REGRESSION MODEL FOR PRIORITIZATION OF CORRIDORS WHEN RETIMING TRAFFIC SIGNALS

by

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Presented to the Faculty of the Graduate School of

The University of Texas Arlington in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

December 2007

Neeraj

and my adoring son

Akul.

ACKNOWLEDGMENTS

It was a great pleasure working on my thesis with Dr. Stephen P. Mattingly. I sincerely acknowledge his guidance and encouragement throughout this thesis. He was extremely patient in his dealings with me. I remember many times when I could not explain myself clearly but Dr. Mattingly understood what I wanted to say anyhow. He was always ready to answer my questions no matter how trivial they were. He was very understanding of the fact that I have to drive almost 45 miles to come to the campus and was always willing to accommodate me.

I am grateful to Dr. James Williams who was my teacher in three courses at UT Arlington. I learned a lot from him. He has an answer for every question related to transportation engineering. Initially, I found him to be a difficult teacher but after a while I became comfortable with his teaching style. In fact, I used to see which course Dr. Williams is teaching so that I can enroll in it. He has always been helpful, kind and understanding throughout my graduate studies at UT Arlington.

I am thankful to Dr. Sia Ardekani, who so graciously agreed to serve in my thesis committee. I have one regret that I could not take any course under him since he is widely regarded to be a good teacher. I am thankful to Dr. Christopher Poe and Dr. Sahadat Hossain, who in my difficult times when I was expecting my son, understood my situation and accommodated me without any problem.

I am grateful to Mr. Francisco Torres, Ms. Natalie Bettger, Ms. Nicole Waldman and Mr. Sasanka Pulipati, who provided me with data for this thesis and helped me by answering several questions related to this work. I am also thankful to Mr. Steven Sun and Mr. P.J. Ammirato for providing the value of NOx.

I thank the Department of Civil and Environmental Engineering, UT Arlington, for providing me the required software and computing facilities. I thank all my colleagues who provided me with great support, both technical and moral, all through my research.

I want to convey my special thanks to my wonderful husband Neeraj who has always been a pillar of my strength. This thesis would not have been possible without him. I want to express my love for my eleven months old son Akul who was a source of constant delight for me throughout this thesis. Finally, I would like to convey my sincere gratitude to my family members, including my parents and parents-in-law, whose support provided me the confidence to achieve this task.

November 15, 2007

ABSTRACT

REGRESSION MODEL FOR PRIORITIZATION OF CORRIDORS WHEN RETIMING TRAFFIC SIGNALS

Publication No. ______

Manjari G. Mittal, M.S.

The University of Texas Arlington, 2007

Supervising Professor: Dr. Stephen P. Mattingly

Traffic signals are used by transportation engineers to safely and efficiently manage vehicle, bicycle and pedestrian traffic on roadways. However, to maintain the effectiveness of traffic signals, traffic signals should be adjusted or *retimed* periodically to match the current traffic patterns. Traffic signal retiming is one of the most cost effective ways available to transportation engineers for reducing delays and mitigating congestion.

A region may contain a large number of traffic signals all of which cannot be retimed at once due to limited availability of funds and other resources; only a subset of

signals can be retimed at any given time. To make the most effective use of (limited) resources, signals to be retimed need to be selected carefully.

This thesis proposes several regression models to estimate the monetary benefits obtained by retiming signals along a corridor based on corridor characteristics such as length, number of signals, and average daily traffic. The estimated benefits are used to rank order corridors to be retimed and those expected to yield the most benefit can then be selected for retiming. The thesis also validates the proposed models and investigates the sensitivity of the models to changes in the values of various factors.

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CHAPTER 1

INTRODUCTION

One of the fundamental problems in transportation engineering is to ensure smooth vehicle traffic flow by minimizing any disruptions and/or delays during travel. One of the major sources of vehicular travel delay is *traffic signals*. Traffic signals are used by transportation engineers to safely and efficiently manage vehicle, bicycle and pedestrian traffic on roadways. For example, traffic signals are used to stop the heavy traffic flow on a major roadway to permit crossing movements from intersecting minor streets. Around two thirds of all miles driven each year are on roadways controlled by traffic signals [1]. In California alone, motorists drive more than 60 billion miles annually on signal-controlled streets [1]. When programmed for optimum timing efficiency, signals can increase the traffic handling capacity of an intersection, and also reduce the delay and occurrence of crashes [2].

1.1 Traffic Signal Retiming

A traffic signal is effective only as long as the traffic patterns used to generate the signal timing do not change significantly. However, traffic patterns often change over time due to growth and other developmental activities in the area. Improper signal timing and inaccurate sequencing can add to driver frustration and increase the number of severe accidents. Therefore, to maintain the effectiveness of traffic signals, the

Federal Highway Administration (FHWA) recommends adjusting or *retiming* signals every two to three years to match the current traffic patterns [3][4]. Sunkari [5] defines signal retiming as**:**

> *A process that optimizes the operation of signalized intersections through a variety of low-cost improvements, including the development and implementation of new signal timing parameters, phasing sequences, improved control strategies, and occasionally, minor roadway improvements.*

One of the biggest benefits of signal retiming is the reduction in the amount of delay experienced by a traveler [5]. In addition to reducing travel delay, signal retiming has several other advantages [1][4][5][6]. First, it can reduce congestion and improve response time for emergency vehicles. Second, it can reduce variations in vehicle-speeds, which in turn can reduce vehicle emissions and improve regional air quality. Third, shorter travel delay and fewer variations in vehicle-speeds can also decrease vehicle fuel consumption. Fourth, retiming can reduce aggressive driving behavior, such as red-light running and the number of lane changes. This, in turn, can decrease the occurrence of severe traffic crashes (especially 90^{o} angle collisions). Finally, signal retiming can postpone or sometimes even eliminate the need to construct additional road capacity. The benefit to cost ratio for a typical signal retiming project is 40:1 [1] [6]. Therefore, many times signal retiming is a much more cost-effective way of improving traffic flow when compared to alternatives such as construction of new lanes.

Signal retiming is typically the responsibility of the agency in charge of operating roadways in the area where signals are located. Retiming a signal can cost anywhere from $300 to $2700 per intersection for the typical four retiming plans (AM, Noon, PM and Off peak periods) depending on the signal type (that is, whether the signal is isolated or interconnected with other signals on the road) [1]. A signal retiming project also typically requires around 20 to 25 staff hours per intersection [1]. If an area contains a large number of signalized intersections, sufficient funds and/or manpower may not be available to retime all signals located in the area at the same time. In such cases, signal retiming has to be done in a phased manner. In each phase, a subset of corridors is selected for signal retiming depending on various factors (*e.g.,* delay, number of stops). (A corridor contains one or more closely spaced intersections such that operation at one intersection may affect operations at the other intersections.) To ensure the most effective use of resources and maximize the benefit to cost ratio, corridors in each phase need to be chosen carefully.

The focus in this thesis is on traffic signal retiming in the Dallas-Fort Worth (DFW) region. Figure 1-1 shows the DFW area on the United States map. The DFW area has around 4000 signalized intersections. The North Central Texas Council of Governments (NCTCOG), the metropolitan planning organization for this region, sponsors signal retiming program (Thoroughfare Assessment Program) in this region with the aim to improve the regional air quality as well as reduce traffic congestion. Improving air quality is an especially important objective because DFW has been classified as a *moderate non-attainment* zone for ozone with respect to air quality requirements by the Environmental Protection Agency (EPA) [7].

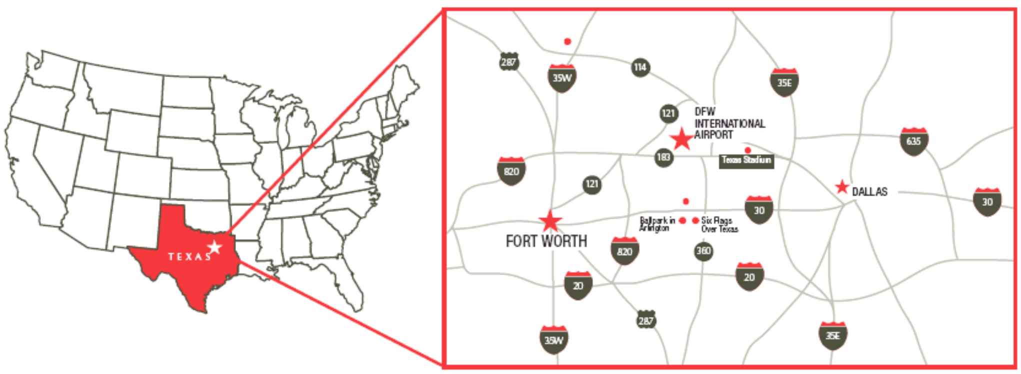

Figure 1-1: Map showing Dallas-Fort Worth region in the U.S. (source: www.fortworth.com).

To select the corridors that will be retimed during a program phase, NCTCOG has developed its own model for *prioritizing* corridors [8]. The model assigns a score to each corridor that needs to be retimed based on three factors: (1) *total delay per signal* experienced by vehicles when traveling through the corridor, (2) *total number of times per signal* vehicles have to stop (*i.e.*, speed is less than 5-10 mph) when traveling through the corridor and (3) system *type* indicating whether the signals along the corridor are interconnected, isolated or partially connected. The delay and the number of stops are used to capture the severity of the existing traffic conditions. The system type captures the amount of effort required for retiming the corridor: a corridor with isolated signals requires more effort to retime than a corridor with interconnected signals. The values for delay and number of stops are normalized to be between 0 and 1. The score for a corridor is obtained by computing a weighted sum of the normalized values as follows.

$$score = W_{delay} \times \frac{delay}{\max(delay)} + W_{stops} \times \frac{stops}{\max(stops)} + W_{type} \times type \qquad (1.1)$$

An expert group decides the weight for each factor. Currently, NCTCOG uses the following values for weights in its ranking model: $W_{delay} = 0.5$, $W_{stops} = 0.3$, and $W_{type} = 0.2$ [8].

1.2 Research Objectives

This thesis builds upon the work by Pulipati [8], who proposed a new approach for quantifying benefits obtained by retiming a corridor. He associated a *project benefit score* with each corridor that has been retimed to capture various types of reductions (in travel time, fuel consumption and NOx emissions) in monetary terms. This thesis extends his work and proposes several regression models based on corridor characteristics before the corridor has been retimed (*e.g.*, length of a corridor, number of signals along a corridor, etc.) to estimate the project benefit score of a corridor. The forecasted project benefit score can be used to prioritize the corridors when selecting a subset of corridors for retiming. The sensitivity of the proposed models to changes in value of time, fuel and NOx one-by-one is also investigated. Finally, the thesis compares the ranking of corridors generated by the proposed models with that used by NCTCOG.

1.3 Related Work

Various Metropolitan Planning Organizations (MPOs) and cities have well-documented procedures for selecting major development projects, such as constructing new highways and reconditioning an existing highway (*e.g.*, by adding new lanes or relocating existing lanes). Turochy [9] describes methods used by various states throughout the United States to prioritize transportation improvement projects. These projects are high cost projects and require a higher range of funds than signal retiming. Low cost projects, such as signal retiming, on the other hand, are not well documented, and little to no research is found on prioritization of signal retiming projects.

Witkowski [10] developed a method for prioritizing signalized intersection operational deficiencies in the City of Tucson, Arizona. He described a two-level screening process for evaluating short to medium term improvements for signalized intersections. These improvements also cost significantly more than signal retiming.

Prior to his work, crash history at an intersection used to be the basis for initial screening of signalized intersections in the City of Tucson. Witkowski [10] proposed a parallel screening of the intersections for operational and safety deficiencies. He proposed a *Deficiency Index (DI)* for ranking the operational deficiencies, which is then used to prioritize intersections based on the decreasing order of DI. Witkowski studied twenty-one independent variables, which fall into five basic categories: *traffic volume,* *present peak hour traffic operations*, *safety*, *air quality* and *transit operations*. He developed a linear utility function for DI, which takes the form:

$$\text{DI} = W_1X_1 + W_2X_2 + \cdots + W_nX_n \tag{1.2}$$

where X_i is the normalized value of criterion i and W_i is the weighting applied to criterion i.

Witkowski [10] judged the interdependence of different criteria using linear regression analysis techniques. The impact of the criteria and their weighting on the ranking was based on a sensitivity analysis. He also considered crash rates for the last three years before the present date, but found that the crash rate did not significantly affect the ranking and therefore ignored them in the rest of the study. In his sensitivity analysis, he examined the variation in ranks, when removing one variable at a time. As the second step of ranking, different weightings were used for different variables and the sensitivity each time was examined. Witkowski prioritized the intersections based on their operational deficiencies, while this thesis aims to prioritize various corridors in need of retiming.

When data cannot be quantified for use in the ranking process, a multiple criteria decision making tool, such as the Analytic Hierarchy Process, can be used for prioritizing alternatives [11]. Guegan *et al.* [11] applied this tool to prioritize traffic calming projects. They used traffic volumes, vehicle speeds, emergency vehicle access and pedestrian facilities and safety as the criteria for evaluation of each alternative.

1.4 Organization of the Thesis

The rest of the thesis is organized as follows. Chapter 2 describes the instrument, and methodology that are used to record corridor data. Chapter 3 discusses corridor characteristics that can potentially influence the benefits obtained after retiming a corridor. The approach proposed by Pulipati for quantifying corridor retiming benefits is described in Chapter 4. In Chapter 5, several regression models for estimating retiming benefits of a corridor based on its characteristics are proposed. The proposed models are validated and their sensitivity analysis is also conducted. Finally, Chapter 6 presents conclusions and Chapter 7 outlines possible directions for future work.

CHAPTER 2

DATA RECORDING: INSTRUMENT AND METHODOLOGY

The data used in this analysis was primarily obtained from NCTCOG. NCTCOG hired consultants to perform travel time (TT) studies *before* and *after* the retiming of each of the corridors where signals were retimed. Travel time studies were performed in both directions during three different periods: AM peak, midday and PM peak. All data used in this thesis was averaged over at least five runs.

The travel time study conducted before retiming a corridor (hereafter referred to as *before* study) is used by NCTCOG to prioritize corridors using its ranking model. The travel time study conducted after a corridor has been retimed (hereafter referred to as *after* study) is used by NCTCOG to measure the effectiveness of retiming. It also helps to document the results for future use. An after study is typically performed after some period of time has passed (*e.g.*, two weeks) since the retiming is completed to allow the traffic to adjust to the changes.

2.1 Data Recording Instrument

Before and after studies for signal retiming projects are basically travel time runs. Sophisticated instruments, such as TDC-12, which is a lightweight *traffic data collector* manufactured by Jamar Technologies, Inc. [12], can be used to record data for these runs. Figure 2-1 shows the TDC-12 instrument:

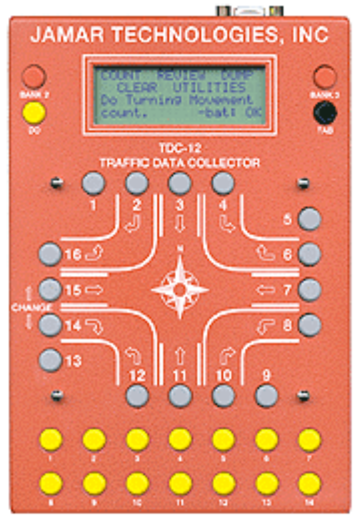

Figure 2-1: TDC-12 instrument (source: www.jamartech.com).

To collect travel time data with a TDC-12, a transmission sensor is installed in a test vehicle. The output from this sensor is then connected to the TDC-12 using an interface cable. When connected to a vehicle, the TDC-12 measures the speed and acceleration of the vehicle at different times along with the travel time and spacing between each intersection. The data from the instrument is later downloaded into a computer and software is used to estimate delays, fuel consumption and emissions (Carbon Monoxide (CO), Hydrocarbons (HC) and Nitrogen Oxides (NO_x)) from the raw data.

2.2 Before and After Studies

A travel time study usually consists of multiple runs. The first run is called the *primary* run and the subsequent runs are called *secondary* runs. In the primary run, node names, where a node corresponds to an intersection, are provided as input. All the runs performed in one direction and during a specified time of day are stored as one study.

At least five runs are performed from the start to the end of the corridor where the start and end points are fixed. The intersections are consistently noted at a specific point, for example, the stop line. The Jamar TDC-12 instrument, when connected to an automobile, records the speed and acceleration information along with the travel time and spacing between each intersection.

