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Effect of Pavement Type on Fuel Consumption and Emissions in City Driving

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EXECUTIVE SUMMARY

The main objective of this study has been to investigate any differences that might exist in fuel consumption and CO_2 emissions when operating a motor vehicle on an Asphalt Concrete (AC) versus a Portland Cement Concrete (PCC) pavement under city driving conditions. The overall study goal has been to recommend consideration of such user costs or savings in the life cycle analysis of alternative pavement designs for city streets.

The selection criteria for test sections included surface material type, surface roughness, longitudinal gradient, and location of the pavement sections. Accordingly, two pairs of street sections in Arlington, Texas (two asphalt and two concrete) were selected for fuel consumption studies. Each pair of streets (one AC and one PCC) had similar gradients and roughness indices. The streets were also approximately parallel so as to minimize the effect of wind direction and velocity during measurement runs.

In the course of the fuel consumption measurements, every attempt was made to either control all other factors that could affect fuel consumption or keep the factors that cannot be controlled the same. These included 1) vehicle mass, 2) tire pressure, 3) fuel type, 4) ambient temperature, 5) humidity, and 6) wind speed and direction. Among these factors, the first three were kept the same for all runs.

Two different driving modes (cruise vs. acceleration) were used in the test runs. Under the constant speed mode, a cruise speed of 30 mph was maintained throughout the test run. In the acceleration mode, the fuel consumption data were collected while accelerating from zero to 30 mph in 10 seconds, yielding an average acceleration rate of 3 mph/second. As shown in the table below, it was found that the fuel consumption rates per unit distance were consistently lower on the PCC sections regardless of the test section, driving mode (acceleration vs. constant speed), and surface condition (dry vs. wet). In all cases, the differences were found to be statistically significant at 10% level of significance. The fuel consumption rates in this table indicate fuel consumption savings of 3% to 17% on PCC pavements depending on the driving mode, surface conditions, and crown and substructure materials and thicknesses. The percentage savings could also vary depending on the vehicle mix.

An analytical tool in the form of a spreadsheet program was also developed to estimate the fuel consumption and emissions savings or costs based on user-specified project conditions, namely pavement type and expected vehicle mix and miles of travel. It was shown that for a typical metropolitan area, these user cost differences could be substantial over the design life of a city

	Surface Condition	
	Dry	Wet
	Average Fuel Consumption (10^{-3} gals/mile)	Average Fuel Consumption (10^{-3} gals/mile)
Road to Six Flags (PCC) Constant Speed of 30 mph	42.2	45.6
Randol Mill Rd (AC) Constant Speed of 30 mph	51.3	55.3
Road to Six Flags (PCC) Acceleration of 3 mph/sec	240.2	226.1
Randol Mill Rd (AC) Acceleration of 3 mph/sec	257.7	259.9
Abram St (PCC) Constant Speed of 30 mph	45.6	54.1
Pecandale Dr (AC) Constant Speed of 30 mph	49.5	55.9
Abram St (PCC) Acceleration of 3 mph/sec	232.8	260.6
Pecandale Dr (AC) Acceleration of 3 mph/sec	247.0	269.3

street pavement. For example, if the annual vehicle miles of travel in the Dallas-Fort Worth (DFW) region in Texas took place hypothetically at a constant speed of 30 mph all on PCC pavements similar to the test sections in this study, the statistically lower fuel rates could result in an annual fuel savings of 177 million gallons and an annual CO_2 reduction of about 0.62 million metric tons. Assuming an average fuel cost of about $2/gallon and an average CO_2 clean-up cost of about $18/metric ton, these differences would amount to a savings of about $365 million per year in the DFW region.

As indicated above, the potential savings or costs in fuel consumed and CO_2 emissions generated can be substantial over the design life of a project. It is therefore recommended that these savings or costs be considered in the life cycle cost analysis of alternative projects. Furthermore, differences in CO_2 emissions should also be considered when estimating carbon footprint of alternative pavement materials. Estimation of carbon footprint is an important step in assessing the sustainability of any city development projects and the life cycle analysis of those projects. In pavement projects, specifically, the focus has long been on estimating carbon footprint associated with the production cycle and the construction phase of various pavement materials. A key finding of this study is that any such sustainability assessment must also consider the emissions differences based on operations of motor vehicles on various pavement surfaces. When considering a 20-50 year design life that is typical for city streets and the annual vehicle miles of travel, such differences could dwarf carbon footprint estimations from the material production or construction phases.

1. Introduction and Problem Definition

1.1 Background

Vehicular fuel consumption and emissions are two increasingly important measures of effectiveness in sustainable transportation systems, particularly considering that mobile sources in the U.S. account for the largest consumption of energy and generation of air pollution. According to the U.S. Bureau of Transportation Statistics (BTS) [18], there were 254,403,082 registered vehicles in the U.S. in 2007. Gasoline, which is the main product from crude oil refining, is one of the major fuels consumed by vehicles in the U.S. with a consumption level of over 70 billion gallons in 2007. This is about half of the total gasoline consumption for any purpose in the U.S.[21] As such, the transportation sector is also the largest emitter of CO_2 among all energy-use sectors such as industrial, residential, and commercial sectors. Among three common fossil fuels – petroleum, natural gas, and coal – 96% of the 2007 U.S. primary transportation energy consumption relied on petroleum or crude oil (Energy Information Administration, U.S. Department of Energy).[19] This trend continues despite the oil price increases which peaked at over $140 a barrel in June 2008.

In motor vehicles, CO_2 is the by-product of the combustion process released to the atmosphere as a tailpipe emission. It is one of the greenhouse gases contributing to global warming. Between 1990 and 2007, the energy-related CO_2 emission of the transportation sector grew the most, a 26.8% increase over the 10-year period and a 1.4% increase from 2006 to 2007 alone (Energy Information Administration, U.S. Department of Energy).[19] As a result, improving energy efficiency of the transportation sector including improving vehicle shape, mass, engine size, and tire quality could play a vital role in reducing fuel consumption and exhaust gas emissions. Pavement surface condition and type and other surface characteristics such as skid resistance, roughness, and longitudinal slope could also affect vehicular fuel consumption.

The Ready-Mix Concrete Research and Education Foundation sponsored this study aimed at comparing vehicular fuel consumption characteristics on two different pavement types, Portland Cement Concrete (PCC) and Asphalt Concrete (AC). The study is conducted through direct fuel measurements in urban driving using an instrumented vehicle on two pavement types (PCC and

AC) under two driving modes (constant speed and acceleration), and for two surface conditions (dry and wet).

1.2 Study Objectives

The main objective of this study is to compare fuel consumption and exhaust emissions of an instrumented test vehicle as a function of pavement surface material through direct field measurements. The study focus is paved city streets since urban driving accounts for a substantial share of the total vehicular energy consumption and emissions generated. Two types of pavement surfaces, namely Portland Cement Concrete and Asphalt Concrete, are studied. Using known scaling factors documented in energy consumption literature relating vehicle mass to fuel consumption, the study results for the test vehicle are extrapolated to other vehicle types in the mix. This allows, as a second study objective, to establish a procedure in a spreadsheet format to estimate the total fuel savings and emissions reductions in a region or over the design life of a project for different pavement type scenarios. The latter would also require data on vehicle mix and vehicle miles traveled over the project design life or within a city or region of interest. The procedure developed herein helps provide the information to generate a life-cycle cost analysis tool including potential fuel savings and emissions reductions in evaluation of pavement design alternatives.

Based on the above objectives, the main outcomes of the study are as follows:

a. Statistical comparison of relative fuel economy differences for concrete and asphalt pavement surfaces under urban driving conditions.

b. A spreadsheet tool to estimate fuel consumption and emissions for the pavement types and surface conditions studied so that the resulting savings or costs could be quantified and incorporated into the life-cycle cost analysis of different pavement design alternatives.

2. Literature Review

The Transportation Research Board (TRB) Special report 285 states that vehicular fuel consumption accounts for half of the total energy consumption in the U.S.[21] About half of that amount is estimated to be due to the urban city driving at speeds below 40 mph.[9] As such, the oil crises of 1970s led to numerous research studies on vehicular fuel consumption. This led to advances in automotive design including lighter vehicles with more efficient engines, more energy efficient tires, smoother roadway alignments and traffic engineering measures such as better timed traffic signals and national speed limit regulations.

The elemental fuel consumption model developed by scientists at the GM Research Lab [6,7] was the widely accepted model among the fuel consumption models developed in the 1970s. This model showed that the fuel consumption in a single vehicle varies greatly depending on many variables including speed, acceleration-deceleration cycle, vehicle mass, mechanical conditions of the vehicle such as tire pressure, wheel alignment, and state of its carburetion system, ambient conditions such as wind and temperature, and pavement surface conditions. The model speculated that about 75% of the variability in a vehicle's fuel consumption is explained by speed alone. Also an important factor influencing the fuel consumption rate is the rolling pavement resistance, which is primarily a function of the pavement surface condition and type. The fuel consumption differences due to rolling resistance were expected to be particularly significant for trucks and other heavy vehicles.

Since the costs of road construction and maintenance constitute a large proportion of the highway infrastructure projects, the World Bank, which provides financial and technical assistance to developing countries, introduced the Highway Design and Maintenance Standards Model[2]. This program accounts for vehicle operating costs in addition to the construction, maintenance, and rehabilitation costs of alternative pavement designs. It also incorporates the life-cycle cost analysis (LCCA) as a basis for decision making in the selection of highway design alternatives.

The life-cycle cost in the Highway Design Model[2], included user costs in addition to conventional construction, maintenance and rehabilitation costs. The user costs were mainly the vehicle operating costs and exogenous costs such as the cost the society incurs as the result of road usage. The vehicle operating cost model contained variables related to vehicle characteristics such as engine size, speed, tire conditions, etc., and road characteristics such as smoothness and slope of the longitudinal profile. The smoothness and slope of the longitudinal profile were the only pavement characteristics used in the model for estimating the vehicle operating costs. The other pavement characteristics such as the pavement type became statistically less significant since data from both paved and unpaved roads were used. To enhance the Highway Design Model work, a New Zealand study by Walls and Smith[23] further suggested that the smoothness of the longitudinal profile has little impact on the fuel consumption for paved roads in good condition.

Papagiannakis and Delwa [11,12,13] developed a software program which highlighted the importance of incorporating vehicle operating costs in the life-cycle cost analysis of pavement projects. Their findings were later implemented in the Pavement Management System program of the Washington State Department of Transportation. They also paid special attention to the effect of roughness on the vehicle operating costs to illustrate the increase in these costs with the deterioration of the pavement.

In addition, many studies have been attempted to systematically assess the effect of pavement surface material type on fuel consumption.[8,15,25,26] Most of these studies focused on fuel consumption of vehicles on highways under fairly high operating speeds. A Canadian study [15] performed measurement of fuel consumption using heavy trucks, while a Swedish study [8] was conducted using passenger cars. Both study results indicated that there was potential fuel savings on PCC over AC pavements. Additionally, the research by Zaniewski et al [25,26] which was the earliest effort to investigate the effect of pavement type on fuel consumption, also pointed out that fuel consumption of a truck when travelling on PCC pavements is lower than when travelling on AC pavements. Because their study was focused on fuel consumption of trucks on highways and also due to other limitations of the methodology employed, this study has received substantial criticism.[3] Partly due to these issues, Zaniewski's findings have not been widely adopted by the pavement engineering community. Zaniewski's findings could also allow incorporating fuel economy improvements and emissions reductions in the life-cycle cost analysis of design alternatives for highway pavements. However, it is not readily clear whether and to what extent they are applicable to city streets, where urban carbon footprint is becoming an increasingly important consideration in the analysis of design alternatives. A synthesis study by the Ontario Hot Mix Producers Association, for example, cites that for every 1,000 kg of Portland cement, approximately 650 kg of carbon dioxide is produced while the carbon in the asphalt cement will never be released into the atmosphere.[4] The Canadian study also compares two residential pavement cross-sections, a PCC and an HMA pavement in southern Ontario. The study then proceeds to estimate the contributions of these two pavement materials to the carbon footprint of a one-kilometer long section and concludes that the HMA pavement generates only 22 percent of the carbon footprint of the PCC pavement. The computations are based solely on estimated CO_2 releases in the materials production as well as construction phase of the projects. While the study accounts for the CO_2 releases from cement kilns in estimating the carbon footprint of PCC projects, the portion of CO_2 releases from oil refineries attributable to asphalt production are not considered in making similar estimates for AC pavements. More importantly, this and other similar studies[22] do not consider the emissions resulting from the operation of motor vehicles over the design life of pavements in these calculations. A key conclusion of the current study is that over the design life of a pavement, the difference in the CO_2 amounts resulting from operation of motor vehicles on various pavement surfaces could be substantial and may in fact dwarf any such differences during the production and construction phases.

3. Experimental Design and Data Collection

3.1 Selection of Road Sections

Four urban street roadway sections (two asphalt and two concrete sections) were selected for fuel consumption studies. The selection criteria included surface material type, surface roughness, longitudinal gradient, and location of the pavement sections. Two sets of concrete pavement versus asphalt pavement sections with similar surface roughness and longitudinal gradient were accordingly selected. Each pair of road sections (one AC and one PCC) was approximately parallel so as to minimize the effect of wind direction and velocity during measurement runs on the two road sections at a given time. Below is a detailed description of each roadway section selected.

3.1.1 The First Test Sites

The Rigid Section

A rigid section chosen was Abram Street (Figure 1a). This is a Continuously Reinforced Concrete Pavement (CRCP). The reinforced concrete slab is 8 inches deep over 2-inch hot mix asphalt concrete type D on an 8-inch lime stabilized subgrade. The roughness measurements were done by the Texas Department of Transportation resulting in an average International Roughness Index (IRI) measurement of 174.6 in/mile. The longitudinal gradient was uphill with the average value of 1.2% in the eastbound direction (direction of observations).

The Flexible Section

Approximately two blocks away and parallel to the rigid section, Pecandale Drive (Figure 1b) was selected as a test section for the asphalt pavement. Its layers include a 7-inch deep hot mix asphalt concrete (1.5-inch Type D and 5.5-inch Type B) on a 6-inch lime stabilized subgrade. The average IRI measurement was measured to be 180.6 in/mile. Comparing with rigid section, the average IRI values are 3% higher. However, they are both in the IRI range for new pavements.[14] The average longitudinal gradient was +1.2% in the direction of observations (eastbound), which was identical to the gradient of the rigid section.

3.1.2 The Second Test Sites

The Rigid Section

The second rigid section was the Road to Six Flags Street (Figure 2a). This section is a Jointed Plain Concrete Pavement (JPCP) with a 7-inch concrete slab on a 6-inch lime stabilized subgrade. The spacing of the transverse joints was 20 feet. The average IRI value was measured to be 323.3 in/mile. The average longitudinal gradient was +0.4% in the direction of observations (westbound).

The Flexible Section

The asphalt pavement section selected was the Randol Mill Road (Figure 2b). It consisted of an 8-inch deep layer of hot mix asphalt concrete (2-inch Type D and 6-inch Type A) on a 6-inch lime stabilized subgrade. The average IRI value was 276.7 in/mile. The IRI values of the last two sections have a difference of 16.8%, with the asphalt section having a smaller IRI (smoother). The average longitudinal gradient was uphill at the rate of 0.6% in the direction of observations (westbound).

Table I summarizes the test section characteristics in terms of pavement types, roughness indices, and longitudinal grades. The details regarding the IRI measurements for each test section are provided in Appendix A. Appendix B shows the longitudinal profile surveys performed for each test section.

3.2 The Test Vehicle

An instrumented model 2000 Chevy Astro van (Figure 3) was utilized as the test vehicle. Fuel consumption measurements were made with an on-board data acquisition system. The fuel sensor, the temperature sensors, and the data acquisition system (shown separately in Figure 4) were connected to the engine as shown schematically in Figure 5. Two fuel sensors made instantaneous measurements of the amount of fuel entering the engine and returning to the tank, with the difference between the fuel intake and the amount returned to the tank being an estimate of fuel consumed. The temperatures of the fuel entering the engine and returning to the tank were also measured using two temperature gauges. In addition to the fuel amounts and fuel temperature, the data acquisition system also recorded the instantaneous vehicle speed.

Table I. Road Section Characteristics

	Road Section	Pavement Type	Details	Average IRI (in/mi)	Longitudinal Slope in Data Collection Direction (%)
First Test Sites	Abram Street	CRCP	8" continuously reinforced concrete over 2" HMAC type D on 8" lime stabilized subgrade	174.6	+1.2
	Pecandale Drive	HMA	7" HMAC (1.5" Type D, 5.5" Type B) on 6" lime stabilized subgrade	180.6	+1.2
Second Test Sites	Road to Six Flags Street	JPCP	7" reinforced concrete on 6" lime stabilized subgrade 20' transverse joint spacing	323.3	+0.4
	Randol Mill Road	HMA	8" HMAC (2" Type D, 6" Type A) on 6" lime stabilized subgrade	276.7	+0.6

1. a. Abram Street

1. b. Pecandale Drive

Figure 1. Abram Street (PCC) vs. Pecandale Drive (AC).

2. a. Road to Six Flags Street

2. b. Randol Mill Road

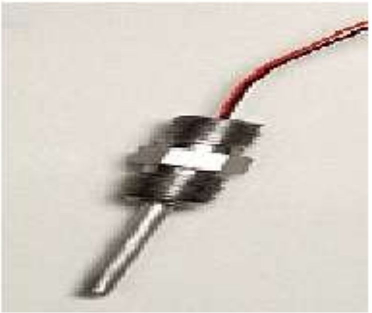
Figure 2. Road to Six Flags Street (PCC) vs. Randol Mill Road (AC).

3.a. The Instrumented 2000 Chevy Astro Van.

3.b. The Inside Set-Up during Data Collection.

Figure 3. The Test Van and Data Collection Set-Up.

4.a. Fuel Meter



4.b. Temperature Gauge

4.c. Data Acquisition System

Figure 4. On-Board Instruments.

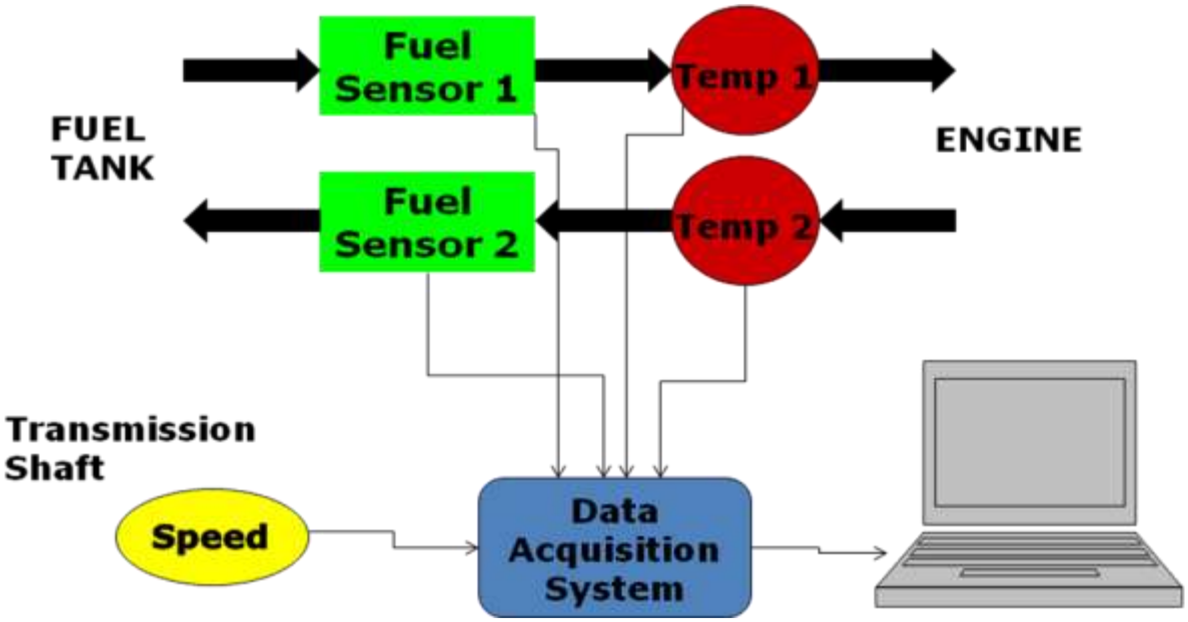


Figure 5. Schematic Diagram of the Sensor and the Data Acquisition System.

