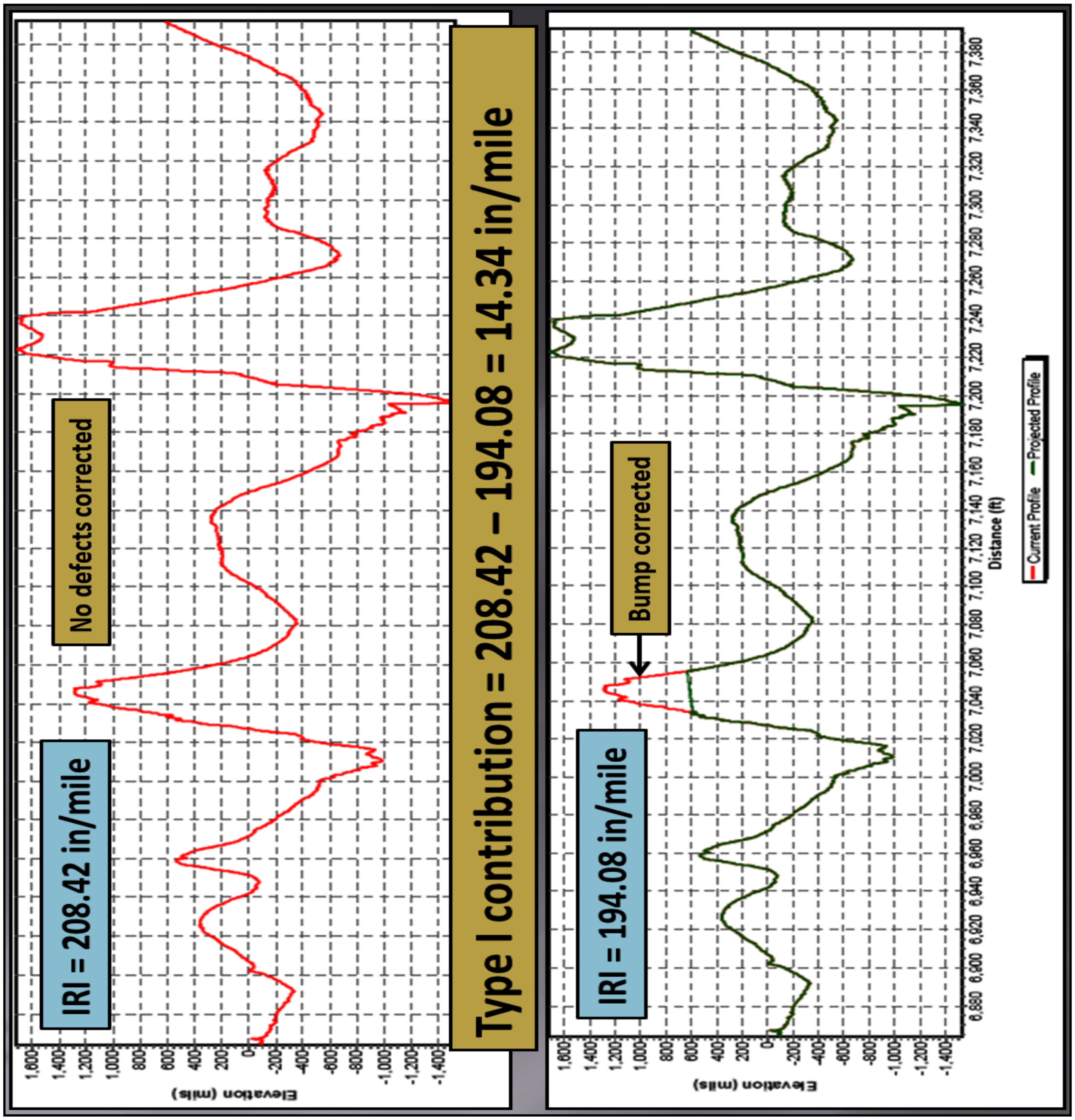


Figure 49. Calculation of Type I Contribution to the Section IRI.

Similar to the *Section IRI* report, you can visually examine the actual and simulated corrected profiles for a particular defect. To view the profile plot, double-click along the row of the defect (except under the *Select Defect* column). The program will then activate a pop-up window, as illustrated in Figure 50.

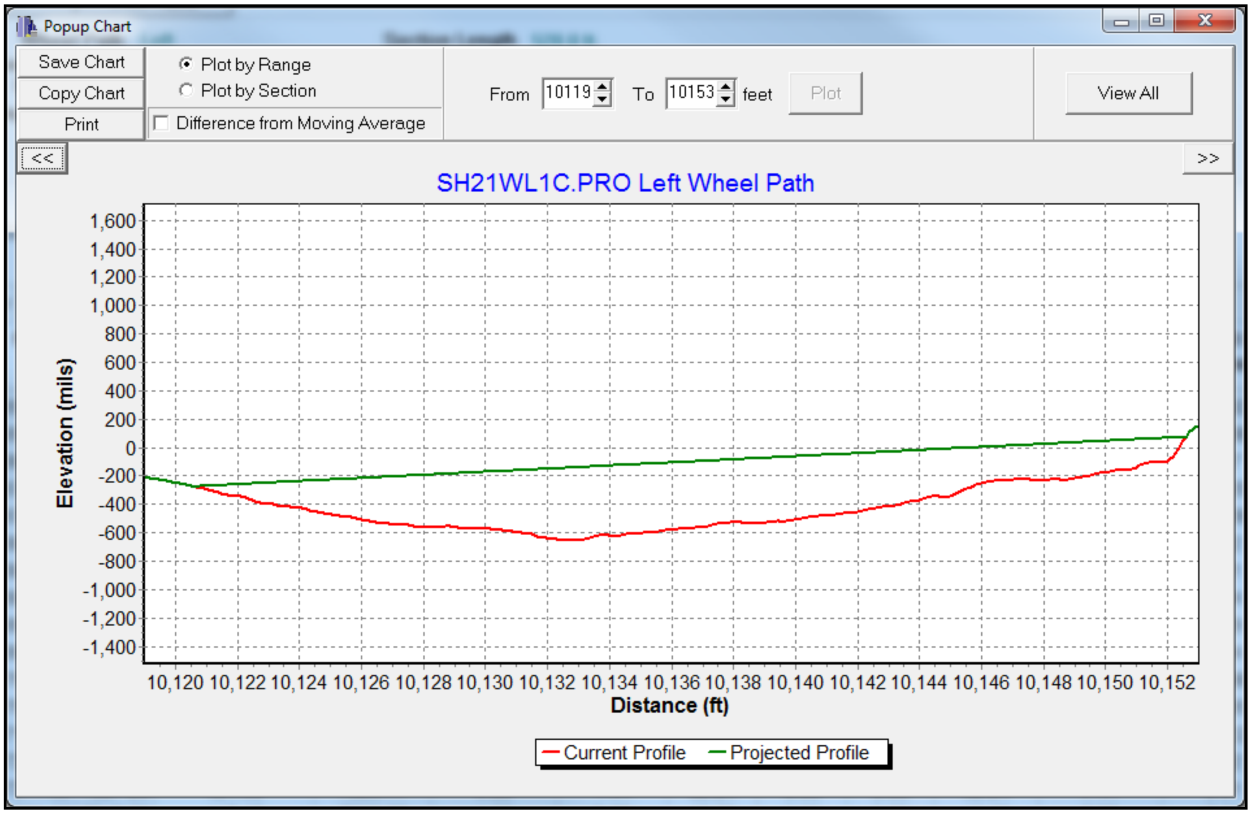


Figure 50. Profile Chart of a Defect.

In addition, the *Results Tab Page* provides a couple of useful features under the *Tools Options* bar, shown in Figure 44. When you click on the *Analysis Tools* button, the program will activate the menu shown in Figure 51, with functions that help you analyze a subset of defects. As mentioned previously, you can select a subset of defects for further analysis by checking/unchecking the checkboxes under the *Select Defect* column. To facilitate this manual checking/unchecking process, the first two options in the *Analysis Tools* menu provide a convenient way to select all bumps or all dips. The third option is to select the defects that need corrective work based on the DCI, which will be explained later in this user's guide. You can also select or unselect all defects, shown as the fourth and the fifth option, respectively. Once the desired set of defects is selected, you can have the program analyze the selected defects by clicking *Analyze Selected Defects*. The program will then run the analysis and create a new scenario associated with the selected defects.

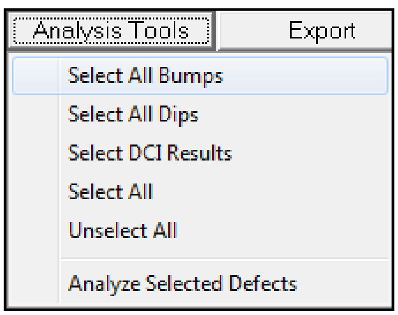


Figure 51. Analysis Tools Menu.

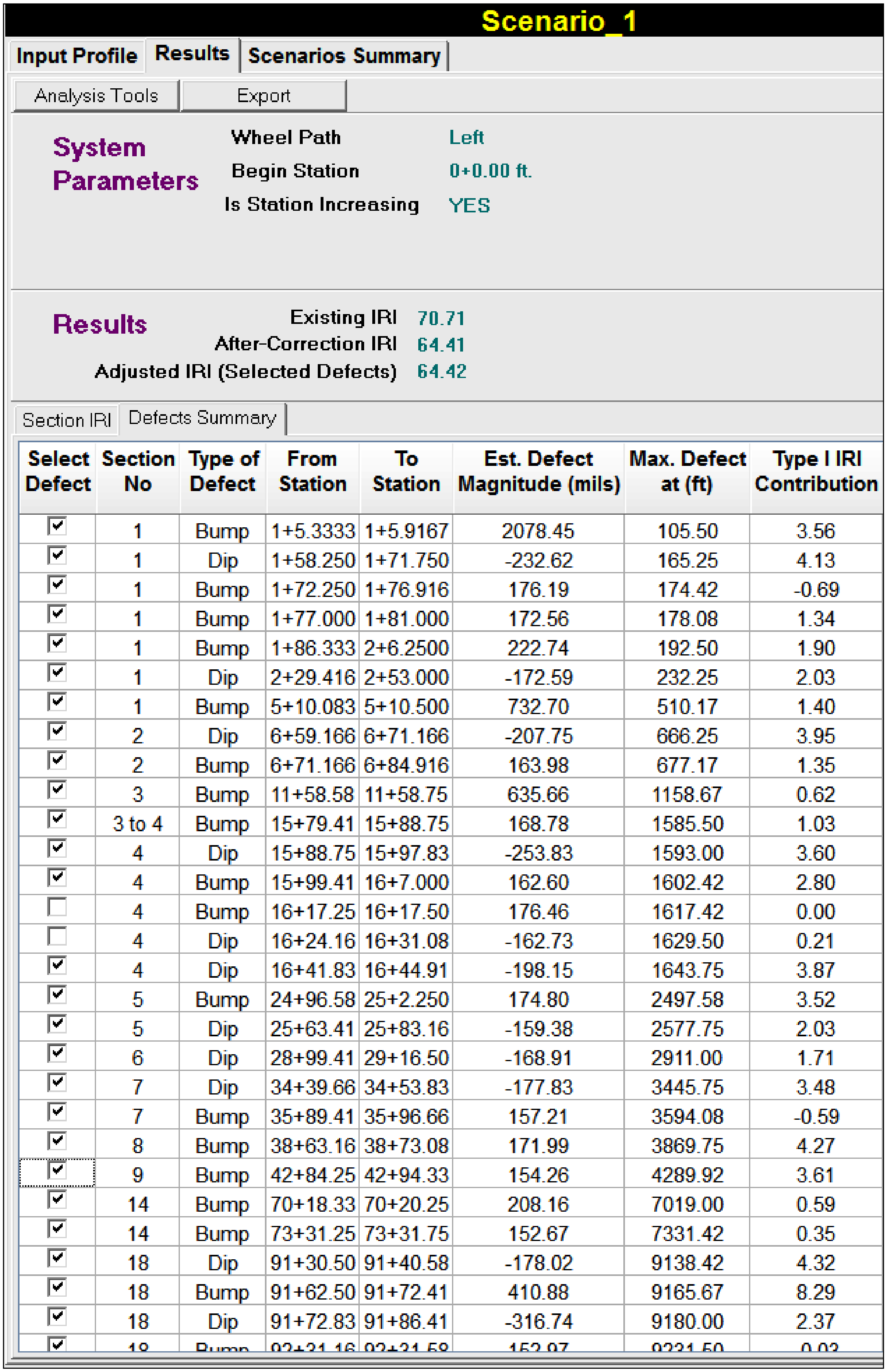
For example, after performing the analysis, the program identifies one bump and one dip in Section 4 that are close to each other. The Type I contributions of these defects to the section IRI are relatively insignificant (Figure 52). In that case, you may decide to uncheck the checkboxes associated with these two defects and rerun the analysis.

Section IRI | Defects Summary

Select Defect	Section No	Type of Defect	From Station	To Station	Est. Defect Magnitude (mils)	Max. Defect at (ft)	Type I IRI Contribution
☑	1	Bump	1+5.3333	1+5.9167	2078.45	105.50	3.56
☑	1	Dip	1+58.250	1+71.750	-232.62	165.25	4.13
☑	1	Bump	1+72.250	1+76.916	176.19	174.42	-0.69
☑	1	Bump	1+77.000	1+81.000	172.56	178.08	1.34
☑	1	Bump	1+86.333	2+6.2500	222.74	192.50	1.90
☑	1	Dip	2+29.416	2+53.000	-172.59	232.25	2.03
☑	1	Bump	5+10.083	5+10.500	732.70	510.17	1.40
☑	2	Dip	6+59.166	6+71.166	-207.75	666.25	3.95
☑	2	Bump	6+71.166	6+84.916	163.98	677.17	1.35
☑	3	Bump	11+58.58	11+58.75	635.66	1158.67	0.62
☑	3 to 4	Bump	15+79.41	15+88.75	168.78	1585.50	1.03
☑	4	Dip	15+88.75	15+97.83	-253.83	1593.00	3.60
☑	4	Bump	15+99.41	16+7.000	162.60	1602.42	2.80
☑	4	Bump	16+17.25	16+17.50	176.46	1617.42	0.00
☑	4	Dip	16+24.16	16+31.08	-162.73	1629.50	0.21
☑	4	Dip	16+41.83	16+44.91	-198.15	1643.75	3.87
☑	5	Bump	24+96.58	25+2.250	174.80	2497.58	3.52
☑	5	Dip	25+63.41	25+83.16	-159.38	2577.75	2.03
☑	6	Dip	28+99.41	29+16.50	-168.91	2911.00	1.71
☑	7	Dip	34+39.66	34+53.83	-177.83	3445.75	3.48
☑	7	Bump	35+89.41	35+96.66	157.21	3594.08	-0.59
☑	8	Bump	38+63.16	38+73.08	171.99	3869.75	4.27
☑	9	Bump	42+84.25	42+94.33	154.26	4289.92	3.61
☑	14	Bump	70+18.33	70+20.25	208.16	7019.00	0.59
☑	14	Bump	73+31.25	73+31.75	152.67	7331.42	0.35
☑	18	Dip	91+30.50	91+40.58	-178.02	9138.42	4.32
☑	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