Once the traffic signals are retimed, a period of time is allowed to pass for the traffic to adjust to the new timing. After allowing enough time for this adjustment, typically at least two weeks, the "after" travel time runs are performed. These runs have the same start and end points and nodes as before.

Remark: Current travel time runs start from the stop line of the signal at one end of a corridor and end at the stop line of the signal at the other end. It has been suggested by Drs. Williams and Ardekani (committee members in the thesis of this author) that, to obtain more accurate results, travel time runs should start and end at the *mid block* of the respective signals.

2.3 Analyzing Raw Data

The raw data recorded by a TDC-12 instrument is analyzed using *PC-Travel*, a travel time and delay data analysis software for the Windows operating system developed by Jamar Technologies, Inc. [12]. The software takes the start and end points of a corridor, and the nodes between them as inputs. When a TDC instrument is attached to a vehicle and calibrated, a calibration coefficient is stored with the data file. This is used in calculating the distance between the selected intersections during data collection. Between every two consecutive nodes, the software calculates travel time, number of stops, average speed, total delay and the time that the speed of the vehicle falls below three different speeds. The total delay is calculated by subtracting the desired travel time, which is at the "normal speed" specified, from the actual travel time.

2.3.1 Computing Fuel Usage and Pollutants Emissions

PC-Travel software also estimates fuel consumption and HC, CO and NO_x emissions from the speed and acceleration data obtained from travel time studies; it takes the variation in speed as a basis for the estimation. The model used in PC-Travel [12] for estimating fuel consumption was developed by the Australian Road Research Board [12]. In the following equations, V = velocity in ft/sec, A = acceleration in ft/sec^2.

$$\text{Fuel (ml/sec)} = k_1 + k_2 V + k_3 V^3 + k_4 AV + k_5 A^2 V \tag{2.1}$$

where

$k_1 = 0.00442$

$k_2 = 0.00442$

$k_3 = 0.0000022$

$k_4 = 0.00762$

$k_5 = 0.000886$

In the above equation, k_1 is the constant idling consumption, k_2 is the rolling resistance constant, k_3 is the aerodynamic drag constant, k_4 and k_5 are positive acceleration constants. The model used in PC-Travel for estimating various types of emissions is the MICRO2 model developed by the Colorado Department of Highways [12]. The equations for HC, CO, and NOx emissions are:

$$\text{Hydrocarbons (grams/sec)} = hc_1 + hc_2 AV + hc_3 A^2 V \tag{2.2}$$

where

$hc_1 = 0.018$

$hc_2 = 0.0005266$

$hc_3 = 0.0000061296$

$$\text{Carbon Monoxide (grams/sec)} = co_1 + co_2 AV + co_3 AV^2 \tag{2.3}$$

where

$co_1 = 0.182$

$co_2 = 0.0079776$

$co_3 = 0.00036227$

$$\text{Nitrogen Oxides (grams/sec)} = \begin{cases} noxa_1 + noxa_2 AV : A > 0 \\ noxb_1 + noxb_2 AV : A < 0 \end{cases} \tag{2.4}$$

where

$noxa_1 = 0.00386$

$noxa_2 = 0.00081446$

$noxb_1 = 0.00143$

$noxb_2 = 0.000017005$

CHAPTER 3

FACTORS AFFECTING RETIMING BENEFITS

This chapter examines various factors that can potentially influence the benefits obtained once a corridor has been retimed, and it also investigates their relationship with each other. Twenty-one recently timed corridors located in the DFW region are considered in the analysis. These twenty-one corridors, along with their location and the two endpoints, are listed in Table 3-1.

Out of twenty-one corridors, two corridors, namely Cole and McKinney, are one-way streets while the remaining nineteen corridors are two-way. The factors or *variables* that can potentially influence retiming benefits are partitioned into two categories: *basic* and *derived*. The first category consists of those variables that have to be measured (*e.g.*, length, number of signals, etc.). The second category consists of those variables that are computed from the basic variables (*e.g.*, signal density, mean spacing, etc.). The basic and derived variables collectively capture the physical and traffic characteristics of a corridor.

3.1 Basic Corridor Variables

Basic corridor variables are typically measured directly using the methodology described in Chapter 2. They are listed as follows:

Table 3-1: Corridors used in the Analysis.

Corridor	City	East or South Limit	West or North Limit
Abram	Arlington	Cooper	360 NB
Cole	Dallas	Knox St	Bowen St
Cedar Springs	Dallas	Kings Rd	Carlisle St
Coit Rd	Dallas	Churchill Way	Mapleshade
Collins St	Arlington	Bardin	Border
Cooper St	Arlington	Debbie	Division
Dallas Pkwy	Dallas	Trinity Mills	Frankford
Division	Arlington	Cooper	Collins
Frankford	Dallas	Appleridge	Stone Hollow
Great SW Pkwy	Arlington	Fairmont	Main St/Division
Irving Blvd	Irving	Willow Creek	Wildwood
Lemmon	Dallas	Inwood Rd	N Washington Ave
Maple	Dallas	Motor	Turtle Creek
Marsh Ln	Dallas	Trinity Mills	Timberglen
McKinney	Dallas	OakGrove Ave	Knox St
Midway	Dallas	Sojourn/Belmeade	Frankford
Oak Lawn	Dallas	Cedar Springs Rd	Avondale Ave
Pioneer Pkwy	Arlington	W FreeWay	SE 14th
Trinity	Dallas	Plumdale	Dallas Pkwy (ES)
Turtle Creek	Dallas	Cedar Springs	Avondale Ave
US 377	Haltom, Keller	Broadway	Keller-Hicks

- *Length:* measures the length of the corridor in miles.
- *Number of Signalized Intersections:* measures the number of signals along the corridor that have to be retimed.
- *Number of Lanes:* measures the number of lanes in the corridor.
- *Speed Limit:* measures the speed limit posted along the corridor. Since different segments in the corridor may have different speed limits, maximum speed limit along the corridor is used.
- *Average Daily Traffic (ADT) for Current Year:* measures the number of motorized vehicles traveling along the corridor on average each day.

- *Measured Travel Time:* measures the time taken by a vehicle to travel through the corridor.
- *Number of Stops:* measures the number of times a vehicle's speed falls below a certain threshold (usually 5-10 mph) while traveling through the corridor.

Variable values for different corridors are collected from various sources including NCTCOG, travel time studies (specifically, before studies) and websites of cities where corridors are located. Length, number of signals, measured travel time and number of stops for a corridor are obtained from the travel time studies conducted for the corridor. Number of lanes and speed limit for a corridor are obtained from the data used by NCTCOG to rank corridors. Finally, ADT for a corridor is calculated using the data obtained from the website of the city where the corridor is located.

Remark: There is a slight mismatch between the length of a corridor and the number of signals to be retimed in the data used by NCTCOG to rank corridors and the travel time studies. For model development, the values given by travel time studies are used.

3.1.1 Calculating ADT for a Corridor

A corridor can be viewed as consisting of multiple segments, where a segment is defined as the portion of the corridor between two given signals (not necessarily consecutive). The data available on a city's website usually specifies ADT for different corridor segments. To compute the ADT for the entire corridor, the thesis simply takes the average of the ADTs of different segments that are part of the corridor. Another and perhaps better way to compute the ADT of a corridor is to compute the *weighted average* of various ADTs, instead of the simple average, where the weight of a segment is given by its length.

Most of the ADTs on cities' websites are for earlier years (prior to the year 2006), which requires an adjustment for the year 2006; the adjustment assumes an annual growth rate of 2%. The growth rate of 2% is consistent with the value used by NCTCOG in their data analysis when computing the score for each corridor. Assuming that the ADT for year x is known. Then, the ADT for year 2006 with a growth rate of r% is given by:

$$\text{ADT for year 2006} = (\text{ADT for year } x) \times \left(1 + \frac{r}{100}\right)^{2006-x} \quad (3.1)$$

The estimated ADT for all corridors is shown in Table 3-2.

3.1.2 Values of Basic Variables for Different Corridors

Values of the basic variables for various corridors are given in Table 3-3.

3.1.3 Uni-variate Analysis of Basic Variables

3.1.3.1 Descriptive Statistics

Table 3-4 shows the descriptive statistics of various basic corridor variables including minimum, maximum, median, mean and standard deviation. The median and mean values for length, number of signals and measured travel time are significantly different with median smaller than the mean by 10%-50%. This indicates that their

Table 3-2: ADT Calculation for Year 2006.

Corridor	Latest Year for which ADT Available	ADT for the Year Available	Estimated ADT for Year 2006
Abram	2006	18466	18466
Cole	2002	6644	7192
Cedar Springs	2001	15647	17275
Coit Rd	2001	45059	49749
Collins St	2006	25948	25948
Cooper St	2006	39767	39767
Dallas Pkwy	1997	47076	56260
Division	2006	17866	17866
Frankford	2000	32403	36491
Great SW Pkwy	2005	22179	22623
Irving Blvd	2005	20450	20859
Lemmon	2000	39511	44496
Maple	2001	16293	17989
Marsh Ln	2001	31376	34642
McKinney	2002	4781	5175
Midway	2001	35740	39460
Oak Lawn	2002	23288	25208
Pioneer Pkwy	2005	27591	28143
Trinity	1997	39211	46861
Turtle Creek	2002	15668	16959
US 377	2005	37043	37784

Table 3-3: Values of Basic Variables for Various Corridors.

Corridor	Length (miles)	Number of Signals	Number of Lanes	Average Daily Traffic	Speed Limit (miles per hour)	Measured Travel Time (seconds)	Number of Stops
Abram	3.05	13	4	18466	40	446.3	3.90
Cole	1.55	7	3	7192	35	244.2	2.13
Cedar Springs	1.42	8	4	17275	35	333.4	3.33
Coit Rd	5.89	20	6	49749	40	894.9	6.27
Collins St	4.29	12	4	25948	35	589.6	5.23
Cooper St	10.57	31	6	39767	40	1,301.6	9.73
Dallas Pkwy	0.50	3	6	56260	40	109.7	1.20
Division	0.98	6	4	17866	40	168.2	1.73
Frankford	2.96	13	6	36491	40	478.4	5.03
Great SW Pkwy	5.37	15	4	22623	40	686.4	5.47
Irving Blvd	4.85	16	4	20859	40	701.1	4.97
Lemmon	2.78	14	6	44496	35	484.6	4.50
Maple	1.44	8	4	17989	35	264.8	2.72
Marsh Ln	1.11	6	6	34642	35	209.5	1.80
McKinney	1.71	8	3	5175	35	298.6	2.40
Midway	1.00	4	6	39460	35	176.5	1.47
Oak Lawn	0.73	5	4	25208	35	167.6	2.17
Pioneer Pkwy	2.34	8	6	28143	45	310.7	2.90
Trinity	1.89	8	4	46861	40	297.7	4.03
Turtle Creek	1.09	6	4	16959	35	157.6	1.20
US 377	9.00	20	4	37784	40	1,198.4	9.70

Table 3-4: Descriptive Statistics for Basic Corridor Variables.

	Minimum	Maximum	Median	Mean	Standard Deviation
Length	0.5	10.57	1.89	3.07	2.73
Number of Signals	3	31	8	11	6.73
Number of Lanes	3	6	4	4.67	1.11
Average Daily Traffic	5175	56260	25948	29010	14029
Speed Limit	35	45	40	40	3
Measured Travel Time	109.7	1301.6	310.7	453.3	337.1
Number of Stops	1.2	9.73	3.33	3.9	2.46

distributions are somewhat skewed and likely contains only a few large values. This is later confirmed by the density histograms of these variables.

3.1.3.2 Density Histograms

Figure 3-1 to Figure 3-5 depict density histograms for various basic corridor variables. As shown, more than half of the corridors are short (less than two miles in length).

3.1.4 Bi-variate Analysis: Correlation Matrix

Table 3-5 shows correlation between various basic variables. As expected, length, number of signals, measured travel time and number of stops are highly correlated (correlation coefficient is at least 0.93). Furthermore, ADT and number of

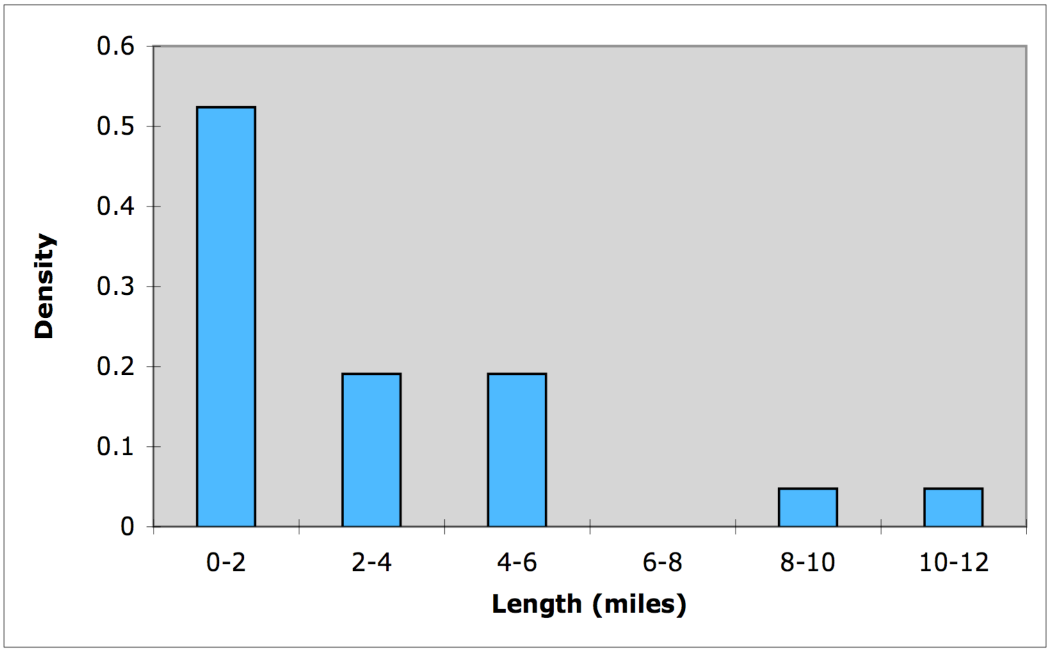

Figure 3-1: Density Histogram for Length.

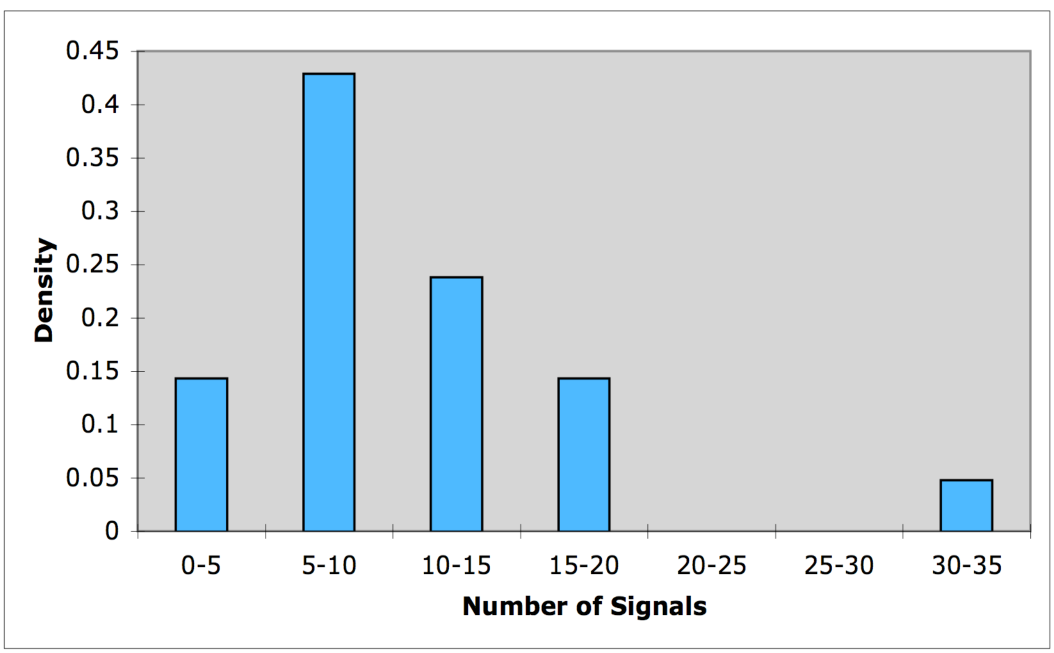

Figure 3-2: Density Histogram for Number of Signals.