3.3 Measurements of Fuel Consumption

Fuel consumption measurements were made on four city street sections, two PCC and two AC. Each PCC and AC section pairs had similar gradient and roughness indices. In addition to pavement type, a number of other factors could affect fuel consumption, including speed, acceleration, gradient, pavement roughness, ambient temperature, atmospheric pressure, wind speed and direction, vehicle mass, tire pressure, and use of auxiliary devices in the vehicle. In order to isolate the effect of pavement type or fuel consumption, all the above factors were either controlled or kept the same during the measurement runs.

The experimental design consisted of two levels and three factors (two pavement types, two pavement surface conditions, and two driving modes), resulting in eight combinations as shown in Table II.

Six runs were necessary for each factor–level combination in order to obtain statistically meaningful conclusions at 90% level of confidence with a ±10% error. Analysis of Variance (ANOVA) was utilized as the main statistical tool for hypothesis testing purposes in comparing fuel consumption differences between the two pavement types, surface conditions, and driving modes.

The variables recorded for each measurement run included:

- Date of observation
- Time of observation
- Ambient air temperature
- Atmospheric pressure
- Relative humidity
- Wind speed and direction
- Temperature of fuel flowing into and out of the tank
- Vehicle weight
- Tire pressure
- Status of auxiliary devices (A/C, radio, headlights, windows, wipers, etc.)

The resulting data were statistically analyzed to determine whether there were significant differences in fuel consumption which could be attributed to driving on different pavement surfaces. Details of the analyses and the results are presented in the following section.

Table II. The Eight Factor-Level Combinations

Factor-Level Combination	Pavement Type	Driving Mode	Surface Ambient Condition
1	PCC	Constant Speed	Dry
2	PCC	Constant Speed	Wet
3	PCC	Acceleration	Dry
4	PCC	Acceleration	Wet
5	AC	Constant Speed	Dry
6	AC	Constant Speed	Wet
7	AC	Acceleration	Dry
8	AC	Acceleration	Wet

4. Data Analysis and Results

In the course of the fuel consumption measurements, every attempt was made to either control all other factors that could affect fuel consumption or keep the factors that cannot be controlled the same. These included 1) vehicle mass, 2) tire pressure, 3) fuel type, 4) ambient temperature, 5) humidity, and 6) wind speed and direction. Among these factors, the first three were kept the same for all runs. Factors 4-6 were recorded for each run so that pairwise comparisons of fuel consumption on different pavements would be made under similar conditions. For example, it would not be appropriate to compare fuel consumption on the asphalt section when there is a 20 mph headwind to that on the concrete pavement when there is a tailwind. Also, fuel consumption characteristics of a vehicle could be different under different temperature or humidity conditions.

Two different driving modes (cruise vs. acceleration) were used in the test runs. Under the constant speed mode, a cruise speed of 30 mph was maintained throughout the test run. In the acceleration mode, the fuel consumption data were collected while accelerating from zero to 30 mph in 10 seconds, yielding an average acceleration rate of 3 mph/second.

To verify that the equipment was functioning properly, the fuel data were used to construct plots of fuel consumption versus temperature and wind speed and direction. Figure 6 depicts the fuel consumed versus the ambient temperature. It shows that the best fuel efficiency is realized around the 70-75°F range. It was also found that there is less fuel efficiency under wet conditions. Both results are consistent with previous literature on vehicular fuel efficiency. For example, an extensive Canadian study [17] found that for most vehicles the best fuel efficiency occurs around room temperature (77°F). The study also found that more fuel is consumed per unit distance under wet roadway conditions compared to dry conditions.

The fuel consumption data were also plotted versus the wind speed and direction, as shown in Figure 7. This figure also clearly shows that, as expected, driving under headwind conditions results in higher fuel consumption than driving under tailwind conditions. As expected, both plots (Figures 6 and 7) also show less fuel efficiency under wet conditions. The expected fuel efficiency trends with temperature, wet/dry conditions, and wind conditions were all confirmed by data presented in Figures 6 and 7, indicating that the equipment readings seem to be fairly accurate in terms of the expected trends in fuel efficiency.

Each data collection session included multiple runs in one or another driving mode along two parallel test sites, one AC and one PCC. After each measurement session, the fuel flow rate in gallons per minute and the cumulative fuel consumed in each scenario were retrieved from the on-board data acquisition system. Two examples of the raw data plots are shown in Figure 8 for PCC at constant speed and in Figure 9 for PCC under the acceleration mode.

4.1 Statistical Comparisons

4.1.1 The First Test Sites: Abram (PCC) vs. Pecandale (AC)

For each driving mode, the total fuel consumed was recorded and the corresponding consumption rate in gallons per mile was calculated, as summarized in Table III. The raw data associated with the summary results in this table are provided in Appendix C.

For these two road sections, the fuel consumption rate for the PCC pavement was observed to be lower than the rate for the AC pavement in both driving modes. The observed differences in fuel consumption rates were tested for statistical significance at 90% level of confidence (10% level of significance). One-sided t-tests were conducted to investigate whether the fuel rates on the PCC sections were statistically lower than the rates on the AC sections, as summarized in Table IV.

Table III. Average Fuel Consumption Rates for Abram Street (PCC) vs. Pecandale Drive (AC)

PCC: Abram Street AC: Pecandale Drive	Surface Condition	
	Dry	Wet
	Average Fuel Consumption (10^{-3} gals/mile)	Average Fuel Consumption (10^{-3} gals/mile)
PCC, Constant Speed of 30 mph	45.6	54.1
AC, Constant Speed of 30 mph	49.5	55.9
PCC, Acceleration of 3 mph/sec	232.8	260.6
AC, Acceleration of 3 mph/sec	247.0	269.3

Table IV. Hypothesis test results for a one-sided t-test (PCC rate < AC rate) at 10% level of significance for Abram Street (PCC) versus Pecandale Drive (AC)

Condition	t-statistics			
	DF	Calculated t	Tabulated t	Result
Dry, Constant Speed of 30 mph	27	1.686	1.3137	significant
Dry, Acceleration of 3 mph/sec	29	3.055	1.3114	significant
Wet, Constant Speed of 30 mph	28	2.337	1.3125	significant
Wet, Acceleration of 3 mph/sec	28	2.165	1.3125	significant

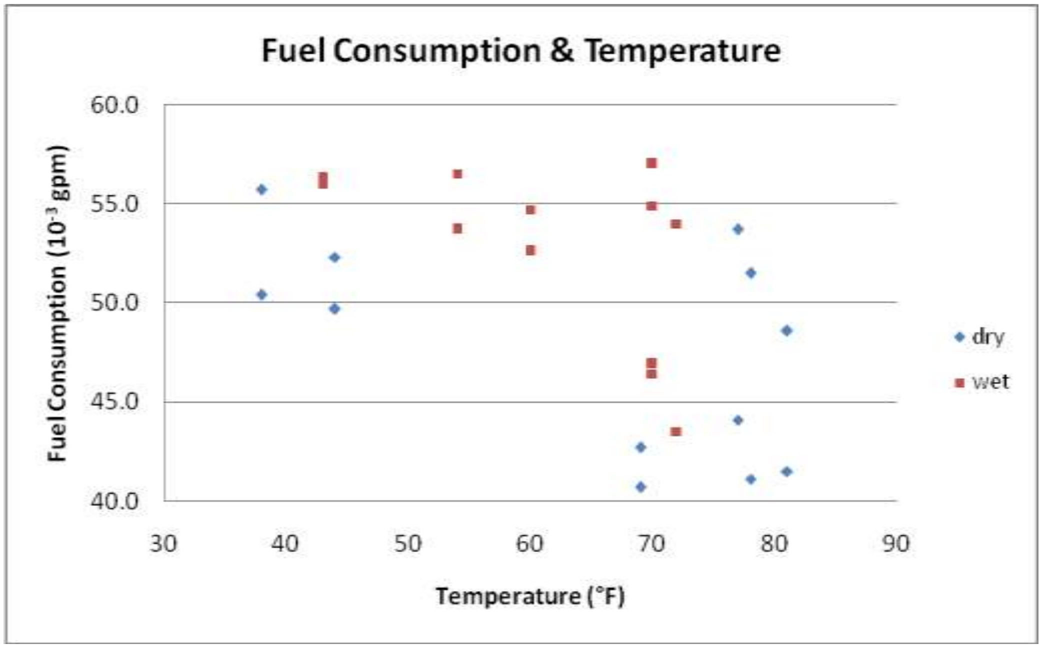


Figure 6. Relationships between Fuel Consumption and Temperature.

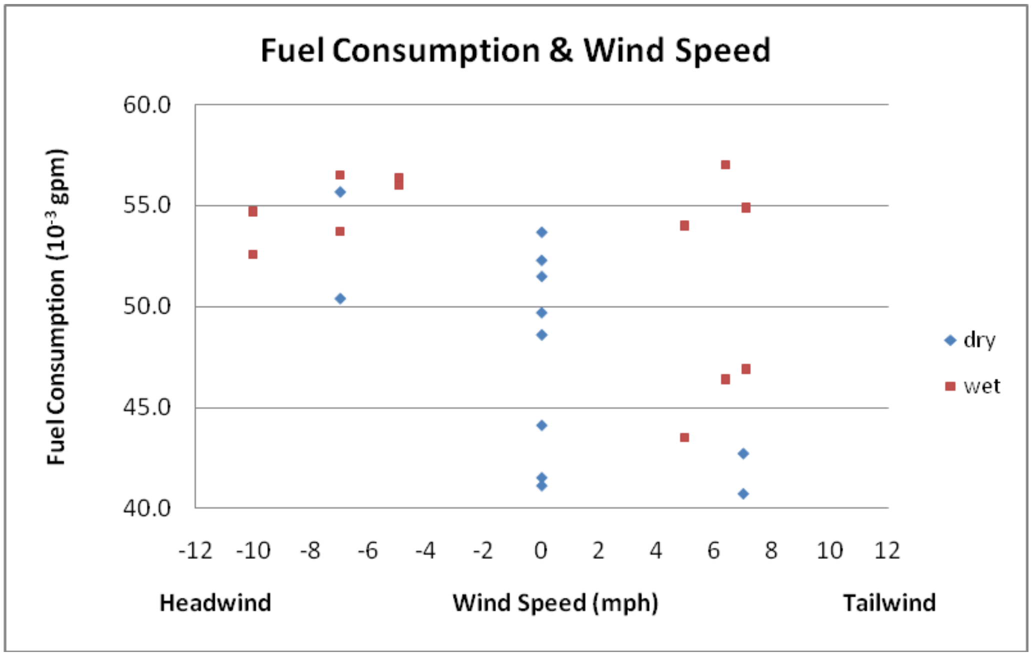


Figure 7. Relationships between Fuel Consumption and Wind Speed.

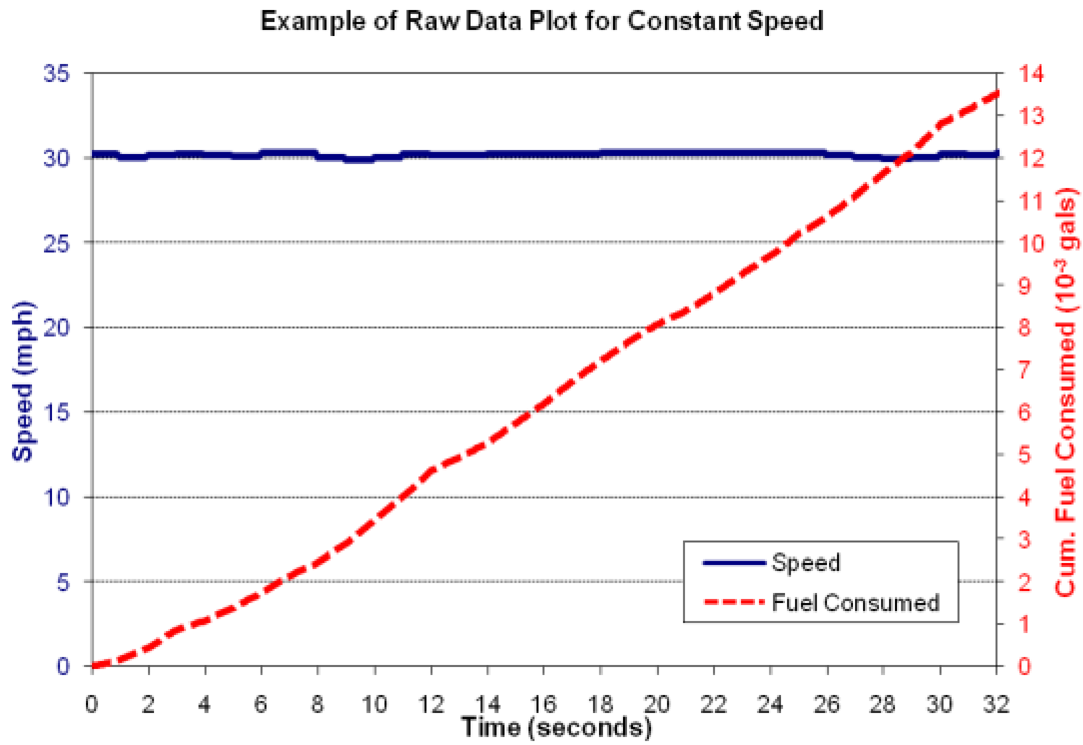


Figure 8. Example of Raw Data Plot for PCC Pavement under Constant Speed Mode.

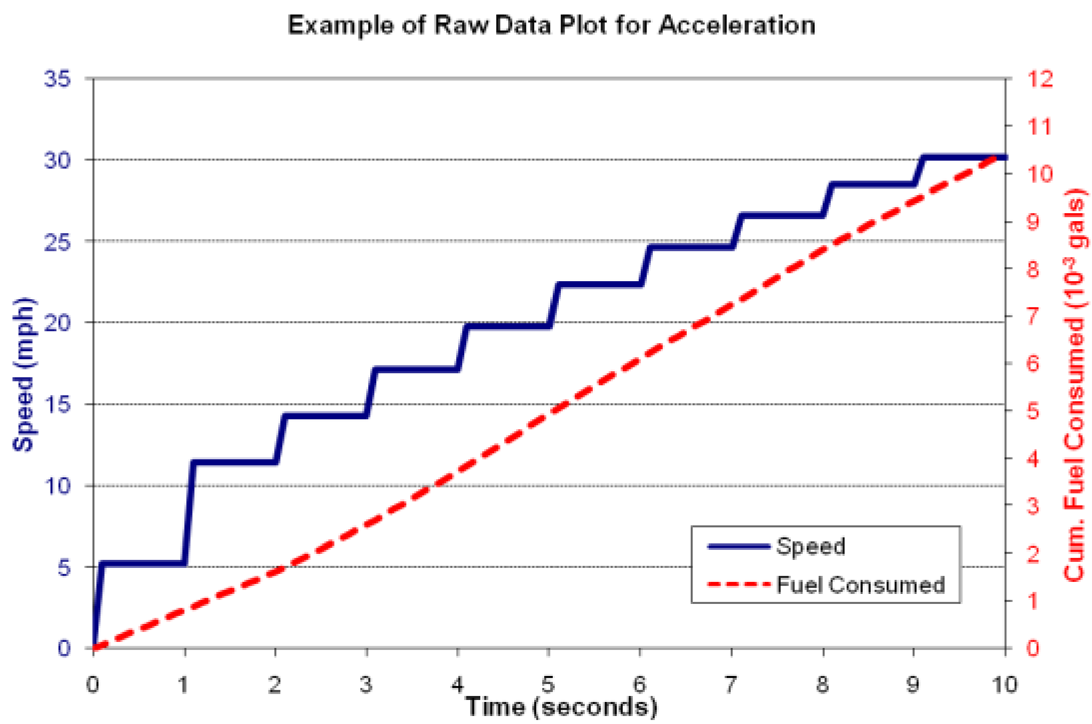


Figure 9. Example of Raw Data Plot for PCC Pavement under Acceleration Mode.

4.1.2 The Second Test Sites: Road to Six Flags (PCC) vs. Randol Mill (AC)

Fuel measurements were conducted on additional road sections to investigate whether the results from the first test sites could be verified. Table V shows the fuel consumption rates for each driving mode on these additional test sections. The raw data associated with these averages are also provided in Appendix C.

As can be seen for both driving modes, the fuel consumption rates are again lower for the PCC pavement compared to the rate for the AC pavement. The results are found to be consistent with those from the first test sites (Table III). Similarly, the observed differences in fuel consumption rates were tested for statistical significance at 90% level of confidence (10% level of significance). Again, one-sided t-tests were conducted to investigate whether the fuel rates on the PCC sections were statistically lower than the rates on the AC sections. Table VI summarizes the hypothesis test results for the second test sites.

It can be observed that for both test sites (Tables IV and VI) the calculated t-values based on fuel rate differences under all conditions were greater than their respective tabulated t-values. Consequently, all observed differences in fuel rates were found to be statistically significant. At a constant speed of 30 mph, regardless of the surface condition (wet or dry), the PCC sections were associated with lower consumption rates and the differences were statistically significant at a 10% level of significance. This was also the case for the acceleration mode.

In this section, a statistical comparison of relative fuel differences of driving on PCC versus AC pavements has been performed. The next section presents the development of a spreadsheet program and its associated Graphical User Interface (GUI) to estimate, based on these results, the life-cycle costs or savings for different city street pavement design alternatives.

Table V. Average Fuel Consumption Rates for the Road to Six Flags (PCC) vs. Randol Mill Road (AC)

PCC: Road to Six Flags AC: Randol Mill Road	Surface Condition	
	Dry	Wet
	Average Fuel Consumption (10^{-3} gals/mile)	Average Fuel Consumption (10^{-3} gals/mile)
PCC, Constant Speed of 30 mph	42.2	45.6
AC, Constant Speed of 30 mph	51.3	55.3
PCC, Acceleration of 3 mph/sec	240.2	226.1
AC, Acceleration of 3 mph/sec	257.7	259.9

Table VI. Hypothesis test results for a one-sided t-test (PCC rate < AC rate) at 10% level of significance for the Road to Six Flags (PCC) versus Randol Mill Road (AC)

Condition	t-statistics			
	DF	Calculated t	Tabulated t	Result
Dry, Constant Speed of 30 mph	28	7.164	1.3125	significant
Dry, Acceleration of 3 mph/sec	28	3.728	1.3125	significant
Wet, Constant Speed of 30 mph	28	9.664	1.3125	significant
Wet, Acceleration of 3 mph/sec	28	7.181	1.3125	significant

5. Economic Analysis

The economic analysis utilizes the fuel consumption rates observed for the test vehicle over two pavement types as a basis for projecting potential costs or savings of one pavement type versus another over a project design life. These rates are also used to project fuel consumption rate differences for other vehicles in the traffic mix using linear projections based on respective vehicle mass ratios. Fuel consumption differences are also used to estimate CO_2 emissions differences utilizing existing models which relate fuel consumption to CO_2 generation.