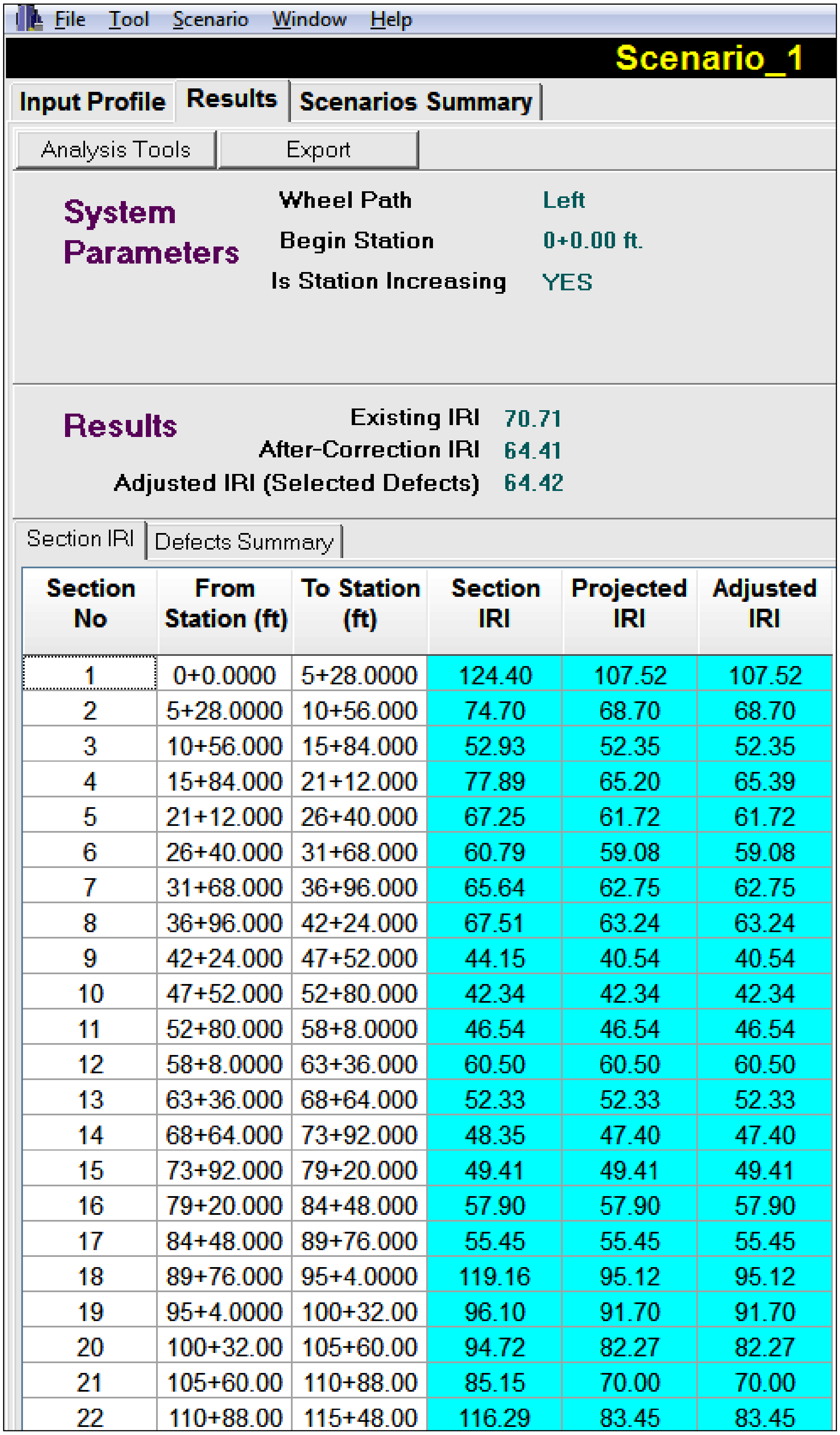
Figure 52. Adjacent Defects with Small Type I IRI Contributions.

You will then see a screen similar to that shown in Figure 53. The program gives a different scenario name for this analysis, which in this example is *Scenario_1*, as shown on top of the figure. Also, the program estimates the overall IRI of the wheel path profile for this analysis and reports this estimate as the *Adjusted IRI* (*Selected Defects*). In contrast to the *After-Correction IRI*, which corresponds to the estimated IRI for the entire wheel path profile with all defects corrected, the adjusted IRI is determined based only on the selected defects. In addition, the program determines the adjusted IRI of each section for the specified subset of defects and incorporates them as part of the *Section IRI* report (Figure 54).



Select Defect	Section No	Type of Defect	From Station	To Station	Est. Defect Magnitude (mils)	Max. Defect at (ft)	Type I IRI Contribution
☑	1	Bump	1+5.3333	1+5.9167	2078.45	105.50	3.56
☑	1	Dip	1+58.250	1+71.750	-232.62	165.25	4.13
☑	1	Bump	1+72.250	1+76.916	176.19	174.42	-0.69
☑	1	Bump	1+77.000	1+81.000	172.56	178.08	1.34
☑	1	Bump	1+86.333	2+6.2500	222.74	192.50	1.90
☑	1	Dip	2+29.416	2+53.000	-172.59	232.25	2.03
☑	1	Bump	5+10.083	5+10.500	732.70	510.17	1.40
☑	2	Dip	6+59.166	6+71.166	-207.75	666.25	3.95
☑	2	Bump	6+71.166	6+84.916	163.98	677.17	1.35
☑	3	Bump	11+58.58	11+58.75	635.66	1158.67	0.62
☑	3 to 4	Bump	15+79.41	15+88.75	168.78	1585.50	1.03
☑	4	Dip	15+88.75	15+97.83	-253.83	1593.00	3.60
☑	4	Bump	15+99.41	16+7.000	162.60	1602.42	2.80
☐	4	Bump	16+17.25	16+17.50	176.46	1617.42	0.00
☐	4	Dip	16+24.16	16+31.08	-162.73	1629.50	0.21
☑	4	Dip	16+41.83	16+44.91	-198.15	1643.75	3.87
☑	5	Bump	24+96.58	25+2.250	174.80	2497.58	3.52
☑	5	Dip	25+63.41	25+83.16	-159.38	2577.75	2.03
☑	6	Dip	28+99.41	29+16.50	-168.91	2911.00	1.71
☑	7	Dip	34+39.66	34+53.83	-177.83	3445.75	3.48
☑	7	Bump	35+89.41	35+96.66	157.21	3594.08	-0.59
☑	8	Bump	38+63.16	38+73.08	171.99	3869.75	4.27
☑	9	Bump	42+84.25	42+94.33	154.26	4289.92	3.61
☑	14	Bump	70+18.33	70+20.25	208.16	7019.00	0.59
☑	14	Bump	73+31.25	73+31.75	152.67	7331.42	0.35
☑	18	Dip	91+30.50	91+40.58	-178.02	9138.42	4.32
☑	18	Bump	91+62.50	91+72.41	410.88	9165.67	8.29
☑	18	Dip	91+72.83	91+86.41	-316.74	9180.00	2.37

Figure 53. Results of Analyzing a Subset of Defects.



Section No	From Station (ft)	To Station (ft)	Section IRI	Projected IRI	Adjusted IRI
1	0+0.0000	5+28.0000	124.40	107.52	107.52
2	5+28.0000	10+56.000	74.70	68.70	68.70
3	10+56.000	15+84.000	52.93	52.35	52.35
4	15+84.000	21+12.000	77.89	65.20	65.39
5	21+12.000	26+40.000	67.25	61.72	61.72
6	26+40.000	31+68.000	60.79	59.08	59.08
7	31+68.000	36+96.000	65.64	62.75	62.75
8	36+96.000	42+24.000	67.51	63.24	63.24
9	42+24.000	47+52.000	44.15	40.54	40.54
10	47+52.000	52+80.000	42.34	42.34	42.34
11	52+80.000	58+8.0000	46.54	46.54	46.54
12	58+8.0000	63+36.000	60.50	60.50	60.50
13	63+36.000	68+64.000	52.33	52.33	52.33
14	68+64.000	73+92.000	48.35	47.40	47.40
15	73+92.000	79+20.000	49.41	49.41	49.41
16	79+20.000	84+48.000	57.90	57.90	57.90
17	84+48.000	89+76.000	55.45	55.45	55.45
18	89+76.000	95+4.0000	119.16	95.12	95.12
19	95+4.0000	100+32.00	96.10	91.70	91.70
20	100+32.00	105+60.00	94.72	82.27	82.27
21	105+60.00	110+88.00	85.15	70.00	70.00
22	110+88.00	115+48.00	116.29	83.45	83.45

Figure 54. Section IRI Report from Analyzing a Subset of Defects.

In addition to the *Analysis Tools* button in the *Results Tab Page*, the *Export* button is used to export the *Section IRI* and *Defects Summary* tables for the DCI analysis that is described shortly in this manual.

Scenarios Summary Tab Page

As illustrated in Figure 55, the *Scenarios Summary* page provides a summary report of the corresponding IRIs for all the scenarios created, with the current loaded scenario highlighted in yellow. Moreover, this page provides users the option to load a different scenario instead of using the *Scenario* menu. To load a different scenario for review, double-click on the row for that scenario. The program will then load and display the results for the selected scenario.

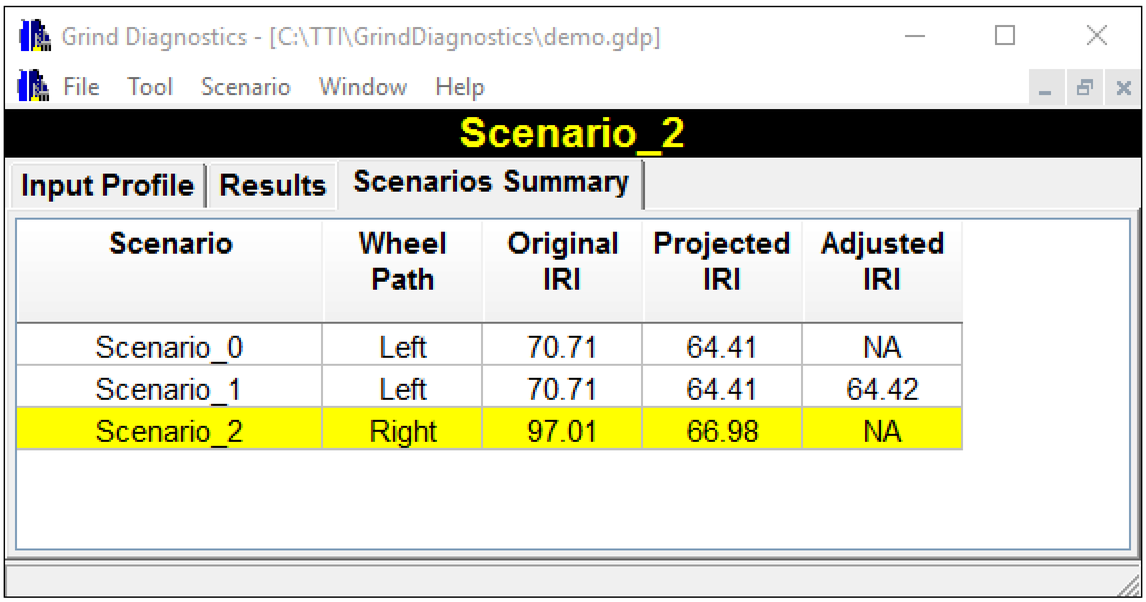


Figure 55. Scenarios Summary Tab Page.

DCI ANALYSIS

While checking the deviation between the measured profile and the moving average profile for each wheel path provides an objective approach to identify defects, some districts have taken the additional step of using a bump rating panel to select the bumps and dips to be corrected based on the panel’s opinion of defect severity from a ride quality point of view. For this reason, TxDOT undertook Project 0-6610, which developed the DCI based on correlating defect characteristics to the need for corrections using data from bump rating panel surveys. This DCI was later recalibrated in a follow-up TxDOT implementation project (5-6610-01) using a larger data set of bump rating panel data. TTI then modified the Grind Diagnostics program to include a methodology for evaluating defect corrections based on the revised DCI equation from this implementation project. The following sections provide instructions on running the DCI analysis to evaluate the need for corrections.

Tool Menu

Figure 56 shows the DCI functions under the program *Tool* menu. *DCI Analysis* allows the user to specify the PRO file and the corresponding defect summary files for both left and right wheel paths to perform a DCI analysis. Once this analysis is done, the user can also perform a cost analysis to estimate the costs of correcting defects for each of four different treatment options used in the program. *DCI Report* plots the defects identified from the profile analysis and organizes the charts into an Excel spreadsheet. The engineer can use the charts in this spreadsheet to help communicate the results from the DCI analysis to other engineers, inspectors, and the contractor.

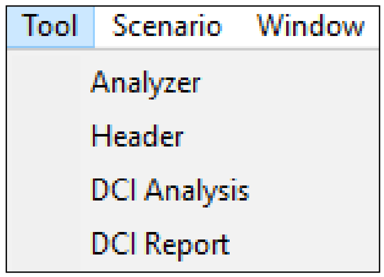


Figure 56. DCI Analysis and DCI Report Functions.

DCI Analysis Screen

Clicking on *DCI Analysis* under the *Tool* menu displays the *DCI Analysis* screen illustrated in Figure 57. On this screen, the user specifies two *Defects Summary* files of the results from the profile analysis. File 1 and File 2 correspond, respectively, to the analysis of the left and right wheel path profiles of the specified PRO file. As noted previously, the user generates these summary files using the *Export* button within the *Results* page. The PRO file should conform to the TxDOT file format specified in Tex-1001-S, which requires GPS data collected during the profile measurements. For convenience, *DCI Analysis* remembers and shows the most recent exported file names and the PRO file name. To specify other input files, click the *Select* button.

The grouping interval specifies the length with which to group the defects found along a given wheel path. By default, the modified Grind Diagnostics program uses an 80-ft interval since this is the length by which defects were grouped and rated in the bump rating panels. Note that the default defect group size of 80 ft is about the length traveled in 1 second at a speed of 55 mph.

To group defects for the DCI analysis, the modified program permits the user to select either a strict application of the specified grouping interval or an approximate application of that interval. When *Strict Match* is selected, a defect will be excluded from the group if its end location is beyond the limit of the specified grouping interval. The actual group length will usually be less than the user’s input. When *Approximate Match* is selected, a defect will be included if its start location is within the specified interval. The actual group length will usually be larger than what the user has specified under this option.

The DCI threshold is used as an indicator of the need for localized roughness corrections. If the calculated DCI value for a defect group is larger than this threshold, the defects within the group need to be corrected. Otherwise, no correction for the group is needed. The default value for this threshold is 0.70, as established from the recalibration of the DCI model in the follow-up implementation project.