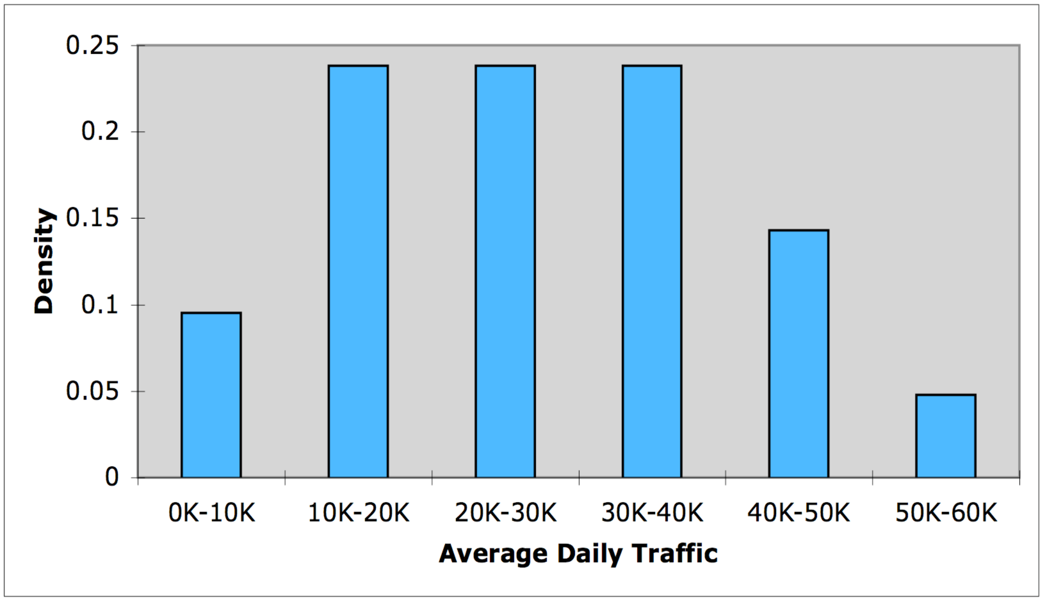

Figure 3-3: Density Histogram for ADT.

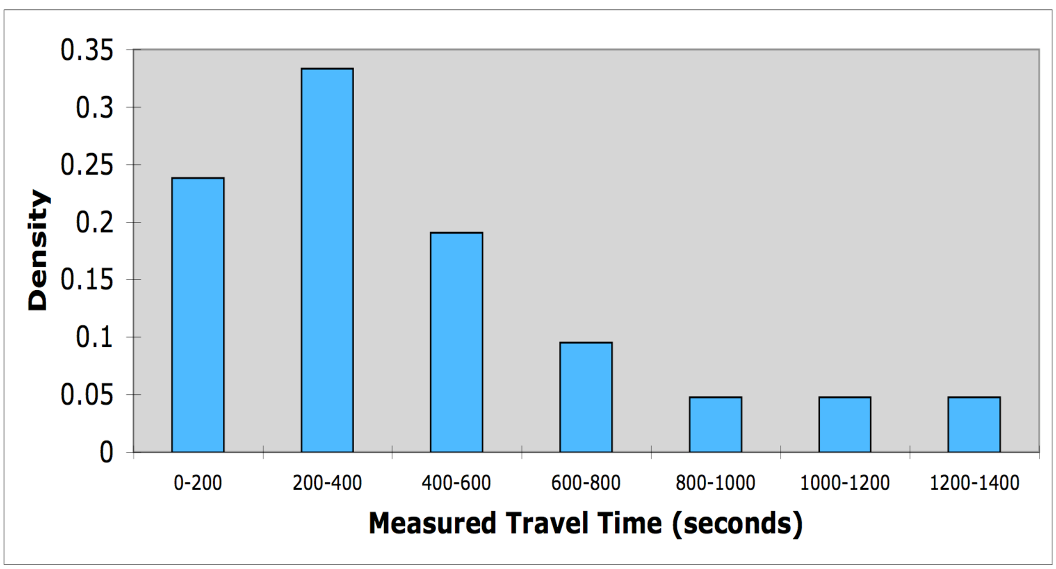

Figure 3-4: Density Histogram for Measured Travel Time.

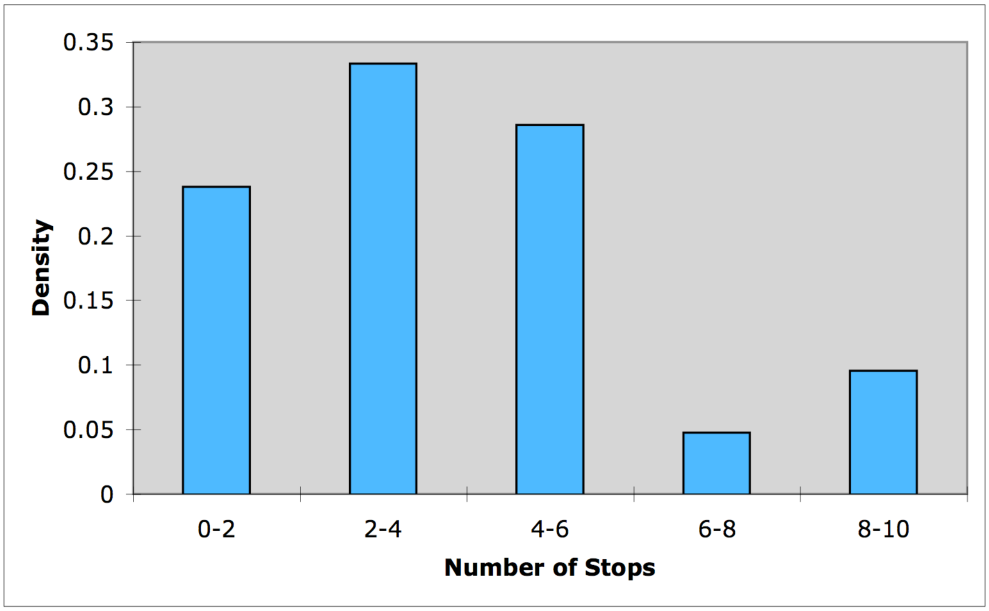

Figure 3-5: Density Histogram for Number of Stops.

lanes also have significant correlation (correlation coefficient is approximately 0.77). Speed limit does not show significant correlation with any of the other variables.

3.2 Derived Corridor Variables

Derived corridor variables are computed using basic corridor variables and other measured data. They are listed as follows:

- *Signal Density:* measures the number of signals in the corridor per mile. It is defined as:

$$\text{signal density} = \frac{\text{number of signals}}{\text{length}} \tag{3.2}$$

- *Mean Signal Spacing:* measures the average spacing between two consecutive signals in the corridor. It is defined as:

Table 3-5: Correlation Matrix of Basic Corridor Variables.

	Length	*Number of Signals*	*Measured Travel Time*	*Number of Stops*	*Number of Lanes*	*Average Daily Traffic*	*Speed Limit*
Length	1.000						
Number of Signals	**0.957**	1.000					
Measured Travel Time	**0.991**	**0.964**	1.000				
Number of Stops	**0.966**	**0.938**	**0.978**	1.000			
Number of Lanes	0.132	0.194	0.139	0.122	1.000		
Average Daily Traffic	0.246	0.237	0.263	0.301	**0.769**	1.000	
Speed Limit	0.394	0.360	0.363	0.376	0.301	0.327	1.000

$$\text{mean signal spacing} = \frac{\text{length}}{\text{number of signals} - 1} \qquad (3.3)$$

- *Standard Deviation of Signal Spacing:* measures the standard deviation in spacing between consecutive signals along a corridor.
- *Travel Time at Speed Limit:* measures the amount of time it will take to travel through the corridor at the posted speed limit. It is defined as:

$$\text{travel time at speed limit (seconds)} = \frac{\text{length} \times 3600}{\text{speed limit (mph)}} \qquad (3.4)$$

- *Delay:* measures the difference between the measured travel time and the travel time at speed limit. It is defined as:

$$\text{delay} = \text{measured travel time} - \text{travel time at speed limit} \qquad (3.5)$$

Values of derived variables for each of the corridors are given in Table 3-6.

Table 3-6: Values of Derived Variables for Various Corridors.

Corridor	**Signal Density (signals/mile)**	**Mean Signal Spacing (miles)**	**Standard Deviation in Signal Spacing (miles)**	**Travel Time At Speed Limit (seconds)**	**Delay (seconds)**
Abram	4.26	0.25	0.2	274.5	171.8
Cole	4.52	0.256	0.21	159.4	84.8
Cedar Springs	5.63	0.20	0.12	146.1	187.3
Coit Rd	3.40	0.31	0.18	530.1	364.8
Collins St	2.80	0.39	0.14	441.3	148.4
Cooper St	2.93	0.35	0.24	951.3	350.3
Dallas Pkwy	6.00	0.25	0.17	45.0	64.7
Division	6.12	0.20	0.1	88.2	80.0
Frankford	4.39	0.25	0.14	266.4	212.0
Great SW Pkwy	2.79	0.38	0.25	483.3	203.1
Irving Blvd	3.30	0.32	0.21	436.5	264.6
Lemmon	5.04	0.21	0.12	285.9	198.7
Maple	5.56	0.21	0.07	148.1	116.7
Marsh Ln	5.41	0.22	0.13	114.2	95.3
McKinney	4.68	0.24	0.2	175.9	122.7
Midway	4.00	0.33	0.07	102.9	73.6
Oak Lawn	6.85	0.18	0.07	75.1	92.5
Pioneer Pkwy	3.42	0.33	0.13	187.2	123.5
Trinity	4.23	0.27	0.18	170.1	127.6
Turtle Creek	5.50	0.22	0.1	112.1	45.5
US 377	2.22	0.47	0.29	810.0	388.4

3.2.1 Uni-variate Analysis

3.2.1.1 Descriptive Statistics

Table 3-7 shows the descriptive statistics of various derived corridor variables including minimum, maximum, median, mean and standard deviation. The median and mean values for travel time at speed limit and delay are significantly different indicating that their distributions are somewhat skewed.

Table 3-7: Descriptive Statistics for Derived Corridor Variables.

	Minimum	Maximum	Median	Mean	Standard Deviation
Signal Density	2.22	6.85	4.39	4.43	1.28
Mean Signal Spacing	0.18	0.47	0.25	0.28	0.08
Standard Deviation in Signal Spacing	0.07	0.29	0.245	0.16	0.06
Travel Time at Speed Limit	45	951.3	175.89	285.9	243.71
Delay	45.45	388.42	127.6	167.4	100.8

3.2.1.2 Density Histograms

Figure 3-6 to Figure 3-10 depict density histograms for various derived corridor variables. As Figure 3-6 shows, more than 60% of the corridors have high signal density of four or more signals per mile implying that two consecutive signals are separated by only a quarter of a mile or less.

3.2.2 Bi-variate Analysis: Correlation Matrix

Table 3-8 shows correlation between derived variables, and between derived and some basic variables. Signal density shows significant negative correlation with length, mean signal spacing, standard deviation in signal spacing, travel time at speed limit and delay. Mean signal spacing, standard deviation in signal spacing, travel time at speed limit and delay show significant positive correlation with each other and with length.

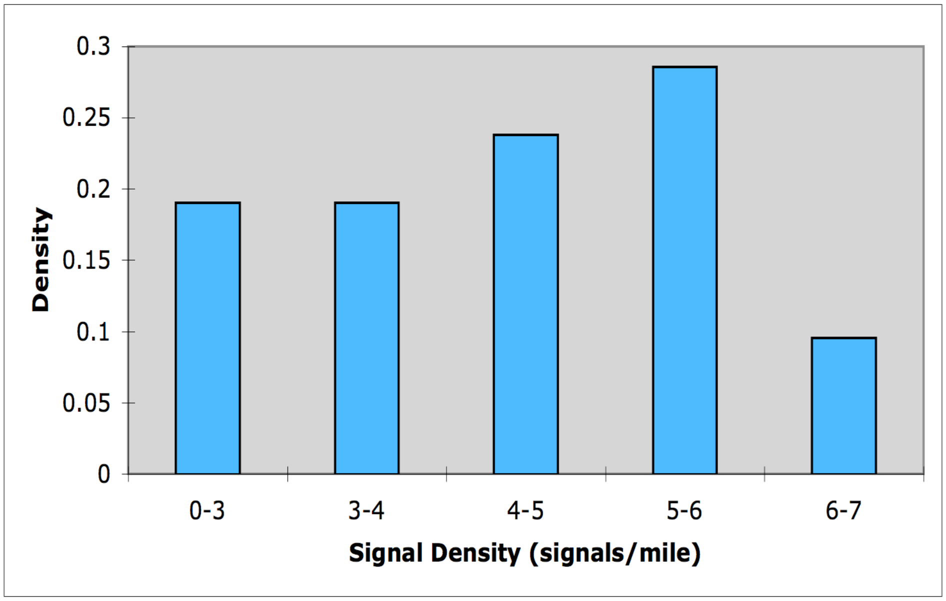

Figure 3-6: Density Histogram for Signal Density.

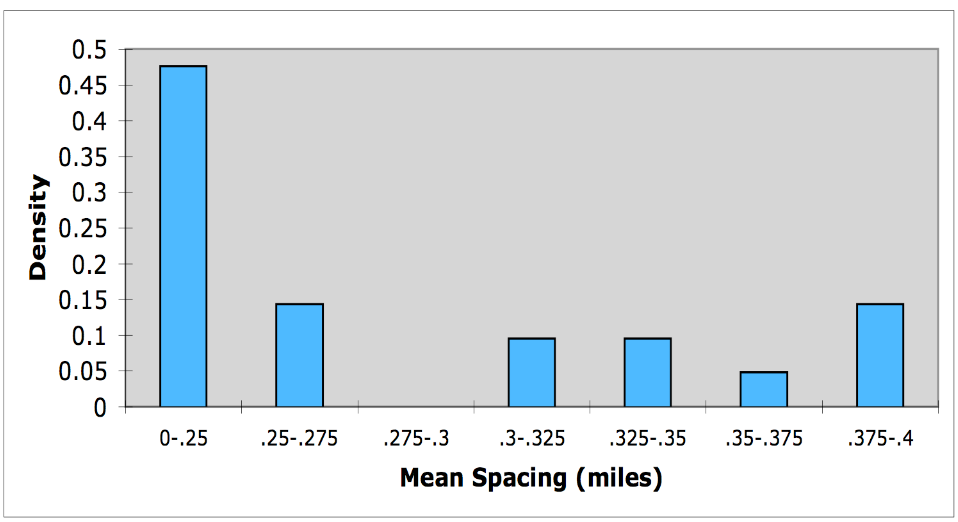

Figure 3-7: Density Histogram for Mean Spacing.

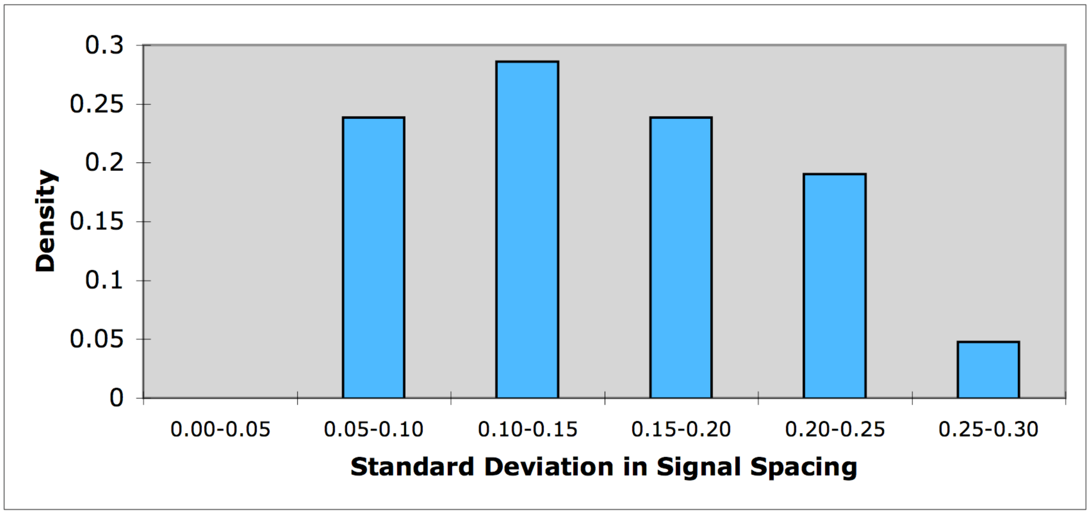

Figure 3-8: Density Histogram for Standard Deviation in Signal Spacing.