An analytical tool in the form of spreadsheet program with a Graphical User Interface (GUI) is also developed. This tool can be used as a decision support tool to estimate fuel consumption and emissions differences as a function of pavement type provided that accurate data are available on the vehicle mix and vehicle miles of travel for a specific project section over its design life. The fuel consumption and emissions differences could also be estimated for a city or region provided that accurate vehicle miles of travel and vehicle mix data are available. These estimates will, however, be predicated on the assumptions that all pavements in the region are similar to the test sections in this study and all vehicle miles of travel occur at a constant speed.

5.1 Estimation of Fuel Consumption and Emissions over a Project Design Life

The average fuel consumption rates summarized in Table VII are used as the basis for development of the afore-mentioned spreadsheet program. As discussed earlier, under both driving modes, the fuel consumption rates for the PCC pavement was found to be statistically (at α = 10%) lower than the corresponding rates for the AC pavement. To illustrate the cumulative effect of these differences, the fuel rates for the constant speed scenario were applied to the annual vehicle miles of travel in the Dallas-Fort Worth (DFW) region of Texas. In 2007, for example, the total annual VMT in the nine-county DFW region was estimated to be 62,697 million miles [10]. The fuel consumption rates in Table VII were applied to this VMT to obtain the total annual fuel consumption estimates for a hypothetical mix of vehicles, as shown in Table VIII (for PCC) and Table IX (for AC).

The CO_2 emissions in the PCC case were estimated using the following empirically-derived regression model [1]:

$$CO_2 \text{ amount in grams/sec} = 0.867 + 0.011\ V + 1.172\ A + 0.208\ A.V$$

Where "V" is the vehicle speed in mph and "A" is the acceleration rate in mph/second. The CO_2 emissions for all other cases were estimated as a ratio of the fuel consumption rate for each respective case relative to the corresponding field-measured rate for the PCC section.

The field-measured fuel rates under the constant speed mode in Tables VIII and IX correspond to the instrumented van (3,000-lb curb mass). For the purpose of calculations summarized in these tables, fuel consumption rates for all other vehicle classes were estimated from the field-measured rate based on the mass ratio of the two respective classes. For example, a 6,000-lb vehicle was estimated to have twice as large a fuel consumption rate than the 3,000-lb test vehicle. This method of approximating fuel consumption rates was based on a number of fuel consumption studies that have shown fuel consumption ratios to be approximately proportional to vehicle mass ratios.[5,24] The total fuel consumption amounts per annum then were estimated using those rates and the total vehicle miles of travel for each vehicle class.

The overall results for the constant speed mode are summarized in Table X. As shown in Table X, if the annual vehicle miles of travel in the DFW region took place at a constant speed of 30 mph all on PCC pavements similar to the ones in our test sections, the statistically lower fuel rate could result in an annual fuel savings of 177 million gallons and an annual CO_2 reduction of about 0.62 million metric tons. Assuming an average fuel cost of about $2/gallon and an average CO_2 clean-up cost of about $18/metric ton[16], these differences would amount to a savings of about $365 million per year in the DFW region, a cost savings which should be considered in the life-cycle cost analysis of alternative city street pavement projects.

Table VII. Average Fuel Consumption Rates for PCC versus AC Sections under Dry Pavement Conditions

	Average Fuel Consumption (10^{-3} gals/mile)	Test Conditions
PCC, Dry, Constant Speed	40.7	Date: November 7, 2008 Temperature: 69 °F Pressure: 30.08 in. Hg Wind: 7mph W (tailwind) Engine: Warm Tire Pressure: 50 psi Tank Level: Full Roughness Index (in/mi): 174.6 (PCC), 180.6 (AC) Longitudinal Slope (%): +1.2 (PCC), +1.2 (AC)
AC, Dry, Constant Speed	42.7	
PCC, Dry, Acceleration	236.4	
AC, Dry, Acceleration	236.9	

Table VIII. Calculations of Annual Fuel Consumption and CO_2 Emissions for the Dallas - Fort Worth Region of Texas under Dry PCC Pavement and Constant Speed Mode.

Average Vehicle Mass (lbs)	% in the mix	VMT (million miles/yr)	Fuel Rate (gals/mi)	Fuel Consumed (million gals/yr)	CO_2 Rate (grams/mi)	Total CO_2 (million metric tons/yr)
3,000	35	21,944	0.0407*	893.1	143.64	3.15
4,000	33	20,690	0.0543	1,122.8	191.52	3.96
5,000	14	8,778	0.0678	595.4	239.40	2.10
6,000	10	6,270	0.0814	510.4	287.28	1.80
7,000	8	5,016	0.0950	476.3	335.16	1.68
∑	100	62,697		**3,598.0**		**12.70**

* Measured in the field

Table IX. Calculations of Annual Fuel Consumption and CO_2 Emissions for the Dallas - Fort Worth Region of Texas under Dry AC Pavement and Constant Speed Mode.

Average Vehicle Mass (lbs)	% in the mix	VMT (million miles/yr)	Fuel Rate (gals/mi)	Fuel Consumed (million gals/yr)	CO_2 Rate (grams/mi)	Total CO_2 (million metric tons/yr)
3,000	35	21,944	0.0427*	937.0	143.64	3.31
4,000	33	20,690	0.0569	1,178.0	191.52	4.16
5,000	14	8,778	0.0712	624.7	239.40	2.20
6,000	10	6,270	0.0854	535.4	287.28	1.89
7,000	8	5,016	0.0996	499.7	335.16	1.76
$\sum$	100	62,697		**3,774.8**		**13.32**

* Measured in the field

Table X. Total Annual Fuel Consumption and CO_2 Emissions for the Dallas-Fort Worth Region of Texas under Each Pavement Types.

	Fuel Consumed (million gals/yr)	Total CO_2 (million metric tons/yr)
PCC, Dry, Constant Speed (30 mph)	**3,598**	**12.70**
AC, Dry, Constant Speed (30 mph)	**3,775**	**13.32**
Total Difference	**177**	**0.62**

5.2 Fuel Consumption and Emission Calculator

A spreadsheet program has been developed as part of this project to estimate the fuel consumption and emissions costs based on the procedure described in section 5.1. Known as "FuelCalc", the Graphical User Interface (GUI) of the program allows easy data entry related to the project conditions. Figure 10 is the first screen of the GUI which requires data on pavement type, surface condition, estimates of current total VMT, gasoline price per gallon, CO_2 clean-up unit cost, design life of the pavement, and the expected annual growth rate. Figure 11, the second GUI screen, requires input on vehicle mix, i.e. the percentage in the mix for each vehicle class. Vehicle classification can be specified by 28 vehicle classes in accordance with the U.S. Environmental Protection Agency (EPA)[20]. Figure 12 shows an example user cost comparison between PCC and AC pavements over a 20-year design life. As shown, if the total vehicle miles of travel took place at a constant speed of 30 mph over PCC pavements compared to AC pavements, there will be a total reduction in fuel consumption and emissions resulting in about $18 billion in savings. These estimates are based an average fuel cost of $2.59 per gallon and an average CO_2 clean-up cost of about $18/metric ton[16].

This section has detailed the development of a decision support tool to estimate the fuel consumption and emissions savings or costs based on a user-specified project condition, namely pavement type and expected vehicle mix and miles of travel. It is shown that for a typical metropolitan area, these user cost differences could be substantial over the design life of a city street pavement, which could range from 20-50 years. It is, therefore, recommended that this type of analysis be incorporated into the overall life cycle cost analysis of alternative design projects as well as in the carbon footprint estimation and sustainability characterization of city street pavement projects.

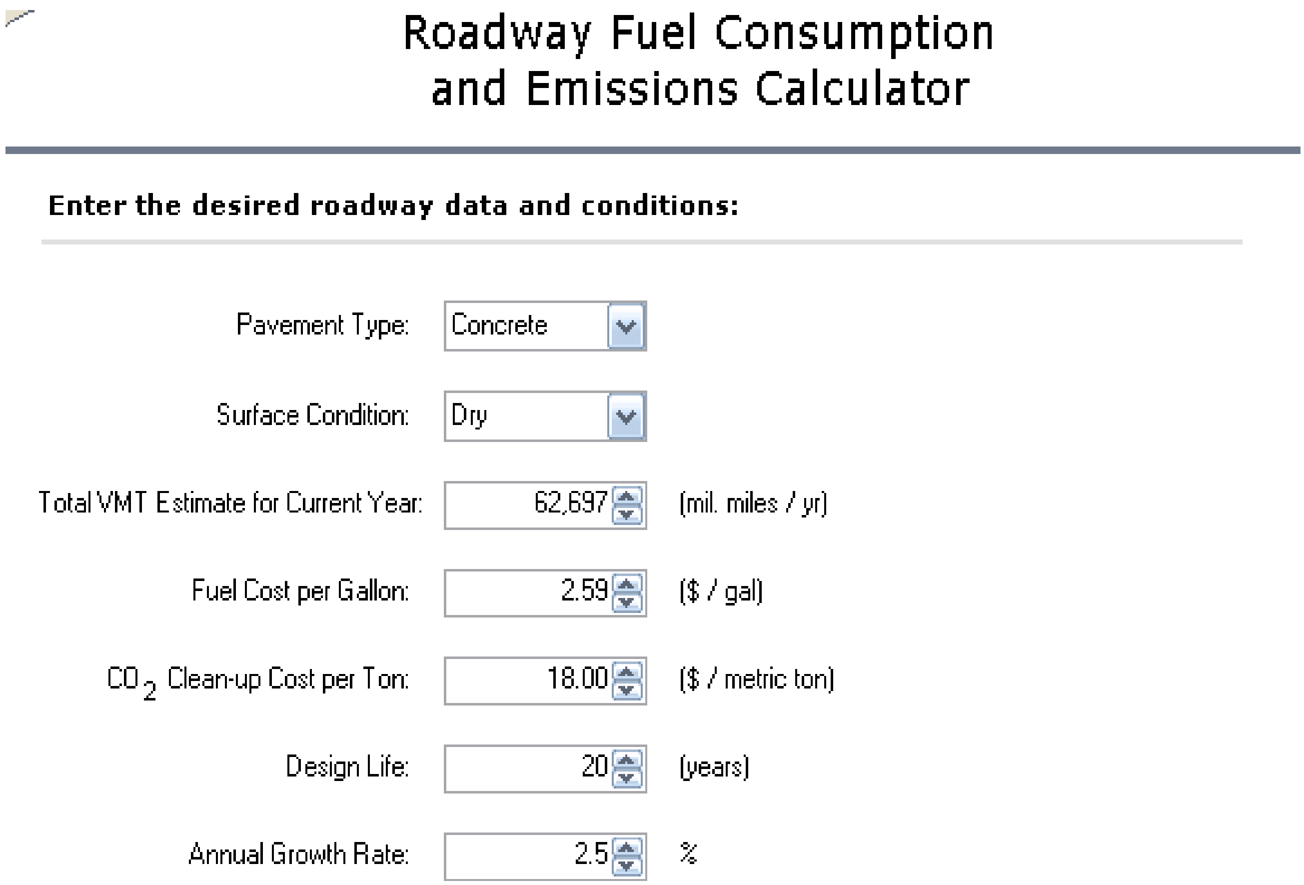


Figure 10. User Specified Input.

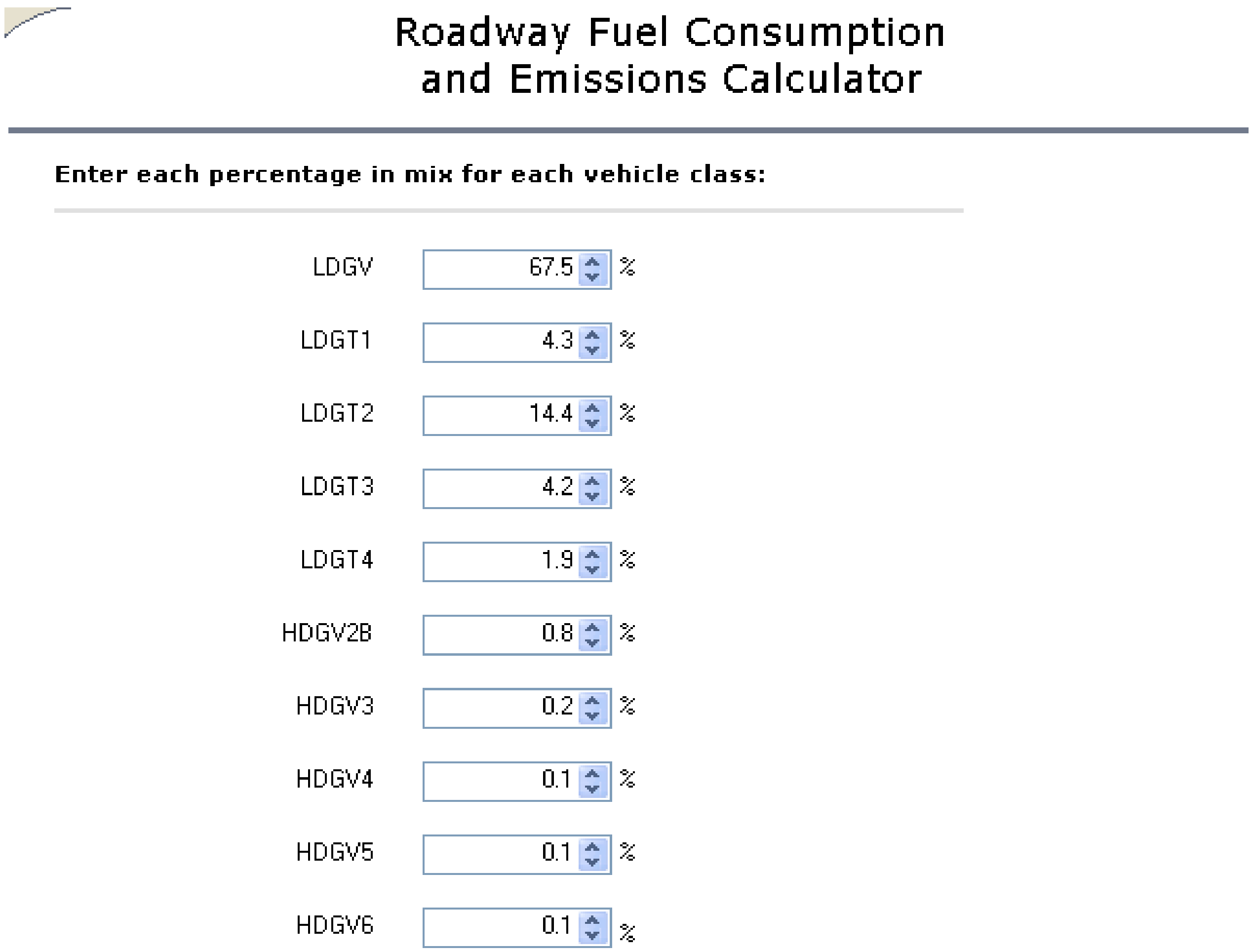


Figure 11. Usage Statistics Input on EPA 28-Vehicle Class.

Roadway Fuel Consumption and Emissions Calculator

Roadway Comparison:

	PCC	AC
Current-year VMT (mil. mi / yr)	62,697	62,697
Total VMT over design life (mil. mi / yr)	1,601,573	1,601,573
Weighted Mean Fuel Rate (gals / mi)	0.0883	0.0927
Avg. Gasoline Cost ($ / gal)	$2.59	$2.59
Avg. CO2 Clean-up Cost ($ / metric ton)	$18.00	$18.00
Over Design Life (20 years):		
Total Fuel Consumed (mil. gals)	141,454	148,405
Fuel Cost (mil. $)	$366,365.10	$384,368.30
Total CO2 Produced (mil. metric tons)	499.22	523.76
Total CO2 Clean-up Cost (mil. $)	$8,986.03	$9,427.60
Total Operating Cost (mil. $)	$375,351.13	$393,795.90
Cost Saving on PCC (mil. $)	**$18,444.77**	

Figure 12. Comparison Summary.

6. Summary and Discussion

6.1 Summary

This study aimed at investigating any statistically significant differences which might exist in fuel consumption rates on typical concrete versus asphalt city streets. The study was conducted through field data collections using an instrumented van. The scope of the study was limited to assessing any such differences through field data collection. However, the study scope did not include any theoretical assessment of pavement/tire interactions or other mechanical reasons as to why such differences might exist.

It was observed that under urban driving speeds of 30 mph, the fuel consumption per unit distance is lower on concrete pavements compared to asphalt pavements. These findings were based on test runs on two sets of typical PCC and AC street sections in Arlington, Texas, with each pair of study sites having similar gradient and roughness index values.

The results were found to hold for either dry or wet surface conditions, although wet surface conditions generally resulted in higher fuel consumption rates compared to dry conditions regardless of pavement type. All observed differences were found to be statistically significant at 10% level of significance.

The potential savings or costs in fuel consumed and CO_2 emissions generated were shown to be substantial over the design life of a project. As a result, it is recommended that these savings or costs be considered in the life cycle cost analysis of alternative projects. Differences in CO_2 emissions should also be considered in life cycle analysis when estimating the carbon footprint of particular pavement materials to be used.

Estimation of carbon footprint is an important step in assessing the sustainability of city development projects and the overall life cycle analysis of projects. In pavement projects, specifically, the focus has been on estimating carbon footprint of the production cycle of various pavement materials as well as the initial construction phase. A key finding of this study is that any such sustainability assessment must also consider the emissions differences based on operations of motor vehicles on various pavement surfaces. When considering a 20-50 year design life that is typical for city streets and the annual vehicle miles of travel, such differences could dwarf carbon footprint estimations from the material production or construction phases.

6.2 Discussion

Critics of this study might argue that the numbers presented herein are not accurate estimates of the actual savings and costs realized in the Dallas-Fort Worth or any other urban region. This is because the examples presented are based on hypothetical mixes of vehicles, all driven at a constant speed of 30 mph. Furthermore, the fuel consumption rates per unit distance are developed based on a fairly limited sample of population of asphalt and concrete pavement types and typical pavement cross-sections in a city. Indeed it can be argued that to have accurate numbers, a more comprehensive study must be conducted which includes the variety of asphalt and concrete mix designs used in city pavements as well as a broader sample of cross-section thicknesses of crown layers and base materials. Such a study should also include direct fuel rate measurements for a variety of vehicle types driven under a range of drive cycles as opposed to extrapolating the fuel consumption characteristics of one vehicle driven at a constant speed to other vehicle types and speed regimes. Thirdly, to better control exogenous factors such as wind speed and direction, temperature, and humidity perhaps the tests should be conducted using pavement sections constructed indoors where the ambient environment is controlled. In addition, IRI values may not be good surrogates for pavement smoothness and rolling resistance. Instead, direct measurements of the skid resistance would be needed for each pavement section being tested. Last but not least, the measurements should be made under a much wider range of ambient humidity and temperatures than typically experienced in the Dallas-Fort Worth region.

Of course, if all these factors are to be considered it could be possible to show beyond doubt that one type of pavement results in better fuel efficiency than another and by how much. This would also substantially improve the accuracy of estimates of user savings and costs. But it is important to note that the numerical examples in this report are intended to illustrate how significant minute differences in fuel consumption and emissions could be over the design life of a project. However, these results are at best applicable to the specific pavement types studied and the test vehicle used. In fact, it would not be feasible to develop, based on these specific results, very accurate estimation algorithms that cover the entire spectrum of vehicle classes and pavement mix designs and cross-sections.

In accounting for user costs or savings for specific design alternatives, a more sensible approach could be to conduct similar tests of differences in fuel consumption rates over pavement sections already constructed to the intended specifications and using a representative vehicle with the highest proportion in the vehicle mix. In this vain, the study results presented used a typical passenger vehicle driven over typical HMA and PCC pavement cross-sections in the study region to illustrate that there could be statistically significant differences in fuel consumption and emissions for one pavement type versus another. Furthermore, numerical examples showed that such differences, while small on a per mile basis, could be very large over the design life of a project and should therefore be considered in any life cycle cost analysis or life cycle analysis of carbon footprints of alternative pavement designs.