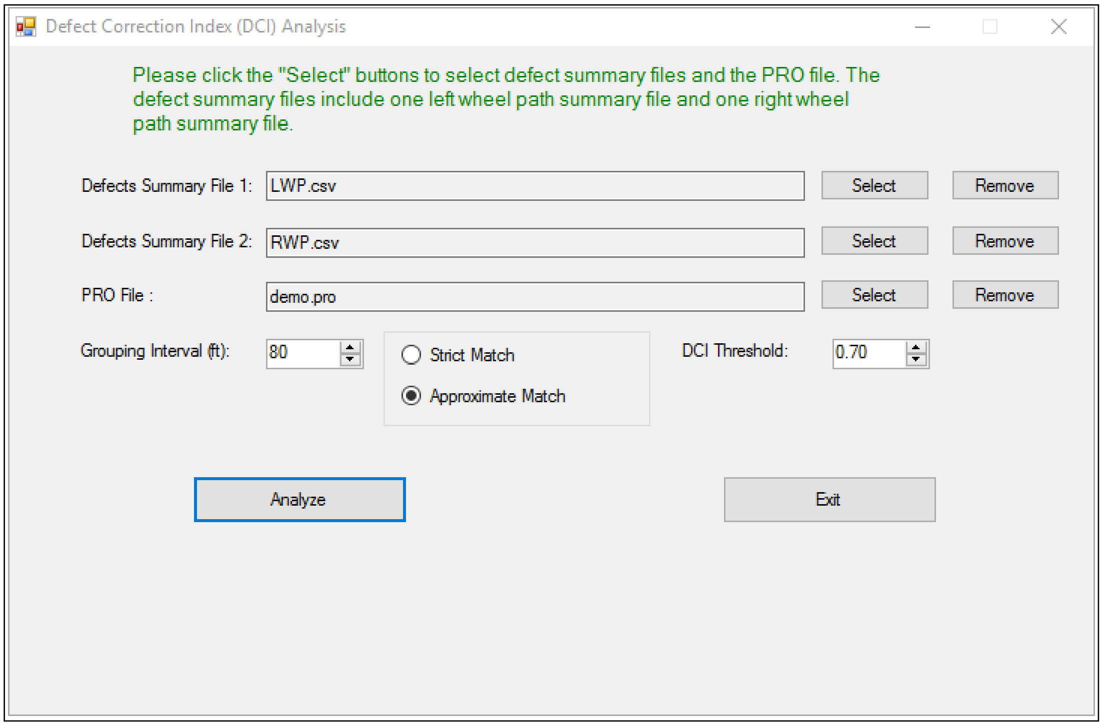


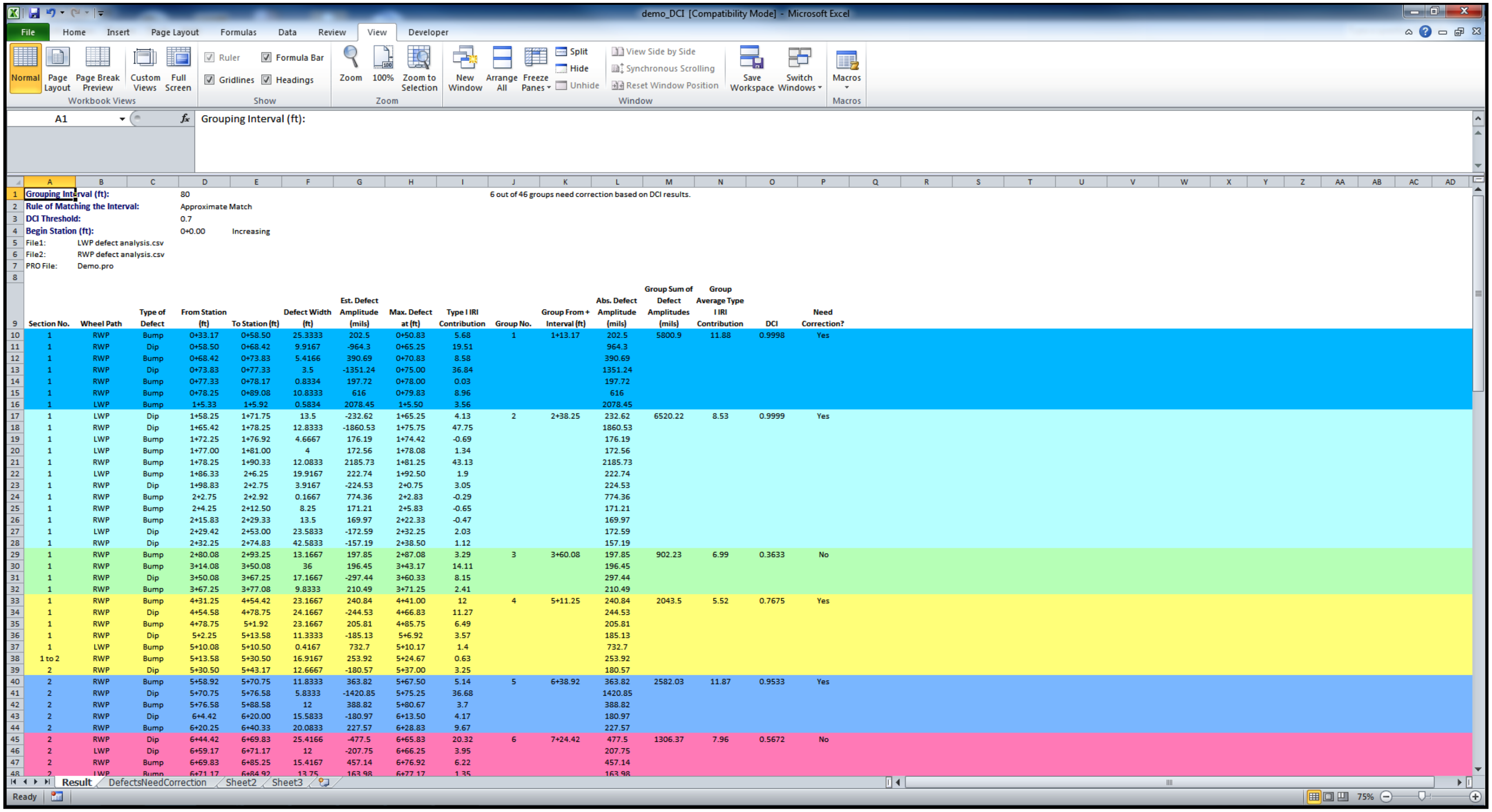
Figure 57. DCI Analysis Screen.

DCI Analysis Result

After specifying the DCI analysis inputs, click on the *Analyze* button of the input screen to run the analysis. The program outputs the results from this analysis in an Excel spreadsheet (Figure 58). This figure shows the output written into the *Result* worksheet. On the first row are shown the total number of defect groups and the number of groups needing correction based on the DCI analysis. The top of the worksheet also shows input information used in the analysis, which include the following:

1. Specified grouping interval.
2. Option selected for grouping the defects.
3. DCI threshold.
4. Beginning station.
5. Defect summary files from the profile analysis.
6. PRO file from the profile measurement.

Both left and right wheel path defects are combined and sorted by the *From Station* value. The defects are grouped according to the specified interval and option selected for grouping them. The output is also color coded to more readily identify the defect groups established from the DCI analysis. By default, the program names the Excel spreadsheet using the PRO input file name followed by *_DCI*.



Grouping Interval (ft): 80
Rule of Matching the Interval: Approximate Match
DCI Threshold: 0.7
Begin Station (ft): 0+0.00 Increasing
File1: LWP defect analysis.csv
File2: RWP defect analysis.csv
PRO File: Demo.pro

6 out of 46 groups need correction based on DCI results.

Section No.	Wheel Path	Type of Defect	From Station (ft)	To Station (ft)	Defect Width (ft)	Est. Defect Amplitude (mils)	Max. Defect at (ft)	Type I IRI Contribution	Group No.	Group From + Interval (ft)	Abs. Defect Amplitude (mils)	Group Sum of Defect Amplitudes (mils)	Group Average Type I IRI Contribution	DCI	Need Correction?
1	RWP	Bump	0+33.17	0+58.50	25.3333	202.5	0+50.83	5.68	1	1+13.17	202.5	5800.9	11.88	0.9998	Yes
1	RWP	Dip	0+58.50	0+68.42	9.9167	-964.3	0+65.25	19.51			964.3				
1	RWP	Bump	0+68.42	0+73.83	5.4166	390.69	0+70.83	8.58			390.69				
1	RWP	Dip	0+73.83	0+77.33	3.5	-1351.24	0+75.00	36.84			1351.24				
1	RWP	Bump	0+77.33	0+78.17	0.8334	197.72	0+78.00	0.03			197.72				
1	RWP	Bump	0+78.25	0+89.08	10.8333	616	0+79.83	8.96			616				
1	LWP	Bump	1+5.33	1+5.92	0.5834	2078.45	1+5.50	3.56			2078.45				
1	LWP	Dip	1+58.25	1+71.75	13.5	-232.62	1+65.25	4.13	2	2+38.25	232.62	6520.22	8.53	0.9999	Yes
1	RWP	Dip	1+65.42	1+78.25	12.8333	-1860.53	1+75.75	47.75			1860.53				
1	LWP	Bump	1+72.25	1+76.92	4.6667	176.19	1+74.42	-0.69			176.19				
1	LWP	Bump	1+77.00	1+81.00	4	172.56	1+78.08	1.34			172.56				
1	RWP	Bump	1+78.25	1+90.33	12.0833	2185.73	1+81.25	43.13			2185.73				
1	LWP	Bump	1+86.33	2+6.25	19.9167	222.74	1+92.50	1.9			222.74				
1	RWP	Dip	1+98.83	2+2.75	3.9167	-224.53	2+0.75	3.05			224.53				
1	RWP	Bump	2+2.75	2+2.92	0.1667	774.36	2+2.83	-0.29			774.36				
1	RWP	Bump	2+4.25	2+12.50	8.25	171.21	2+5.83	-0.65			171.21				
1	RWP	Bump	2+15.83	2+29.33	13.5	169.97	2+22.33	-0.47			169.97				
1	LWP	Dip	2+29.42	2+53.00	23.5833	-172.59	2+32.25	2.03			172.59				
1	RWP	Dip	2+32.25	2+74.83	42.5833	-157.19	2+38.50	1.12			157.19				
1	RWP	Bump	2+80.08	2+93.25	13.1667	197.85	2+87.08	3.29	3	3+60.08	197.85	902.23	6.99	0.3633	No
1	RWP	Bump	3+14.08	3+50.08	36	196.45	3+43.17	14.11			196.45				
1	RWP	Dip	3+50.08	3+67.25	17.1667	-297.44	3+60.33	8.15			297.44				
1	RWP	Bump	3+67.25	3+77.08	9.8333	210.49	3+71.25	2.41			210.49				
1	RWP	Bump	4+31.25	4+54.42	23.1667	240.84	4+41.00	12	4	5+11.25	240.84	2043.5	5.52	0.7675	Yes
1	RWP	Dip	4+54.58	4+78.75	24.1667	-244.53	4+66.83	11.27			244.53				
1	RWP	Bump	4+78.75	5+1.92	23.1667	205.81	4+85.75	6.49			205.81				
1	RWP	Dip	5+2.25	5+13.58	11.3333	-185.13	5+6.92	3.57			185.13				
1	LWP	Bump	5+10.08	5+10.50	0.4167	732.7	5+10.17	1.4			732.7				
1 to 2	RWP	Bump	5+13.58	5+30.50	16.9167	253.92	5+24.67	0.63			253.92				
2	RWP	Dip	5+30.50	5+43.17	12.6667	-180.57	5+37.00	3.25			180.57				
2	RWP	Bump	5+58.92	5+70.75	11.8333	363.82	5+67.50	5.14	5	6+38.92	363.82	2582.03	11.87	0.9533	Yes
2	RWP	Dip	5+70.75	5+76.58	5.8333	-1420.85	5+75.25	36.68			1420.85				
2	RWP	Bump	5+76.58	5+88.58	12	388.82	5+80.67	3.7			388.82				
2	RWP	Dip	6+4.42	6+20.00	15.5833	-180.97	6+13.50	4.17			180.97				
2	RWP	Bump	6+20.25	6+40.33	20.0833	227.57	6+28.83	9.67			227.57				
2	RWP	Dip	6+44.42	6+69.83	25.4166	-477.5	6+65.83	20.32	6	7+24.42	477.5	1306.37	7.96	0.5672	No
2	LWP	Dip	6+59.17	6+71.17	12	-207.75	6+66.25	3.95			207.75				
2	RWP	Bump	6+69.83	6+85.25	15.4167	457.14	6+76.92	6.22			457.14				
2	LWP	Bump	6+71.17	6+84.92	13.75	163.98	6+77.17	1.35			163.98				

Figure 58. Excel Worksheet Identifying Defects Detected from Measured Profile.

For each group, the program calculates the DCI using the sum of the amplitudes and the average of the Type I IRI contributions of the defects within the group. If the calculated DCI is greater than 0.70, then corrective work is needed, as indicated by *yes* in Column P. Otherwise, the listing will show *no* under that column for the given defect group. Note that Figure 58 shows only a partial listing of the defects determined from the analysis. The *Result* worksheet will have as many rows as there are defects identified in the input profile data plus the rows of header information.

In addition to the *Result* worksheet, the modified Grind Diagnostics program writes the defect groups needing correction in a separate worksheet (aptly labeled *DefectsNeedCorrection* in Figure 58). In this way, the engineer can readily identify these defect groups by opening that worksheet in Excel. Figure 59 gives an example listing of defects needing corrections as determined from the DCI analysis.

COST ANALYSIS

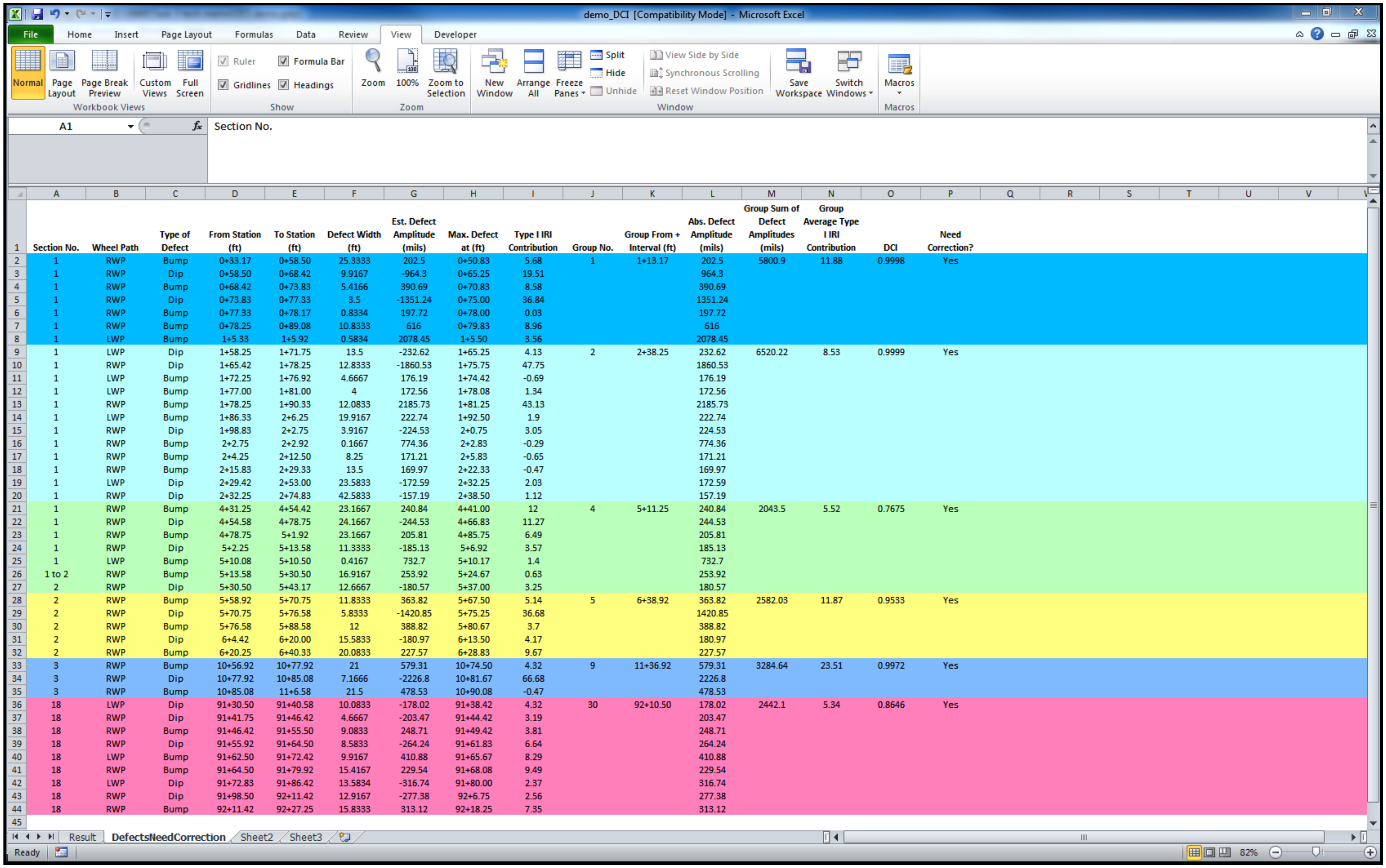
The modified Grind Diagnostics program also includes a cost analysis function to estimate the costs of the following four options for correcting defects identified from the DCI analysis:

1. Grind Only.
2. Mill and Fill.
3. Overlay.
4. Spot Overlay.

This function is activated after the DCI analysis is completed. Specifically, the program activates the *Cost Analysis* button of the *DCI Analysis* screen, as illustrated in Figure 60. Click on this button to have the program estimate the costs associated with each of the above repair options. By default, repairs are done on the defects identified as needing corrections from the DCI analysis. The program outputs the cost estimates in an Excel spreadsheet (Figure 61). By default, the program names this spreadsheet using the input PRO file name followed by *_DCICostAnalysis*.

As shown in Figure 61, the cost analysis spreadsheet includes a *Summary Sheet* that identifies the district and county where the project is located, and a table that shows the cost of each repair option included in the program. The district and county are pulled from the first header card of the input PRO file. The user can also click on the *County* field to access a pull-down menu of Texas counties. Once a county is selected from this menu, the program fills in the TxDOT district where the specified county is located.

The *Summary Sheet* includes a cost table and a listing of locations where corrections are to be made for each repair alternative. The cost table shows two groups of cost estimates. The first group, labeled *TxDOT Perspective*, gives estimates calculated using historical bid prices. The other group, labeled *Contractor Perspective*, uses estimates of manpower, material, and equipment requirements along with corresponding unit costs for these items to evaluate the cost for each alternative. The cost information given under this group reflects what the contractor's actual cost could be for each repair option. These estimates use hourly rates for labor based on federal requirements and *Blue Book* rates for equipment use. The costs given under *Contractor Perspective* will generally be higher than the costs given under *TxDOT Perspective*, which are based on historical bid prices for associated items within a given repair option.