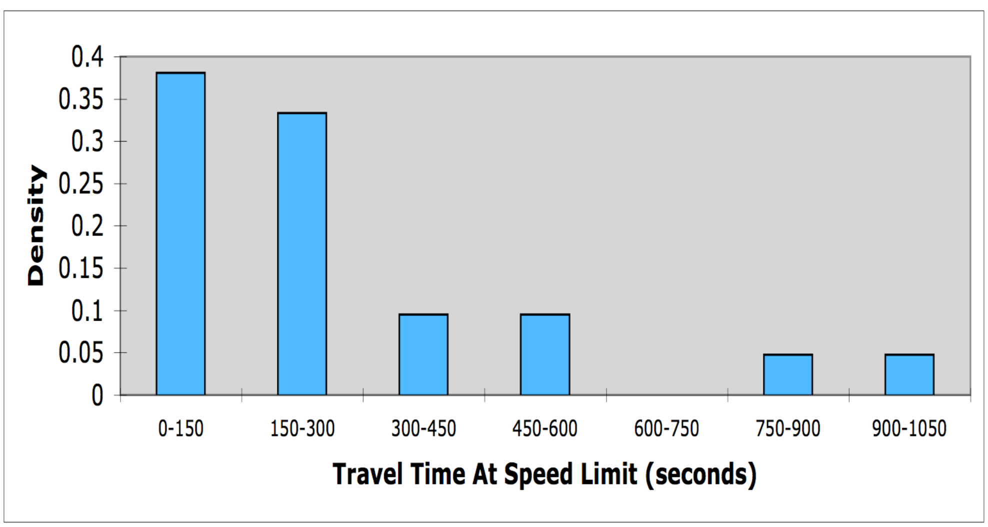

Figure 3-9: Density Histogram for Travel Time at Speed Limit.

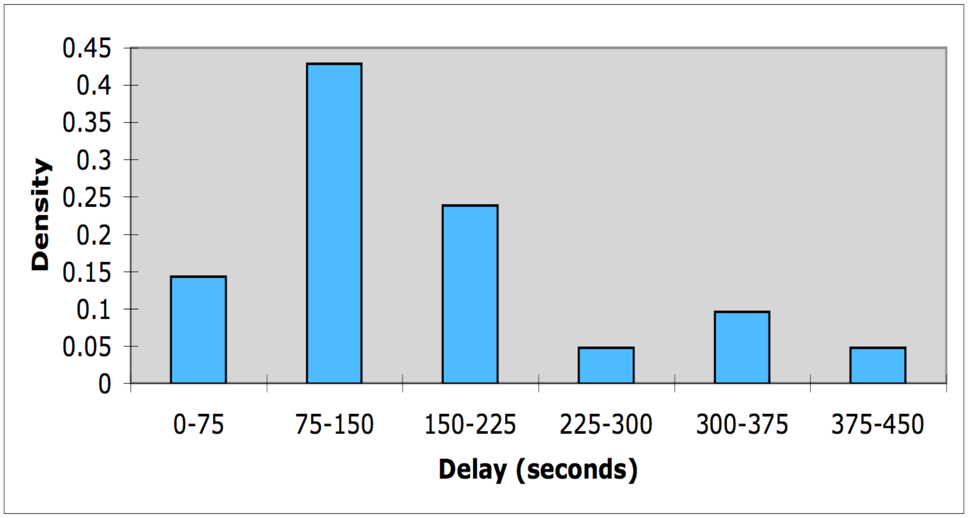

Figure 3-10: Density Histogram for Delay.

Table 3-8: Correlation Matrix of Some Basic and Derived Variables.

	Length	*Average Daily Traffic*	*Speed Limit*	*Signal Density*	*Mean Signal Spacing*	*Standard Deviation in Signal Spacing*	*Travel Time at Speed Limit*	*Delay*
Length	1.000							
Average Daily Traffic	0.246	1.000						
Speed Limit	0.394	0.327	1.000					
Signal Density	**-0.787**	-0.155	-0.438	1.000				
Mean Signal Spacing	**0.751**	0.233	0.410	**-0.923**	1.000			
Standard Deviation in Signal Spacing	**0.724**	0.057	0.433	**-0.689**	**0.654**	1.000		
Travel Time at Speed Limit	**0.998**	0.235	0.343	**-0.786**	**0.749**	**0.713**	1.000	
Delay	**0.902**	0.314	0.386	**-0.676**	**0.595**	**0.645**	**0.897**	1.000

CHAPTER 4

COMPUTING RETIMING BENEFIT

This chapter describes a method to *quantify* the benefits obtained after a corridor has been retimed. Specifically, a *project benefit (PB) score* is associated with each corridor to capture the *monetary* benefits obtained as a result of retiming the corridor. The savings obtained in the following three metrics are considered when computing the benefit score:

- *Savings in Travel Time:* Retiming a corridor may improve traffic flow and increase the average speed of a vehicle traveling through the corridor. As a result, a vehicle may be able to travel through the corridor is less time than before.
- *Savings in Fuel Consumption:* After retiming, a vehicle is able to travel through the corridor with fewer variations in speeds (that is, fewer number of accelerations and decelerations). This in turn may reduce the consumption of fuel by a vehicle, which may result in substantial savings for its driver. With gasoline prices expected to increase significantly in the next decade, savings in fuel will gain even more importance.
- *Savings in NOx Emissions:* The DFW region is classified as a moderate non-attainment region for the eight-hour ozone standard with an attainment date of June 15, 2010. A vast majority of NOx emissions comes from on-and-off

road vehicles. Therefore, reducing NOx emissions as much as possible becomes a critical need. Fewer variations in vehicular speeds after retiming may help reduce their emissions into the atmosphere. This in turn helps to decrease the pollution in the region and to improve the air quality for its residents.

The thesis's objective is to convert the savings in all three metrics into monetary units. To that end, a monetary value must be assigned to each metric as discussed next.

4.1 Assigning Monetary Values to the Three Metrics

4.1.1 Value of Time

Assigning a single value to time is a difficult task. After all, different people may associate vastly different values with time. A novel methodology for estimating value of time is proposed in [14]. In [14], automobile trips are divided into two categories: *on-the-job trips* and *off-the-job trips* (*e.g.*, leisure trips). On-the-job trips are observed to constitute 9.9% of the total automobile trips, whereas the remaining 90.1% trips fall in the second category. To compute the value of time for on-the-job trips, an average vehicle occupancy of 1.22, average wage of $16.25/hour and fringe benefits of $6.44/hour are used. To compute the value of time for off-the-job trips, an average vehicle occupancy of 1.58 and average wage of $13.96/hour are used. The value of time is then given by the weighted average of the value of time for the two types of trips. This gives the average value of time as $15.31/hour.

4.1.2 Value of Fuel

A value of \$2.71/gallon is used, which is the average price of gasoline in Texas in the last week of October 2007 [13].

4.1.3 Value of NOx

To assign a monetary value to NOx emissions, the author contacted Mr. Steve Sun, who is involved in Emissions Banking and Trading Programs at the Air Quality Division of Texas Commission of Environmental Quality (TCEQ). He gave a value of \$6,500/tonne. Mr. P. J. Ammirato, who is an Associate at Environmental Markets Evolution Markets Inc., gave another value of \$4,000/tonne. However, that value is for use in electric generating compliance markets. In this analysis, the value of \$6,500/tonne is used.

Table 4-1: Values of Various Metrics used in Computing the PB Scores.

Metric	**Value**
Time	\$15.31/hour
Fuel	\$2.71/gallon
NOx	\$6,500/tonne

4.2 Computing Project Benefit Scores

Benefits obtained after retiming a corridor in general depends on the traffic pattern (*e.g.*, traffic volume, traffic density, etc.) of the corridor. The traffic pattern of a corridor during a weekday is typically divided into three categories: AM peak, PM peak and midday (MD). Table 4-2 shows the recommended signal timing operating schedule for a weekday.

Table 4-2: Recommended Signal Timing Operating Schedule for a Weekday.

	AM Peak	Midday	PM Peak
Monday to Thursday	7 AM to 9:30 AM	11 AM to 4 PM and 7 PM to 9:30 PM	4 PM to 7 PM
Friday	7 AM to 9:30 AM	11AM to 3 PM and 7 PM to 11 PM	3 PM to 7 PM

Based on the above table, the thesis uses the following durations for various travel periods during a weekday.

Table 4-3: Duration of Various Travel Periods.

Travel Period	Duration (hours)
AM Peak	2.5
Midday	7.5
PM Peak	3.0

Taking direction into account, a two-way corridor has six different periods, and a one-way has three. Travel time studies, which include before and after studies, are conducted separately during each travel period. Using the before and after studies, the computed savings per vehicle is obtained for each metric during each travel period as follows:

$$\begin{gathered}\textit{savings per vehicle in metric x during travel period y} \\ = \\ \textit{value of x per vehicle during y before retiming} - \\ \textit{value of x per vehicle during y after retming}\end{gathered} \tag{4.1}$$

where x is either travel time, fuel consumption or NOx emissions. As an example, Table 4-4 and Table 4-5 show Before and After study data, respectively, for Abram (Eastbound AM Peak) as generated by PC-Travel software. In the tables, length is in feet, travel time, total delay and time ≤ x mph (where x is 0, 35 or 55) are in seconds, fuel consumption is in gallons and NOx emissions is in grams.

Table 4-4: Before Study for Abram (East Bound AM Peak).

Node Number	Length	Node Names	Travel Time	Number of Stops	Average Speed	Total Delay	Time ≤ 0 mph	Time ≤ 35 mph	Time ≤ 55 mph	Fuel	NOx
1	0	Cooper									
2	1200	West	31.4	0.2	26.1	13.4	3.2	29.6	31.4	0.012	0.84
3	726	Pecan	21.2	0.4	23.3	10	1.8	16	21.2	0.008	0.4
4	368	Center	10	0.2	25.1	4	0	9.2	10	0.004	0.35
5	400	Mesquite	11	0.2	24.8	4.8	0	10.8	11	0.004	0.32
6	738	East	15.2	0	33.1	3.4	0	9.6	15.2	0.007	0.48
7	1844	Collins	84.6	0.8	14.9	56.6	38	68.8	84.6	0.023	0.58
8	4033	Stadium/ Browning	85.4	0.4	32.2	24.2	3.6	29	85.4	0.037	2.18
9	1231	New York	34.6	0.6	24.3	15.6	5	21.2	34.6	0.014	1.02
10	1472	Tom Vandergriff	28.8	0	34.8	6.2	0	10.4	28.8	0.014	0.9
11	1156	Sherry	31.4	0.2	25.1	13.4	6.6	16.6	31.4	0.012	0.58
12	2580	360 SBFR	66.8	0.6	26.3	27.6	13.2	34.6	66.8	0.025	1
13	312	360 NBFR	8.4	0	25.3	3.4	0	8	8	0.004	0.36

Table 4-5: After Study for Abram (East Bound AM Peak).

Node Number	Length	Node Names	Travel Time	Number of Stops	Average Speed	Total Delay	Time ≤ 0 mph	Time ≤ 35 mph	Time ≤ 55 mph	Fuel	NO
1	0	Cooper									
2	1201	West	28	0.2	29.2	9	0	21.6	28	0.014	1.23
3	740	Pecan	13.8	0	36.6	2.2	0	4.6	13.8	0.006	0.3
4	365	Center	7.2	0	34.6	1.2	0	1.4	7.2	0.003	0.12
5	386	Mesquite	10	0.2	26.3	4	1.6	4.4	10	0.004	0.2
6	744	East	13.6	0	37.3	1.8	0	4	13.6	0.007	0.37
7	1865	Collins	43	0.4	29.6	14.6	4.2	18	43	0.017	0.66
8	3996	Stadium/ Browning	74	0.2	36.8	13	3.4	11	74	0.035	1.57
9	1230	New York	29.8	0.4	28.1	10.8	2	13.8	29.8	0.012	0.65
10	1477	Tom Vandergriff	31.2	0.2	32.3	8.6	2.4	12.8	31.2	0.016	1.11
11	1155	Sherry	30	0.4	26.3	12	1.4	17.4	30	0.012	0.58
12	2593	360 SBFR	77.2	0.6	22.9	37.4	20	50.4	77.2	0.028	1.35
13	340	360 NBFR	11.8	0	19.6	6.8	0	11.4	11.4	0.004	0.22

Table 4-6 shows savings in various measures computed for Abram during different travel periods. To compute the savings for all the vehicles, the number of vehicles traveling through the corridor during a travel period, which is referred to as the *travel count* of that period, needs to be estimated. The author obtained data from NCTCOG that contained travel counts for 15 minutes duration measured six times in a row. These travel counts are summed to compute travel counts for 90 minutes duration during each travel period; using these totals, the thesis estimates the travel counts for each travel period as follows:

Table 4-6: Savings in Various Measures for Abram (also shows Percentage Savings). All Savings are Per Mile and are obtained by dividing the Value by Corridor Length.

Direction	Travel Period	Travel Time	Number of Stops	Average Speed	Total Delay	Time ≤ 0 mph	Time ≤ 35 mph	Time ≤ 55 mph	Fuel	NOx
East Bound	AM Peak	19.7	0.33	-1.19	20.2	12.0	30.7	19.7	0	0.22
		13.98%	27.92%	-13.82%	33.65%	51.08%	35.38%	13.99%	4.97%	7.4%
	PM Peak	8.4	0.27	-0.56	8.6	-0.4	26.7	8.3	0	0.04
		5.33%	18.41%	-7.15%	11.29%	-1.37%	21.27%	5.29%	-0.2%	1.33%
	MD	48.1	1.25	-3.03	48.6	24.4	72.9	48.2	0.01	0.5
		30.45%	75.93%	-39.6%	63.29%	87.08%	60.74%	30.56%	14.7%	16.25%
West Bound	AM Peak	12.0	0.68	-3.86	12.2	-4.2	27.4	12.1	0	0.11
		8.83%	54.52%	-44.24%	22.22%	-27.76%	32.56%	8.88%	0.98%	4.18%
	PM	4.7	-0.3	-1.36	4.5	7.4	8.1	4.8	0	-0.47
		3.08%	-23.18%	-16.95%	6.25%	23.33%	7.93%	3.11%	-2.9%	-16.63%
	MD Peak	-13.8	-0.28	-1.35	-13.4	-14.9	2.8	-13.9	-0.01	-0.59
		-10.36%	-32.83%	-14.5%	-25.82%	-99.95%	2.94%	-10.45%	-12.81%	-24.06%

$$\textit{travel count for AM peak} = \frac{150}{90} \times \textit{(travel count for 90 minutes duration during AM peak)} \qquad (4.2)$$

$$\textit{travel count for Midday} = \frac{450}{90} \times \textit{(travel count for 90 minutes duration during Midday)} \qquad (4.3)$$

$$\textit{travel count for PM peak} = \frac{180}{90} \times \textit{(travel count for 90 minutes duration during PM peak)} \qquad (4.4)$$

Table 4-7 shows travel counts for different travel periods for nineteen corridors. Travel count data was not available for Cedar Springs and Turtle Creek.

Table 4-7: Travel Counts for Different Travel Periods for Various Corridors.