References

1. Afotey, B. (2008). *Statistical Approach to the Development of a Micro Scale Model for Estimating Exhaust Emissions from Light Duty Gasoline Vehicles.* Ph.D. Dissertation. Department of Civil Engineering, The University of Texas at Arlington, Arlington, Texas.

2. Archondo-Callao, R. S. and Faiz, A. (1994). *Estimating Vehicle Operating Costs*. World Bank Publications Department, Washington, D.C.

3. Beign, P. and Biggs, D. C. (1993). *Critique of Texas Research and Development Foundation on Vehicle Operating Cost Model.* Transportation Research Board No. 1395, Transportation Research Board, Washington, D.C.

4. Brown, A. (2009). *Carbon Footprint of HMA and PCC Pavements.* The Ontario Hot Mix Producer Association, Mississauga, Ontario, Canada.

5. Chang, M. F., Evans, L., Herman, R., and Wasielewski, P. (1976). *The Influence of Vehicle Characteristics, Driver Behavior, and Ambient Temperature on Gasoline Consumption in Urban Traffic.* Transportation Research Record 599, 25-30.

6. Evans, L., Herman, R., and Lam, T. N. (1976a). *Gasoline Consumption in Urban Traffic*, Society of Automotive Engineers, SAE Paper 760048.

7. Evans, L., Herman, R., and Lam, T. N. (1976b). *Multivariate Analysis of Traffic Factors Related to Fuel Consumption in Urban Driving*, Transportation Science, and Vol.10, No.2, pp 205-215.

8. Jonsson, P. and Hultqvist, B. (2008). *Measurement of Fuel Consumption on Asphalt and Concrete Pavements, North of Uppsala*, Swedish National Road and Transport Research Institute, Linköping, Sweden.

9. Larson, T. (1992). *The Bridge*, National Academy of Engineering, Vol. 22, No. 1.

10. North Central Texas Council of Government (2007). *Transportation Conformity Determination for the Mobility 2030: The Metropolitan Transportation Plan and 2006-2008 Transportation Improvement Program as Amended.* http://www.nctcog.org/trans/air/conformity/ConformityDeterminations.asp

11. Papagiannakis, A. T. (1999b). On the Relationship between Truck Operating Costs and Pavement Roughness, *SAE Technical Paper Series* No. 1999-01-3783, Society of Automotive Engineers, Warrendale, PA.

12. Papagiannakis, A. T. and Delwar, M. (1999a). *Methodology to Improve Pavement Investment Decisions*. Final Report to National Cooperative Highway Research Program for Study 1-33, Transportation Research Board, Washington, D.C.

13. Papagiannakis, A. T. and Delwar, M. (2001a*). Incorporating User Costs into Pavement Management Decisions.* Proceedings of the Fifth International Conference on Managing Pavements. Seattle, Washington.

14. Sayers, M. W. and Karamihas, S. M. (1998). *The Little Book of Profiling.* The Regent of the University of Michigan.

15. Taylor, G. W. and Patten, J. D. (2006). *Effect of Pavement Structure on Vehicle Fuel Consumption – Phase III*, Technical Report CSTT-HVC-TR-068, Portland Cement Association, Skokie, Illinois.

16. The Carbon Emissions Offset Directory (2009). http://www.ecobusinesslinks.com/carbon_offset_wind_credits_carbon_reduction.htm

17. The Transportation Energy program, Ontario Ministry of Transportation and Communications (1982). *A Technical Background Document for Automotive Fuel Economy.* Report # DRS-82-01.

18. The U.S. Bureau of Transportation Statistics (2009). http://www.bts.gov/

19. The U.S. Department of Energy, Energy Information Administration (2008). http://www.eia.doe.gov/

20. The U.S. Environmental Protection Agency, Office of Transportation and Air Quality (2003). *User's Guide to MOBILE6.1 and MOBILE6.2.* EPA420-R-03-010.

21. TRB Special Report 285 (2006). *The Fuel Tax and Alternatives for Transportation Funding*, Transportation Research Board, Washington, D.C.

22. VicRoads (2008). *Moving towards carbon neutral road construction - The Mickleham Road Project.* http://www.vicroads.vic.gov.au/Home/Moreinfoandservices/Environment/GreenhouseAndClimateChange.htm

23. Walls, J. and Smith, M. R. (1998). *Life-Cycle Cost Analysis in Pavement Design – Interim Technical Bulletin*. Federal Highway Administration, Office of Engineering, Pavement Division, Washington, D.C.

24. Wood, R. A., Downing, B. R., and Pearce, T. C. (1981). *Energy Consumption of an Electric, a Petrol and a Diesel Powered Light Goods Vehicles in Central London Traffic.* TRRL Report LR 1021, Transport and Road Research Laboratory, Crowthorne, Berkshire.

25. Zaniewski, J. P. (1989). *Effect of Pavement Surface Type on Fuel Consumption*, Report # SR289.01P, Portland Cement Association, Skokie, Illinois.

26. Zaniewski, J. P., Butler, B. C., Cunningham, G., Elkins, G. E., Paggi, M. S., and Machemehl, R. (1982). *Vehicle Operating Costs, Fuel Consumption, and Pavement type and Condition Factors*, Final Report # DOT-FH-11-9678, Federal Highway Administration, Washington, D.C.

APPENDIX A

International Roughness Index Measurements

Ride Quality Analysis Rel 2008.11.11
TxDOT Smoothness Specification 5880 Pay Schedule 3
Report run on Friday Feb 27 2009 2:59:30PM
Input profile data file created Friday Feb 27 2009 10:30:14AM

District 2
Area Office Ft worth
County 220
CSJ JEFF HOWDES
Phone FM2122E
Input file t:\dalpme\uta project with profiler\cty220_abram_st_20090227_1628.pro
*** eastbound outside lane
*** Beg Station 0000+00.0

Highway ABRAM_ST
Beg RM 0000 +00.000
Beg Station 0000+00.0
Lane roadbed K1
Name

No Bump penalties assessed.
Bonus paid for average IRIs of 30($600) to 60($0)
No penalties assessed for high IRIs.
Bonus NOT paid in sections with bump.

Profile Length(Miles) 0.7276 Length(Station Units) 0038+41.7ft.

Distance	Station	Type	Width(feet)	Elev(inches)
00.0129	0000+68.1	Dip	.5	-.17
00.0132	0000+69.9	Dip	.4	-.16
00.0262	0001+38.5	Dip	2.5	-.17
00.0382	0002+01.8	Bump	.2	.15
00.0670	0003+53.9	Bump	.2	.15
00.0993	0005+24.5	Bump	2.0	.20
00.0998	0005+26.7	Bump	2.5	.20
00.1003	0005+29.4	Bump	.4	.16
00.1051	0005+54.8	Bump	.2	.15
00.1052	0005+55.4	Bump	1.3	.20
00.1313	0006+93.5	Dip	2.9	-.23
00.1457	0007+69.2	Dip	.4	-.16
00.1461	0007+71.2	Dip	.4	-.15
00.2070	0010+93.2	Dip	4.2	-.25
00.2079	0010+97.5	Dip	.2	-.15
00.2080	0010+98.1	Dip	.4	-.16
00.2081	0010+98.8	Dip	.9	-.17
00.2094	0011+05.7	Bump	.2	.15
00.2095	0011+06.1	Bump	2.2	.18
00.2102	0011+09.7	Bump	.2	.15
00.2391	0012+62.5	Dip	5.8	-.28
00.2416	0012+75.6	Bump	2.4	.19
00.2615	0013+80.7	Bump	.2	.15
00.2873	0015+17.2	Dip	.9	-.17
00.2875	0015+18.2	Dip	.4	-.16
00.2877	0015+19.0	Dip	.5	-.16
00.2878	0015+19.7	Dip	.4	-.16
00.2906	0015+34.2	Bump	.2	.16
00.2907	0015+34.8	Bump	.4	.15
00.3441	0018+16.6	Bump	.2	.15
00.3443	0018+17.7	Bump	2.5	.20
00.3451	0018+22.1	Bump	.2	.15
00.3474	0018+34.2	Dip	.7	-.17
00.3570	0018+84.9	Dip	.7	-.16
00.3573	0018+86.7	Dip	1.3	-.16
00.3579	0018+90.0	Dip	.2	-.15
00.3608	0019+05.2	Bump	1.1	.17
00.3611	0019+06.5	Bump	11.1	.24
00.3645	0019+24.4	Dip	6.0	-.21
00.3657	0019+30.8	Dip	.9	-.17
00.3682	0019+44.2	Bump	.4	.16

Distance	Station	Type	Width(feet)	Elev(inches)
00.3683	0019+44.8	Bump	.2	.15
00.3684	0019+45.3	Bump	.4	.15
00.3687	0019+46.8	Bump	3.1	.21
00.3701	0019+54.2	Dip	5.4	-.45
00.3717	0019+62.6	Bump	6.0	.32
00.3753	0019+81.4	Dip	.9	-.18
00.3812	0020+12.5	Bump	5.6	.37
00.3828	0020+21.2	Dip	3.4	-.25
00.3865	0020+40.8	Bump	4.4	.18
00.3874	0020+45.7	Bump	.4	.16
00.3889	0020+53.5	Dip	10.3	-.38
00.3925	0020+72.2	Bump	.7	.16
00.3926	0020+73.1	Bump	4.5	.26
00.3952	0020+86.9	Dip	3.4	-.20
00.3975	0020+98.9	Bump	9.3	.42
00.3999	0021+11.4	Dip	8.2	-.27
00.4015	0021+20.1	Dip	.2	-.15
00.4016	0021+20.5	Dip	.2	-.15
00.4022	0021+23.7	Dip	1.1	-.46
00.4052	0021+39.7	Bump	1.8	.24
00.4153	0021+92.7	Bump	4.0	.24
00.4208	0022+21.7	Dip	3.1	-.20
00.4225	0022+31.0	Bump	4.5	.22
00.4243	0022+40.4	Dip	.5	-.18
00.4263	0022+51.0	Dip	5.6	-.27
00.4287	0022+63.5	Bump	6.4	.23
00.4391	0023+18.7	Bump	.4	.15
00.4449	0023+49.0	Dip	1.1	-.16
00.4459	0023+54.6	Bump	.4	.16
00.4461	0023+55.1	Bump	.2	.15
00.4463	0023+56.2	Bump	4.0	.26
00.4479	0023+65.1	Dip	1.5	-.18
00.4487	0023+68.9	Dip	1.3	-.20
00.4577	0024+16.7	Bump	.9	.16
00.4886	0025+80.0	Dip	4.4	-.22
00.4916	0025+95.6	Bump	.2	.15
00.4984	0026+31.8	Bump	.2	.15
00.4996	0026+38.1	Dip	.9	-.18
00.5020	0026+50.8	Bump	.5	.15
00.5022	0026+51.5	Bump	.7	.16
00.5056	0026+69.5	Dip	.5	-.17
00.5085	0026+84.7	Dip	1.3	-.17
00.5119	0027+02.9	Dip	4.7	-.30
00.5321	0028+09.3	Bump	1.8	.17
00.5426	0028+65.2	Dip	1.8	-.21
00.5456	0028+80.9	Bump	.5	.17
00.5460	0028+83.1	Bump	2.7	.24
00.5488	0028+97.5	Dip	.4	-.15
00.5621	0029+67.7	Dip	1.3	-.17
00.5791	0030+57.5	Dip	1.6	-.18
00.5795	0030+59.9	Dip	2.7	-.19
00.5821	0030+73.7	Bump	4.0	.20
00.5831	0030+78.8	Bump	.5	.16
00.5848	0030+87.5	Dip	2.0	-.17
00.5953	0031+43.0	Dip	.4	-.15
00.5971	0031+52.5	Dip	.4	-.18
00.5988	0031+61.9	Bump	1.1	.19
00.6071	0032+05.3	Bump	1.5	.18
00.6134	0032+38.5	Dip	.4	-.16
00.6135	0032+39.0	Dip	.2	-.15
00.6189	0032+67.7	Dip	6.0	-.26
00.6255	0033+02.4	Bump	.9	.17
00.6391	0033+74.4	Dip	4.2	-.24

Distance	Station	Type	Width(feet)	Elev(inches)
00.6400	0033+79.3	Dip	.9	-.18
00.6494	0034+29.1	Bump	4.4	.23
00.6587	0034+78.1	Dip	9.6	-.73
00.6614	0034+92.2	Bump	2.0	.18
00.6620	0034+95.1	Bump	1.8	.25
00.6656	0035+14.6	Bump	8.5	.27
00.6691	0035+33.1	Dip	.7	-.20
00.6712	0035+44.2	Bump	.9	.18
00.6718	0035+47.2	Bump	.7	.16
00.6722	0035+49.1	Bump	.2	.15
00.6760	0035+69.0	Dip	9.3	-.25
00.6887	0036+36.2	Dip	.2	-.15
00.6887	0036+36.5	Dip	1.1	-.16
00.6920	0036+54.0	Dip	10.3	-.39
00.6954	0036+71.6	Bump	3.4	.18
00.7035	0037+14.4	Dip	.4	-.27
00.7042	0037+18.2	Bump	2.0	.30
00.7047	0037+20.8	Bump	.2	.15
00.7073	0037+34.5	Dip	4.4	-.21
00.7119	0037+58.9	Bump	6.5	.25
00.7144	0037+71.9	Bump	1.3	.16
00.7177	0037+89.5	Dip	2.4	-.20
00.7240	0038+22.9	Dip	.2	-.15

Bumps/dips detected 127

Distance	Station	PSI	IRI(L)	IRI(R)	Avg IRI	Pay*SectLen	Pay
00.1000	5+28.0	3.28	122.57	122.69	123.00	$ 0*(0.1000/0.10)	$0
00.2000	10+56.0	3.23	115.95	135.38	126.00	$ 0*(0.1000/0.10)	$0
00.3000	15+84.0	3.13	130.34	133.65	132.00	$ 0*(0.1000/0.10)	$0
00.4000	21+12.0	2.24	201.61	197.43	200.00	$ 0*(0.1000/0.10)	$0
00.5000	26+40.0	2.11	174.49	247.55	211.00	$ 0*(0.1000/0.10)	$0
00.6000	31+68.0	2.17	187.56	223.46	206.00	$ 0*(0.1000/0.10)	$0
00.7000	36+96.0	2.10	202.62	220.75	212.00	$ 0*(0.1000/0.10)	$0
00.7276	38+41.7	1.97	209.38	237.45	223.00	$ 0*(0.0277/0.10)	$0
						Pay Adjustment Subtotal	$0

Ave Left IRI 164 Ave Right IRI 185.1 Ave IRI 174.55

Total IRI adjustments $ 0
Total Bump adjustments $ 0
Total adjustments $ 0

Ride Quality Analysis Rel 2008.11.11
TxDOT Smoothness Specification 5880 Pay Schedule 3
Report run on Friday Feb 27 2009 3:03:50PM
Input profile data file created Friday Feb 27 2009 10:25:48AM

District 2
Area Office FT worth
County 220
CSJ JEFF HOWDES
Phone FM2122E
Input file t:\dalpme\uta project with profiler\cty220_pecandale_st_20090227_1624.pro
*** eastbound outside lane
*** Beg Station 0000+00.0

Highway PECANDALE_DR
Beg RM 0000 +00.000
Beg Station 0000+00.0
Lane roadbed K1
Name

No Bump penalties assessed.
Bonus paid for average IRIs of 30($600) to 60($0)
No penalties assessed for high IRIs.
Bonus NOT paid in sections with bump.

Profile Length(Miles) 0.3612 Length(Station Units) 0019+07.1ft.

Distance	Station	Type	Width(feet)	Elev(inches)
00.0009	0000+04.5	Bump	.7	.19
00.0019	0000+09.8	Dip	4.0	-.25
00.0033	0000+17.6	Bump	2.2	.18
00.0039	0000+20.3	Bump	1.3	.17
00.0050	0000+26.5	Dip	3.4	-.23
00.0074	0000+39.2	Dip	.5	-.16
00.0076	0000+39.9	Dip	.2	-.15
00.0078	0000+41.2	Dip	.2	-.15
00.0079	0000+41.7	Dip	4.0	-.22
00.0112	0000+59.2	Bump	4.7	.25
00.0138	0000+72.8	Dip	4.2	-.24
00.0167	0000+88.0	Bump	7.4	.22
00.0188	0000+99.5	Dip	8.3	-.30
00.0321	0001+69.7	Bump	3.1	.17
00.0350	0001+84.8	Dip	.4	-.16
00.0489	0002+58.3	Bump	.2	.15
00.0490	0002+58.6	Bump	1.6	.18
00.0506	0002+67.3	Dip	3.6	-.20
00.0603	0003+18.4	Dip	.2	-.15
00.0604	0003+18.7	Dip	.7	-.17
00.0942	0004+97.1	Bump	.5	.16
00.0957	0005+05.1	Dip	5.4	-.25
00.1192	0006+29.4	Dip	2.9	-.23
00.1643	0008+67.8	Dip	4.2	-.27
00.1672	0008+82.8	Bump	2.0	.19
00.1703	0008+99.0	Dip	2.9	-.17
00.1922	0010+14.6	Bump	.2	.15
00.1923	0010+15.5	Bump	.2	.15
00.1932	0010+20.2	Dip	5.1	-.44
00.1954	0010+31.6	Bump	.7	.18
00.1956	0010+32.6	Bump	2.4	.21
00.2027	0010+70.3	Bump	.2	.16
00.2028	0010+71.0	Bump	1.3	.18
00.2034	0010+73.8	Bump	.4	.16
00.2533	0013+37.7	Dip	.9	-.16
00.2541	0013+41.5	Dip	.9	-.18
00.2550	0013+46.5	Dip	3.3	-.20
00.2577	0013+60.9	Bump	7.1	.27
00.2592	0013+68.3	Bump	4.0	.21
00.2608	0013+77.2	Dip	6.7	-.51
00.2626	0013+86.7	Bump	2.7	.20

Distance	Station	Type	Width(feet)	Elev(inches)
00.2642	0013+95.2	Bump	2.9	.22
00.2795	0014+75.6	Bump	2.9	.22
00.2810	0014+83.8	Dip	.2	-.15
00.2812	0014+84.5	Dip	.4	-.15
00.2915	0015+39.3	Dip	.2	-.15
00.2916	0015+39.8	Dip	.5	-.17
00.3080	0016+26.4	Dip	.7	-.18
00.3093	0016+33.0	Bump	8.3	.20
00.3160	0016+68.3	Dip	1.1	-.16
00.3564	0018+81.8	Dip	.2	-.17
00.3565	0018+82.2	Dip	.2	-.15
00.3565	0018+82.5	Dip	4.4	-.22
00.3583	0018+91.6	Bump	1.6	.17
00.3586	0018+93.6	Bump	.5	.16
00.3588	0018+94.5	Bump	.5	.16

Bumps/dips detected 56

Distance	Station	PSI	IRI(L)	IRI(R)	Avg IRI	Pay*SectLen	Pay
00.1000	5+28.0	2.33	153.45	230.29	192.00	$ 0*(0.1000/0.10)	$0
00.2000	10+56.0	2.53	114.39	237.37	176.00	$ 0*(0.1000/0.10)	$0
00.3000	15+84.0	2.55	120.08	227.13	174.00	$ 0*(0.1000/0.10)	$0
00.3612	19+07.1	2.46	125.35	236.88	181.00	$ 0*(0.0612/0.10)	$0
						Pay Adjustment Subtotal	$0

Ave Left IRI 128.6 Ave Right IRI 232.5 Ave IRI 180.55

Total IRI adjustments $ 0

Total Bump adjustments $ 0

Total adjustments $ 0

Ride Quality Analysis Rel 2006.12.04
Report run on Friday, Jan 8 2010 3:50:57PM
Input profile data file created Tuesday, Dec 15 2009 8:17:16AM

District: 2
Area Office: UTA
County: 220
Name: MILES HICKS
Phone: 214-319-6474

Highway: RD_TO_SIX_FLAGS RUN1
Beg RM: 0000 +00.000
Beg Station: 0000+00.0
CSJ: 0000-00-000
Lane designation: K8

Input file: t:\dalpme\uta project with profiler\rd to six flags run1.pro

No Bump penalties assessed.
Total length profile: 0.2963 miles or 0015+64.5 station units.