Section No.	Wheel Path	Type of Defect	From Station (ft)	To Station (ft)	Defect Width (ft)	Est. Defect Amplitude (mils)	Max. Defect at (ft)	Type I IRI Contribution	Group No.	Group From + Interval (ft)	Abs. Defect Amplitude (mils)	Group Sum of Defect Amplitudes (mils)	Group Average Type I IRI Contribution	DCI	Need Correction?
1	RWP	Bump	0+33.17	0+58.50	25.3333	202.5	0+50.83	5.68	1	1+13.17	202.5	5800.9	11.88	0.9998	Yes
1	RWP	Dip	0+58.50	0+68.42	9.9167	-964.3	0+65.25	19.51			964.3				
1	RWP	Bump	0+68.42	0+73.83	5.4166	390.69	0+70.83	8.58			390.69				
1	RWP	Dip	0+73.83	0+77.33	3.5	-1351.24	0+75.00	36.84			1351.24				
1	RWP	Bump	0+77.33	0+78.17	0.8334	197.72	0+78.00	0.03			197.72				
1	RWP	Bump	0+78.25	0+89.08	10.8333	616	0+79.83	8.96			616				
1	LWP	Bump	1+5.33	1+5.92	0.5834	2078.45	1+5.50	3.56			2078.45				
1	LWP	Dip	1+58.25	1+71.75	13.5	-232.62	1+65.25	4.13	2	2+38.25	232.62	6520.22	8.53	0.9999	Yes
1	RWP	Dip	1+65.42	1+78.25	12.8333	-1860.53	1+75.75	47.75			1860.53				
1	LWP	Bump	1+72.25	1+76.92	4.6667	176.19	1+74.42	-0.69			176.19				
1	LWP	Bump	1+77.00	1+81.00	4	172.56	1+78.08	1.34			172.56				
1	RWP	Bump	1+78.25	1+90.33	12.0833	2185.73	1+81.25	43.13			2185.73				
1	LWP	Bump	1+86.33	2+6.25	19.9167	222.74	1+92.50	1.9			222.74				
1	RWP	Dip	1+98.83	2+2.75	3.9167	-224.53	2+0.75	3.05			224.53				
1	RWP	Bump	2+2.75	2+2.92	0.1667	774.36	2+2.83	-0.29			774.36				
1	RWP	Bump	2+4.25	2+12.50	8.25	171.21	2+5.83	-0.65			171.21				
1	RWP	Bump	2+15.83	2+29.33	13.5	169.97	2+22.33	-0.47			169.97				
1	LWP	Dip	2+29.42	2+53.00	23.5833	-172.59	2+32.25	2.03			172.59				
1	RWP	Dip	2+32.25	2+74.83	42.5833	-157.19	2+38.50	1.12			157.19				
1	RWP	Bump	4+31.25	4+54.42	23.1667	240.84	4+41.00	12	4	5+11.25	240.84	2043.5	5.52	0.7675	Yes
1	RWP	Dip	4+54.58	4+78.75	24.1667	-244.53	4+66.83	11.27			244.53				
1	RWP	Bump	4+78.75	5+1.92	23.1667	205.81	4+85.75	6.49			205.81				
1	RWP	Dip	5+2.25	5+13.58	11.3333	-185.13	5+6.92	3.57			185.13				
1	LWP	Bump	5+10.08	5+10.50	0.4167	732.7	5+10.17	1.4			732.7				
1 to 2	RWP	Bump	5+13.58	5+30.50	16.9167	253.92	5+24.67	0.63			253.92				
2	RWP	Dip	5+30.50	5+43.17	12.6667	-180.57	5+37.00	3.25			180.57				
2	RWP	Bump	5+58.92	5+70.75	11.8333	363.82	5+67.50	5.14	5	6+38.92	363.82	2582.03	11.87	0.9533	Yes
2	RWP	Dip	5+70.75	5+76.58	5.8333	-1420.85	5+75.25	36.68			1420.85				
2	RWP	Bump	5+76.58	5+88.58	12	388.82	5+80.67	3.7			388.82				
2	RWP	Dip	6+4.42	6+20.00	15.5833	-180.97	6+13.50	4.17			180.97				
2	RWP	Bump	6+20.25	6+40.33	20.0833	227.57	6+28.83	9.67			227.57				
3	RWP	Bump	10+56.92	10+77.92	21	579.31	10+74.50	4.32	9	11+36.92	579.31	3284.64	23.51	0.9972	Yes
3	RWP	Dip	10+77.92	10+85.08	7.1666	-2226.8	10+81.67	66.68			2226.8				
3	RWP	Bump	10+85.08	11+6.58	21.5	478.53	10+90.08	-0.47			478.53				
18	LWP	Dip	91+30.50	91+40.58	10.0833	-178.02	91+38.42	4.32	30	92+10.50	178.02	2442.1	5.34	0.8646	Yes
18	RWP	Dip	91+41.75	91+46.42	4.6667	-203.47	91+44.42	3.19			203.47				
18	RWP	Bump	91+46.42	91+55.50	9.0833	248.71	91+49.42	3.81			248.71				
18	RWP	Dip	91+55.92	91+64.50	8.5833	-264.24	91+61.83	6.64			264.24				
18	LWP	Bump	91+62.50	91+72.42	9.9167	410.88	91+65.67	8.29			410.88				
18	RWP	Bump	91+64.50	91+79.92	15.4167	229.54	91+68.08	9.49			229.54				
18	LWP	Dip	91+72.83	91+86.42	13.5834	-316.74	91+80.00	2.37			316.74				
18	RWP	Dip	91+98.50	92+11.42	12.9167	-277.38	92+6.75	2.56			277.38				
18	RWP	Bump	92+11.42	92+27.25	15.8333	313.12	92+18.25	7.35			313.12				

Figure 59. Excel Worksheet Identifying Defects Needing Correction.

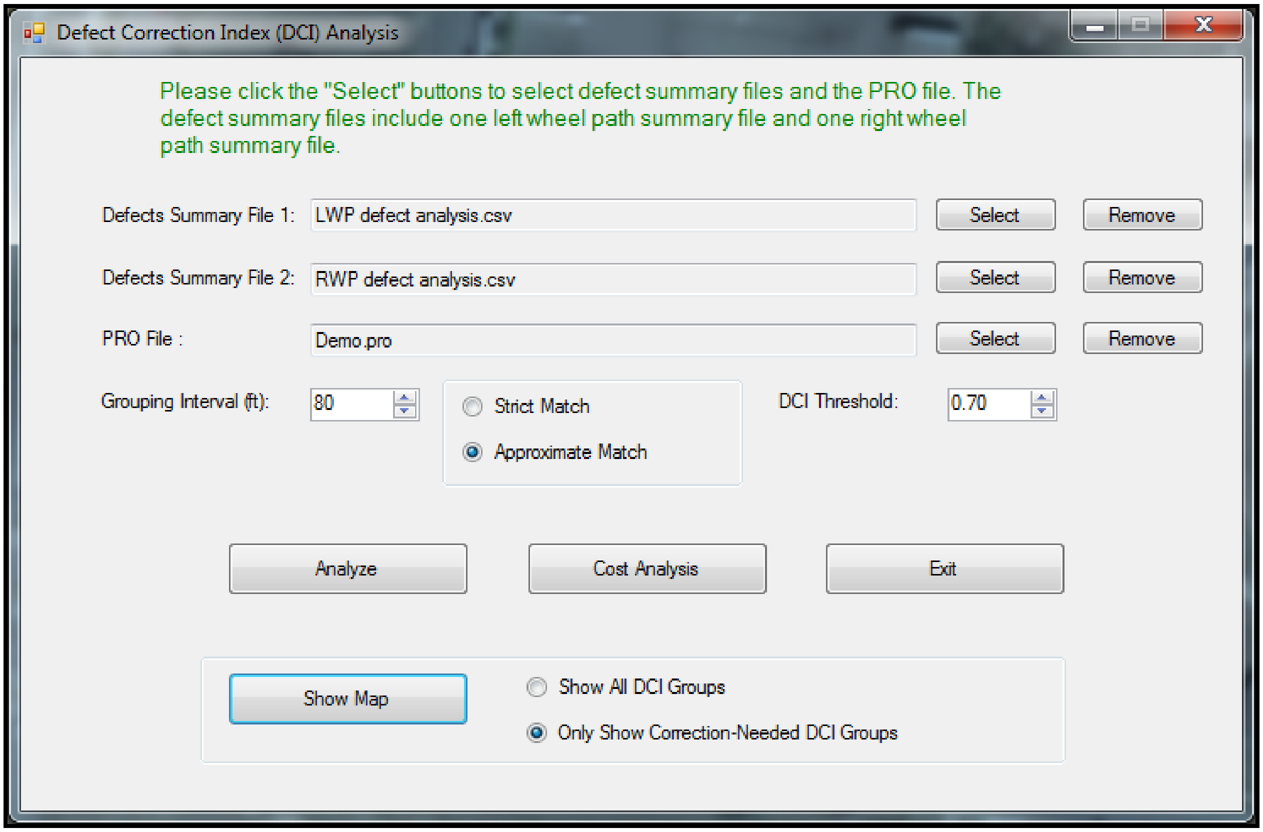
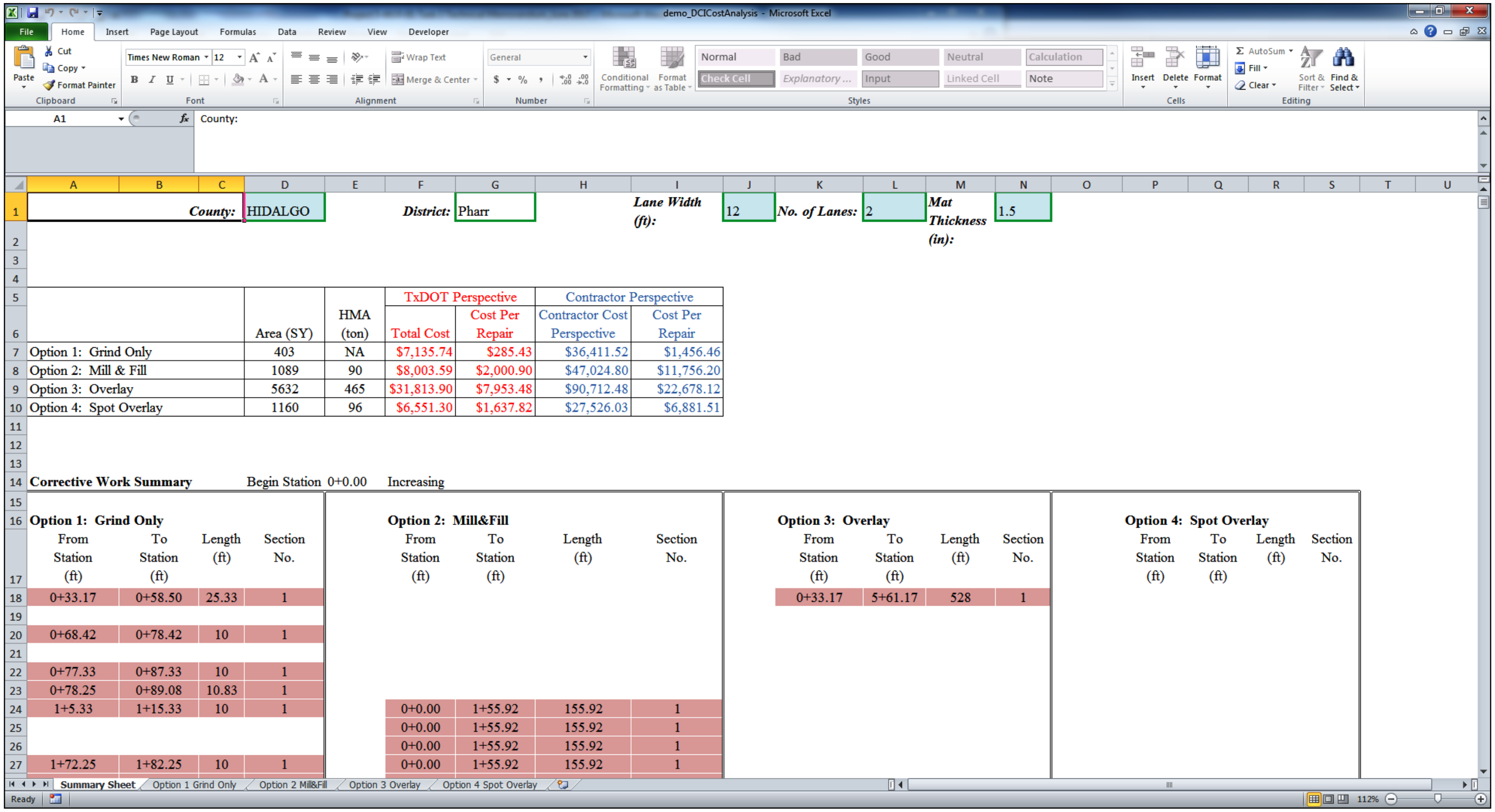


Figure 60. Cost Analysis and Show Map Buttons Activated after DCI Analysis.

To view detailed information on the cost rates along with the labor, material, and equipment estimates used to evaluate the cost for each option, click on the corresponding tab for the repair alternative at the bottom of the spreadsheet. For example, click on *Option 1 Grind Only* to view the data used to estimate the cost of this option. This action brings up the worksheet illustrated in Figure 62. The top of the worksheet shows the assumed makeup of the grinding crew and equipment. To the right of this table, the worksheet shows additional information, which includes the number of repair locations and the estimated area to be ground in square yards. These estimates are based on the DCI analysis results.

Following the *Grinding Crew* and *General Information* tables are the unit bid price estimates used to calculate the cost of the *Grind-Only* alternative under the *TxDOT Perspective*. Below this information, the worksheet shows the rates for calculating the contractor's cost. Scroll down the worksheet to view the rates for different cost categories that include labor, equipment, materials, and other. For this example, Figure 63 shows the information used by the program to estimate the contractor's cost for the *Grind-Only* alternative. To view similar cost information for another repair option, click on its tab.