Corridor Name	**East/North Bound**			**West/South Bound**		
	AM Peak	**MD**	**PM Peak**	**AM Peak**	**MD**	**PM Peak**
Abram	1538	5282	1861	1168	4501	2067
Cole	-	-	-	1200	2295	1034
Coit Rd	3295	10803	7121	6535	10807	4751
Collins St	2896	5816	2807	1461	6154	3829
Cooper St	4997	10610	4429	2324	11143	6437
Dallas Pkwy	973	5051	3020	3374	5364	1531
Division	1941	4791	1902	1217	5000	2818
Frankford	3284	6053	3704	2318	5898	4142
Great SW Pkwy	2145	3220	1416	901	3198	2860
Irving Blvd	1460	3460	1554	1100	4242	2599
Lemmon	3303	13750	6198	3717	11050	4562
Maple	1005	5025	2570	1572	4385	1694
Marsh Ln	1687	5433	5025	5182	5964	2717
McKinney	1072	7150	3302	-	-	-
Midway	1411	7819	6434	6644	8801	2952
Oak Lawn	1417	6300	2042	1463	7255	3010
Pioneer Pkwy	2053	5102	3040	1506	5287	3255
Trinity	2178	5633	2418	1514	6023	3056
US 377	2550	7165	3987	3287	7099	3904

Using travel counts for a travel period, the thesis computes the total savings in each metric for a weekday as follows:

$$\text{savings in metric } x \text{ for a weekday} = \sum_{\text{each travel period } y} (\text{savings per vehicle in } x \text{ during } y) \times (\text{travel count for } y) \tag{4.5}$$

where x is either travel time, fuel consumption or NOx emissions. Next, using the monetary values assigned to different metrics, the total monetary savings for a weekday are computed as follows:

$$\begin{aligned} &\textit{monetary savings for a weekday} = \\ &\qquad (\textit{value of time} \times \textit{savings in travel time for a weekday}) + \\ &\qquad (\textit{value of fuel} \times \textit{savings in fuel for a weekday}) + \\ &\qquad (\textit{value of NOx} \times \textit{savings in NOx for a weekday}) \end{aligned} \tag{4.6}$$

A corridor is typically retimed once every three years. Therefore, assuming 251 working days in a year, the project benefit score for a corridor is given by:

$$\begin{aligned} \textit{project benefit score} &= (\textit{monetary savings for a weekday}) \times \\ &\quad (\textit{number of working days in a year}) \times (\textit{number of years}) \\ &= 753 \times \textit{monetary savings for a weekday} \end{aligned} \tag{4.7}$$

Table 4-8 presents project benefit scores for various corridors along with the project benefit scores per vehicle. The latter are obtained by dividing the overall score by the total travel counts for all travel periods. The table contains scores for only nineteen corridors because, as explained before, travel counts are not available for Cedar Springs and Turtle Creek. In this thesis, unless otherwise indicated, the project benefit score of a corridor is expressed in thousands of dollars.

Table 4-8: Project Benefit Scores of Various Corridors.

Corridor	PB Scores for All Vehicles (Thousand Dollars)	Sum of All Travel Counts	PB Scores per Vehicle (Dollars)
Abram	2698	16415	164.37
Cole	700	4529	154.55
Coit Rd	15235	43312	351.76
Collins St	4353	22962	189.57
Cooper St	121	39940	3.02
Dallas Pkwy	1403	19313	72.63
Division	2415	17669	136.70
Frankford	7262	25399	285.91
Great SW Pkwy	358	13740	26.06
Irving Blvd	3342	14416	231.85
Lemmon	7413	42580	174.10
Maple	1894	16251	116.55
Marsh Ln	4346	26008	167.11
McKinney	1368	11524	118.43
Midway	3612	34061	106.04
Oak Lawn	4963	21487	231.00
Pioneer Pkwy	7721	20243	381.40
Trinity	2772	20821	133.11
US 377	20276	27991	724.36

CHAPTER 5

REGRESSION MODELS FOR ESTIMATING RETIMING BENEFITS

This chapter presents various regression models that can be used to predict PB score of a corridor based on its physical and traffic characteristics.

5.1 Correlation between Observed PB Scores and Corridor Variables

The correlation between observed PB scores and all corridor variables is first computed. The results are shown in Table 5-1 and Table 5-2. The maximum correlation is achieved with delay, and its correlation coefficient is 0.612. Further, the correlation is positive with all corridor variables except signal density.

Table 5-1: Correlation between PB Scores and Basic Corridor Variables.

Length	Number of Signals	Measured Travel Time	Number of Stops	Number of Lanes	Average Daily Traffic	Speed Limit
0.400	0.316	0.464	0.486	0.227	0.385	0.236

Table 5-2: Correlation between PB Scores and Derived Corridor Variables.

Signal Density	Mean Signal Spacing	Standard Deviation in Signal Spacing	Travel Time At Speed Limit	Delay
-0.355	0.425	0.195	0.392	**0.612**

As can be observed in Table 5-1, the PB of Cooper St is quite low even though it is the longest corridor. Therefore, the scatter plots between PB score and some of the corridors variables are drawn. They are shown in Figure 5-1 and Figure 5-2.

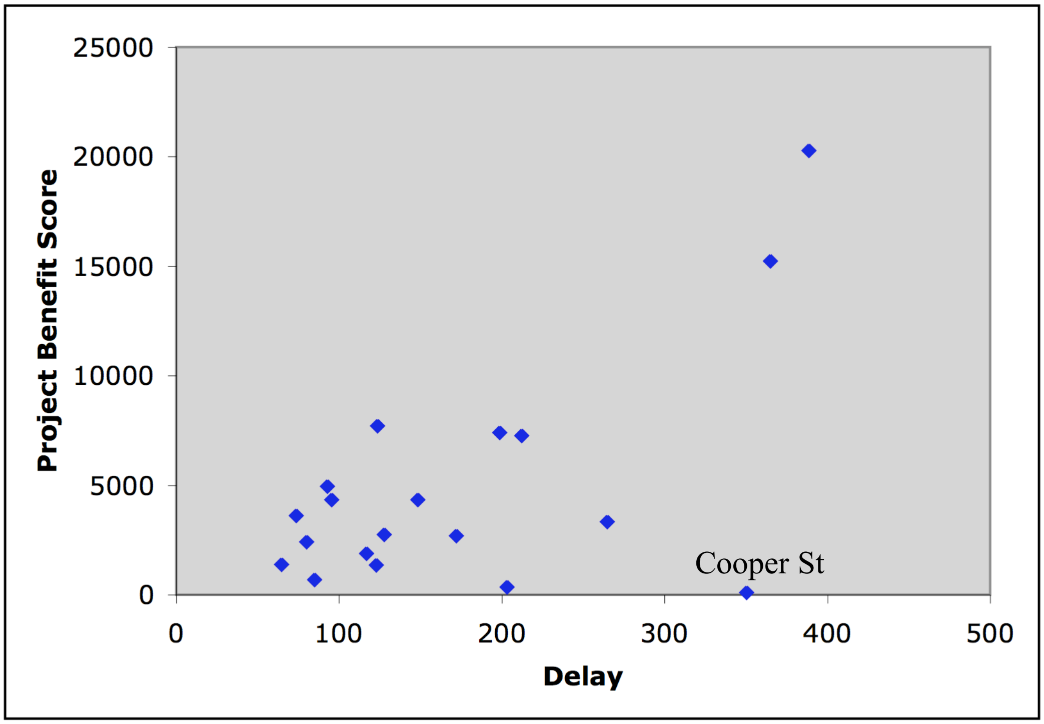

Figure 5-1: Scatter Plot between PB Scores and Delay.

The point corresponding to Cooper St has been labeled explicitly in the two figures. Clearly, Cooper St appears to be an outlier. Therefore, hereafter, the analysis is conducted without Cooper St. Table 5-3 and Table 5-4 show the correlation between PB scores and corridor variables after Cooper St has been removed.

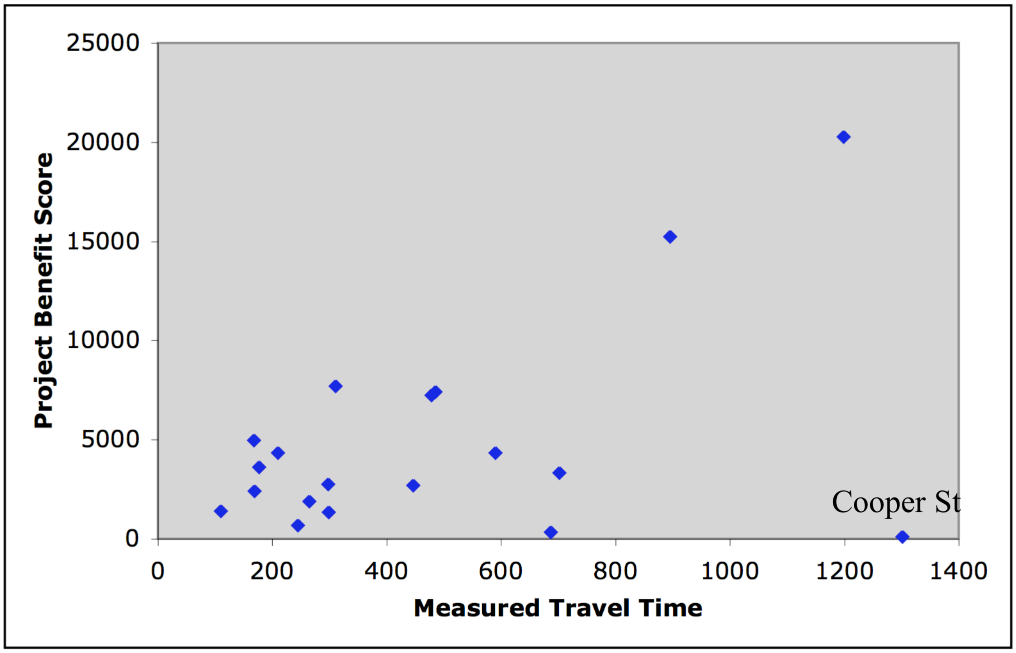

Figure 5-2: Scatter Plot between PB Scores and Measured Travel Time.

Table 5-3: Correlation between PB Scores and Basic Corridor Variables (without Cooper St).

Length	Number of Signals	Measured Travel Time	Number of Stops	Number of Lanes	Average Daily Traffic	Speed Limit
0.713	**0.657**	**0.745**	**0.745**	0.305	0.437	0.279

Table 5-4: Correlation between PB Scores and Derived Corridor Variables (without Cooper St).

Signal Density	Mean Signal Spacing	Standard Deviation in Signal Spacing	Travel Time At Speed Limit	Delay
-0.439	0.493	0.279	**0.700**	**0.798**

As can be seen, after Cooper St has been removed, the correlation between PB scores and almost all corridor variables increases. For some of the variables, the increase is quite significant. For example, the correlation with measured travel time increases from 0.464 to 0.745. The correlation with number of signals, number of stops and travel time at speed limit also increases significantly. One of the reasons why Cooper St may be an outlier is that it is a long corridor with large average daily traffic and high signal density. As a result, signal retiming by itself may not yield much benefits, and major improvements may be required to improve traffic conditions.

5.2 Constructing Regression Models for Estimating PB Score

5.2.1 Regression Models assuming no Interaction between Variables

The regression models are first constructed without assuming interaction between corridor variables. The regression models with the highest adjusted R^2 value are shown in Table 5-5. The maximum value for adjusted R^2 is 0.657, which is relatively low. Therefore, regression models assuming interaction between corridor variables are constructed as described in next section. From now on, only regression models constructed using one or more interaction variables will be considered.

Table 5-5: Regression Models assuming no Interaction between Corridor Variables.

Model	**First Variable**		**Second Variable**		**Adjusted R^2**
	Name	**Significance**	**Name**	**Significance**	
NM1	ADT	0.100	Delay	0.000	0.657
NM2	ADT	0.079	Number of stops	0.001	0.592
NM3	ADT	0.040	Length	0.001	0.583

5.2.2 Regression Models assuming Interaction between Variables

To improve regression models, basic and derived variables are combined to compute several interaction variables. They are as follows:

$$V_1 = \frac{\text{ADT} \times \text{Delay}}{\text{Signal Density}} \tag{5.1}$$

$$V_2 = \text{ADT} \times \text{Length} \tag{5.2}$$

$$V_3 = \frac{\text{Delay}}{\text{Length} \times (\text{Number of Signals})} \tag{5.3}$$

$$V_4 = \frac{\text{Number of Stops}}{\text{Length} \times (\text{Number of Signals})} \tag{5.4}$$

$$V_5 = \frac{\text{Measured Travel Time}}{\text{Length} \times (\text{Number of Signals})} \tag{5.5}$$

The values of the computed variables V_1 to V_5 for various corridors are depicted in Table 5-6. When constructing regression models, actually many more interaction variables are computed, but only those variables that are ultimately used in the proposed regression models are presented. Table 5-7 shows correlation between PB scores and the five interaction variables V_1 to V_5 along with the variable V_6 = standard deviation of signal spacing.

As the table shows, variables V_1 and V_2 are highly correlated (correlation coefficient is 0.990). Further, both are highly correlated with PB score (correlation coefficients are 0.916 and 0.889, respectively). Variables V_3, V_4 and V_5 are also highly correlated with each other with correlation coefficients of at least 0.975. Further, they are negatively correlated with all other variables.

Table 5-6: Variables Computed from Basic and Derived Corridor Variables.

Corridor	V_1	V_2	V_3	V_4	V_5
Abram	744439	56321	4.33	0.10	11.26
Cole	135000	11148	7.81	0.20	22.51
Coit Rd	5344275	293022	3.10	0.05	7.60
Collins St	1376367	111317	2.88	0.10	11.45
Dallas Pkwy	606670	28130	43.13	0.80	73.13
Division	233362	17509	13.60	0.29	28.60
Frankford	1761199	108013	5.51	0.13	12.43
Great SW Pkwy	1644671	121486	2.52	0.07	8.52
Irving Blvd	1672846	101166	3.41	0.06	9.03
Lemmon	1755262	123699	5.10	0.12	12.45
Maple	377831	25904	10.13	0.24	22.99
Marsh Ln	610747	38453	14.31	0.27	31.45
McKinney	135741	8849	8.97	0.18	21.83
Midway	726191	39460	18.40	0.37	44.12
Oak Lawn	340597	18402	25.36	0.60	45.93
Pioneer Pkwy	1016384	65855	6.60	0.16	16.60
Trinity	1412648	88567	8.44	0.27	19.69
US 377	6604228	340056	2.16	0.05	6.66

Table 5-7: Correlation between PB Scores, Interaction Variables V_1 to V_5 and Derived Variable V_6 = Standard Deviation in Signal Spacing.

	PB Score	V_1	V_2	V_3	V_4	V_5	V_6
PB Score	1.000						
V_1	**0.916**	1.000					
V_2	**0.889**	**0.990**	1.000				
V_3	-0.318	-0.401	-0.472	1.000			
V_4	-0.344	-0.439	**-0.507**	**0.984**	1.000		
V_5	-0.373	-0.467	**-0.540**	**0.986**	**0.975**	1.000	
V_6	0.279	**0.527**	0.141	-0.386	-0.436	-0.440	1.000

In this thesis, seven regression models are proposed by selecting one variable from the set $\{V_1, V_2\}$ and, for some models, one variable from the set $\{V_3, V_4, V_5, V_6\}$. The seven models along with their adjusted R^2 values are shown in Table 5-8. The first two models IM1 and IM2 are one variable regression models. The remaining five are two variable regression models.

Model IM3 has the highest adjusted R^2 values of 0.881, which implies that it can explain at least 88.1% variation in the value of the PB score. Further, all models except model IM2 have adjusted R^2 value of at least 0.8. Also, note that models that use variable V_1 generally have better adjusted R^2 values than models that use variable V_2. The significance of the variables and the constant in the models is shown in Table 5-9. As the table shows, the first variable in all seven models is highly significant (significance value has zeros in the first three decimal digits). For the one variable regression model IM2, significance for the constant is quite bad. On the other hand, for two variable regression models, all significance values are less than or equal to 0.05 implying that, in all of the two variable regression models, there is a more than 95% probability that the value of the two variable coefficients and the constant is non-zero.

5.3 Validating Regression Models

Proposed regression models are validated using the corridors not used in constructing the regression models: Cedar Springs and Turtle Creek. Since travel counts for the two corridors are not available, their travel counts are first estimated for each of

Table 5-8: Regression Models for Predicting PB Score.

Model	First Variable	Second Variable	Coefficient of First Variable	Coefficient of Second Variable	Constant	Adjusted R^2
IM1	V_1	-	0.0027	-	1127.7	0.830
IM2	V_2	-	0.0498	-	701.1	0.777
IM3	V_1	V_6	0.0031	-22654	4096.1	0.881
IM4	V_2	V_6	0.0574	-21492	3429.3	0.817
IM5	V_1	$\frac{1}{V_3}$	0.0034	-12110	2352.9	0.866
IM6	V_1	$\frac{1}{V_4}$	0.0035	-318.3	2417.7	0.866
IM7	V_2	$\frac{1}{V_5}$	0.0740	-64351	2902.1	0.836

Table 5-9: Significance of Coefficients and Constant in the Models.

Model	Significance		
	First Variable	Second Variable	Constant
IM1	0.000	-	0.109
IM2	0.000	-	0.400
IM3	0.000	0.014	0.004
IM4	0.000	0.050	0.034
IM5	0.000	0.035	0.010
IM6	0.000	0.036	0.009
IM7	0.000	0.020	0.018

the travel periods using their ADT. The observed PB scores are then compared with those obtained using each of the five models.