Distance	Station	Type	Width(feet)	Elev(inches)
00.0027	0000+14.1	Bump	.2	.154
00.0027	0000+14.5	Bump	.2	.162
00.0028	0000+14.8	Bump	2.0	.312
00.0037	0000+19.7	Dip	7.9	-.308
00.0053	0000+27.8	Dip	.7	-.266
00.0057	0000+30.4	Bump	.4	.186
00.0064	0000+34.0	Bump	6.1	.252
00.0144	0000+76.2	Dip	5.1	-.227
00.0154	0000+81.5	Dip	.7	-.168
00.0252	0001+33.2	Dip	1.6	-.183
00.0275	0001+45.1	Bump	.9	.168
00.0284	0001+49.8	Bump	.4	.170
00.0285	0001+50.5	Bump	1.6	.173
00.0288	0001+52.3	Bump	.4	.165
00.0289	0001+52.8	Bump	6.7	.216
00.0346	0001+82.8	Bump	4.9	.244
00.0364	0001+92.2	Dip	14.1	-.487
00.0394	0002+08.1	Bump	.2	.154
00.0400	0002+11.2	Bump	3.4	.313
00.0439	0002+31.8	Bump	.2	.153
00.0440	0002+32.2	Bump	.9	.167
00.0453	0002+39.2	Dip	.2	-.156
00.0454	0002+39.7	Dip	.4	-.156
00.0495	0002+61.2	Dip	4.0	-.203
00.0520	0002+74.6	Bump	.5	.193
00.0521	0002+75.3	Bump	2.3	.205
00.0527	0002+78.4	Bump	.7	.167
00.0529	0002+79.3	Bump	.5	.185
00.0541	0002+85.8	Dip	.2	-.151
00.0565	0002+98.5	Bump	2.3	.172
00.0635	0003+35.5	Bump	.2	.155
00.0639	0003+37.5	Bump	1.1	.184
00.0655	0003+46.0	Bump	2.5	.211
00.0666	0003+51.6	Bump	.2	.152
00.0674	0003+55.7	Dip	.2	-.151
00.0678	0003+58.1	Dip	1.8	-.233
00.0682	0003+60.1	Dip	.4	-.155
00.0700	0003+69.6	Bump	2.9	.246
00.0716	0003+78.0	Dip	.2	-.291
00.0720	0003+80.3	Dip	.4	-.212
00.0723	0003+81.6	Dip	.5	-.172
00.0724	0003+82.3	Dip	1.4	-.182
00.0727	0003+83.9	Dip	4.9	-.227
00.0747	0003+94.4	Bump	5.2	.278
00.0765	0004+04.2	Dip	7.0	-.306
00.0803	0004+23.8	Bump	3.3	.181
00.0902	0004+76.2	Bump	1.1	.186
00.0913	0004+82.2	Bump	.7	.160
00.0952	0005+02.8	Dip	.9	-.204

Distance	Station	Type	Width(feet)	Elev(inches)
00.0954	0005+03.9	Dip	2.3	-.188
00.0962	0005+07.7	Dip	.9	-.176
00.0964	0005+08.9	Dip	1.6	-.188
00.0979	0005+16.7	Bump	.4	.164
00.0980	0005+17.2	Bump	6.0	.594
00.0994	0005+24.7	Dip	3.3	-.736
00.1001	0005+28.3	Dip	.2	-.160
00.1011	0005+33.9	Bump	.5	.186
00.1015	0005+35.7	Dip	8.9	-.433
00.1036	0005+47.2	Bump	3.3	.261
00.1044	0005+51.4	Bump	1.4	.209
00.1048	0005+53.2	Bump	.2	.152
00.1048	0005+53.6	Bump	3.4	.251
00.1061	0005+60.2	Bump	4.3	.200
00.1074	0005+67.1	Dip	6.0	-.237
00.1095	0005+78.1	Bump	2.7	.224
00.1177	0006+21.5	Dip	2.7	-.185
00.1183	0006+24.6	Dip	.2	-.152
00.1192	0006+29.3	Bump	3.8	.223
00.1254	0006+62.1	Bump	7.4	.334
00.1272	0006+71.7	Bump	.2	.154
00.1280	0006+75.7	Dip	1.1	-.174
00.1309	0006+91.2	Bump	1.3	.190
00.1312	0006+92.7	Bump	.2	.159
00.1327	0007+00.6	Dip	.2	-.152
00.1337	0007+05.9	Bump	.9	.173
00.1345	0007+10.2	Bump	.7	.159
00.1354	0007+14.7	Dip	6.9	-.418
00.1372	0007+24.3	Bump	2.3	.191
00.1382	0007+29.5	Bump	.9	.169
00.1385	0007+31.5	Bump	.4	.154
00.1417	0007+48.3	Bump	2.3	.174
00.1422	0007+50.9	Bump	.2	.152
00.1447	0007+64.0	Dip	1.4	-.313
00.1450	0007+65.8	Dip	4.7	-.283
00.1461	0007+71.4	Dip	.2	-.151
00.1473	0007+77.8	Dip	.2	-.154
00.1483	0007+83.0	Bump	.7	.172
00.1489	0007+86.4	Bump	4.7	.245
00.1503	0007+93.5	Bump	4.7	.365
00.1517	0008+00.9	Dip	.5	-.182
00.1519	0008+01.8	Dip	.2	-.151
00.1521	0008+02.9	Dip	6.5	-.284
00.1543	0008+14.8	Bump	4.7	.256
00.1559	0008+23.1	Dip	4.2	-.181
00.1594	0008+41.7	Bump	2.7	.447
00.1631	0008+61.2	Dip	3.3	-.193
00.1638	0008+64.9	Dip	1.4	-.352
00.1714	0009+05.0	Dip	2.2	-.204
00.1733	0009+15.3	Bump	3.4	.388
00.1747	0009+22.3	Dip	.4	-.158
00.1748	0009+22.8	Dip	2.9	-.228
00.1794	0009+47.1	Bump	1.8	.354
00.1798	0009+49.2	Bump	1.6	.216
00.1809	0009+55.2	Dip	4.0	-.247
00.1828	0009+64.9	Bump	.2	.152
00.1832	0009+67.3	Bump	5.1	.269
00.1842	0009+72.5	Bump	.2	.162
00.1872	0009+88.2	Bump	3.3	.314
00.1888	0009+96.9	Dip	1.3	-.181
00.1898	0010+02.2	Dip	1.4	-.174
00.1907	0010+06.7	Bump	7.9	.384
00.1930	0010+19.0	Dip	5.6	-.458

Distance	Station	Type	Width(feet)	Elev(inches)
00.1947	0010+27.8	Bump	4.5	.263
00.1968	0010+39.2	Dip	4.5	-.218
00.1978	0010+44.4	Dip	.2	-.158
00.1983	0010+46.8	Bump	4.3	.393
00.2003	0010+57.4	Dip	5.6	-.319
00.2029	0010+71.4	Dip	3.3	-.254
00.2059	0010+87.1	Dip	1.1	-.176
00.2068	0010+91.8	Bump	3.3	.255
00.2085	0011+00.6	Dip	.5	-.178
00.2108	0011+12.9	Bump	2.5	.224
00.2120	0011+19.6	Bump	1.6	.261
00.2147	0011+33.7	Bump	2.0	.205
00.2189	0011+55.9	Dip	.2	-.162
00.2195	0011+58.8	Bump	5.1	.227
00.2215	0011+69.3	Dip	3.3	-.234
00.2233	0011+79.2	Bump	6.5	.255
00.2258	0011+92.4	Dip	4.7	-.325
00.2320	0012+25.1	Bump	.7	.170
00.2338	0012+34.5	Bump	2.5	.252
00.2379	0012+56.4	Dip	8.1	-.333
00.2401	0012+67.7	Bump	9.2	.266
00.2435	0012+85.4	Bump	.9	.167
00.2444	0012+90.5	Dip	.7	-.154
00.2449	0012+93.0	Dip	.9	-.177
00.2451	0012+94.1	Dip	.2	-.151
00.2452	0012+94.7	Dip	2.5	-.196
00.2494	0013+16.9	Bump	2.9	.208
00.2529	0013+35.3	Dip	.7	-.172
00.2551	0013+46.7	Bump	.5	.156
00.2553	0013+47.8	Bump	.2	.154
00.2554	0013+48.3	Bump	.5	.156
00.2640	0013+93.7	Dip	.2	-.157
00.2641	0013+94.6	Dip	8.3	-.249
00.2666	0014+07.8	Bump	9.9	.354
00.2690	0014+20.6	Dip	6.9	-.369
00.2726	0014+39.6	Dip	.7	-.176
00.2743	0014+48.2	Bump	1.4	.189
00.2746	0014+50.0	Bump	5.8	.306
00.2762	0014+58.5	Dip	4.7	-.280
00.2772	0014+63.4	Dip	.2	-.156
00.2772	0014+63.8	Dip	.2	-.158
00.2773	0014+64.3	Dip	1.3	-.177
00.2783	0014+69.4	Bump	.2	.160
00.2784	0014+69.7	Bump	2.2	.169
00.2789	0014+72.4	Bump	1.1	.167
00.2791	0014+73.7	Bump	1.4	.256
00.2804	0014+80.4	Bump	.2	.156
00.2805	0014+80.9	Bump	.4	.157
00.2806	0014+81.5	Bump	1.4	.181
00.2820	0014+88.9	Dip	.2	-.153
00.2821	0014+89.6	Dip	5.6	-.416
00.2849	0015+04.2	Bump	.2	.151
00.2850	0015+05.0	Bump	1.4	.179
00.2854	0015+06.8	Bump	.9	.175
00.2868	0015+14.5	Dip	4.7	-.202
00.2886	0015+23.9	Bump	6.7	.269
00.2911	0015+36.9	Dip	.4	-.170
00.2912	0015+37.7	Dip	.2	-.164
00.2914	0015+38.4	Dip	.2	-.165
00.2916	0015+39.8	Dip	.7	-.162
00.2921	0015+42.2	Dip	1.3	-.169
00.2939	0015+51.7	Bump	1.4	.172

Total bumps/dips detected: 174

Distance	Station	PSI	IRI(L)	IRI(R)	Avg IRI	Pay*SectionLength	Pay
00.1000	5+28.0	1.49	252.54	289.22	271.00	-$	Corrective Work
00.2000	10+56.0	.70	362.96	362.09	363.00	-$	Corrective Work
00.2963	15+64.5	1.06	318.92	318.58	319.00	-$	Corrective Work

Pay Adjustment Subtotal= $ 0

Ave Left IRI: 311.4   Ave Right IRI: 323.4   Ave IRI: 317.4

Total IRI adjustments: $0

No bump adjustments applied.

Ride Quality Analysis Rel 2006.12.04
Report run on Friday, Jan 8 2010 3:51:26PM
Input profile data file created Tuesday, Dec 15 2009 8:17:42AM

District: 2
Area Office: UTA
County: 220
Name: MILES HICKS
Phone: 214-319-6474
Input file: t:\dalpme\uta project with profiler\rd to six flags run2.pro

Highway: RD_TO_SIX_FLAGS RUN2
Beg RM: 0000 +00.000
Beg Station: 0000+00.0
CSJ: 0000-00-000
Lane designation: K8

No Bump penalties assessed.
Total length profile: 0.2902 miles or 0015+32.3 station units.

Distance	Station	Type	Width(feet)	Elev(inches)
00.0007	0000+03.8	Bump	.4	.179
00.0020	0000+10.3	Bump	.2	.151
00.0020	0000+10.7	Bump	3.6	.243
00.0069	0000+36.3	Bump	1.3	.191
00.0072	0000+37.9	Bump	.4	.179
00.0074	0000+38.8	Bump	.5	.169
00.0093	0000+49.3	Dip	6.0	-.224
00.0202	0001+06.8	Dip	1.3	-.166
00.0232	0001+22.7	Dip	.2	-.161
00.0233	0001+23.0	Bump	.4	.189
00.0234	0001+23.6	Bump	1.8	.182
00.0238	0001+25.6	Bump	7.4	.209
00.0295	0001+55.9	Bump	5.2	.266
00.0315	0001+66.4	Dip	13.2	-.510
00.0350	0001+84.6	Bump	3.6	.320
00.0389	0002+05.4	Bump	.2	.157
00.0403	0002+13.0	Dip	.5	-.160
00.0446	0002+35.2	Dip	2.9	-.215
00.0451	0002+38.3	Dip	.2	-.155
00.0469	0002+47.9	Bump	.7	.192
00.0471	0002+48.8	Bump	1.3	.191
00.0474	0002+50.2	Bump	.4	.156
00.0477	0002+51.7	Bump	.2	.151
00.0478	0002+52.2	Bump	1.1	.185
00.0491	0002+59.3	Dip	.2	-.156
00.0515	0002+71.9	Bump	1.6	.178
00.0518	0002+73.7	Bump	.4	.159
00.0585	0003+08.8	Bump	.2	.151
00.0589	0003+11.1	Bump	1.1	.198
00.0603	0003+18.5	Bump	3.6	.259
00.0615	0003+24.7	Bump	.5	.174
00.0621	0003+27.9	Dip	6.5	-.270
00.0640	0003+38.0	Dip	.2	-.154
00.0642	0003+38.9	Dip	.2	-.161
00.0657	0003+46.9	Bump	2.3	.185
00.0662	0003+49.4	Bump	.9	.169
00.0664	0003+50.7	Bump	.7	.174
00.0672	0003+54.8	Dip	.4	-.339
00.0677	0003+57.4	Dip	1.1	-.270
00.0693	0003+65.7	Dip	.7	-.361
00.0695	0003+66.8	Dip	.9	-.645
00.0699	0003+69.1	Bump	4.2	.255
00.0715	0003+77.4	Dip	7.0	-.381
00.0749	0003+95.5	Bump	.2	.153
00.0752	0003+97.1	Bump	3.3	.199
00.0852	0004+49.9	Bump	.9	.198
00.0902	0004+76.4	Dip	3.4	-.263
00.0910	0004+80.4	Dip	.2	-.156
00.0913	0004+82.0	Dip	.2	-.154

Distance	Station	Type	Width(feet)	Elev(inches)
00.0927	0004+89.6	Bump	.5	.159
00.0929	0004+90.3	Bump	3.6	.578
00.0936	0004+94.1	Bump	2.3	.332
00.0943	0004+98.1	Dip	3.4	-1.477
00.0953	0005+03.0	Bump	2.0	.260
00.0965	0005+09.5	Dip	1.3	-.255
00.0971	0005+12.6	Dip	5.2	-.424
00.0990	0005+22.7	Bump	3.1	.265
00.0998	0005+27.0	Bump	.2	.156
00.0999	0005+27.4	Bump	3.1	.236
00.1010	0005+33.3	Bump	4.9	.191
00.1024	0005+40.6	Dip	6.3	-.250
00.1045	0005+51.8	Bump	.2	.153
00.1046	0005+52.1	Bump	2.2	.217
00.1127	0005+95.1	Dip	1.4	-.181
00.1131	0005+96.9	Dip	.7	-.163
00.1141	0006+02.7	Bump	3.3	.231
00.1148	0006+06.1	Bump	.4	.170
00.1195	0006+30.9	Dip	.7	-.163
00.1204	0006+35.6	Bump	7.8	.346
00.1222	0006+45.2	Bump	.4	.163
00.1229	0006+49.1	Dip	1.3	-.176
00.1234	0006+51.3	Dip	.2	-.152
00.1259	0006+64.7	Bump	1.4	.188
00.1277	0006+74.1	Dip	.7	-.173
00.1278	0006+75.0	Dip	.2	-.151
00.1287	0006+79.3	Bump	.9	.182
00.1295	0006+83.6	Bump	1.3	.168
00.1304	0006+88.3	Dip	6.7	-.427
00.1319	0006+96.7	Bump	3.4	.219
00.1330	0007+02.1	Bump	.2	.151
00.1330	0007+02.4	Bump	1.4	.187
00.1335	0007+05.0	Bump	.4	.153
00.1345	0007+10.4	Dip	.5	-.156
00.1368	0007+22.5	Bump	.2	.156
00.1369	0007+22.8	Bump	.9	.164
00.1396	0007+37.3	Dip	1.4	-.324
00.1400	0007+39.3	Dip	4.9	-.288
00.1410	0007+44.5	Dip	.5	-.167
00.1423	0007+51.6	Dip	.2	-.151
00.1432	0007+56.1	Bump	.2	.152
00.1433	0007+56.5	Bump	.9	.178
00.1440	0007+60.1	Bump	4.5	.235
00.1452	0007+66.6	Bump	4.9	.361
00.1466	0007+74.0	Dip	1.8	-.183
00.1470	0007+76.0	Dip	6.7	-.307
00.1492	0007+87.7	Bump	5.4	.236
00.1509	0007+96.7	Dip	4.3	-.241
00.1524	0008+04.9	Bump	.4	.163
00.1544	0008+15.2	Bump	2.7	.420
00.1581	0008+34.9	Dip	2.7	-.198
00.1588	0008+38.5	Dip	1.1	-.343
00.1663	0008+78.0	Dip	2.2	-.215
00.1683	0008+88.5	Bump	3.6	.376
00.1696	0008+95.7	Dip	3.4	-.226
00.1744	0009+20.7	Bump	1.6	.301
00.1747	0009+22.5	Bump	1.8	.254
00.1758	0009+28.4	Dip	2.3	-.201
00.1764	0009+31.2	Dip	1.4	-.173
00.1781	0009+40.4	Bump	2.2	.194
00.1786	0009+43.3	Bump	1.1	.214
00.1822	0009+62.1	Bump	.9	.178
00.1824	0009+63.3	Bump	.2	.151