	Area (SY)	HMA (ton)	TxDOT Perspective Total Cost	TxDOT Perspective Cost Per Repair	Contractor Perspective Contractor Cost Perspective	Contractor Perspective Cost Per Repair
Option 1: Grind Only	403	NA	$7,135.74	$285.43	$36,411.52	$1,456.46
Option 2: Mill & Fill	1089	90	$8,003.59	$2,000.90	$47,024.80	$11,756.20
Option 3: Overlay	5632	465	$31,813.90	$7,953.48	$90,712.48	$22,678.12
Option 4: Spot Overlay	1160	96	$6,551.30	$1,637.82	$27,526.03	$6,881.51

Corrective Work Summary Begin Station 0+0.00 Increasing

Option 1: Grind Only

From Station (ft)	To Station (ft)	Length (ft)	Section No.
0+33.17	0+58.50	25.33	1
0+68.42	0+78.42	10	1
0+77.33	0+87.33	10	1
0+78.25	0+89.08	10.83	1
1+5.33	1+15.33	10	1
1+72.25	1+82.25	10	1

Option 2: Mill&Fill

From Station (ft)	To Station (ft)	Length (ft)	Section No.
0+0.00	1+55.92	155.92	1
0+0.00	1+55.92	155.92	1
0+0.00	1+55.92	155.92	1
0+0.00	1+55.92	155.92	1

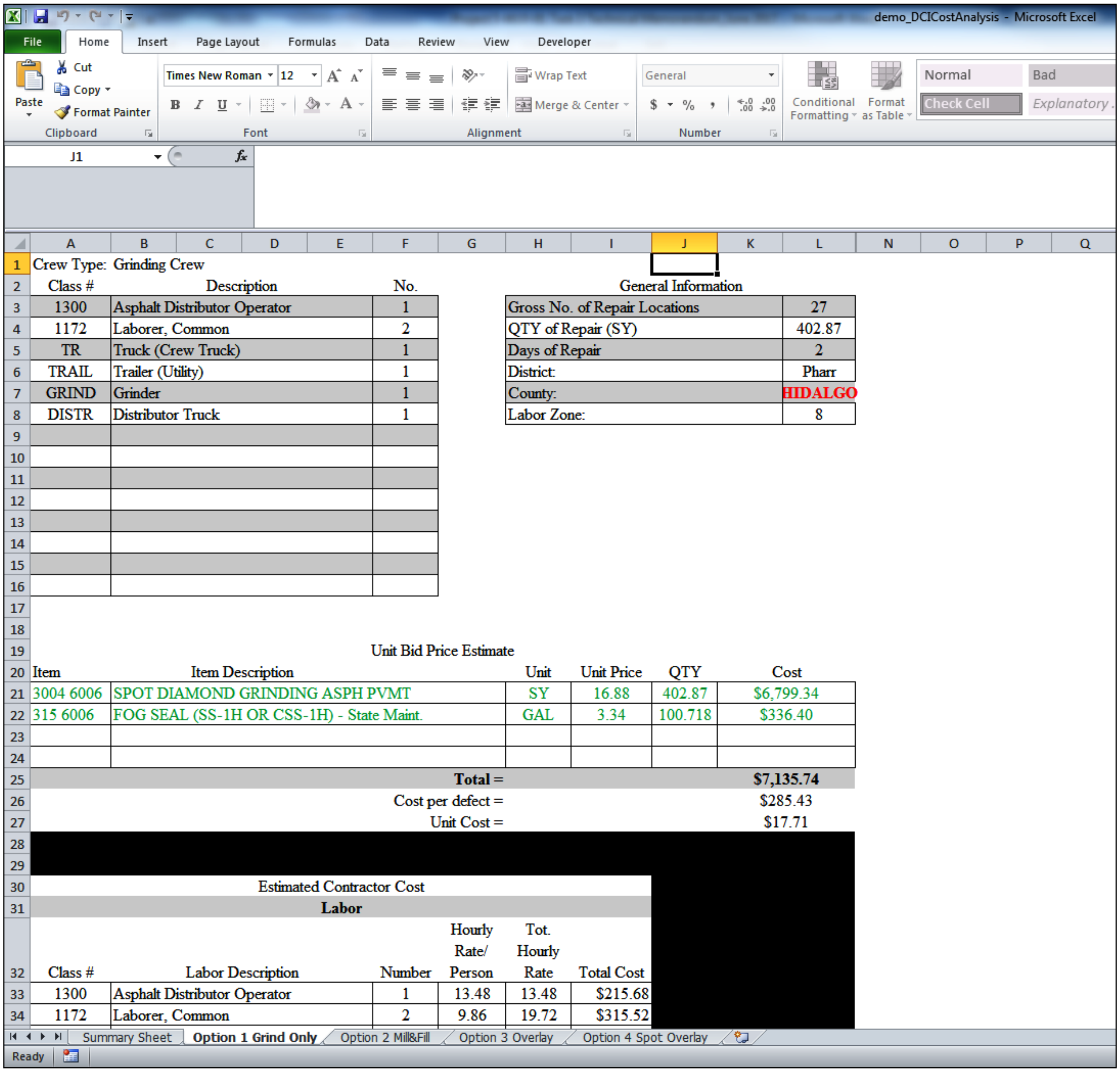
Option 3: Overlay

From Station (ft)	To Station (ft)	Length (ft)	Section No.
0+33.17	5+61.17	528	1

Option 4: Spot Overlay

From Station (ft)	To Station (ft)	Length (ft)	Section No.

Figure 61. Cost Analysis Spreadsheet.



Crew Type: Grinding Crew

Class #	Description	No.
1300	Asphalt Distributor Operator	1
1172	Laborer, Common	2
TR	Truck (Crew Truck)	1
TRAIL	Trailer (Utility)	1
GRIND	Grinder	1
DISTR	Distributor Truck	1

General Information

Gross No. of Repair Locations	27
QTY of Repair (SY)	402.87
Days of Repair	2
District:	Pharr
County:	HIDALGO
Labor Zone:	8

Unit Bid Price Estimate

Item	Item Description	Unit	Unit Price	QTY	Cost
3004 6006	SPOT DIAMOND GRINDING ASPH PVMT	SY	16.88	402.87	$6,799.34
315 6006	FOG SEAL (SS-1H OR CSS-1H) - State Maint.	GAL	3.34	100.718	$336.40
	Total =				**$7,135.74**
	Cost per defect =				$285.43
	Unit Cost =				$17.71

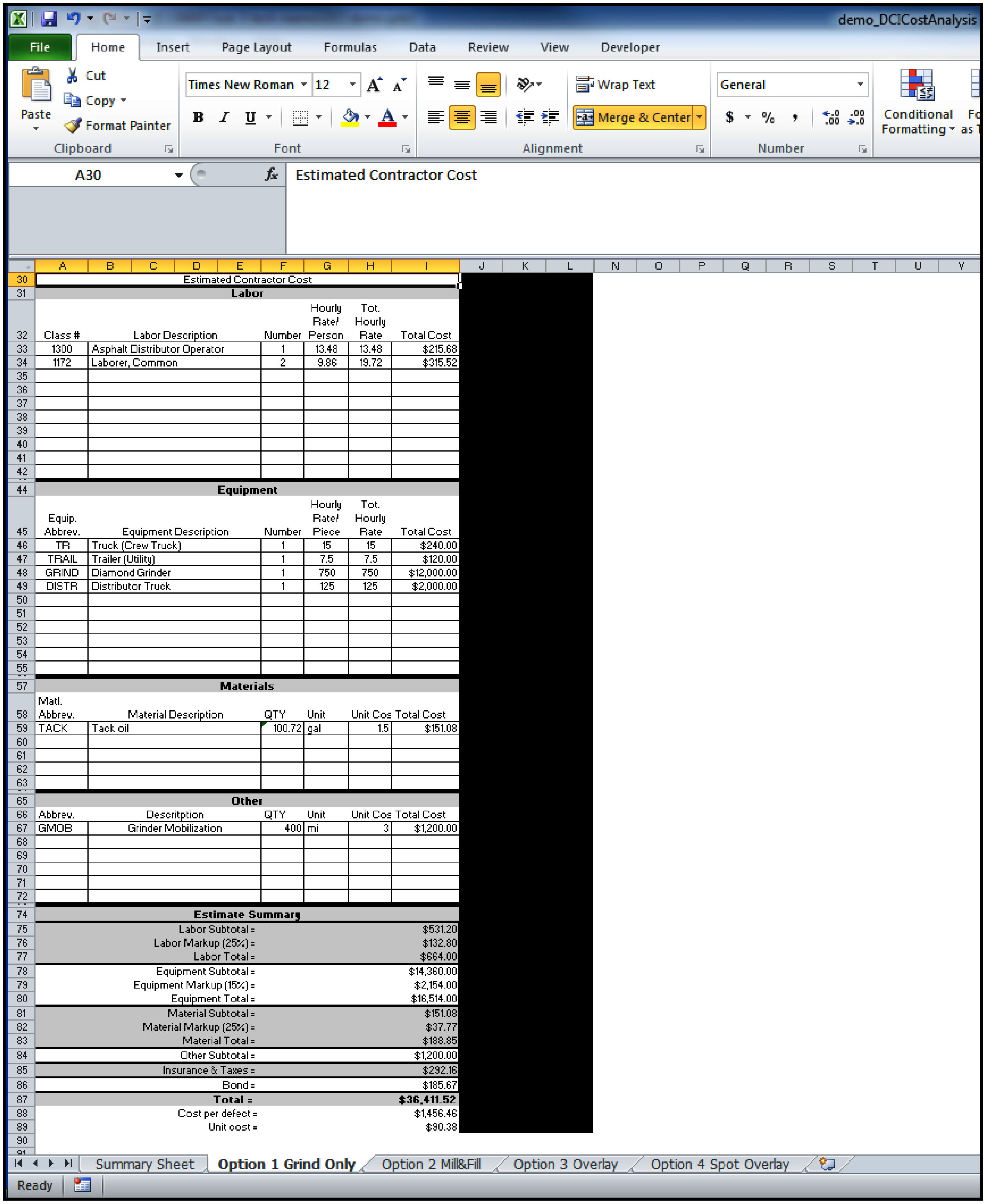
[redacted]

Estimated Contractor Cost

Labor

Class #	Labor Description	Number	Hourly Rate/ Person	Tot. Hourly Rate	Total Cost
1300	Asphalt Distributor Operator	1	13.48	13.48	$215.68
1172	Laborer, Common	2	9.86	19.72	$315.52

Figure 62. Worksheet to Estimate Cost of Grind-Only Alternative.



30	Estimated Contractor Cost					
31	**Labor**					
32	Class #	Labor Description	Number	Hourly Rate/ Person	Tot. Hourly Rate	Total Cost
33	1300	Asphalt Distributor Operator	1	13.48	13.48	$215.68
34	1172	Laborer, Common	2	9.86	19.72	$315.52
35						
36						
37						
38						
39						
40						
41						
42						
44	**Equipment**					
45	Equip. Abbrev.	Equipment Description	Number	Hourly Rate/ Piece	Tot. Hourly Rate	Total Cost
46	TR	Truck (Crew Truck)	1	15	15	$240.00
47	TRAIL	Trailer (Utility)	1	7.5	7.5	$120.00
48	GRIND	Diamond Grinder	1	750	750	$12,000.00
49	DISTR	Distributor Truck	1	125	125	$2,000.00
50						
51						
52						
53						
54						
55						
57	**Materials**					
58	Matl. Abbrev.	Material Description	QTY	Unit	Unit Cos	Total Cost
59	TACK	Tack oil	100.72	gal	1.5	$151.08
60						
61						
62						
63						
65	**Other**					
66	Abbrev.	Descritption	QTY	Unit	Unit Cos	Total Cost
67	GMOB	Grinder Mobilization	400	mi	3	$1,200.00
68						
69						
70						
71						
72						
74	**Estimate Summary**					
75		Labor Subtotal =				$531.20
76		Labor Markup (25%) =				$132.80
77		Labor Total =				$664.00
78		Equipment Subtotal =				$14,360.00
79		Equipment Markup (15%) =				$2,154.00
80		Equipment Total =				$16,514.00
81		Material Subtotal =				$151.08
82		Material Markup (25%) =				$37.77
83		Material Total =				$188.85
84		Other Subtotal =				$1,200.00
85		Insurance & Taxes =				$292.16
86		Bond =				$185.67
87		**Total =**				**$36,411.52**
88		Cost per defect =				$1,456.46
89		Unit cost =				$90.38
90						

Figure 63. Rates for Estimating Contractor's Cost under Grind-Only Alternative.

MAP DISPLAY OF ANALYSIS RESULTS

To provide a visual display of the defects determined from the DCI analysis, TTI researchers added a map function to the Grind Diagnostics program. In this way, the user can view the locations of defects from a map to better communicate where corrections need to be made to improve ride quality. Note that an Internet connection must be available and the computer's Wi-Fi turned on to use the map function.

After the DCI analysis ends, the modified program displays the *Show Map* button in the DCI Analysis input screen, illustrated in Figure 60. Clicking this button shows a map with markers identifying defects found from the analysis. By default, the program displays only the defect groups identified from the DCI analysis as needing correction. However, the user can show all DCI groups by clicking this option in the *DCI Analysis* input menu.

Figure 64 illustrates an example map generated by the modified Grind Diagnostics program. This figure shows a satellite view of the roadway. To change from a satellite to a map view, right-click on the display and select *Map*. To view other defects found along the project, drag the map with the mouse up or down and side-to-side, as needed. Use the mouse to zoom in and view more details or to zoom out and view a wider area. The map function uses the GPS data in the input PRO file to determine the approximate locations of defects found from the analysis.

Embedded within the map are data on each defect. To view the embedded data, zoom in as needed on the defects of interest and position the mouse on a given defect marker to view the data associated with that defect. Figure 65 illustrates an example. For any selected defect, the modified Grind Diagnostics program provides the following information:

1. Wheel path and section where the defect is found.
2. Defect limits relative to the start of the profile.
3. Defect width.
4. Location of the defect peak relative to the start of the profile.
5. Defect magnitude.
6. Type I IRI contribution associated with the defect.

In addition to the preceding information, the program also shows the defect group at the mouse position, the calculated DCI for that group, the DCI threshold, and whether the defect group needs to be corrected or not. In the example illustrated in Figure 65, the DCI is close to 1, which exceeds the specified DCI threshold of 0.70. The group of defects joined by the red line in the figure needs to be corrected based on the DCI. The program uses a red line to identify a group of defects that need corrective work and a green line to identify a group where corrective work can be waived based on the DCI. The example given in Figure 65 shows a defect group immediately upstream of Group No. 1, where corrective work is also indicated according to the calculated DCI for that group.

GRAPHICAL OUTPUT

To help users communicate results from the evaluation of corrective measures to improve existing ride quality, TTI researchers added a graphical function to the Grind Diagnostics program to generate charts showing the defects to be corrected. Note that the DCI analysis must first be performed before this graphical function can be used. To use this function, go to the *Tool* menu and click on *DCI Report*. The program then displays the input menu shown in Figure 66.

Figure 64. Example Illustration of Map Identifying Defects Found.

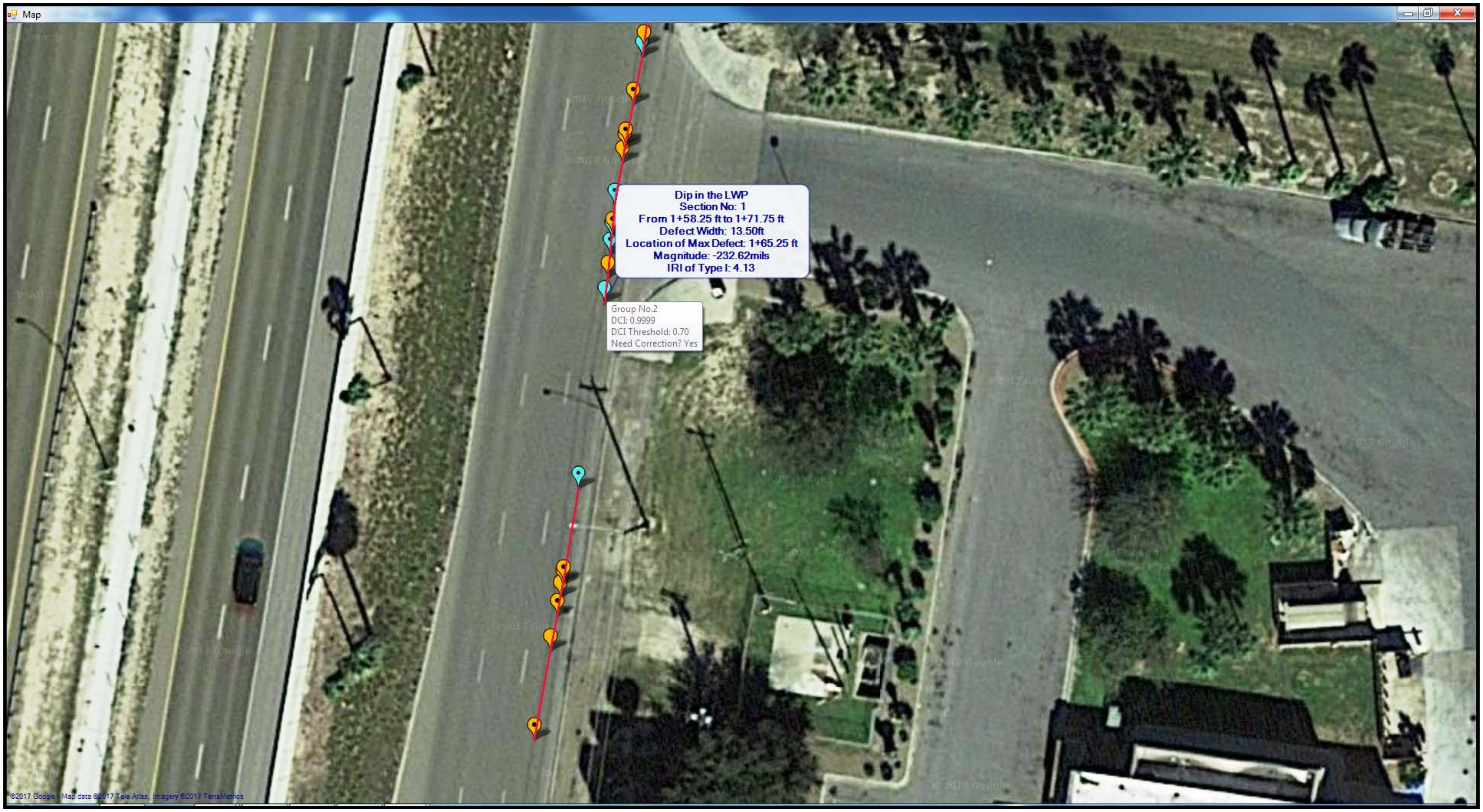


Figure 65. Illustration of Defect Data Embedded in Map.