5.3.1 Estimating Travel Counts using ADT

To estimate the travel counts for Cedar Springs and Turtle Creek, the following well-known formula is used:

$$\text{Hourly Volume for Travel Period } x = K_x \times D_x \times \text{ADT} \qquad (5.6)$$

where

K_x = Hourly Distribution Factor for Travel Period x
D_x = Design Distribution Factor for Travel Period x
ADT = Average Daily Traffic

The K and D factors can be estimated for each travel period of the two corridors. These factors in combination with ADT can be used to determine the hourly volumes using equation (5.6). By multiplying hourly volume for a travel period with the duration of that period, the travel count for that period can be estimated. To estimate the K and D factors for each travel period, corridors that are located in the same area and have the same orientation as the given corridors are identified. If two corridors are located in the same area and have the same orientation, then they are likely to have K and D factors that are *similar* to each other. To estimate the factors for Cedar Springs, Maple is used, and, to estimate the factors for Turtle Creek, Oak Lawn is used. Table 5-10 and Table 5-11 show estimated travel counts for Cedar Springs and Turtle Creek corridors.

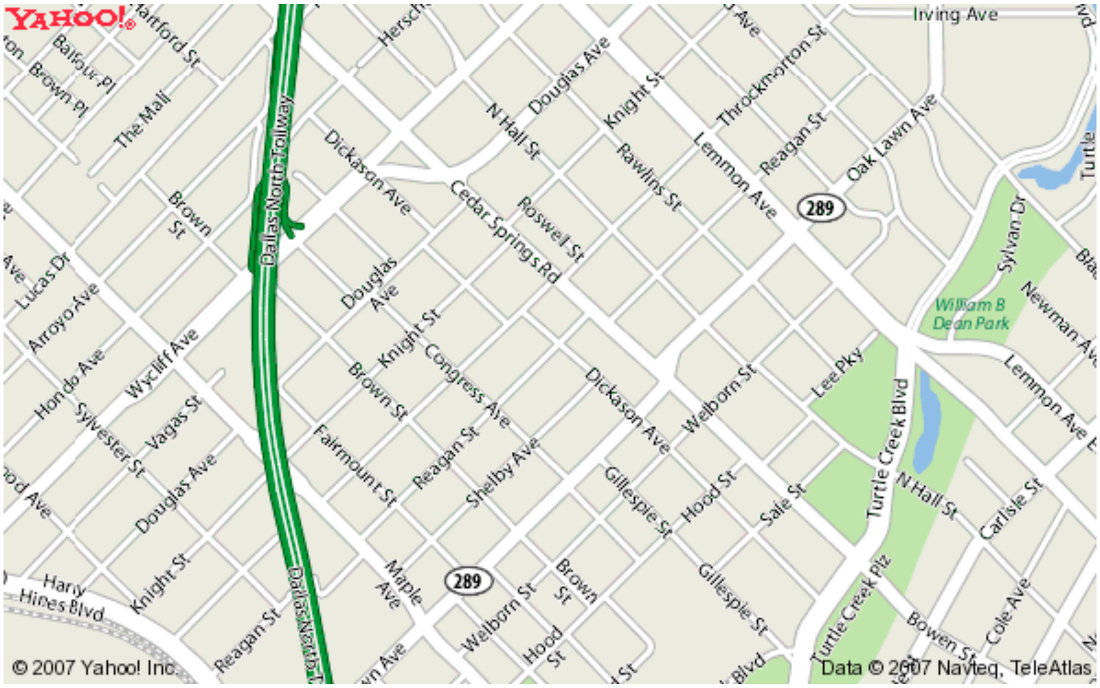

Figure 5-3: Map showing Cedar Springs and Turtle Creek along with the Corridors used to Estimate their K and D Factors.

Table 5-10: Estimated Travel Counts for Cedar Springs.

Travel Period		**Estimated $K_x \times D_x$**	**Hourly Volume**	**Travel Count**
Direction	**Duration**			
North/West Bound	AM Peak	0.035	604	1509
	MD	0.033	561	4211
	PM Peak	0.031	542	1627
South/East Bound	AM Peak	0.022	386	965
	MD	0.037	643	4826
	PM Peak	0.048	823	2468

Table 5-11: Estimated Travel Counts for Turtle Creek.

Travel Period		Estimated $K_x \times D_x$	Hourly Volume	Travel Count
Direction	**Duration**			
North/West Bound	AM Peak	0.022	381	953
	MD	0.033	565	4238
	PM Peak	0.027	458	1374
South/East Bound	AM Peak	0.023	398	984
	MD	0.038	651	4881
	PM Peak	0.040	675	2025

5.3.2 Comparing Observed and Predicted PB Scores

The comparison of PB scores calculated using the formula in Chapter 4 and scores predicted using the seven models for Cedar Springs and Turtle Creek is given in Table 5-12. The table also presents the percentage difference between the scores for the seven models.

Table 5-12: Comparison of Calculated PB Scores with Estimated PB Scores. Percentage Change less than 20% is shown in Bold.

Corridor	Calculated PB Scores (thousand dollars)	Estimated PB Scores using Regression Models						
		IM1	**IM2**	**IM3**	**IM4**	**IM5**	**IM6**	**IM7**
Cedar Springs	3425	2685	1922	3264	2341	3565	3367	2524
		-21.62%	-43.89%	**-4.7%**	-31.67%	**4.07%**	**-1.7%**	-26.31%
Turtle Creek	1424	1508	1620	2311	2378	1092	1182	1600
		5.9%	**13.78%**	62.28%	67.03%	-23.28%	**-17.0%**	**12.38%**

As can be observed, model IM6 provides the best estimate of PB scores for both corridors; both estimates are within 20% of the calculated value. Models IM1, IM5 and

IM7 are also fairly good at estimating PB scores. Estimated scores for one of the corridors has less than 15% error and for the other corridor has 20%-30% error. Models IM2 and IM3 are able to closely estimate PB score (*i.e.*, at most 20% error in the predicted value) for only one of the corridors. Model IM4 is the worst in predicting PB scores. Its estimate for both the corridors has more than 30% error.

5.4 Conducting Sensitivity Analysis

5.4.1 Testing Sensitivity of Coefficients and the Constant

To test the sensitivity, the value of the three metrics (travel time, fuel and NOx) is changed one-by-one and the value of the two coefficients and the constant in each model is re-computed. The results are shown in Table 5-13 to Table 5-18.

As the tables clearly show, all seven regression models are much more sensitive to the changes in the value of time than to changes in the value of other metrics. For example, when the value of time is changed by 25% (decreased or increased), the two coefficients and the constant in all the seven models also change significantly (by 19%-30%). On the other hand, when the value of fuel or the value of NOx is changed by 25%, changes in the two coefficients and the constant for all five models is very small (less than 5% in the case of fuel and less than 2% in the case of NOx). Therefore, based on the analysis, savings in travel time is much more important metric to maximize in order to maximize the benefits of retiming a corridor.

Table 5-13: Changes in the Parameters of the Regression Models when Value of Time is decreased by 25%.

Model	Coefficient of First Variable		Coefficient of Second Variable		Constant		Adjusted R^2
	% Change	Significance	% Change	Significance	% Change	Significance	
IM1	-21.91	0.000	-	-	-25.95	0.134	0.825
IM2	-22.04	0.000	-	-	-27.56	0.443	0.769
IM3	-22.48	0.000	-26.19	0.024	-26.12	0.008	0.868
IM4	-22.67	0.000	-26.77	0.074	-26.93	0.054	0.802
IM5	-22.16	0.000	-23.15	0.043	-24.49	0.014	0.859
IM6	-21.42	0.000	-19.83	0.034	-22.68	0.011	0.863
IM7	-22.07	0.000	-22.11	0.023	-23.43	0.023	0.827

Table 5-14: Changes in the Parameters of the Regression Models when Value of Time is increased by 25%.

Model	Coefficient of First Variable		Coefficient of Second Variable		Constant		Adjusted R^2
	% Change	Significance	% Change	Significance	% Change	Significance	
IM1	21.89	0.000	-	-	25.93	0.097	0.831
IM2	22.03	0.000	-	-	27.54	0.375	0.780
IM3	22.47	0.000	26.17	0.010	26.10	0.002	0.887
IM4	22.66	0.000	26.75	0.038	26.92	0.025	0.825
IM5	22.14	0.000	23.13	0.032	24.47	0.008	0.869
IM6	21.41	0.000	19.82	0.038	22.67	0.009	0.866
IM7	22.05	0.000	22.10	0.018	23.41	0.016	0.840

Table 5-15: Changes in the Parameters of the Regression Models when Value of Fuel is decreased by 25%.

Model	Coefficient of First Variable		Coefficient of Second Variable		Constant		Adjusted R^2
	% Change	Significance	% Change	Significance	% Change	Significance	
IM1	-2.66	0.000	-	-	0.25	0.098	0.832
IM2	-2.55	0.000	-	-	1.36	0.377	0.780
IM3	-2.27	0.000	0.26	0.010	0.25	0.003	0.887
IM4	-2.12	0.000	0.69	0.039	0.82	0.026	0.825
IM5	-2.54	0.000	-2.07	0.032	-0.96	0.008	0.869
IM6	-3.06	0.000	-4.36	0.038	-2.21	0.009	0.866
IM7	-2.61	0.000	-2.73	0.018	-1.74	0.016	0.840

Table 5-16: Changes in the Parameters of the Regression Models when Value of Fuel is increased by 25%.

Model	Coefficient of First Variable		Coefficient of Second Variable		Constant		Adjusted R^2
	% Change	Significance	% Change	Significance	% Change	Significance	
IM1	2.66	0.000	-	-	-0.25	0.123	0.827
IM2	2.55	0.000	-	-	-1.36	0.423	0.772
IM3	2.27	0.000	-0.26	0.019	-0.25	0.006	0.874
IM4	2.12	0.000	-0.69	0.062	-0.82	0.044	0.809
IM5	2.54	0.000	2.07	0.038	0.96	0.012	0.862
IM6	3.06	0.000	4.36	0.034	2.21	0.010	0.864
IM7	2.61	0.000	2.73	0.021	1.74	0.020	0.831

Table 5-17: Changes in the Parameters of the Regression Models when Value of NOx is decreased by 25%.

Model	Coefficient of First Variable		Coefficient of Second Variable		Constant		Adjusted R^2
	% Change	Significance	% Change	Significance	% Change	Significance	
IM1	-0.45	0.000	-	-	0.68	0.106	0.830
IM2	-0.42	0.000	-	-	1.18	0.392	0.777
IM3	-0.27	0.000	0.91	0.012	0.85	0.003	0.882
IM4	-0.22	0.000	1.07	0.045	1.09	0.031	0.820
IM5	-0.32	0.000	0.2	0.034	0.43	0.009	0.867
IM6	-0.54	0.000	-0.82	0.036	-0.12	0.009	0.865
IM7	-0.34	0.000	-0.17	0.019	0.16	0.017	0.837

Table 5-18: Changes in the Parameters of the Regression Models when Value of NOx is increased by 25%.

Model	Coefficient of First Variable		Coefficient of Second Variable		Constant		Adjusted R^2
	% Change	Significance	% Change	Significance	% Change	Significance	
IM1	0.45	0.000	-	-	-0.68	0.113	0.830
IM2	0.42	0.000	-	-	-1.18	0.408	0.776
IM3	0.27	0.000	-0.91	0.015	-0.85	0.004	0.879
IM4	0.22	0.000	-1.07	0.054	-1.09	0.038	0.815
IM5	0.32	0.000	-0.20	0.037	-0.43	0.010	0.865
IM6	0.54	0.000	0.82	0.035	0.12	0.010	0.866
IM7	0.34	0.000	0.17	0.020	-0.16	0.019	0.835

5.4.2 Testing Sensitivity of Corridor Ranks

To test for sensitivity, PB scores predicted using the regression models are used to rank corridors in the decreasing order of their scores. The value of time, fuel and NOx is then varied one-by-one and the mean change in the rank of a corridor as computed by the same model (albeit with different coefficients and constants) is determined. Specifically, consider a regression model for predicting PB scores, say IMx, where $x \in \{1, \ldots, 7\}$. Also, consider a metric y, where y is time, fuel or NOx. Then the mean change in rank for model IMx when metric y is changed, is given by:

$$\frac{1}{|S|} \cdot \sum_{c \in S} \left| \text{rank of } c \text{ for IM}x \text{ with base value for } y - \text{ rank of } c \text{ for IM}x \text{ with new value for } y \right| \qquad (5.7)$$

where S denotes the set of corridors. The mean change in the rank of a corridor is computed for two data sets. The first data set consists of 21 corridors that are used in developing the regression models. The second data set consists of 179 corridors that NCTCOG has used to prioritize corridors in 2003. The results are shown in Table 5-19 and Table 5-20.

Table 5-19: Mean Change in Rank of Corridors in the Data Set used when Values of Different Metrics are Changed.

Metric Changed	Change	Mean Change in Rank						
		IM1	IM2	IM3	IM4	IM5	IM6	IM7
Time	-25%	0	0	0	0.29	0	0.10	0
Time	+25%	0	0	0.10	0.10	0	0.29	0
Fuel	-25%	0	0	0.10	0.10	0	0.29	0
Fuel	+25%	0	0	0	0.19	0	0.10	0
NOx	-25%	0	0	0.10	0	0	0.10	0
NOx	+25%	0	0	0	0.10	0	0.10	0

Table 5-20: Mean Change in Rank of Corridors in NCTCOG Data Set when Values of Different Metrics are Changed.

Metric Changed	Change	Mean Change in Rank						
		IM1	IM2	IM3	IM4	IM5	IM6	IM7
Time	-25%	0	0	-	-	0.23	0.59	0
Time	+25%	0	0	-	-	0.16	0.34	0.01
Fuel	-25%	0	0	-	-	0.11	0.37	0
Fuel	+25%	0	0	-	-	0.15	0.32	0.03
NOx	-25%	0	0	-	-	0.11	0.01	0.06
NOx	+25%	0	0	-	-	0.15	0.09	0

The sensitivity of models IM3 and IM4 cannot be tested with NCTCOG data set because both models use standard deviation of signal spacing as one of the variables but the NCTCOG data set does not have information about this variable. As the two tables indicate, ranks computed using models IM1 and IM2 do not show any change whatsoever when metric values are changed with both data sets. Although all other models also appear to be fairly stable, model IM7 exhibits the best stability among them. Even with NCTCOG data set that contains 179 corridors, the mean change in ranking for model IM7 is at most 0.06.

5.5 Comparing Corridor Rankings Obtained using NCTCOG Model and Proposed Regression Models

First, the ranks of the corridors, which are part of the data set used for analysis in the thesis, is computed using the observed PB scores, the NCTCOG model and the seven proposed regression models. Since the NCTCOG model uses system type, the NCTCOG data set is used to obtain the system type for each corridor. Due to differences in the two data sets, the system type can only be obtained for eleven corridors. The results are shown in Table 5-21. The mean difference in rank between various models is shown in Table 5-22.

As can be seen from the table, the mean difference in the rank between various models is between 1.64 and 1.82. Also, the mean difference in the rank as given by the observed PB scores and various models is between 1.45 and 2.36. Therefore, the results in Table 5-23 are inconclusive and do not show much difference between various models. For further analysis, the mean difference in the ranks of the corridors in NCTCOG data set is also computed. The results are given in Table 5-23.

Table 5-21: Ranks Obtained using Various Models.

Corridor	Ranks Obtained using Various Models								
	Observed PB Score	**NCTCOG Model**	**IM1**	**IM2**	**IM3**	**IM4**	**IM5**	**IM6**	**IM7**
Abram	9	9	9	9	11	11	11	11	11
Coit Rd	2	1	2	2	2	2	2	2	2
Collins St	7	8	7	5	5	4	9	5	5
Division	10	10	11	11	10	10	10	10	10
Frankford	5	3	3	6	4	5	3	3	4
Great SW Pkwy	11	7	6	4	8	6	7	7	6
Irving Blvd	8	11	5	7	6	7	5	8	8
Lemmon	4	2	4	3	3	3	4	4	3
Oak Lawn	6	5	10	10	9	9	8	9	9
Pioneer Pkwy	3	6	8	8	7	8	6	6	7
US 377	1	4	1	1	1	1	1	1	1

Table 5-22: Mean Change in Rank for Corridors Common in Two Datasets.