Distance	Station	Type	Width(feet)	Elev(inches)
00.1825	0009+63.9	Bump	.2	.158
00.1834	0009+68.6	Dip	.9	-.175
00.1836	0009+69.6	Dip	4.0	-.205
00.1849	0009+76.1	Dip	.2	-.157
00.1856	0009+80.1	Bump	8.3	.459
00.1872	0009+88.6	Bump	.7	.187
00.1874	0009+89.5	Bump	1.6	.204
00.1879	0009+92.2	Dip	5.4	-.816
00.1894	0010+99.8	Bump	5.6	.301
00.1933	0010+20.8	Dip	.2	-.155
00.1937	0010+22.6	Bump	1.1	.239
00.1943	0010+26.0	Dip	.7	-.182
00.1953	0010+31.2	Dip	4.9	-.265
00.1983	0010+47.1	Dip	.4	-.161
00.2012	0010+62.1	Dip	.4	-.157
00.2018	0010+65.4	Bump	6.5	.255
00.2035	0010+74.2	Dip	1.6	-.183
00.2042	0010+78.2	Dip	1.1	-.164
00.2059	0010+87.3	Bump	1.8	.229
00.2070	0010+93.0	Bump	.5	.176
00.2082	0010+99.2	Dip	.4	-.165
00.2083	0011+99.7	Dip	.5	-.165
00.2096	0011+06.9	Bump	2.3	.231
00.2139	0011+29.3	Dip	.2	-.152
00.2145	0011+32.6	Bump	5.2	.262
00.2163	0011+42.2	Dip	4.2	-.285
00.2184	0011+53.0	Bump	6.5	.283
00.2209	0011+66.6	Dip	3.4	-.398
00.2254	0011+90.1	Dip	1.3	-.194
00.2257	0011+91.7	Dip	.2	-.152
00.2270	0011+98.7	Bump	.7	.171
00.2288	0012+07.9	Bump	2.3	.252
00.2329	0012+29.8	Dip	8.1	-.311
00.2351	0012+41.4	Bump	9.2	.261
00.2386	0012+59.6	Bump	.4	.155
00.2399	0012+66.7	Dip	2.2	-.184
00.2404	0012+69.5	Dip	1.3	-.172
00.2444	0012+90.7	Bump	2.9	.207
00.2480	0013+09.5	Dip	.4	-.154
00.2481	0013+10.2	Dip	.2	-.151
00.2504	0013+22.1	Bump	.5	.163
00.2531	0013+36.6	Dip	.2	-.165
00.2586	0013+65.5	Dip	.7	-.216
00.2589	0013+67.1	Dip	.2	-.151
00.2590	0013+67.6	Dip	9.4	-.253
00.2617	0013+81.7	Bump	9.9	.332
00.2641	0013+94.4	Dip	7.9	-.372
00.2694	0014+22.2	Bump	1.1	.173
00.2696	0014+23.5	Bump	.4	.159
00.2697	0014+24.0	Bump	5.8	.304
00.2712	0014+31.8	Dip	7.8	-.284
00.2734	0014+43.3	Bump	6.0	.244
00.2746	0014+49.7	Bump	.4	.175
00.2755	0014+54.5	Bump	1.3	.172
00.2758	0014+56.2	Bump	.5	.158
00.2769	0014+62.0	Dip	.4	-.169
00.2770	0014+62.5	Dip	.9	-.183
00.2772	0014+63.6	Dip	4.9	-.398
00.2802	0014+79.3	Bump	.9	.167
00.2804	0014+80.4	Bump	1.6	.181
00.2819	0014+88.3	Dip	6.0	-.206
00.2837	0014+98.1	Bump	6.1	.285
00.2862	0015+11.3	Dip	1.4	-.175

Distance	Station	Type	Width(feet)	Elev(inches)
00.2872	0015+16.3	Dip	.4	-.156
00.2873	0015+16.9	Dip	.4	-.162
00.2874	0015+17.4	Dip	.2	-.156

Total bumps/dips detected: 178

Distance	Station	PSI	IRI(L)	IRI(R)	Avg IRI	Pay*SectionLength	Pay
00.1000	5+28.0	1.16	273.44	341.58	308.00	-$	Corrective Work
00.2000	10+56.0	.71	370.01	354.11	362.00	-$	Corrective Work
00.2902	15+32.3	1.08	314.27	318.92	317.00	-$	Corrective Work
					Pay Adjustment Subtotal=	$	0

Ave Left IRI: 319.4   Ave Right IRI: 338.9   Ave IRI: 329.15

Total IRI adjustments: $0

No bump adjustments applied.

Ride Quality Analysis Rel 2006.12.04
Report run on Friday, Jan 8 2010 3:49:42PM
Input profile data file created Tuesday, Dec 15 2009 8:14:16AM

District: 2
Area Office: UTA
County: 220
Name: MILES HICKS
Phone: 214-319-6474

Highway: RANDOL_MILL RUN1
Beg RM: 0000 +00.000
Beg Station: 0000+00.0
CSJ: 0000-00-000
Lane designation: K6

Input file: t:\dalpme\uta project with profiler\randal mill rd run1.pro

No Bump penalties assessed.
Total length profile: 0.2726 miles or 0014+39.3 station units.

Distance	Station	Type	Width(feet)	Elev(inches)
00.0045	0000+23.8	Dip	.4	-.158
00.0048	0000+25.1	Dip	.7	-.192
00.0074	0000+39.2	Bump	.2	.160
00.0076	0000+39.9	Bump	.2	.169
00.0091	0000+47.9	Dip	8.5	-.306
00.0114	0000+60.0	Bump	1.8	.256
00.0124	0000+65.4	Bump	2.3	.226
00.0164	0000+86.5	Bump	2.3	.181
00.0169	0000+89.2	Bump	.5	.164
00.0194	0001+02.6	Bump	6.1	.239
00.0206	0001+08.9	Bump	.5	.171
00.0208	0001+09.7	Bump	1.1	.192
00.0215	0001+13.5	Dip	11.0	-.366
00.0247	0001+30.4	Bump	5.4	1.059
00.0301	0001+59.2	Dip	7.8	-.234
00.0322	0001+70.0	Bump	2.5	.180
00.0354	0001+87.0	Bump	.4	.158
00.0357	0001+88.3	Bump	1.3	.174
00.0359	0001+89.7	Bump	.4	.168
00.0387	0002+04.5	Bump	.9	.159
00.0390	0002+05.8	Bump	.2	.159
00.0391	0002+06.3	Bump	5.1	.211
00.0407	0002+14.8	Dip	1.3	-.173
00.0450	0002+37.6	Bump	1.4	.176
00.0461	0002+43.4	Dip	3.4	-.226
00.0496	0002+62.1	Dip	.9	-.162
00.0510	0002+69.4	Bump	.5	.157
00.0590	0003+11.3	Bump	6.5	.313
00.0602	0003+18.0	Bump	.7	.164
00.0610	0003+21.9	Dip	1.8	-.182
00.0640	0003+37.7	Dip	7.4	-.260
00.0668	0003+52.7	Bump	4.7	.199
00.0694	0003+66.4	Bump	3.6	.201
00.0713	0003+76.7	Dip	5.1	-.218
00.0780	0004+11.7	Bump	.4	.155
00.0817	0004+31.4	Bump	4.9	.216
00.0827	0004+36.7	Bump	.7	.157
00.0829	0004+37.6	Bump	.2	.152
00.0830	0004+38.5	Bump	1.1	.184
00.0854	0004+50.9	Dip	.4	-.151
00.0855	0004+51.7	Dip	.2	-.155
00.0857	0004+52.8	Dip	1.8	-.221
00.0877	0004+63.0	Dip	.4	-.176
00.0895	0004+72.6	Dip	5.8	-.431
00.0911	0004+80.8	Bump	.2	.151
00.0911	0004+81.1	Bump	7.0	.208
00.0949	0005+01.0	Bump	.4	.160
00.0952	0005+02.8	Bump	.2	.152
00.0953	0005+03.2	Bump	.5	.163

Distance	Station	Type	Width(feet)	Elev(inches)
00.0983	0005+19.1	Bump	1.8	.203
00.0996	0005+25.7	Dip	6.0	-.240
00.1028	0005+42.9	Bump	.4	.178
00.1030	0005+44.0	Bump	.7	.178
00.1089	0005+75.2	Dip	.9	-.176
00.1111	0005+86.4	Bump	.5	.153
00.1118	0005+90.1	Bump	1.3	.188
00.1121	0005+92.0	Bump	.5	.160
00.1135	0005+99.1	Dip	2.7	-.256
00.1140	0006+02.2	Dip	.2	-.158
00.1164	0006+14.8	Bump	.5	.159
00.1166	0006+15.7	Bump	.5	.166
00.1256	0006+63.2	Dip	.5	-.160
00.1258	0006+64.1	Dip	1.4	-.187
00.1318	0006+95.7	Bump	2.0	.203
00.1338	0007+06.6	Bump	.2	.152
00.1339	0007+07.1	Bump	.7	.152
00.1343	0007+08.9	Bump	5.1	.546
00.1356	0007+15.8	Dip	5.2	-.332
00.1369	0007+23.0	Bump	8.9	.435
00.1391	0007+34.6	Dip	14.6	-.486
00.1422	0007+50.9	Bump	.5	.172
00.1428	0007+53.7	Bump	9.2	.383
00.1549	0008+18.1	Bump	2.9	.281
00.1561	0008+24.0	Dip	.4	-.166
00.1740	0009+18.5	Dip	.5	-.158
00.1742	0009+19.6	Dip	3.4	-.203
00.1751	0009+24.5	Dip	2.3	-.203
00.1763	0009+30.6	Bump	4.0	.239
00.1842	0009+72.7	Dip	1.6	-.172
00.1849	0009+76.1	Bump	6.3	.467
00.1863	0009+83.7	Dip	1.3	-.173
00.1870	0009+87.2	Dip	2.7	-.183
00.1905	0010+05.6	Dip	2.2	-.171
00.2013	0010+62.7	Dip	.2	-.155
00.2032	0010+72.8	Bump	1.1	.188
00.2040	0010+77.0	Bump	.4	.156
00.2054	0010+84.5	Bump	1.3	.174
00.2060	0010+87.4	Bump	1.4	.185
00.2084	0011+00.3	Dip	.2	-.167
00.2086	0011+01.5	Dip	.2	-.154
00.2208	0011+66.0	Bump	.2	.151
00.2209	0011+66.4	Bump	1.8	.199
00.2271	0011+98.9	Dip	3.8	-.259
00.2298	0012+13.4	Bump	.4	.161
00.2299	0012+14.1	Bump	3.8	.219
00.2312	0012+20.6	Bump	9.6	.405
00.2335	0012+33.1	Dip	10.7	-.549
00.2364	0012+48.2	Bump	2.5	.244
00.2402	0012+68.5	Bump	.4	.154
00.2404	0012+69.2	Bump	.4	.159
00.2405	0012+69.9	Bump	.5	.171
00.2573	0013+58.6	Dip	.4	-.159
00.2574	0013+59.2	Dip	4.9	-.202
00.2591	0013+68.2	Bump	6.1	.332
00.2630	0013+88.6	Bump	.9	.170
00.2654	0014+01.1	Bump	1.1	.177
00.2661	0014+05.0	Dip	5.6	-.236
00.2706	0014+28.7	Bump	3.1	.257

Total bumps/dips detected: 108

Distance	Station	PSI	IRI(L)	IRI(R)	Avg IRI	Pay*SectionLength	Pay
00.1000	5+28.0	1.24	257.67	338.31	298.00	-$	Corrective Work
00.2000	10+56.0	1.62	214.94	300.44	258.00	-$	Corrective Work
00.2726	14+39.3	1.42	245.70	311.12	278.00	-$	Corrective Work

Pay Adjustment Subtotal= $ 0

Ave Left IRI: 238.8 Ave Right IRI: 317.2 Ave IRI: 278

Total IRI adjustments: $0

No bump adjustments applied.

Ride Quality Analysis Rel 2006.12.04
Report run on Friday, Jan 8 2010 3:50:38PM
Input profile data file created Tuesday, Dec 15 2009 8:12:00AM

District: 2
Area Office: UTA
County: 220
Name: MILES HICKS
Phone: 214-319-6474
Highway: RANDOL_MILL RUN2
Beg RM: 0000 +00.000
Beg Station: 0000+00.0
CSJ: 0000-00-000
Lane designation: K8
Input file: t:\dalpme\uta project with profiler\randal mill rd run2.pro

No Bump penalties assessed.
Total length profile: 0.271 miles or 0014+30.9 station units.

Distance	Station	Type	Width(feet)	Elev(inches)
00.0054	0000+28.4	Dip	2.2	-.236
00.0081	0000+42.8	Bump	1.6	.271
00.0087	0000+45.9	Dip	.2	-.151
00.0088	0000+46.3	Dip	.2	-.154
00.0089	0000+46.8	Dip	.2	-.152
00.0090	0000+47.3	Dip	.5	-.174
00.0100	0000+52.8	Dip	8.1	-.329
00.0121	0000+63.8	Bump	2.3	.265
00.0132	0000+69.9	Bump	2.5	.264
00.0172	0000+91.1	Bump	2.3	.178
00.0178	0000+93.8	Bump	.5	.169
00.0179	0000+94.5	Bump	.2	.152
00.0203	0001+07.3	Bump	6.0	.223
00.0217	0001+14.7	Bump	.9	.192
00.0224	0001+18.2	Dip	10.8	-.364
00.0255	0001+34.8	Bump	5.8	.351
00.0310	0001+63.5	Dip	.4	-.151
00.0311	0001+64.0	Dip	1.1	-.175
00.0313	0001+65.5	Dip	1.4	-.177
00.0317	0001+67.3	Dip	4.5	-.225
00.0331	0001+74.9	Bump	1.1	.171
00.0366	0001+93.3	Bump	.5	.159
00.0369	0001+94.8	Bump	.2	.152
00.0401	0002+11.6	Bump	4.9	.217
00.0417	0002+20.4	Dip	.5	-.158
00.0455	0002+40.1	Bump	.2	.152
00.0459	0002+42.5	Bump	2.2	.201
00.0471	0002+48.6	Dip	2.9	-.210
00.0520	0002+74.4	Bump	.7	.169
00.0599	0003+16.5	Bump	7.9	.302
00.0620	0003+27.5	Dip	1.4	-.164
00.0650	0003+43.1	Dip	7.6	-.258
00.0678	0003+57.9	Bump	4.0	.202
00.0686	0003+62.4	Bump	.2	.154
00.0704	0003+71.5	Bump	2.5	.193
00.0709	0003+74.2	Bump	.9	.157
00.0724	0003+82.1	Dip	5.6	-.210
00.0790	0004+17.0	Bump	.2	.151
00.0827	0004+36.9	Bump	5.1	.207
00.0838	0004+42.3	Bump	.2	.151
00.0839	0004+43.2	Bump	.2	.151
00.0841	0004+43.9	Bump	1.1	.178
00.0867	0004+57.8	Dip	1.8	-.242
00.0887	0004+68.3	Dip	.5	-.187
00.0905	0004+78.0	Dip	5.8	-.427
00.0920	0004+85.8	Bump	5.4	.235
00.0931	0004+91.4	Bump	.2	.155
00.0932	0004+92.0	Bump	1.4	.171
00.0959	0005+06.2	Bump	.5	.162

Distance	Station	Type	Width(feet)	Elev(inches)
00.0960	0005+07.0	Bump	.2	.152
00.0963	0005+08.2	Bump	.2	.153
00.0994	0005+24.7	Bump	1.6	.224
00.1006	0005+31.2	Dip	6.0	-.254
00.1040	0005+49.2	Bump	.7	.195
00.1100	0005+80.8	Dip	.4	-.153
00.1119	0005+90.8	Bump	1.1	.162
00.1121	0005+92.0	Bump	.4	.153
00.1128	0005+95.7	Bump	2.9	.191
00.1143	0006+03.2	Dip	4.5	-.252
00.1173	0006+19.3	Bump	.2	.156
00.1174	0006+20.0	Bump	.7	.156
00.1176	0006+21.0	Bump	.5	.161
00.1265	0006+68.1	Dip	2.5	-.177
00.1340	0007+07.7	Dip	.4	-.159
00.1346	0007+10.6	Bump	8.5	.472
00.1365	0007+20.9	Dip	5.2	-.359
00.1380	0007+28.4	Bump	8.7	.393
00.1401	0007+39.8	Dip	14.6	-.463
00.1432	0007+55.9	Bump	.5	.166
00.1437	0007+58.6	Bump	9.4	.385
00.1559	0008+23.1	Bump	2.9	.272
00.1570	0008+29.1	Dip	.2	-.159
00.1749	0009+23.4	Dip	.7	-.154
00.1751	0009+24.5	Dip	3.4	-.195
00.1760	0009+29.3	Dip	2.3	-.205
00.1772	0009+35.5	Bump	3.8	.256
00.1780	0009+40.0	Bump	.4	.157
00.1851	0009+77.6	Dip	1.6	-.180
00.1858	0009+81.0	Bump	6.1	.464
00.1879	0009+92.0	Dip	2.7	-.198
00.1913	0010+09.9	Dip	2.9	-.196
00.2041	0010+77.9	Bump	.2	.151
00.2049	0010+81.7	Bump	.5	.174
00.2063	0010+89.2	Bump	1.1	.171
00.2068	0010+91.9	Bump	1.8	.197
00.2094	0011+05.9	Dip	.5	-.164
00.2159	0011+40.2	Dip	.4	-.156
00.2218	0011+70.9	Bump	1.8	.218
00.2237	0011+81.4	Dip	.2	-.152
00.2280	0012+03.6	Dip	3.4	-.260
00.2307	0012+17.9	Bump	4.0	.248
00.2318	0012+23.7	Bump	.2	.153
00.2321	0012+25.5	Bump	9.4	.403
00.2344	0012+37.6	Dip	10.7	-.540
00.2373	0012+52.7	Bump	2.2	.252
00.2412	0012+73.7	Bump	.5	.177
00.2414	0012+74.4	Bump	.7	.183
00.2584	0013+64.4	Dip	4.3	-.198
00.2601	0013+73.2	Bump	5.8	.385
00.2639	0013+93.3	Bump	.4	.162
00.2663	0014+05.9	Bump	.9	.176
00.2669	0014+09.2	Dip	6.1	-.237

Total bumps/dips detected: 102

Distance	Station	PSI	IRI(L)	IRI(R)	Avg IRI	Pay*SectionLength	Pay
00.1000	5+28.0	1.19	259.95	347.92	304.00	-$	Corrective Work
00.2000	10+56.0	1.66	210.48	296.91	254.00	-$	Corrective Work
00.2710	14+30.9	1.55	234.09	296.64	265.00	-$	Corrective Work

Pay Adjustment Subtotal= $ 0

Ave Left IRI: 234.9 Ave Right IRI: 315.7 Ave IRI: 275.3

Total IRI adjustments: $0

No bump adjustments applied.