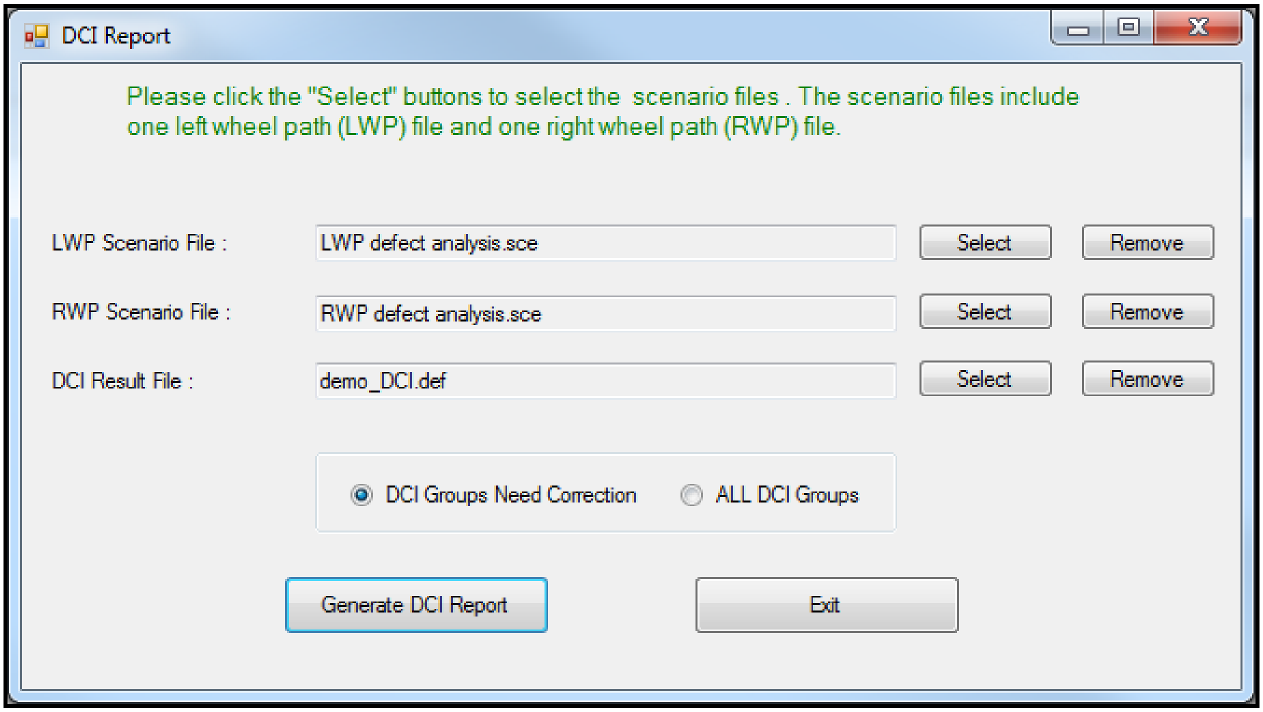


Figure 66. DCI Report Input Screen.

The graphical function requires a scenario file for each wheel path and the *DCI Analysis* result file. For convenience, the program remembers the files generated from the most recent DCI analysis and displays the names of these files in the input menu, as shown in Figure 66. Alternatively, one can use the *Select* buttons to specify the files for generating the defect charts. After specifying the input files, click on *Generate DCI Report* to plot the charts. Grind Diagnostics draws the charts by defect groups and gives users the option to plot only the defects that need corrections according to the DCI analysis or to plot all the defect groups. The program outputs the defect charts into an Excel spreadsheet, as illustrated in Figure 67. Each worksheet is labeled with the defect group number. For the example shown, the DCI analysis identified six defect groups where corrections need to be made (Group 1, Group 2, Group 4, Group 5, Group 9, and Group 30, as identified earlier in Figure 59). To view the charts for a given defect group, click on its tab in the Excel spreadsheet (Figure 67). This particular example shows the charts of the defects found in DCI Group 30. The user can print charts from this spreadsheet or put them into a document or presentation file to help communicate the results from the analysis.

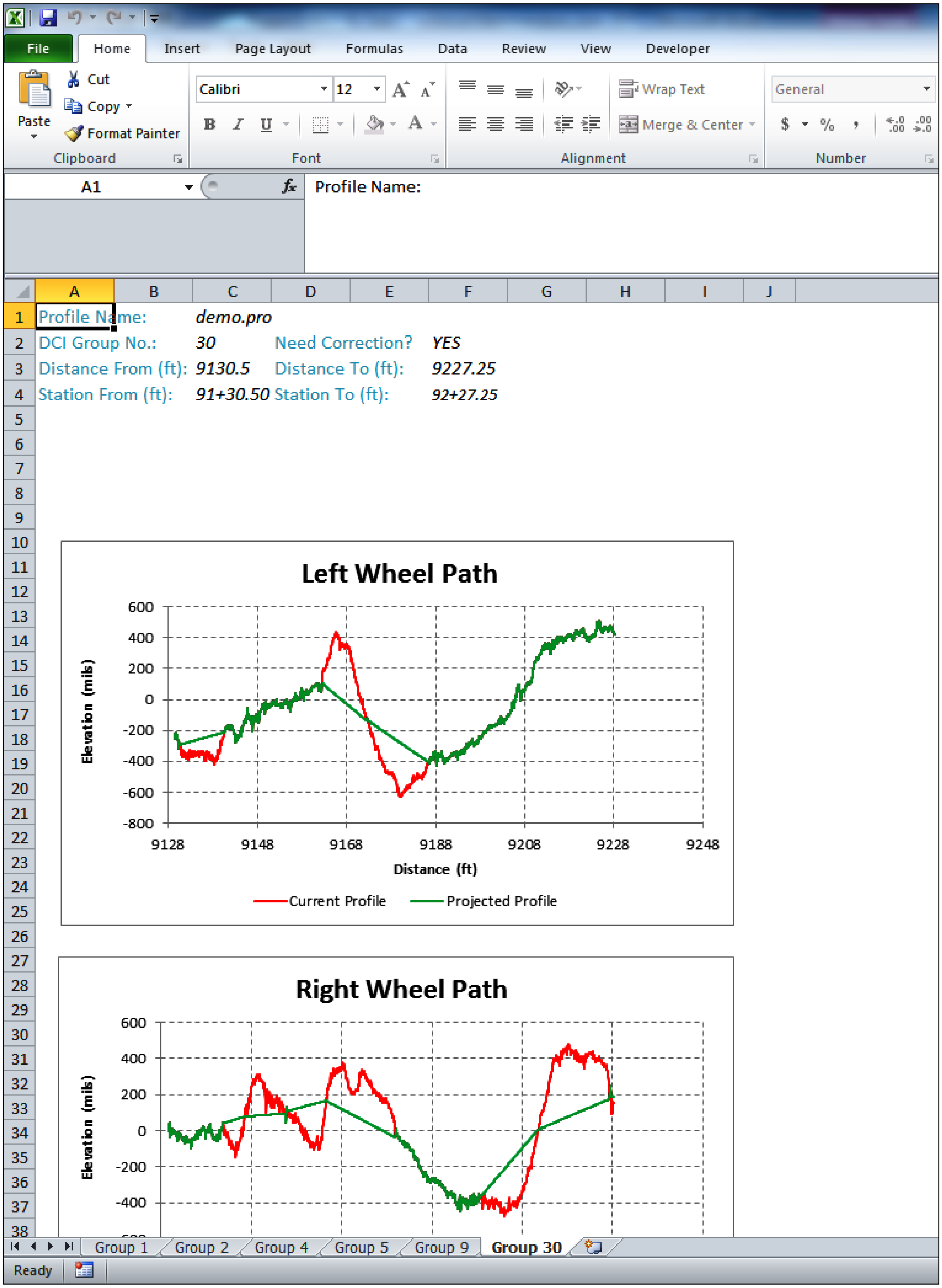


Figure 67. Excel Spreadsheet of Defect Charts Determined from DCI Analysis.

SELECT DCI RECOMMENDED DEFECTS AND PERFORM ANALYSIS

After the DCI analysis is completed, the user has the option of running a profile analysis on each wheel path where only the defects identified as needing corrections are selected. To perform this analysis, first load the scenario for the wheel path of interest, as previously described. Then click on the *Results* tab to access the *Analysis Tools* button (Figure 68).

Click on *Select DCI Results* to update the *Defects Summary* table so that only the defects needing corrections are checked. Then, click on *Analyze Selected Defects* under *Analysis Tools* to perform a profile analysis, determine the adjusted IRI for each section along the wheel path, and estimate the overall wheel path IRI for the specified subset of defects. Figure 69 shows an example Section IRI table from this analysis. This example shows results from analyzing the right wheel path profile. A similar analysis may be performed for the left wheel path.

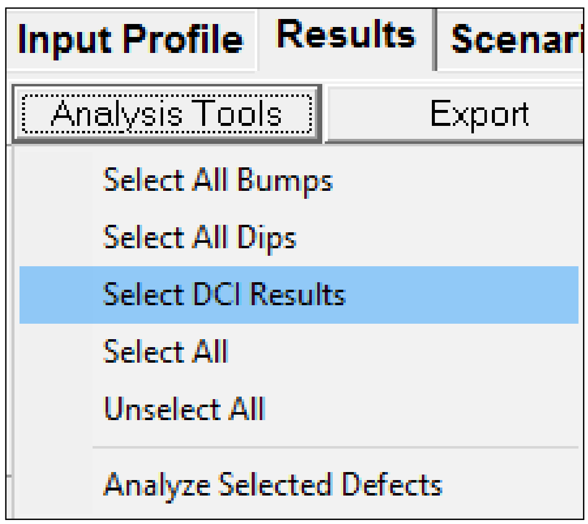


Figure 68. Select DCI Results Function under Analysis Tools.

Input Profile | Results | Scenarios Summary

Analysis Tools | Export

System Parameters

Wheel Path: Right

Begin Station: 0+0.00 ft.

Is Station Increasing: YES

Results

Existing IRI: 97.01

After-Correction IRI: 66.98

Adjusted IRI (Selected Defects): 77.86

Section IRI | Defects Summary

Section No	From Station (ft)	To Station (ft)	Section IRI	Projected IRI	Adjusted IRI
1	0+0.0000	5+28.0000	392.77	132.30	157.31
2	5+28.0000	10+56.000	202.38	85.60	133.03
3	10+56.000	15+84.000	174.86	82.83	93.14
4	15+84.000	21+12.000	72.12	60.88	72.12
5	21+12.000	26+40.000	43.91	43.58	43.91
6	26+40.000	31+68.000	76.30	66.13	76.30
7	31+68.000	36+96.000	58.14	55.47	58.14
8	36+96.000	42+24.000	64.96	64.71	64.96
9	42+24.000	47+52.000	50.58	45.39	50.58
10	47+52.000	52+80.000	42.97	42.97	42.97
11	52+80.000	58+8.0000	46.50	46.50	46.50
12	58+8.0000	63+36.000	64.88	64.53	64.88
13	63+36.000	68+64.000	47.22	43.92	47.22
14	68+64.000	73+92.000	42.34	42.34	42.34
15	73+92.000	79+20.000	72.33	72.33	72.33
16	79+20.000	84+48.000	52.75	52.75	52.75
17	84+48.000	89+76.000	61.59	61.27	61.59
18	89+76.000	95+4.0000	132.33	83.45	98.55
19	95+4.0000	100+32.00	90.58	72.68	90.58
20	100+32.00	105+60.00	111.31	80.44	111.31
21	105+60.00	110+88.00	100.63	70.85	100.63
22	110+88.00	115+48.00	133.65	101.60	133.65

Figure 69. Section IRI Table from Analysis of DCI Selected Defects on Right Wheel Path.

APPENDIX II. TXDOT TEST METHOD TEX-1001-S WITH PROPOSED REVISIONS FOR GRIND DIAGNOSTIC PROGRAM APPLICATION

Test Procedure for

OPERATING INERTIAL PROFILERS AND EVALUATING PAVEMENT PROFILES

TxDOT Designation: Tex-1001-S

Effective Date: January 1, 2017

1. SCOPE

1.1 This test method:

- covers use of an inertial profiler for ride quality measurements using Surface Test Type B for quality control (QC) and quality assurance (QA) testing,
- describes the inertial profiler apparatus as well as major and minor repairs and adjustments,
- covers calibration verification procedures,
- outlines the procedures for collecting inertial profile data on paving projects,
- prescribes the required test data description and data format and gives examples,
- provides and references the methodology used to detect areas of localized roughness, and
- details the certification of inertial profilers and inertial profiler operators.

1.2 Perform this test method as a QA test for use with the appropriate smoothness specification for paving operations. This method is recommended when using inertial profilers for QC testing.

1.3 Use the inertial profile data files obtained by following this test method as input to the RIDE QUALITY software program. The RIDE QUALITY software will perform ride summary calculations on the input data and report the bonus and penalties. The RIDE QUALITY software will also detect the location and magnitude of any areas of localized roughness contained in the paving project for acceptance tests.

1.4 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. APPARATUS

2.1 *Housing vehicle,* capable of traveling at minimum speeds of 12 mph while collecting pavement profile data.

2.2 *Distance measuring subsystem,* verified accurate to within 1 ft. per ~~528~~ 500 ft. of actual distance traveled on verification tests of horizontal calibration described in Section 4.

2.3 *Inertial referencing subsystem,* capable of measuring the movement of the housing vehicle as it traverses the pavement under test.

2.4 *Non-contact height measurement subsystem,* capable of measuring the height from the mounted sensor face to the surface of the pavement under test.

2.5 Inertial profiler:

- must include hardware and software capable of producing and storing inertial profiles by combining the data from the inertial referencing subsystem, the distance subsystem, and the height measurement subsystem;
- must have the capability of measuring and storing profile elevations ~~at 3 in. intervals or less (capable of outputting these elevations~~ in the format described in Section 6~~)~~;
- must have the capability of summarizing (computing) the profile elevation data into summary roughness statistics over a section length equal to 0.1 mi. (summary roughness statistic is the International Roughness Index [IRI] for each longitudinal path profiled);
- should have design to allow field calibration and verification of calibration for the distance measurement (horizontal) subsystem and the height measurement (vertical) subsystem described in Section 8; and
- must be certified for use in Texas (described in Section 8).

Note 1—For consistent pavement profile determination, maintain air pressure on the wheels of the housing vehicle according to the manufacturer’s specification. The housing vehicle and all system components must be in good repair and proven to be within the manufacturer’s specifications. The operator of the inertial profiler must have all tools and components necessary to adjust and operate the inertial profiler according to the manufacturer’s instructions.

3. REPAIR AND ADJUSTMENT OF INERTIAL PROFILERS

3.1 Major component repairs or replacement that would require recertification of the inertial profiler include, but are not limited to, the following:

- the accelerometer and its associated hardware,
- the non-contact height sensor and its associated hardware,

- the distance measuring instrument, or
- any printed circuit board necessary for the collection of raw sensor data or the processing of the inertial profiles and IRI.

3.2 The operator of the inertial profiler may make minor adjustments to the equipment without having to complete the recertification process as long as the adjustments allow the equipment to fulfill the procedure in Section 4. Minor adjustments to the system include, but are not limited to, the following:

- inspecting, resoldering, or replacing connectors;
- cleaning components, normal adjustments to voltage levels as required by the manufacturer; and
- setting software parameters and scale factors as required by the manufacturer.

---

4. VERIFYING CALIBRATION

4.1 The following verification procedures are required for QA testing and are recommended when using an inertial profiler as a QC instrument on a daily basis.

4.2 **Standards:**

4.2.1 *Horizontal:*

4.2.1.1 The horizontal or longitudinal calibration standard will be a straight roadway test section at least 528 ft. in length.