	NCTCOG Model	**IM1**	**IM2**	**IM3**	**IM4**	**IM5**	**IM6**	**IM7**
Observed PB Score	1.82	1.82	2.00	1.64	1.82	1.64	1.45	1.64
NCTCOG Model	0	2.00	2.36	2.00	2.18	1.64	1.64	1.82

Table 5-23: Mean Change in Rank for Corridors in NCTCOG Dataset.

IM1	**IM2**	**IM3**	**IM4**	**IM5**	**IM6**	**IM7**
36.05	49.03	-	-	35.94	33.35	43.24

The results indicate that the rankings given by the regression models are quite different from those given by the NCTCOG model. Since travel time studies for most of the corridors in NCTCOG data set are not available, it is not possible to compare the rankings with those given by the observed PB scores. Therefore, further research needs to be conducted to determine which ranking methodology yields better results.

5.6 Comparing Various Regression Models

Based on the analysis, the best regression model for predicting PB scores is IM1. It is simple (uses only one interaction problem), provides fairly good estimate of the PB score of a corridor, and yields highly stable ranks. Other regression models that have good performance are IM5 and IM7. However, since both models use highly correlated corridor variables (*e.g.*, length and number of signals), they may be vulnerable to the *multicollinearity* problem. The objective of this thesis to simply predict the PB score of a corridor and strictly speaking not to investigate the factors that may affect the PB score of a corridor. Therefore, even if the models use highly correlated variables, they can still be used to predict PB scores and multicollinearity is usually not considered to be a problem in this case.

CHAPTER 6

CONCLUSIONS

In this thesis, several regression models have been proposed that can be used to predict the monetary benefits that retiming a corridor is expected to yield based on the projected savings in travel time, fuel consumption and NOx emissions. The models use corridor characteristics, such as its length, vehicular delay (calculated as difference between measured travel time and desired travel time), signal density, average daily volume, to estimate the monetary benefits. The predicted monetary benefits can then be used to rank corridors when selecting a subset of corridors to be retimed.

Unlike the NCTCOG methodology, which only uses "delay" experienced by a vehicle when traveling through a corridor, the proposed methodology also takes into account other benefits to the society such as reduction in pollution (through reduction in NOx emissions). The rankings produced by the NCTCOG methodology depend on the weights assigned to various factors. These weights are selected by an expert group and as such are subject to personal biases of members in the expert group. The proposed methodology, on the other hand, does not suffer from any such biases; the parameters of the models, namely the values of different coefficients and the constant, are computed using *statistical* methods. Therefore, the author believes that the methodology proposed in this thesis is superior to that currently being used by NCTCOG.

The regression models proposed in this thesis assume that no land use development has occurred in between the “Before” and “After” studies of a corridor. Land use development may cause significant changes in traffic patterns thereby invalidating the projected benefits, which implicitly assume that traffic patterns do not change drastically while signal retiming is being completed.

CHAPTER 7

FUTURE WORK

The regression models proposed in the thesis were constructed using data obtained from travel time studies of only nineteen corridors. Two other corridors were used to validate the models. The relatively small data set used in constructing the models might have restricted the accuracy of the proposed models. More accurate models might be constructed by using travel time studies of more corridors when they become available.

When computing the PB score for a corridor, only savings in NOx emissions were considered to capture the reduction in air pollution obtained as a result of retiming the corridor. Retiming may also reduce other types of emissions, including CO and HC emissions, which have also been linked to air pollution. In addition, CO_2 is widely believed to be linked to global warming and regulations are being considered by EPA to control its emissions. Future research can take savings in other types of emissions into consideration when computing the PB score of a corridor.

FHWA recommends retiming signals once every two to three years. Therefore, the formula for the PB score used in this thesis computes benefits obtained from retiming a corridor over a period of three years. However, the formula assumes that travel counts for different periods do not change with time. A more realistic approach is to assume a certain growth rate in travel counts every year (say, 2%) and then compute the PB score under this assumption. This will provide a better estimate of retiming benefits and improve the regression models.

Currently, as per the proposal in the thesis, the corridors to be retimed are ranked in the decreasing order of their PB scores. Another factor that may be considered when ranking corridors is the *cost* of retiming a corridor. As the data indicates, different corridors have different numbers of signals to be retimed and therefore are likely to have different costs associated with retiming. A better approach for ranking corridors may be to order them based on their *benefit to cost ratio*.

Different people may have vastly different values for travel time. For example, a low income person may not mind spending a few extra seconds when traveling through a corridor. On the other hand, a person earning very high income will want to spend as little time as possible on the road. The approach used in [14] for computing the value of travel time does not take this difference in the behavior of people with different income levels into account. A new approach that can account for such differences is needed when computing the value of travel time.

Another issue when calculating monetary savings due to reduction in travel time is that small savings in travel time per vehicle (*e.g.*, 0.5 seconds) may be insignificant. However, when savings for all vehicles are combined, it may yield a large number that may not be an accurate indicator of (and actually overestimate) the benefits obtained due to reduction in travel time. This is especially important because the sensitivity analysis indicates that the regression models are much more sensitive to travel time than to other factors.

APPENDIX A

SAVINGS TABLES FOR ALL CORRIDORS

Table A-1: Savings Table for Abram. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	**AM**	19.7	0.33	-1.19	20.2	12.0	30.7	19.7	0.0027	0.47	1.42	0.22
		13.98%	27.92%	-13.82%	33.65%	51.08%	35.38%	13.99%	4.97%	9.18%	2.82%	7.40%
	PM	8.4	0.27	-0.56	8.6	-0.4	26.7	8.3	0.0001	0.09	-2.42	0.04
		5.33%	18.41%	-7.15%	11.29%	-1.37%	21.27%	5.29%	-0.20%	1.67%	-4.72%	1.33%
	MD	48.1	1.25	-3.03	48.6	24.4	72.9	48.2	0.0082	1.12	3.90	0.50
		30.45%	75.93%	-39.60%	63.29%	87.08%	60.74%	30.56%	14.70%	20.66%	7.72%	16.25%
West Bound	**AM**	12.0	0.68	-3.86	12.2	-4.2	27.4	12.1	0.0005	0.17	-3.93	0.11
		8.83%	54.52%	-44.24%	22.22%	-27.76%	32.56%	8.88%	0.98%	3.51%	-8.45%	4.18%
	PM	4.7	-0.30	-1.36	4.5	7.4	8.1	4.8	0.0016	-0.37	-3.96	-0.47
		3.08%	-23.18%	-16.95%	6.25%	23.33%	7.93%	3.11%	-2.90%	-7.12%	-8.05%	-16.63%
	MD	-13.8	-0.28	-1.35	-13.4	-14.9	2.8	-13.9	-0.0063	-0.83	-8.99	-0.59
		-10.36%	-32.83%	-14.50%	-25.82%	-99.95%	2.94%	-10.45%	-12.81%	-18.31%	-19.94%	-24.06%

Table A-2: Savings Table for Cole. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
South Bound	AM	-13.69	-0.51	0.24	23.21	-13.24	111.52	40.12	0.00	-0.41	-3.73	-0.18
		-9.01%	-57.22%	1.47%	32.76%	-64.05%	74.71%	26.51%	-7.38%	-8.46%	-8.62%	-6.89%
	PM	-16.07	0.13	0.30	22.37	-16.76	95.77	33.92	-0.01	-0.83	-9.42	-0.56
		-10.64%	8.28%	1.95%	31.89%	-86.21%	70.77%	22.54%	-10.73%	-16.30%	-20.92%	-19.25$
	MD	8.31	0.38	-0.88	42.41	7.52	107.64	66.28	0.00	-0.04	-4.04	-0.11
		4.92%	22.54%	-6.12%	48.39%	18.98%	73.34%	39.44%	0.54%	-0.75%	-8.12%	-3.55%

Table A-3: Savings Table for Cedar Springs. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	**AM**	11.43	-0.03	-0.99	48.77	8.30	146.73	59.35	0.00	-0.37	-6.82	-0.55
		5.17%	-1.23%	-7.70%	35.01%	12.07%	66.54%	26.91%	-2.75%	-5.60%	-12.60%	-16.56%
	PM	-17.56	-2.41	-0.05	15.78	-31.49	121.22	37.08	-0.02	-2.67	-21.79	-2.56
		-7.48%	-141.89%	-0.42%	10.29%	-43.84%	51.83%	15.83%	-28.66%	-39.99%	-38.24%	-82.05%
	MD	26.53	-0.33	-1.48	65.15	-4.19	151.25	92.42	0.00	-0.42	-7.70	-0.81
		11.96%	-15.92%	-11.94%	45.51%	-7.01%	68.37%	41.78%	-5.90%	-6.86%	-15.02%	-28.88%
West Bound	**AM**	66.94	0.97	-2.43	100.70	51.92	195.20	121.11	0.01	0.85	4.21	-0.24
		29.20%	36.15%	-18.69%	67.84%	69.96%	87.12%	52.92%	13.74%	11.94%	7.30%	-6.31%
	PM	-19.76	-1.42	1.27	14.20	-39.87	116.26	36.15	-0.01	-1.64	-17.67	-1.26
		-8.33%	-67.23%	10.30%	9.07%	-55.42%	49.23%	15.28%	-20.16%	-22.57%	-29.08%	-33.64%
	MD	34.09	0.31	-2.22	67.67	-5.18	161.81	94.64	0.00	-0.50	-13.12	-0.89
		12.85%	9.57%	-20.54%	36.70%	-5.66%	61.09%	35.73%	-4.05%	-6.40%	-21.49%	-23.10%

Table A-4: Savings Table for Coit Rd. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	11.65	0.06	-0.33	11.43	9.53	11.80	11.62	0.00	-0.06	-2.72	-0.24
		8.48%	9.21%	-6.89%	20.32%	34.18%	15.34%	8.47%	1.15%	-1.28%	-5.77%	-9.73%
	PM	29.14	0.33	-0.23	28.99	24.01	34.16	29.14	0.00	0.42	2.58	-0.05
		14.40%	17.84%	-5.44%	23.96%	32.86%	21.58%	14.40%	6.32%	6.62%	4.29%	-1.73%
	MD	7.65	0.23	-0.50	7.40	1.58	10.29	7.62	0.00	-0.08	-4.54	-0.15
		5.94%	32.84%	-10.36%	15.54%	7.20%	16.27%	5.92%	-0.81%	-1.92%	-10.10%	-6.25%
South Bound	AM	14.56	0.37	-0.32	14.48	8.58	14.97	14.56	0.00	-0.20	-4.98	-0.42
		9.00%	30.04%	-7.11%	17.97%	20.62%	13.93%	9.01%	-0.05%	-3.86%	-9.58%	-15.17%
	PM	7.45	0.30	-0.30	7.20	0.12	13.58	7.45	0.00	-0.08	-3.98	-0.13
		4.90%	24.31%	-7.11%	10.15%	0.35%	14.03%	4.90%	-1.39%	-1.60%	-8.12%	-5.04%
	MD	29.54	0.54	-1.25	29.66	17.83	36.94	29.44	0.00	0.45	-1.30	0.07
		22.92%	75.96%	-25.84%	62.28%	81.28%	58.43%	22.88%	7.75%	10.37%	-2.89%	2.84%

Table A-5: Savings Table for Collins St. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	5.95	0.19	-0.53	6.00	2.81	6.33	5.81	0.00	0.19	3.00	0.08
		4.56%	21.05%	-8.05%	12.09%	24.59%	8.78%	4.46%	2.26%	3.64%	5.36%	2.56%
	PM	8.23	0.42	-0.87	8.42	-4.70	10.68	8.09	0.00	-0.16	-6.67	-0.18
		5.92%	31.03%	-14.26%	14.47%	-33.11%	12.86%	5.82%	-2.56%	-2.93%	-12.32%	-5.44%
	MD	11.45	0.35	-0.56	11.68	7.24	8.27	11.22	0.00	-0.42	-8.67	-0.55
		8.69%	28.85%	-8.76%	22.80%	35.76%	12.56%	8.53%	-2.61%	-8.58%	-17.44%	-19.36%
South Bound	AM	34.27	1.03	-1.81	34.88	10.99	49.56	34.18	0.01	1.44	10.06	1.05
		23.61%	78.57%	-30.79%	54.10%	68.31%	52.89%	23.57%	15.51%	24.99%	17.25%	29.22%
	PM	23.85	0.99	-1.47	24.23	5.92	29.16	23.71	0.01	0.84	4.56	0.57
		15.39%	60.00%	-26.06%	32.68%	25.30%	28.51%	15.32%	9.80%	14.27%	7.89%	16.16%
	MD	5.83	0.44	-0.86	5.95	1.75	4.59	5.70	0.00	0.37	0.85	0.36
		4.72%	47.50%	-12.56%	13.92%	13.77%	7.74%	4.61%	3.66%	7.64%	1.71%	12.40%

Table A-6: Savings Table for Cooper St. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	0.19	0.09	0.00	-0.48	-4.27	-0.38	0.42	0.00	-0.51	-9.62	-0.45
		0.16%	11.75%	0.14%	-1.34%	-35.19%	-0.73%	0.36%	-5.50%	-11.35%	-18.93%	-16.97%
	PM	1.31	0.17	0.02	0.93	-3.61	0.68	6.60	0.00	-0.47	-10.19	-0.40
		1.03%	15.91%	0.74%	1.98%	-22.39%	0.99%	5.17%	-5.45%	-9.54%	-19.18%	-13.49%
	MD	4.92	0.23	-0.12	3.41	-0.83	5.35	12.78	0.00	-0.27	-7.20	-0.28
		4.06%	23.09%	-4.38%	8.08%	-6.07%	8.71%	10.60%	-3.49%	-5.95%	-14.47%	-10.59%
South Bound	AM	6.28	-0.02	-0.30	6.08	-0.26	9.92	10.00	0.00	-0.52	-10.55	-0.54
		5.55%	-2.48%	-10.02%	18.08%	-2.14%	20.21%	8.91%	-6.04%	-11.90%	-21.46%	-21.47%
	PM	1.14	-0.10	-0.01	1.28	-1.52	6.64	2.79	0.00	-0.99	-14.94	-0.96
		0.84%	-9.67%	-0.42%	2.31%	-7.49%	7.95%	2.07%	-9.12%	-21.21%	-30.36%	-37.95%
	MD	5.23	0.15	-0.21	2.84	-5.11	12.57	12.96	0.00	-0.11	-7.00	-0.06
		4.18%	15.82%	-7.75%	6.25%	-34.21%	17.77%	10.38%	-3.55%	-2.24%	-13.39%	-2.15%

Table A-7: Savings Table for Dallas Pkwy. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	-5.15	0.85	-1.64	-6.19	-15.38	-2.31	-4.38	0.00	0.72	3.56	0.86
		-2.04%	26.19%	-4.75%	-3.83%	-18.39%	-1.13%	-1.74%	4.43%	8.04%	4.17%	16.75%
	PM	187.33	3.39	4.69	186.74	145.48	200.54	188.51	0.03	3.39	26.39	0.26
		41.94%	54.66%	12.43%	52.50%	66.82%	46.49%	42.29%	29.49%	27.15%	25.70%	4.61%
	MD	13.47	0.84	-2.21	14.34	3.27	7.62	15.47	0.00	0.35	0.33	0.20
		10.17%	41.02%	-3.77%	33.53%	80.34%	10.69%	11.69%	6.76%	5.64%	0.54%	4.52%
South Bound	AM	-36.14	-1.17	16.81	-37.50	-10.18	-53.27	-34.58	0.00	-0.37	7.20	-0.03
		-32.65%	#NULL!	25.84%	-187.02%	#NULL!	-81.48%	-31.35%	-8.98%	-6.58%	11.38%	-0.73%
	PM	69.64	0.03	-7.59	69.65	64.31	69.83	70.80	0.01	1.29	15.54	0.00
		32.78%	1.74%	-18.78%	56.57%	75.66%	44.85%	33.45%	16.77%	17.17%	19.84%	-0.02%
	MD	35.48	-0.78	-8.27	31.98	31.74	47.75	36.26	0.00	0.61	5.37	-0.03
		19.79%	-65.35%	-19.10%	36.58%	55.98%	37.15%	20.36%	6.41%	8.59%	7.13%	-0.62%