APPENDIX B

Sample Survey of Longitudinal Grade

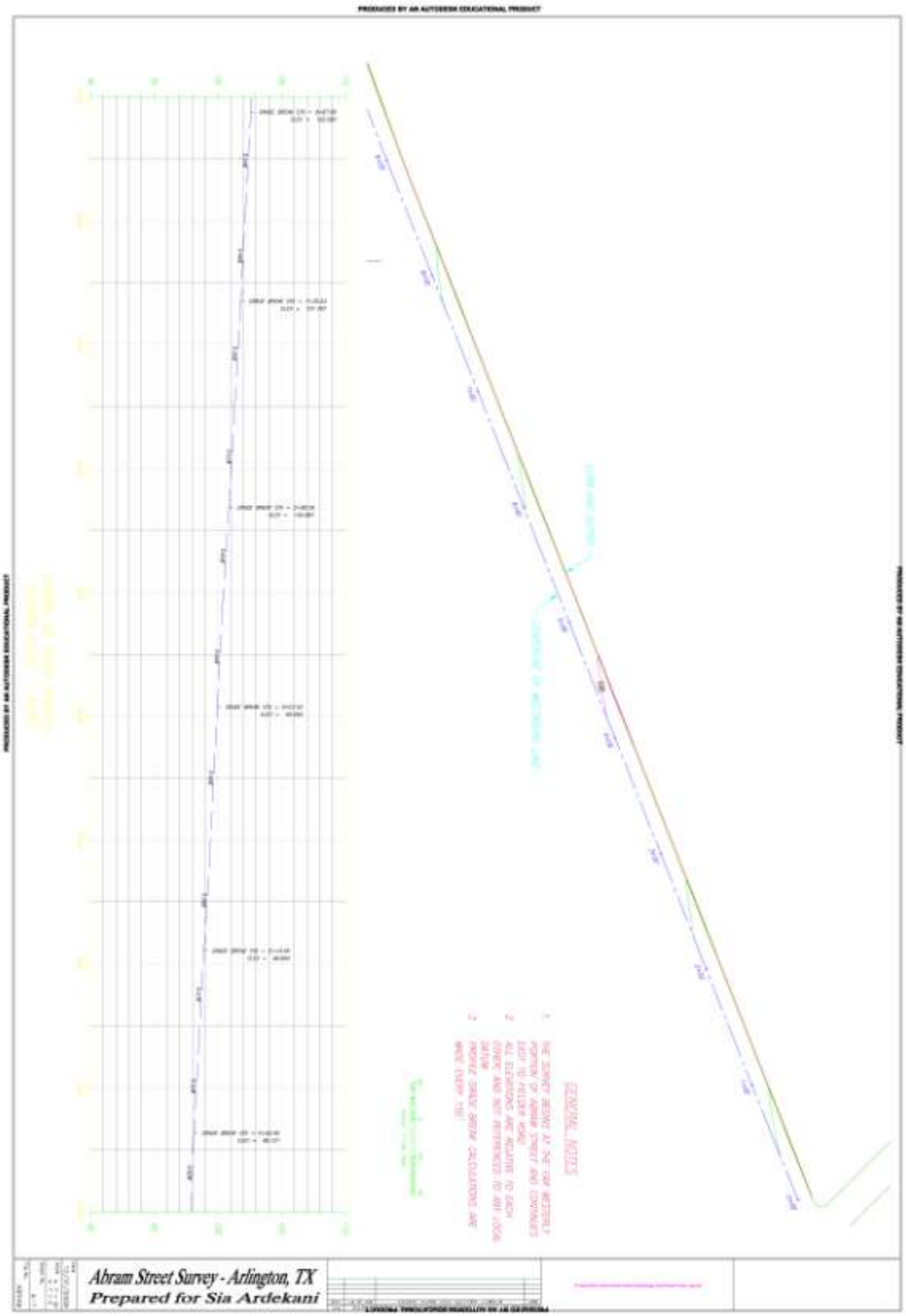


Exhibit B-1. Longitudinal Grade for Abram Street (PCC) in Arlington, TX (Part 1).

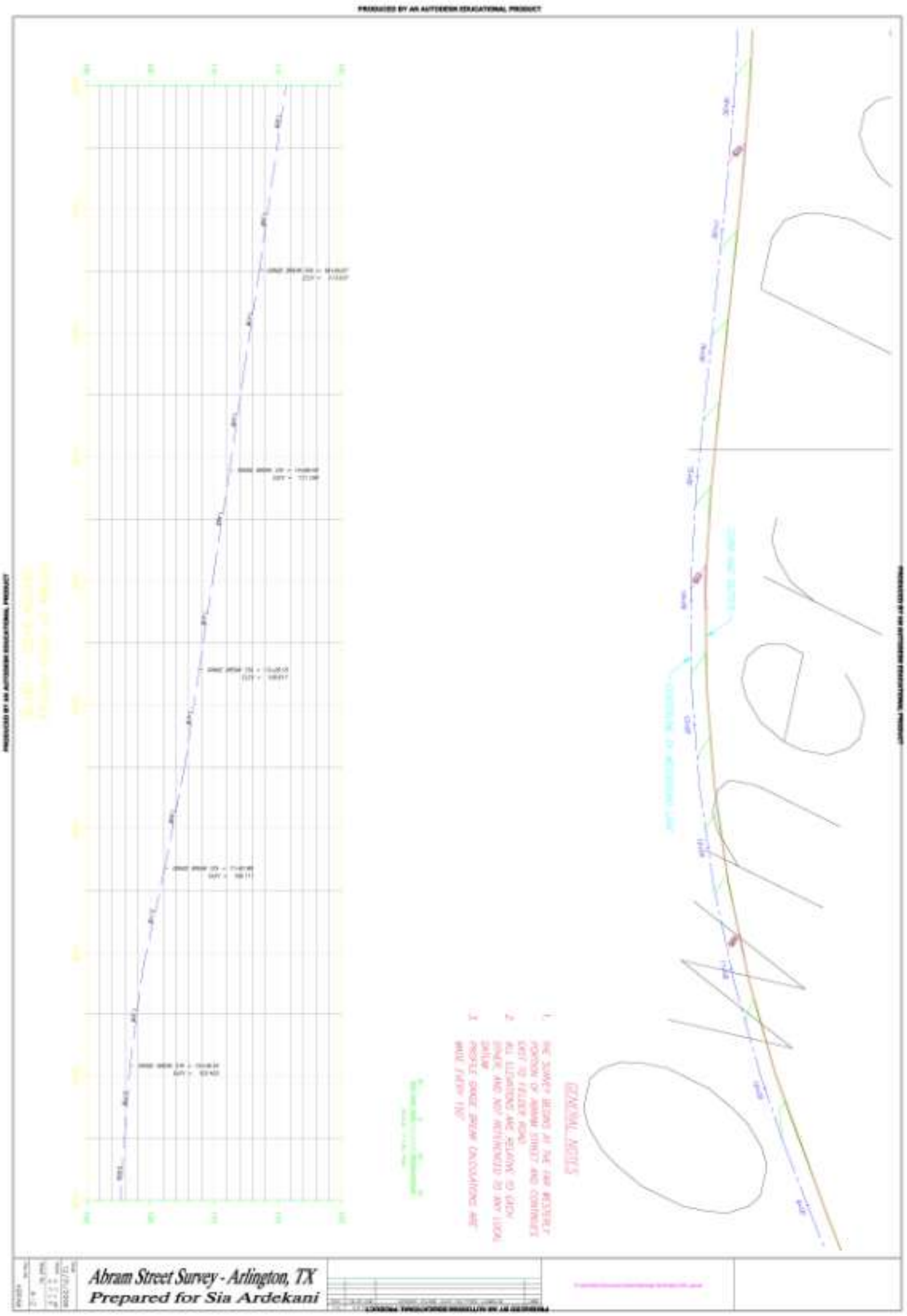


Exhibit B-2. Longitudinal Grade for Abram Street (PCC) in Arlington, TX (Part 2).

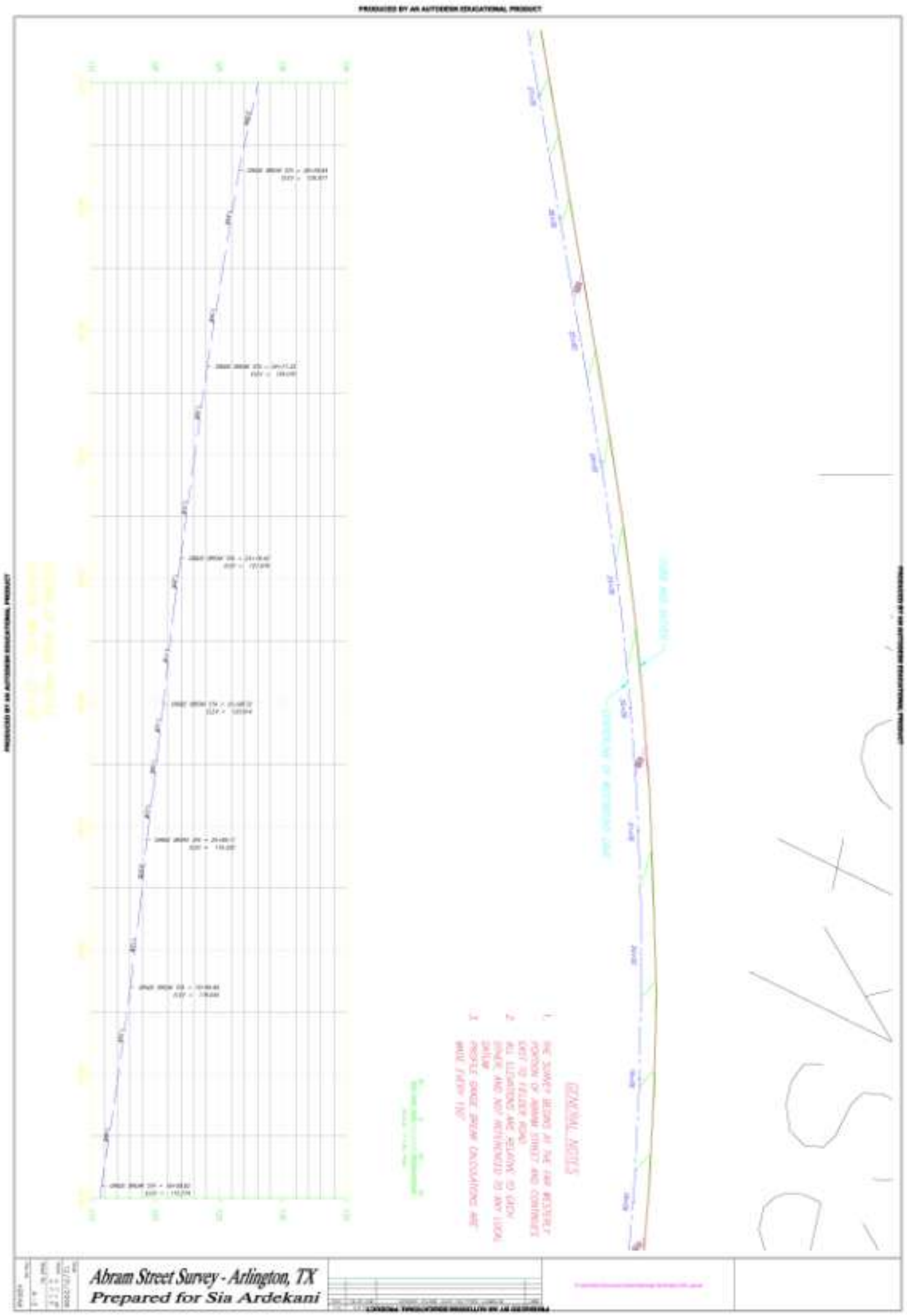


Exhibit B-3. Longitudinal Grade for Abram Street (PCC) in Arlington, TX (Part 3).

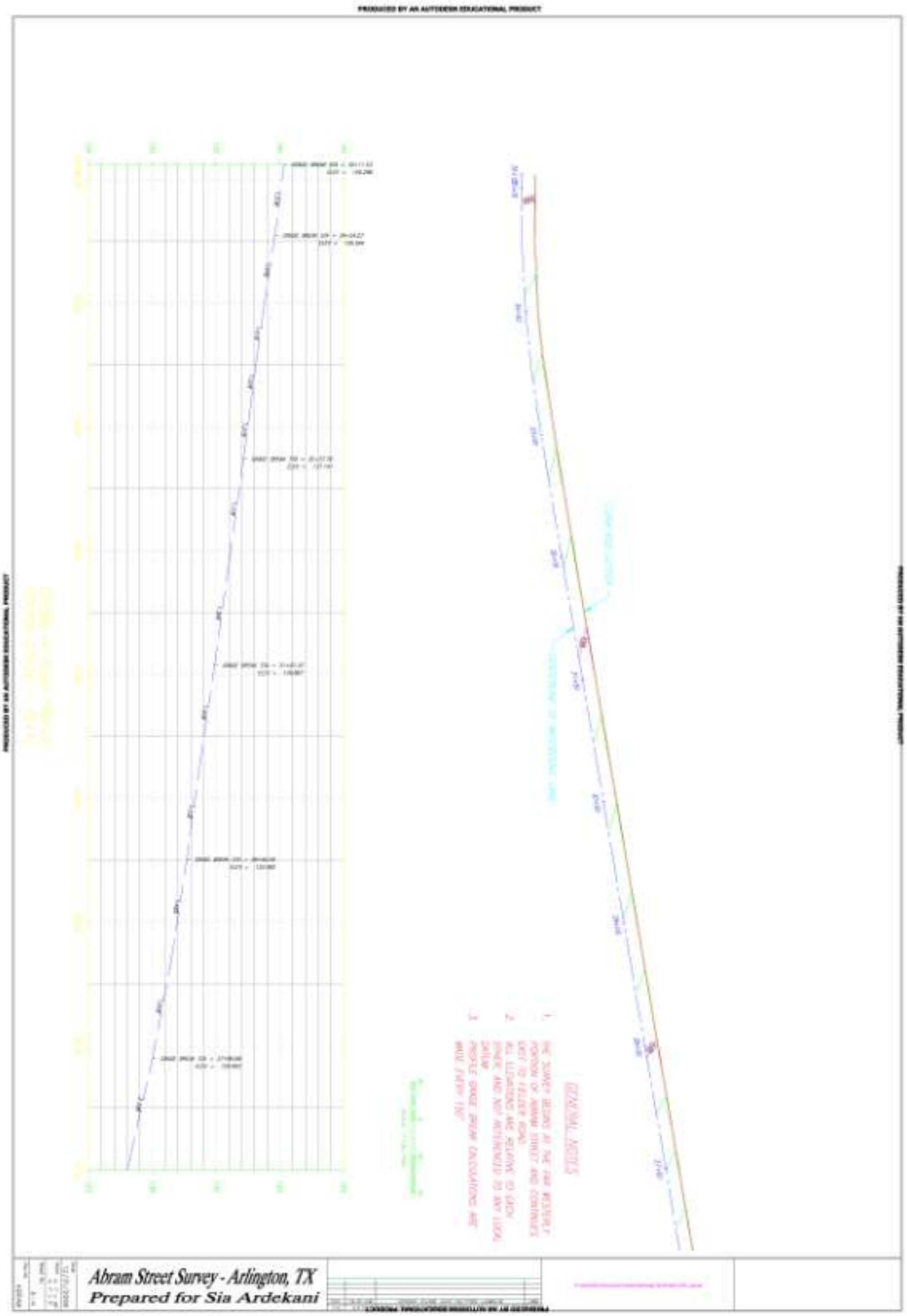


Exhibit B-4. Longitudinal Grade for Abram Street (PCC) in Arlington, TX (Part 4).

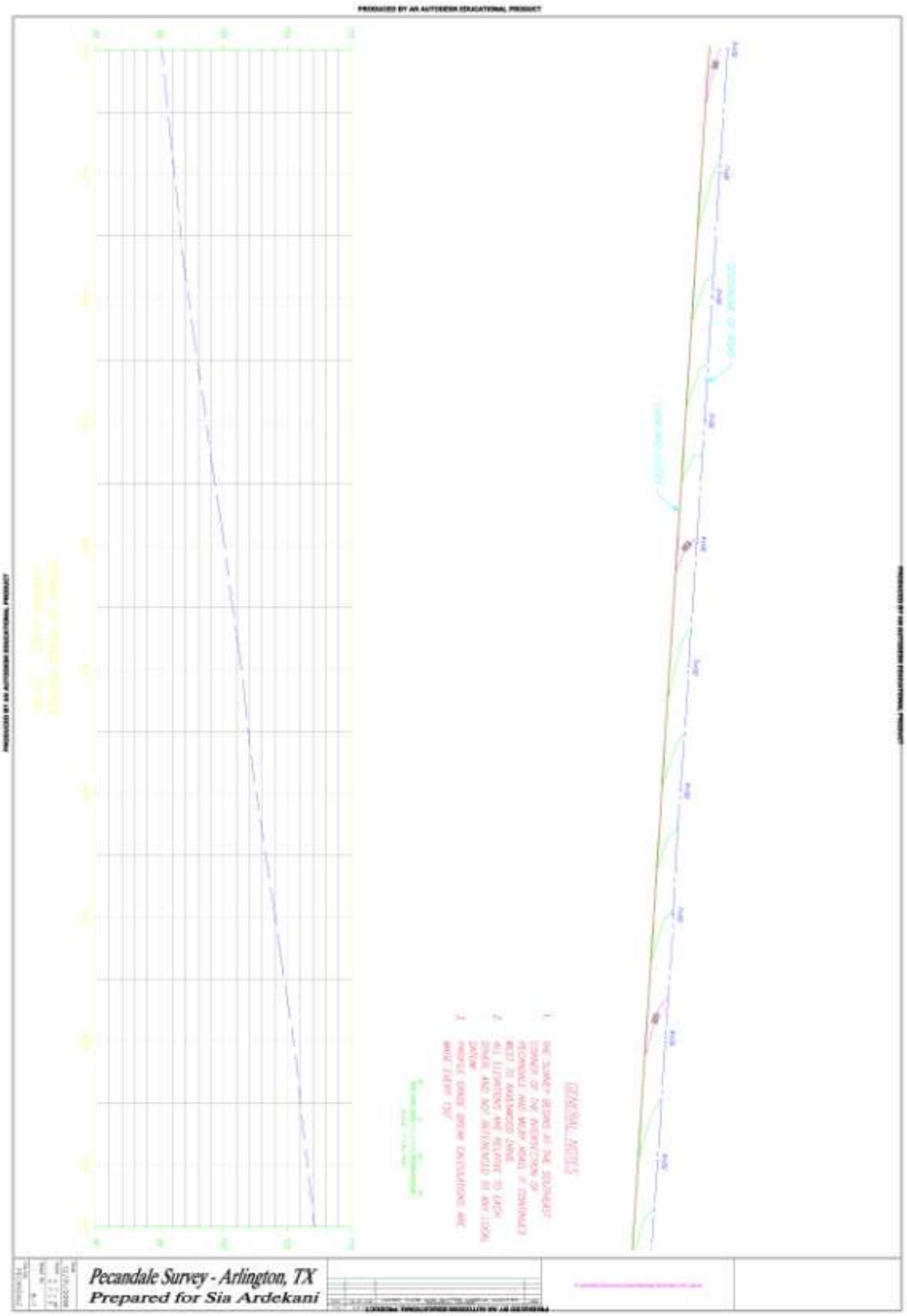


Exhibit B-5. Longitudinal Grade for Pecandale Drive (AC) in Arlington, TX (Part 1).

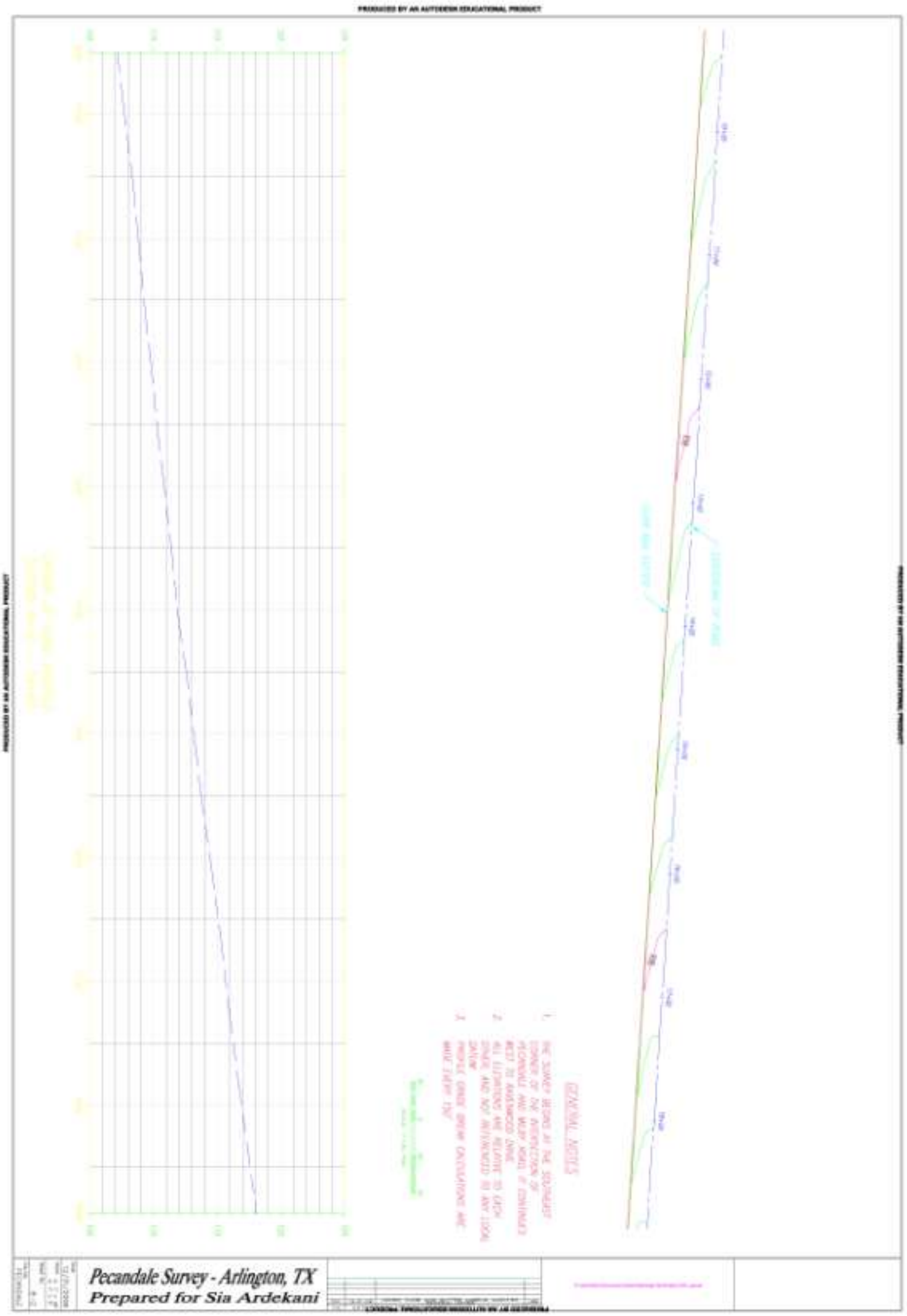


Exhibit B-6. Longitudinal Grade for Pecandale Drive (AC) in Arlington, TX (Part 2).