4.2.1.2 Using an invar ~~steel~~ ~~measurement~~ tape, ~~or electronic measuring device,~~ measure the ground distance precisely to within 0.1%.

4.2.2 *Vertical:*

4.2.2.1 The vertical measurement standards will be flat plates of known thicknesses.

4.2.2.2 Mark the plates with the known thicknesses.

4.2.2.3 As a minimum, test a base plate and a 1-in. measurement plate.

4.2.2.4 Measure plate thickness accurate to within 0.001 in.

4.3 **Procedures:**

4.3.1 *Frequency of Verifying Calibration:*

4.3.1.1 Perform the horizontal and vertical verification of calibration of the inertial profiler before use on each paving project according to the manufacturer's recommendations.

4.3.1.2 Check the tire air pressure on the wheels of the housing vehicle and maintain according to the manufacturer's recommendations.

4.3.1.3 Maintain a log and keep it with the inertial profiler to provide a verification of calibration history.

4.3.2 *Horizontal Verification of Calibration:*

4.3.2.1 Perform the horizontal (longitudinal) verification of calibration by navigating the inertial profiler over a measured test section at least 528 ft. in length.

4.3.2.2 The inertial profiler's distance measuring subsystem must measure the length of the test section to within 0.2% of its actual length.

4.3.2.3 As necessary, adjust the inertial profiler's distance measurement subsystem according to the manufacturer's guidelines.

4.3.2.4 Failure to meet the specified tolerance will require recalibration by the contractor and reverification as described under Section 4.

4.3.3 *Vertical Verification of Calibration:*

4.3.3.1 Perform the vertical verification of calibration on a flat and level area using the flat plate of known thickness. Perform the test indoors when windy conditions exist.

4.3.3.2 Place the base plate under the inertial profiler's non-contact height sensor. The inertial profiler's height measurement subsystem takes a height measurement. Use this measurement as the reference height for subsequent measurements.

4.3.3.3 Place a 1-in. plate on top of the reference plate below the non-contact sensor. The inertial profiler's height measurement subsystem measures this displacement to within 0.01 in. of the 1-in. plate's thickness.

4.3.3.4 Remove the 1-in. plate and verify that the inertial profiler's height measurement system returns to the original reference plate's displacement to within 0.01 in. Failure to meet the specified tolerance will require recalibration. If the recalibration requires major repair, as noted under Section 3, then recertify the profiler at the Pavement Profiler Evaluation Facility located at the ~~Riverside~~ RELLIS Campus of Texas A&M University. Section 8 describes the certification procedure. Reverify, if minor repairs are required, as indicated under Section 3.

4.3.4 *Quality Control:*

4.3.4.1 When using a profilograph for quality control purposes, convert the zero inch blanking band average PI (in inches/mile), per 0.1-mi. section, into estimated average IRI (in inches/mile) using the following equation:

$$IRI = \frac{4.445 \times PI}{1 + (0.02073 \times PI)}$$

5. PROCEDURE

5.1 Locate and mark all "leave-out" sections as directed by the Engineer. Do not evaluate "leave-out" sections for the payment of bonuses or penalties. "Leave-out" sections will include any additional pavement length as prescribed in the smoothness specification including the first and last 100 ft. of the paving project.

5.2 Before measuring, clean the roadway path of all debris and other loose material.

5.3 Operate the inertial profiler at a constant speed of 12 mph or greater when measuring the pavement profile. Failure to maintain this minimum speed will cause the inertial referencing subsystem to "droop"; hence, the pavement profile elevations will not be usable. Re-measure any pavement segment where the average operational speed per 0.1 mi. is less than 12 mph.

5.4 A pre-section length of roadway is required to "settle" the inertial profiler's filters. This pre-section should be at least 200 ft. in length and located immediately before the section of pavement under test. Depending on the type of filter used with the inertial profiler, a lead-out may also be required immediately after the section of pavement under test to correct for phase shifts introduced by filtering. The lead-out length should conform to the operating requirement set by the profiler manufacturer. Typically, this length varies from 200 to 300 ft. Set the long wavelength cutoff to 200 ft. for profile measurements.

5.4.1 Take the inertial profile measurements on two longitudinal lines spaced 69 in. apart, corresponding to the wheel paths of each pavement travel lane.

5.4.2 The profile location will normally lie 3 ft. from and parallel to the approximate location of the pavement lane edge.

5.4.3 If the inertial profiler is capable of measuring profiles from two longitudinal wheel paths during a single pass, then the wheel path spacing will be 69 in., measured center-to-center of the laser footprints.

5.5 Collect measurements in the direction of traffic. Set up the profiler to trigger data recording automatically at the starting location of the pavement section to be tested. Optionally, set up the profiler to stop data recording automatically at the end of this section. When using an inertial profiler that collects a single wheel path per pass, take care to ensure that the measurements from each wheel path in a travel lane start and stop at the same longitudinal locations.

5.6 Mark "leave-out" sections.

5.6.1 Place event markers in the elevation data that correspond to the location of each "leave-out" section during the measurement process.

5.6.2 Refer to Section 6.1.4 of this test method for proper location of event markers in the data file.

5.7 *Data Collection:*

5.7.1 Perform QA data collection at the end of the paving operation or staged as prescribed by the Engineer.

5.7.2 Collect pavement profiles on a project in a single data file per travel lane when both wheel paths are measured during a single pass and event markers are used to mark “leave-outs”;, or

5.7.3 Collect pavement profiles on a project in two data files per travel lane when a single wheel path is measured during a single pass and event markers are used to mark “leave-outs”;, or

5.7.4 Collect pavement profiles on a project in multiple data files per travel lane when “leave-outs” are specifically excluded from the test measurements made with the inertial profiler.

5.8 Submit to the Engineer a table that identifies the lanes, wheel paths, and distance locations tested for each file created during the QA testing. ~~Present~~ Provide the profile elevation data to the Engineer in an electronic format (via email, CD, or USB drive), as described in Section 6 of this test method.

NOTE 2—The Engineer will use the RIDE QUALITY program to calculate the IRI values and associated pay factors.

5.9 The Engineer will:

- compute a summary roughness statistic for each 0.1 mi. pavement segment. (This roughness statistic is the IRI.)
- calculate and record the IRI from each longitudinal line profiled for a pavement travel lane. (The payment schedule will be based on the average IRI calculated from both wheel paths in a travel lane.)
- calculate and record the locations of areas of localized roughness.

5.10 Calculate the pay adjustment for segment lengths less than 0.1 mi. and greater than 50 ft. as illustrated below:

$$Pay\ Adjustment = \$460 \times \left(\frac{0.075}{0.10}\right) = \$345$$

Where:

0.075 mi. = the length of the short section in this example

37 in./mi. = measured IRI in this example, and

$460 = the pay for a full 0.1 mi. section with an IRI = 37 in./mi.

6. TEST DATA DESCRIPTION AND FORMAT

6.1 *Standard Test Data:*

6.1.1 Report test data in mils and in an ASCII file. This will permit the Department to directly input profile data, collected with any inertial profiler, into its data reduction program for QA testing. Each record should be separated by a carriage return and line feed (CRLF). A comma should separate each header and data entry in a record. Section 6.2 illustrates the required format of the data file. The following information provides a description of the required format, referred to as the TxDOT .PRO format.

6.1.2 *First Record*—consists of the following items, each separated only by a comma, with no blanks or spaces between items in the record:

- The first item is the identifier for the record. Write this item as HEAD3 in the data file as illustrated in Section 6.2.
- Date of profile measurement in mmddyyyy format, where mm is the numeric designation for the month, dd is the day, and yyyy is the year—zero fill the first digit for the months of January to September (01 to 09). Likewise, zero fill the first digit for days 01 to 09 of a given month.
- District where profile measurements were made in ## format—note that ## is the two-digit numeric designation for the given district. Zero fill the first digit for districts 01 to 09.
- County number in ### format—Zero fill the leading digits as necessary.
- Highway name in $$####$ format where "$" represents a character descriptor following PMIS convention—the first two characters designate the highway system, e.g., interstate, US highway, state highway, farm-to-market. Always fill in these characters, which may be any of the letters from A to Z, using upper case. Allow no blanks or spaces in the highway system designation. Zero fill leading digits as necessary in the highway name. The last character is a suffix. It is usually blank or N, S, E, or W (north, south, east, or west); for park roads, it can be blank or A–Z; for business routes it can be A–Z (except I and O).
- Beginning reference marker of the measurement in ####$±##.### format—zero fill the leading entries in the first four digits of the beginning reference marker as necessary. Likewise, zero fill the first digit following the + or – sign as necessary. The character following the first four digits is a suffix. It may be any of the letters A to Z, written in upper case, or a blank (space). Following the suffix is a + or – sign, indicating the relative direction of the offset, in miles, from the beginning reference marker. The offset is specified by the number following the + or – sign. As necessary, zero fill the trailing entries to the right of the decimal point in the offset, e.g., 0412 +05.300, not 0412 +05.3. Reference marker numbers range from 0010 to 0999. (The fourth digit is provided to accommodate future expansion of the highway system.)
- Lane tested in $# format following PMIS convention (see PMIS Lane Designations)—The first character designates the roadbed and may be any of the letters K, R, L, A, and X, written in upper case. It cannot be a blank or space. Fill in the digit following the first character that may take on a value from 0 to 9.

- Additional Notes—The Engineer can run a "List of Sections to be Rated" report in PMIS to obtain the correct highway and reference marker designations to be used for testing. The resulting profile data, once converted to PMIS format, can be stored in PMIS using Rating Cycle = 'C' (for Contractor).

6.1.2.1 *Second Record*—consists of the following variables, each separated only by a comma, with no blanks or spaces between variables:

- The first variable is the identifier for the record. Write this as CMET3 in the data file as illustrated in Section 6.2.
- Model designation of the ~~lightweight~~ profiler used for testing—this variable or item in the record may consist of 1 to 20 characters. Allowed entries are the letters A to Z, numbers 0 to 9, +, - , #, $, &, colon, dash, period, asterisk, tilde, underscore, blank, forward slash, left parenthesis or bracket, and right parenthesis or bracket. Enter letters in upper or lower case. ~~Do not allow blanks~~.
- The third, fourth, fifth, and sixth items in the record must show the profiler certification level (described in Section 8), profiler operator name, profiler serial number, and the long wavelength cutoff (ft.) for the high-pass filter used to determine the profile elevations recorded in the PRO file. Each of these items may consist of 1 to 20 characters. Allowed entries are the same as those identified for the model designation described above.
- The seventh item in the record is the certification code for the given profiler. The profiler certification code is the vehicle identification number (VIN) attached to the vehicle of the inertial profiling system. Allowed entries are the same as those identified for the model designation described above.
- The last item in the record is the certification date in mmddyyyy format. Zero fill the first digit for the months of January to September (01 to 09). Likewise, zero fill the first digit for days 01 to 09 of a given month.

6.1.2.2 *Third Record*—consists of the following variables, each separated only by a comma, with no blanks or spaces between variables:

- Manufacturer of the ~~lightweight~~ profiler—this variable or item in the record may consist of 1 to 20 characters. Allowed entries are the same as those identified for the model designation specified in the second record of the data file.
- The unit of elevation used to report profile—under the current Department practice, unit is entered as mil (0.001 in.)~~, as shown in Section 6~~. Enter all three letters in lower case.
- The wheel path measured—designated as L for left, R for right, or LR for dual wheel path profilers, with no blanks or spaces separating the L and R in the LR designation. Note, L and R are relative to the direction of traffic on the lane surveyed. For dual wheel path profilers, report the relative elevations in left–right order. As a result, for dual wheel path profilers, always designate the wheel paths as LR.
- The reporting interval (distance between successive relative elevation measurements) in inches or meters—the maximum reporting interval is 2 in. (0.0508 m).

- The unit of the reporting interval item—either i = inch or m = meter. Write the unit in lower case.

6.1.2.3 *Fourth Record*— consists of the initial GPS readings corresponding to the starting location of the pavement section under test. GPS readings should conform to the WGS-84 standard and include the following variables, each separated only by a comma, with no blanks or spaces between variables:

- Latitude (Lat)—measured in decimal degrees to the sixth place.
- Longitude (Lon)—measured in decimal degrees to the sixth place with no implicit (-) on longitude output.
- Altitude (Alt)—elevation or height above sea level to the nearest foot.
- Heading (Hdg)—bearing information in degrees.
- Speed (Spd)—speed information in miles per hour (mph).

6.1.2.4 *Fifth Record*—reserve fifth record for text comments. The record can hold up to 80 characters

6.1.3 The first five records of the ASCII data file are header cards. Following the fifth header record, report the relative measurements at each longitudinal location. For profilers that measure only one wheel path in a given run, each data record will have the relative elevation measured at the given location along the test wheel path followed by the comment code. In addition to this information, there will be data records with GPS readings corresponding to different locations along the test wheel path. The distance interval between GPS readings will depend on the sampling rate of the GPS receiver and the profiler test speed. As a minimum, collect GPS readings at a rate of 1 Hz. The GPS readings will follow the comment code and will include the latitude, longitude, altitude, heading and speed as described in Section 6.1.1.4. A comma will separate each variable in the data record. Make profile measurements in the direction of traffic. There will be as many records following the fifth header card as collected elevation measurements in the longitudinal locations.

6.1.4 For profilers capable of measuring two wheel paths in a travel lane at the same time with one pass, each data record will have the relative elevation measured using the sensors on the left side of the profiler, the relative elevation measured using the sensors on the right side, and the comment code. In addition, there will be data records with GPS readings as described in Section 6.1.2. A comma will separate each variable in the data record. Make profile measurements in the direction of traffic. For dual path profilers, set the spacing between wheel path sensors at 69 in. to be consistent with Department practice.

6.1.5 Comment codes will be a single numeric character from 0 to 9. There will be a comma separating this code from the last reported elevation at a given measurement location. Include elevation data with a code of zero in the determination of IRIs and pay adjustments. Exclude elevation data with non-zero comment code. Write the non-zero comment codes to the data file through the entire length of each “leave out” area. Likewise, write the zero comment codes through the entire length of each segment included in the pay adjustment calculations based on Surface Test Type B. Section 6.2 includes a sample data file.

6.2 Example Profile Data File:

Note 3—Line numbers to the left are only for description purposes and are not part of each record.

1. HEAD3,08242016,17,021,SH0047S,0413 +00.200,R1
2. CMET3,Profiler_Model,HMA,John Doe,1001,200.0,123456ABCDEF,~~07~~10112015
3. Manufacturer,mil,LR,2.0,i
4. 23.785523,-98.232200,858,220,50
5. PRO file for project with GPS coordinates collected during the test
6. 412,303,0
7. 424,327,0
8. 411,342,0
9. 413,348,0
10. 396,349,0
11. 391,345,9
12. 395,343,9
13. 411,369,9
14. 422,376,9
15. 422,366,9
16. 398,379,9
17. 410,390,9
18. 407,361,9
19. 393,357,0
20. 398,365,0
21. 385,393,0
22. 394,399,0
23. 392,373,0
24. 405,366,0
25. 404,371,0
26. 417,371,0
27. 395,344,0
28. 366,332,0
29. 357,303,0
30. 328,272,0
31. 338,100,0,23.785533,-98.232209,857,222,50
32. 422,366,0

33. 398,379,0

34. 410,390,0

35. 407,361,0

36. 393,357,0

37. 398,365,0

38. 385,393,0

39. 394,399,0

40. 392,373,0

41. 405,366,0

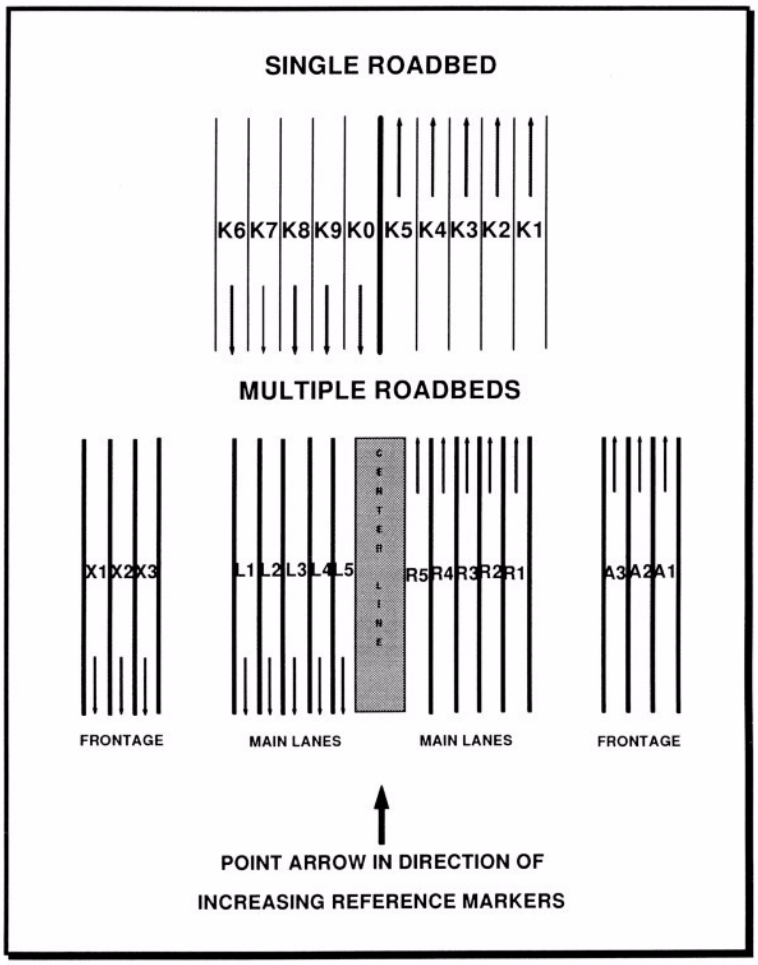


Figure 1—PMIS Lane Designations

7. DETECTING LOCALIZED ROUGHNESS

7.1 Using the RIDE QUALITY program, identify areas of localized roughness with the same measured profiles required for QA tests. The program will identify the defect locations and provide the defect magnitudes in the manner described in Section 7.2, except that the program will analyze and output the results by wheel path.