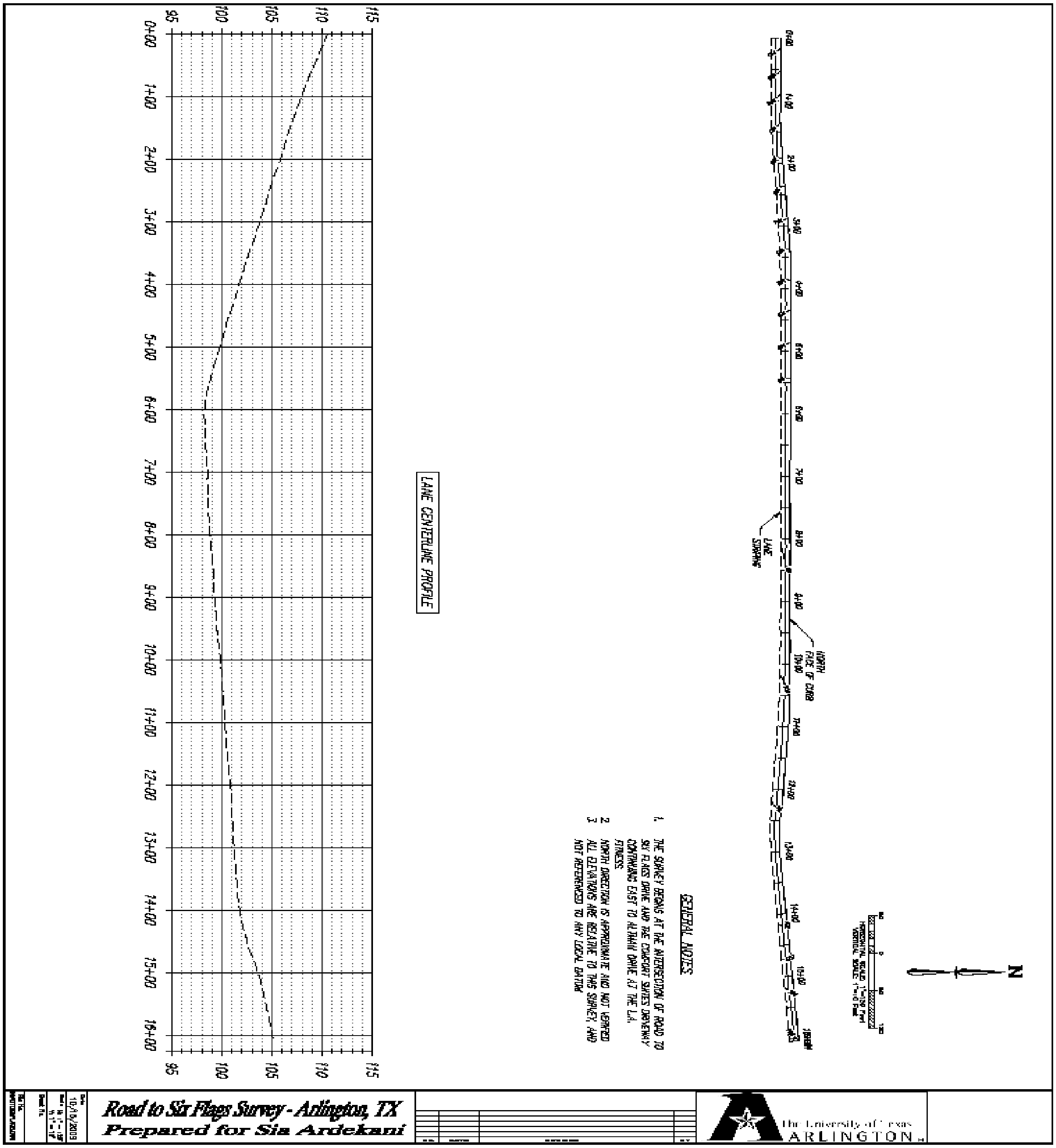


Exhibit B-7. Longitudinal Grade for Road to Six Flags Street (PCC) in Arlington, TX.

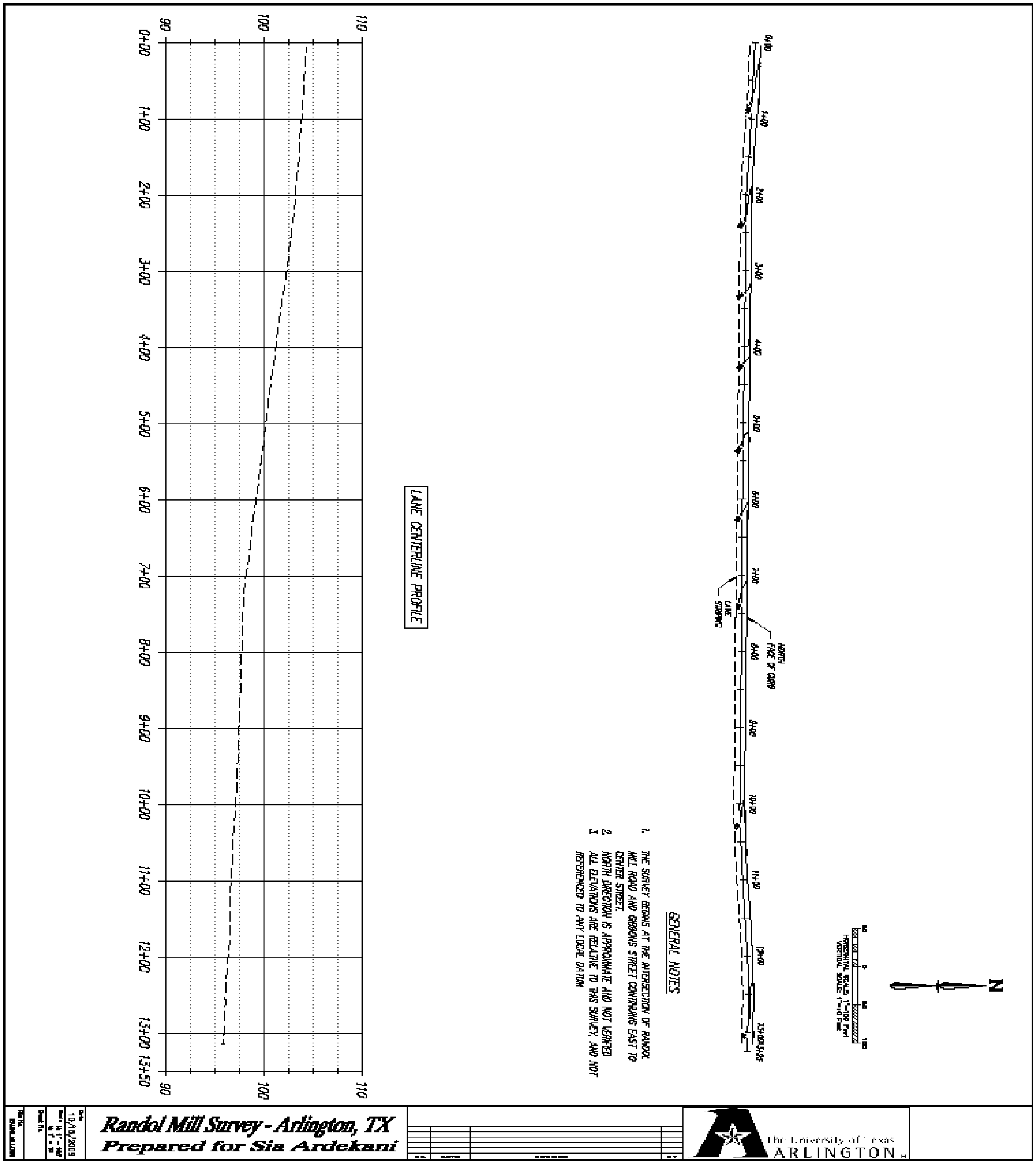


Exhibit B-8. Longitudinal Grade for Randol Mill Road (AC) in Arlington, TX.

APPENDIX C

Fuel Measurement Raw Data

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Dry/Constant Speed	November 7, 2008	1	11.3	39.3	**45.6**
		2	11.0	41.0	
		3	10.1	39.8	
		4	11.8	42.7	
		5	10.6	39.1	
		6	10.8	42.2	
	December 5, 2008	7	12.1	50.4	
	January 16, 2009	8	13.1	57.1	
		9	8.3	46.8	
		10	7.0	42.0	
		11	14.2	51.6	
		12	24.5	49.0	
		13	25.8	51.6	
AC/Dry/Constant Speed	November 7, 2008	1	7.3	46.2	**49.5**
		2	10.1	42.6	
		3	9.9	41.3	
		4	10.0	42.2	
		5	9.2	41.2	
		6	9.6	42.5	
	December 5, 2008	7	16.4	62.8	
		8	12.9	53.0	
		9	13.3	56.2	
		10	12.2	50.7	
	January 16, 2009	11	11.5	56.5	
		12	7.1	49.6	
		13	12.6	54.2	
		14	11.1	47.7	
		15	11.6	52.9	
		16	12.3	52.6	

Exhibit C-1. Fuel Measurement of Abram (PCC) vs. Pecandale (AC) on Dry Surface at Constant Speed of 30 mph.

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Wet/Constant Speed	January 26, 2009	1	27.2	54.4	**54.1**
		2	28.3	56.6	
		3	27.1	54.3	
		4	28.7	57.4	
		5	28.6	57.4	
	April 12, 2009	6	13.1	52.6	
		7	13.0	52.0	
		8	13.6	54.4	
		9	13.9	55.7	
		10	13.5	54.1	
	April 17, 2009	11	13.7	53.1	
		12	14.0	52.5	
		13	13.8	50.3	
		14	13.9	51.3	
		15	13.9	55.6	
AC/Wet/Constant Speed	January 26, 2009	1	13.3	57.1	**55.9**
		2	13.8	58.7	
		3	13.4	57.2	
		4	12.3	56.3	
		5	12.2	52.6	
	April 12, 2009	6	12.1	58.4	
		7	13.0	58.5	
		8	13.1	56.2	
		9	11.1	54.1	
		10	12.7	55.4	
	April 17, 2009	11	10.7	55.8	
		12	11.0	56.4	
		13	9.6	52.8	
		14	9.6	52.5	
		15	10.2	56.0	

Exhibit C-2. Fuel Measurement of Abram (PCC) vs. Pecandale (AC) on Wet Surface at Constant Speed of 30 mph.

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Dry/Constant Speed	July 3, 2009	1	5.3	39.8	**42.2**
		2	5.6	42.1	
		3	5.9	45.0	
		4	4.6	39.5	
		5	5.5	41.2	
	July 23, 2009	6	5.5	43.8	
		7	6.2	46.6	
		8	5.3	46.9	
		9	5.4	40.6	
		10	5.7	42.7	
	July 24, 2009	11	4.9	36.6	
		12	6.2	46.5	
		13	5.4	41.3	
		14	5.1	38.5	
		15	5.7	42.6	
AC/Dry/Constant Speed	July 3, 2009	1	7.4	55.8	**51.3**
		2	5.4	44.2	
		3	5.7	45.3	
		4	6.3	48.0	
		5	6.2	49.7	
	July 23, 2009	6	5.8	51.5	
		7	6.3	50.7	
		8	6.0	59.2	
		9	6.4	55.5	
		10	6.2	51.5	
	July 24, 2009	11	5.9	52.8	
		12	6.5	52.2	
		13	5.9	50.1	
		14	6.2	50.5	
		15	6.1	52.0	

Exhibit C-3. Fuel Measurement of Road to Six Flags (PCC) vs. Randol Mill (AC) on Dry Surface at Constant Speed of 30 mph.

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Wet/Constant Speed	July 30, 2009	1	6.1	45.8	**45.6**
		2	6.1	47.5	
		3	6.4	48.2	
		4	6.0	44.7	
		5	6.4	48.4	
	September 13, 2009	6	6.3	47.4	
		7	6.2	47.2	
		8	6.6	49.5	
		9	5.8	43.6	
		10	5.9	44.3	
	September 13, 2009	11	5.2	41.2	
		12	5.7	45.3	
		13	5.7	44.1	
		14	4.8	39.2	
		15	6.4	47.8	
AC/Wet/Constant Speed	July 30, 2009	1	6.3	54.4	**55.3**
		2	6.2	56.6	
		3	6.4	52.6	
		4	7.6	57.1	
		5	7.2	53.7	
	September 13, 2009	6	6.4	56.4	
		7	6.5	57.4	
		8	6.1	55.1	
		9	6.2	53.6	
		10	7.3	62.7	
	September 13, 2009	11	6.1	52.2	
		12	6.0	55.0	
		13	5.8	55.2	
		14	5.9	54.8	
		15	6.1	52.5	

Exhibit C-4. Fuel Measurement of Road to Six Flags (PCC) vs. Randol Mill (AC) on Wet Surface at Constant Speed of 30 mph.

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Dry/Acceleration	November 7, 2008	1	10.2	245.8	**232.8**
		2	9.9	240.2	
		3	10.0	242.3	
		4	9.6	232.7	
		5	9.5	229.6	
		6	9.4	227.8	
	December 5, 2008	7	9.3	224.4	
		8	9.4	228.4	
		9	9.3	226.2	
		10	9.1	220.8	
	January 16, 2009	11	9.8	236.8	
		12	10.1	243.6	
		13	9.1	220.2	
		14	10.0	242.1	
		15	10.2	246.7	
		16	9.0	217.0	
AC/Dry/Acceleration	November 7, 2008	1	9.8	236.2	**247.0**
		2	10.2	247.6	
		3	9.4	228.0	
		4	9.9	240.6	
		5	9.9	240.2	
		6	9.4	228.7	
	December 5, 2008	7	9.6	232.8	
		8	10.4	251.4	
		9	9.6	232.4	
		10	10.1	245.5	
	January 16, 2009	11	11.1	269.0	
		12	10.1	243.8	
		13	11.3	273.9	
		14	11.0	266.7	
		15	11.1	268.6	

Exhibit C-5. Fuel Measurement of Abram (PCC) vs. Pecandale (AC) on Dry Surface at Acceleration of 3 mph/second.

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Wet/Acceleration	January 26, 2009	1	11.2	272.2	**260.6**
		2	10.3	249.7	
		3	11.6	280.7	
		4	10.5	255.0	
		5	10.9	264.8	
	April 12, 2009	6	10.7	258.8	
		7	10.9	264.8	
		8	10.5	254.2	
		9	10.2	247.4	
		10	10.9	263.3	
	April 17, 2009	11	10.8	262.6	
		12	11.6	280.7	
		13	10.4	252.7	
		14	10.0	241.4	
		15	10.8	260.3	
AC/Wet/Acceleration	January 26, 2009	1	11.1	269.4	**269.3**
		2	11.2	270.9	
		3	11.6	280.7	
		4	10.9	264.1	
		5	10.5	254.2	
	April 12, 2009	6	11.7	283.7	
		7	11.3	274.7	
		8	10.9	264.8	
		9	10.4	252.7	
		10	11.5	279.2	
	April 17, 2009	11	11.3	273.2	
		12	11.5	277.7	
		13	10.5	254.2	
		14	10.7	258.0	
		15	11.6	281.5	

Exhibit C-6. Fuel Measurement of Abram (PCC) vs. Pecandale (AC) on Wet Surface at Acceleration of 3 mph/second.

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Dry/Acceleration	July 3, 2009	1	10.9	263.3	**240.2**
		2	9.3	224.0	
		3	10.3	248.9	
		4	10.4	251.2	
		5	10.6	257.1	
	July 23, 2009	6	9.5	230.8	
		7	9.5	230.0	
		8	9.6	231.5	
		9	9.9	239.9	
		10	9.7	233.8	
	July 24, 2009	11	10.3	248.9	
		12	9.7	235.3	
		13	10.3	250.5	
		14	9.7	234.4	
		15	9.2	223.2	
AC/Dry/Acceleration	July 3, 2009	1	10.5	253.5	**257.7**
		2	10.6	257.3	
		3	11.9	287.5	
		4	10.5	254.2	
		5	10.7	258.0	
	July 23, 2009	6	11.9	288.3	
		7	10.3	248.2	
		8	10.4	252.0	
		9	10.8	261.8	
		10	10.3	250.5	
	July 24, 2009	11	10.0	242.9	
		12	10.4	252.0	
		13	10.8	261.8	
		14	10.1	244.4	
		15	10.5	253.5	

Exhibit C-7. Fuel Measurement of Road to Six Flags (PCC) vs. Randol Mill (AC) on Dry Surface at Acceleration of 3 mph/second.

	Study Date	No.	Fuel Consumed (10^{-3} gals)	Fuel Consumed (10^{-3} GPM)	**Average Fuel Consumption (10^{-3} GPM)**
PCC/Wet/Acceleration	July 30, 2009	1	10.3	249.7	**226.1**
		2	9.5	230.0	
		3	9.4	227.0	
		4	9.1	220.2	
		5	9.1	219.4	
	September 13, 2009	6	10.4	252.0	
		7	9.2	221.7	
		8	8.9	215.6	
		9	8.8	212.6	
		10	9.3	224.7	
	September 13, 2009	11	9.8	237.6	
		12	9.2	222.5	
		13	9.5	229.3	
		14	8.8	212.6	
		15	9.0	217.2	
AC/Wet/Acceleration	July 30, 2009	1	11.8	286.8	**259.9**
		2	10.7	258.8	
		3	10.8	261.0	
		4	10.8	261.8	
		5	10.7	258.8	
	September 13, 2009	6	11.3	273.9	
		7	10.5	254.2	
		8	11.6	281.5	
		9	10.8	261.0	
		10	11.1	267.9	
	September 13, 2009	11	9.9	239.1	
		12	10.3	249.7	
		13	9.9	239.1	
		14	10.6	256.5	
		15	10.3	248.2	

Exhibit C-8. Fuel Measurement of Road to Six Flags (PCC) vs. Randol Mill (AC) on Wet Surface at Acceleration of 3 mph/second.