7.2 To determine the pay adjustments due to localized roughness, the RIDE QUALITY program will:

- average each elevation point from the two longitudinal profiles from a travel lane to produce a single averaged wheel path profile,
- apply a 25 ft. moving average filter to the single average wheel path profile,
- determine the difference between the averaged wheel path and the 25 ft. moving average filtered profiles for every profile point, and
- identify deviations greater than 0.150 in. as detected areas of localized roughness. (Positive deviations are “bumps,” and negative deviations are “dips.”)

7.2.1 The procedure implemented is a modification of the methodology described in the following reference: *Application of Profile Data to Detect Localized Roughness* by Emmanuel Fernando and Carl Bertrand, Transportation Research Record 1813, Transportation Research Board, Washington, D.C., 2002, pages 55–61.

Note 4—The Engineer may use the Grind Diagnostics program to further assess the need for correcting the defects identified on each wheel path using the RIDE QUALITY bump template. Grind Diagnostics does not override the pay adjustments determined by the RIDE QUALITY program. Rather, Grind Diagnostics is a tool with which to determine corrective actions to fix defects and improve ride quality based on the defect correction index (DCI). This index relates road user perception of defect severity to measured surface profile characteristics. The original development of the DCI is described in the following reference: *Relationship between Surface Profile Characteristics and the Need for Localized Roughness Correction* by Fernando, E. G., R. S. Walker, and M. Mikhail, Journal of the Transportation Research Board No. 2504, Transportation Research Board, Washington, D. C., 2015, pages 95 – 103.

8. INERTIAL PROFILER CERTIFICATION

8.1 This section provides minimum certification requirements for inertial profilers used for quality assurance testing of surface smoothness on Department paving projects where the profile-based smoothness specification is enforced. The Texas A&M Transportation Institute (TTI) administers the inertial profiler certification for the Department.

8.2 The certification procedure covers test equipment that measures longitudinal surface profile based on an inertial reference system mounted on an inertial transport vehicle such as that shown in Figure 2. The intent of minimum requirements stipulated herein is to address the need for accurate, precise, uniform, and comparable profile measurements during construction.

Figure 2—Illustration of a Lightweight Inertial Profiler Developed by the Department

8.3 **Minimum Requirements:**

8.3.1 *Operating Parameters*:

8.3.1.1 The inertial profiler must be capable of providing relative elevation measurements that meet the following requirements:

- Reporting Interval—the interval at which relative profile elevations are reported must be less than or equal to 2 in.
- Long Wavelength Cutoff —the algorithm for filtering the profile data must use a long wavelength cutoff of 200 ft. to be consistent with current Department practice.

8.3.1.2 The profiler must also be able to calculate and report the IRI (in./mi.) from the corresponding measured profile and permit the operator to:

- automatically trigger the start of data collection at the designated location;
- provide the measured profiles in electronic text files following the format prescribed by the Department in Section 6;
- evaluate profiler accuracy and repeatability as described in this document; and
- verify the height and distance measurements as described herein.

8.3.2 *Equipment Certification:*

8.3.2.1 On an annual basis, the inertial profiler must undergo certification tests to establish that it complies with the minimum requirements for accuracy and repeatability set forth in this test method. A profiler must also undergo certification testing after undergoing major component repairs or replacements as identified in this test method.

8.3.2.2 To monitor compliance with this requirement, an item will be included in the contract documents for a given project attesting that the contractor knows and understands the requirements for profiler certification as stipulated in this test method and that each profiler used on the project is current in its certification. Equipment certification involves using the inertial profiler to collect profile data on test sections designated by the Department for this purpose. Before equipment certification, the owner of the profiler should verify the horizontal and vertical calibration of his or her equipment following the procedures given under Sections 4.3.2 and 4.3.3. Perform additional verifications of calibration as recommended by the equipment manufacturer. Conduct this verification at the owner's facility to permit making necessary recalibrations before the scheduled date of certification testing.

8.3.2.3 *Profile Tests:*

- *Test Sections*—Certify profilers on test sections representative of the pavements on which the profiler will be used for ride quality assurance testing. Profiler certification is tied to the certification level the profiler successfully passed as shown in Table 1. Each section will be 0.1 mi. in length. Make ten repeat runs of the inertial profiler on the designated wheel path of each test section in the prescribed direction of measurement. To evaluate the profiles from the test equipment, measure the profile of the test wheel path on each section using static level methods.

Table 1—Inertial Profiler Certification Levels*

Profiler Certification Level	**Hot-Mix Asphalt (HMA)**			**Portland Cement Concrete (PCC) Pavement**		
	Dense-graded		**~~Open-graded~~ PFC/SMA**	**Transversely-tined**		**Longitudinally-tined**
	Smooth	**Medium smooth**		**Smooth**	**Medium smooth**	
HMA	X	X	X			
PCC2				X	X	
PCC1				X	X	X
HMA/PCC2	X	X	X	X	X	
HMA/PCC1	X	X	X	X	X	X

~~Note:~~ *The owner of the profiler will select the inertial profiler certification level for testing.

Test Data—Refer to Section 6 for descriptions and formats of the .PRO files to be submitted from certification tests.

8.3.2.4 During the certification tests, the same wheel paths are profiled in the designated direction for all runs on a given test section. Operators of single-path inertial profilers will run each wheel path separately and provide test data by wheel path on each test section. To facilitate the analysis of the data, name the files from the tests described herein according to the following convention:

- Reserve the first four characters of the file name for identifying the profiler tested, provided by the testing agency, on or before the day of testing.
- The fifth character is an underscore,"_".
- The sixth, seventh, and eighth characters will be HMA for runs made on a hot-mix asphalt section, or PCC for runs made on a Portland cement concrete section.
- The ninth character is the section ID for the given pavement type (HMA or PCC). The testing agency ~~must~~shall provide the section ID, which will range from A to Z.
- The 10th and 11th characters will designate the run number (01 to 10).

- The 12th character will designate wheel path tested. For dual path profilers, use the letter B to indicate profiling both wheel paths in the same run.~~; f~~For single-path profilers, use L or R to indicate profiling the left or right wheel path, respectively, in the given run.

8.3.2.5 Use the extension .PRO for the data files generated from testing.

8.3.2.6 The testing agency will analyze test data submitted by the equipment operator to establish the repeatability and accuracy of the test profiles.

- *Profile Repeatability*—to evaluate profile repeatability, compute the variance of the 10 repeat measurements at each reporting interval for each wheel path surveyed. Determine the average variance, and take the square root of this statistic. To pass the profile repeatability test, the square root of the average variance must not exceed 35 mils on each wheel path.
- *Profile Accuracy*—the testing agency will establish the benchmark or reference profiles on the test section using static methods such as the rod and level, Dipstick, Walking Profiler, SurPRO, and/or other suitable devices that provide unfiltered profiles. Reference elevations will be collected at 2-inch intervals or less.
  - The testing agency will use devices that measure and integrate differential elevations, such as the Dipstick, Walking Profiler, and the SurPRO, to establish the benchmark profiles; however, the testing agency will check the measurements from these devices with the rod and level at distances along the test wheel path that are multiples of the reporting interval for the specific device used.
  - Collect rod and level measurements such that the sight distance between the level and the rod is no more than 100 ft. at each setup station. Collect reference profile measurements on the designated wheel path of each test section as well as on the section lead-in and lead-out. The lead-in distance will be at least 300 ft. The lead-out distance will conform to the profiler manufacturer's operating requirement.
  - Filter the reference profiles using the same filter type implemented with the profiler tested. For this purpose, the owner or manufacturer of the profiler will provide a Windows-compatible computer program to accomplish this filtering. The testing agency will use this program to filter the reference profiles for evaluating the accuracy of the measurements from the profiler. This program must be set up to permit use of a 200 ft. long wavelength cutoff and to read the reference profile from an ASCII or text file in the TxDOT .PRO format. Additionally, the program must output the filtered reference profile in an ASCII or text file in the TxDOT .PRO format. The testing agency will keep the executable copy of the filter program.
  - Synchronize the test profiles as necessary so that the interval between reported elevations is the same as the interval between points in the filtered reference profiles. To evaluate accuracy, determine the average profile from the ten repeat runs on a given wheel path by computing the mean of the relative elevations from the ten repeat runs on a point-by-point basis, i.e., at each reporting interval. In the same manner, determine the average of the filtered

reference profiles on the test wheel path. Use at least three repeat measurements for the determination of the average filtered reference profile. Calculate differences between the average test profile and the average filtered reference profile , point-by-point. Compute the average of these differences (μ_1) and the average of the absolute differences (μ_2) to establish the accuracy of the inertial profiler. To pass the accuracy test, the average of the point-to-point differences, μ_1, must be within ±15 mils, and the average of the absolute differences, μ_2, must not be greater than 50 mils for each wheel path tested.

8.3.2.7 The testing agency shall determine the repeatability of the IRIs in the following manner:

- Compute ten IRI values using the profiles from the ten repeat runs made on a given wheel path.
- For each test wheel path, compute the standard deviation of the IRIs.
- To pass IRI repeatability, the IRI standard deviation must not exceed 2.5 in/mi on each wheel path tested.

8.3.2.8 The average of the IRIs is also determined for each wheel path. To evaluate the accuracy of the IRIs from the test data, compare the average IRI against the corresponding average determined from the unfiltered reference profiles. The absolute difference between the average IRIs from the profiler and the reference must not exceed 6.0 in./mi. for each wheel path tested.

---

9. TEST RESULTS

9.1 The testing agency will report the certification results by pavement type tested (HMA/PCC). The report will include the following information:

- identification of the profiler tested to include the model, profiling system serial number, and the vehicle identification number;
- operator of the profiler;
- names of the individuals from the testing agency who conducted the test;
- date of test;
- section and wheel paths tested;
- filter type, name of the filter program, and the applicable program version number used to evaluate the profiler accuracy;
- type of lasers installed on the inertial profiler;
- overall determination from ~~the~~ test on given group of sections: Pass or Fail; and
- individual test results determined from the profile data, which will include:
    - the profile repeatability statistic;
    - statistics, $\mu 1$ and $\mu 2$, for evaluating the accuracy of the profiles with respect to the reference;

- standard deviation of the IRIs computed from the profiles; and

- the difference between the average of the IRIs determined from the profiler test data on a given wheel path, and the average of the IRIs determined from the unfiltered reference profiles on the same wheel path.

9.2 The testing agency will determine the appropriate certification level based on the profiler's test results. For the profiler to be certified at the certification level the owner selected prior to testing, the profiler must pass on all test sections within that level. However, a profiler that fails on any one section may still be certified under a lower level if it passes on the test sections assigned to that lower level. Table 2 identifies the applicable cases. The testing agency will provide a decal showing the profiler certification level and expiration date (month and year) of the certification.

Table 2—Determination of Profiler Certification Level

Selected Profiler Certification Level	Profiler Performance on Test Sections	Assigned Profiler Certification Level
HMA	Fails one or more of the HMA test sections	No certification
PCC2	Fails one or more of the transversely-tined test sections	No certification
PCC1	Fails the longitudinally-tined section but passes on all transversely-tined sections	Profiler certifies under PCC2
PCC1	Fails one or all transversely-tined sections	No certification
HMA/PCC2	Fails one or more of the HMA sections but passes all transversely-tined sections	Profiler certifies under PCC2
HMA/PCC2	Fails one or all transversely-tined sections but passes all HMA sections	Profiler certifies under HMA
HMA/PCC2	Fails one or more of the HMA sections and fails one or all transversely-tined sections	No certification
HMA/PCC1	Fails the longitudinally-tined section but passes on all HMA and transversely-tined sections	Profiler certifies under HMA/PCC2
HMA/PCC1	Fails one or more of the HMA sections but passes all PCC sections	Profiler certifies under PCC1
HMA/PCC1	Fails one or more of the HMA sections and the longitudinally-tined section but passes all transversely-tined sections	Profiler certifies under PCC2
HMA/PCC1	Fails one or all transversely-tined sections but passes all HMA sections	Profiler certifies under HMA
HMA/PCC1	Fails one or more of the HMA sections and fails one or all transversely-tined sections	No certification

10. OPERATOR CERTIFICATION

10.1 Operators of inertial profilers used for QA testing of pavement ride quality must pass a proficiency test and be certified to operate an inertial profiler in Texas. The Texas A&M Transportation Institute administers the test for the Department. The test for inertial profiler operator certification will include the following:

- current specifications and/or special provisions for ride quality for pavement surfaces,

- Tex-1001-S, and
- verification of profiler calibration and collection of profile data.

10.2 Applicants for operator certification must pass both written and practical examinations.

10.3 The written examination will cover the following items:

10.3.1 *Ride Specifications:* Required documentation for equipment and operators:

- applicable areas profiled under Item 585 and Item 247 (flexible base ride specification) and
- quality assurance testing under Item 585 and Item 247.

10.3.2 *Tex-1001-S*:

- inertial profiler components,
- verification of profiler calibration,
- profile measurements with inertial profilers,
- profile data format, and
- inertial profiler certification.

10.4 The practical examination will cover the following areas:

- verification of profiler calibration and
- profile measurements.

10.5 To qualify as a certified inertial profiler operator in Texas, the applicant must:

- pass the written examination with a score of 70% or higher;
- pass the practical examination for verification of profiler calibration, demonstrated on the profiler operated by the applicant; and
- pass the practical examination for profile measurements, demonstrated on the profiler operated by the applicant.

10.6 The applicant will demonstrate that he or she can perform the horizontal and vertical calibrations described under Section 4. Additionally, the applicant will perform profile measurements along a given route established by the testing agency. The route will be at least 2,500 ft. long, with designated 0.1 mi. test sections and “leave-out” segment(s). The applicant will profile the designated wheel paths of the test route in the specified direction following the procedures given in this test method. He or she will provide the test data in electronic files following the requirements stipulated in Section 6. For the practical examination, the applicant’s performance is evaluated as passing or failing. The applicant must pass both areas of the practical examination and obtain a score of 70% or higher in the written examination to qualify as a certified inertial profiler operator in Texas.

10.7 Upon passing the proficiency test, the testing agency will give the successful applicant an identification card, which will verify the certification to operate an inertial profiler for QA testing on Department paving projects. The card will identify the specific types or brands of inertial profilers for which the operator certification is valid. This card will also specify the issue date and the expiration date of the certification. The Department has the authority to revoke the card before the expiration date because of misuse.

10.8 Upon expiration, recertification of the operator will require successful completion of another proficiency test as described in this Section for inertial operator certification.

11. ARCHIVED VERSIONS

11.1 Archived versions are available.