Table A-8: Savings Table for Division. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	AM	17.30	0.82	-3.68	37.62	3.32	121.15	56.79	0.00	0.29	-0.94	0.11
		9.76%	44.88%	-15.68%	39.17%	8.78%	75.13%	32.14%	4.41%	4.97%	-1.82%	3.44%
	PM	24.90	0.10	0.48	48.74	24.92	146.25	48.58	0.00	0.04	1.20	-0.44
		14.39%	7.20%	1.86%	52.90%	67.33%	87.90%	28.20%	3.94%	0.86%	2.52%	-17.05%
	MD	14.65	0.20	1.94	36.49	5.25	122.01	58.77	0.00	-0.34	-3.61	-0.61
		8.65%	12.40%	7.30%	41.60%	16.05%	78.03%	34.78%	-1.97%	-6.72%	-7.68%	-24.17%
West Bound	AM	40.44	1.82	-10.68	62.31	9.06	135.89	97.60	0.01	1.55	6.32	1.16
		24.31%	74.90%	-50.67%	72.71%	39.24%	89.43%	58.96%	16.52%	26.36%	12.35%	33.24%
	PM	36.15	1.62	-4.53	60.19	26.94	162.78	44.95	0.01	0.68	3.20	0.14
		19.61%	79.87%	-21.52%	58.18%	64.97%	90.20%	24.49%	12.74%	11.64%	6.31%	4.48%
	MD	13.05	-0.20	2.65	34.12	5.28	117.95	58.50	0.00	-0.55	-5.53	-0.82
		8.47%	-16.62%	9.21%	47.34%	23.04%	83.24%	38.07%	-3.71%	-11.93%	-12.65%	-36.53%

Table A-9: Savings Table for Frankford. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	AM	-4.06	0.56	-0.60	-15.21	-4.46	1.53	-3.86	0.00	0.36	3.29	0.41
		-2.49%	31.68%	-6.97%	-21.17%	-12.31%	1.31%	-2.37%	2.02%	5.61%	5.20%	10.57%
	PM	3.65	-0.06	0.60	3.94	8.43	3.23	3.71	0.00	0.26	7.58	0.05
		2.55%	-6.37%	5.91%	7.48%	25.69%	3.80%	2.60%	2.87%	4.55%	11.86%	1.34%
	MD	47.52	1.16	-2.96	44.59	29.63	60.96	47.52	0.01	1.76	13.54	1.05
		31.20%	68.30%	-34.22%	71.55%	80.92%	63.89%	31.23%	17.86%	27.27%	19.83%	26.02%
West Bound	AM	51.55	1.75	-2.65	42.33	41.88	58.85	51.55	0.01	1.82	14.91	1.00
		28.22%	70.36%	-34.45%	45.97%	75.17%	43.85%	28.25%	21.35%	26.64%	21.88%	25.33%
	PM	29.54	0.61	-0.53	29.18	22.67	34.97	29.61	0.01	0.83	9.23	0.27
		15.69%	30.28%	-5.73%	29.96%	33.57%	26.53%	15.74%	9.04%	11.70%	12.28%	6.57%
	MD	30.47	0.88	-2.64	29.16	20.06	40.45	30.40	0.01	1.42	12.68	0.95
		21.75%	68.60%	-27.47%	57.20%	60.15%	53.06%	21.73%	13.50%	22.95%	18.09%	24.55%

Table A-10: Savings Table for Great SW Pkwy. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	**AM**	21.50	0.11	-0.27	20.85	20.44	16.06	21.46	0.00	0.42	3.85	0.04
		14.19%	10.23%	-5.62%	29.51%	48.54%	18.62%	14.18%	6.94%	7.57%	6.50%	1.19%
	PM	19.03	0.15	-0.40	18.48	9.89	15.82	18.99	0.00	0.47	3.16	0.19
		14.12%	14.39%	-7.61%	34.29%	35.55%	24.60%	14.11%	5.77%	8.88%	5.54%	6.07%
	MD	2.63	0.08	-0.10	2.44	2.18	-4.46	2.62	0.00	-0.15	-2.20	-0.19
		2.31%	8.50%	-1.67%	7.45%	17.31%	-11.12%	2.31%	-0.54%	-3.23%	-4.44%	-7.00%
South Bound	**AM**	-4.06	0.04	0.08	-3.83	-7.59	-6.92	-4.03	0.00	-0.05	-1.26	0.04
		-3.21%	3.29%	1.59%	-8.33%	-46.24%	-11.30%	-3.18%	-1.39%	-0.91%	-2.29%	1.31%
	PM	-23.92	-0.49	0.18	-23.95	-20.68	-29.33	-23.92	0.00	-0.11	0.57	0.28
		-19.09%	-48.30%	3.30%	-53.84%	-122.52%	-52.66%	-19.10%	-5.23%	-2.24%	1.01%	9.02%
	MD	3.51	0.08	-0.12	3.26	-0.21	0.59	3.51	0.00	0.10	0.21	0.06
		3.05%	8.76%	-2.01%	9.53%	-1.68%	1.38%	3.05%	0.15%	2.11%	0.40%	1.97%

Table A-11: Savings Table for Irving Blvd. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	AM	-1.38	-0.22	0.03	-1.41	-1.82	71.13	7.11	0.00	-0.33	-3.14	-0.32
		-1.05%	-27.97%	0.59%	-2.82%	-13.32%	76.97%	5.42%	-4.71%	-6.56%	-6.02%	-10.80%
	PM	3.33	-0.23	-0.15	3.90	-0.87	77.35	11.91	0.00	0.11	1.76	0.06
		2.45%	-29.40%	-2.65%	7.05%	-5.98%	78.42%	8.76%	-0.39%	2.03%	3.09%	1.78%
	MD	6.06	0.03	-0.62	5.91	-4.54	71.38	19.54	0.00	0.17	-0.86	0.16
		4.66%	3.36%	-10.95%	11.99%	-39.71%	77.91%	15.03%	-0.96%	3.22%	-1.55%	4.96%
West Bound	AM	4.07	0.11	-0.36	4.20	-7.25	77.68	15.67	0.00	0.07	-1.01	0.07
		2.96%	11.51%	-6.48%	7.36%	-52.14%	75.23%	11.39%	-1.73%	1.29%	-1.95%	2.25%
	PM	25.25	0.16	-0.73	25.46	13.73	106.09	29.90	0.00	0.76	7.67	0.36
		14.83%	12.51%	-15.25%	28.48%	38.41%	78.28%	17.58%	8.24%	12.38%	12.36%	10.40%
	MD	24.99	0.36	-0.85	24.92	9.44	96.85	32.59	0.00	0.43	1.19	0.10
		15.61%	25.51%	-17.25%	31.40%	29.99%	77.94%	20.36%	5.23%	7.71%	2.13%	3.21%

Table A-12: Savings Table for Lemmon. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	AM	6.96	-0.22	-0.24	27.59	7.96	98.05	49.10	0.00	-0.71	-8.53	-0.86
		3.92%	-17.47%	-2.98%	28.68%	14.94%	65.96%	27.65%	-6.10%	-12.61%	-16.08%	-29.30%
	PM	2.76	0.01	-0.80	24.27	6.94	117.71	29.00	0.00	-0.96	-10.92	-1.05
		1.58%	0.40%	-9.59%	26.04%	15.32%	73.82%	16.61%	-7.80%	-17.25%	-21.50%	-36.17%
	MD	19.97	0.34	-1.64	42.27	16.73	112.49	45.81	0.00	-0.43	-8.12	-0.73
		12.13%	24.26%	-19.60%	50.92%	43.33%	82.62%	27.85%	-0.36%	-7.93%	-16.23%	-25.55%
West Bound	AM	-33.72	-0.43	1.93	-15.70	-34.37	61.22	-1.97	-0.01	-1.38	-15.14	-0.81
		-21.26%	-29.47%	21.85%	-20.38%	-140.36%	44.33%	-1.24%	-19.74%	-26.78%	-32.75%	-28.92%
	PM	-3.52	0.14	1.43	15.61	-8.14	90.73	33.65	0.00	-0.39	-7.99	-0.24
		-1.96%	6.53%	16.48%	15.93%	-18.01%	57.51%	18.79%	-5.25%	-6.13%	-14.48%	-6.59%
	MD	-7.19	0.15	0.89	10.86	-18.48	96.76	24.67	0.00	-0.35	-9.60	-0.08
		-3.77%	7.09%	11.58%	9.96%	-40.20%	54.10%	12.94%	-6.49%	-5.66%	-18.23%	-2.41%

Table A-13: Savings Table for Maple. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	AM	-30.14	-0.41	-0.07	7.16	-31.93	99.07	25.24	-0.01	-1.08	-13.56	-0.52
		-15.55%	-27.11%	-0.47%	6.34%	-61.34%	52.53%	13.05%	-15.82%	-17.91%	-26.19%	-16.73%
	PM	-21.85	-0.28	-1.57	13.59	-34.88	107.87	29.98	-0.01	-1.99	-22.62	-1.62
		-10.85%	-11.76%	-11.01%	11.33%	-75.23%	54.26%	14.91%	-23.18%	-31.32%	-42.07%	-47.42%
	MD	16.62	0.75	-2.68	49.75	13.91	128.07	78.00	0.00	-0.43	-7.64	-0.66
		9.03%	37.57%	-16.98%	48.10%	25.89%	74.08%	42.49%	-2.98%	-6.99%	-14.07%	-19.67%
West Bound	AM	-16.64	-1.00	0.77	21.33	-4.38	135.27	19.29	-0.01	-1.18	-9.56	-1.02
		-8.94%	-51.47%	5.46%	20.25%	-13.03%	74.40%	10.40%	-14.25%	-19.42%	-19.12%	-29.76%
	PM	-24.62	-0.14	-1.90	6.76	-31.92	100.60	29.28	-0.01	-1.23	-13.46	-0.81
		-14.72%	-8.38%	-12.43%	7.89%	-130.03%	61.34%	17.56%	-18.91%	-22.66%	-28.44%	-27.07%
	MD	4.35	-0.01	-1.52	38.38	-2.52	124.75	66.28	-0.01	-1.07	-15.53	-1.07
		2.57%	-0.67%	-9.64%	43.53%	-7.17%	75.30%	39.33%	-11.27%	-18.06%	-30.45%	-30.73%

Table A-14: Savings Table for Marsh Ln. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	104.73	1.62	-9.79	99.89	74.17	138.88	105.08	0.02	3.03	19.26	1.52
		49.02%	100.00%	-43.65%	91.04%	100.00%	78.05%	49.31%	33.77%	40.16%	27.37%	35.37%
	PM	66.28	1.45	-9.83	62.37	37.21	92.01	66.63	0.01	1.45	2.97	0.59
		38.91%	89.00%	-43.07%	93.06%	99.52%	69.02%	39.24%	20.64%	22.06%	4.84%	14.51%
	MD	65.88	1.61	-12.25	55.91	35.66	94.96	66.24	0.01	1.06	-2.04	0.25
		38.09%	89.99%	-61.17%	80.61%	88.04%	70.37%	38.38%	15.40%	17.73%	-3.74%	7.18%
South Bound	AM	-14.82	-0.51	0.16	-15.35	7.05	-17.65	-14.48	0.00	-0.60	-4.64	-0.46
		-7.11%	-28.24%	0.94%	-14.75%	13.60%	-9.05%	-6.97%	-5.71%	-8.74%	-7.82%	-11.75%
	PM	102.87	0.90	-8.82	94.58	74.24	129.95	103.40	0.02	1.54	8.50	-0.12
		47.91%	55.91%	-43.27%	85.39%	92.88%	73.69%	48.24%	24.18%	24.26%	14.03%	-3.91%
	MD	23.85	-0.16	-2.13	20.99	11.19	43.55	24.55	0.00	0.50	2.70	0.13
		15.95%	-12.48%	-8.66%	44.08%	49.23%	41.77%	16.44%	4.70%	8.75%	4.80%	3.80%

Table A-15: Savings Table for McKinney. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	-15.84	0.00	1.13	24.78	-5.15	135.39	7.83	0.00	-0.32	-3.42	-0.04
		-9.08%	-0.06%	9.27%	26.39%	-18.40%	78.18%	4.50%	-5.59%	-5.93%	-7.71%	-1.28%
	PM	-17.17	-0.81	1.46	22.46	-9.67	105.30	35.01	-0.01	-1.22	-10.02	-1.02
		-10.43%	-62.99%	11.63%	26.83%	-33.75%	70.52%	21.30%	-15.63%	-23.24%	-21.89%	-36.34%
	MD	-11.20	-0.83	1.11	26.86	1.12	128.70	22.77	0.00	-0.51	-3.06	-0.39
		-6.10%	-59.00%	9.42%	26.08%	2.78%	72.34%	12.43%	-5.95%	-9.28%	-6.41%	-13.96%

Table A-16: Savings Table for Midway. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	-74.79	-1.59	11.35	-87.18	-37.16	-98.72	-75.37	-0.01	-1.37	-3.17	-0.36
		-67.07%	-814.37%	35.21%	-485.29%	-223.91%	-304.55%	-68.19%	-26.00%	-29.85%	-5.76%	-13.46%
	PM	104.87	1.44	-9.86	100.62	88.14	126.27	105.45	0.02	2.32	14.60	0.67
		39.13%	47.85%	-62.43%	61.12%	76.49%	52.33%	39.41%	26.06%	29.46%	21.21%	17.92%
	MD	32.86	0.51	-6.13	27.19	19.38	52.88	33.64	0.00	0.36	-0.34	-0.12
		22.02%	42.37%	-25.10%	58.66%	73.26%	49.77%	22.58%	6.79%	6.75%	-0.66%	-3.90%
South Bound	AM	9.27	0.02	-6.38	5.85	-7.31	24.97	9.87	0.00	-0.34	-6.74	-0.43
		4.40%	1.01%	-33.01%	5.45%	-12.01%	14.25%	4.69%	-2.35%	-5.03%	-10.78%	-12.03%
	PM	36.68	0.41	-2.53	29.11	29.14	53.80	37.47	0.00	0.33	-4.23	-0.21
		23.66%	50.79%	-9.00%	56.34%	71.39%	54.60%	24.20%	7.46%	6.41%	-8.04%	-7.55%
	MD	20.46	0.31	-3.66	18.99	12.86	27.64	21.24	0.00	-0.01	-4.23	-0.31
		12.51%	26.14%	-15.43%	31.55%	31.89%	23.76%	13.01%	2.84%	-0.24%	-7.44%	-8.99%

Table A-17: Savings Table for Oak Lawn. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	48.34	0.00	-3.16	82.09	37.57	172.30	117.95	0.00	-0.07	-2.63	-0.92
		24.44%	-0.24%	-10.57%	70.81%	62.88%	87.35%	59.79%	4.10%	-1.13%	-5.01%	-30.74%
	PM	36.74	0.84	-7.07	74.86	6.53	174.77	87.46	0.00	-0.80	-16.55	-1.28
		13.41%	20.13%	-34.77%	38.97%	6.66%	63.91%	31.99%	-4.23%	-9.58%	-25.88%	-28.58%
	MD	84.36	2.21	-8.35	122.19	52.13	223.99	122.44	0.01	1.37	6.42	0.11
		30.19%	47.04%	-42.87%	61.78%	52.78%	81.28%	43.95%	16.99%	16.18%	9.58%	2.48%
South Bound	AM	25.80	0.25	-8.38	56.60	-4.69	141.58	108.66	0.00	-0.54	-12.75	-0.86
		14.62%	18.54%	-27.00%	60.22%	-16.80%	80.24%	61.58%	-5.58%	-9.65%	-27.21%	-28.76%
	PM	2.27	-0.03	0.18	40.27	-5.79	132.87	54.84	0.00	-0.92	-12.21	-0.97
		1.18%	-2.01%	0.59%	36.18%	-11.24%	68.85%	28.42%	-8.03%	-15.50%	-23.99%	-31.51%
	MD	76.26	2.99	-10.68	112.67	43.72	215.07	121.51	0.01	0.80	-1.91	-0.32
		28.84%	68.31%	-49.29%	61.88%	48.53%	81.32%	45.94%	13.14%	9.90%	-3.02%	-7.48%

Table A-18: Savings Table for Pioneer Pkwy. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	AM	53.94	1.36	-	53.56	30.65	69.28	53.94	0.02	3.03	25.31	2.37
		37.99%	93.99%	-	87.85%	93.36%	87.84%	37.99%	26.99%	48.89%	38.53%	59.24%
	PM	83.33	1.48	-	55.71	12.68	76.36	82.91	0.03	3.92	31.76	2.88
		59.56%	96.21%	-	95.02%	95.60%	94.92%	59.43%	49.49%	64.56%	52.15%	71.71%
	MD	68.99	1.13	-	41.85	8.38	58.27	68.99	0.02	2.90	24.21	1.98
		50.95%	82.90%	-	77.37%	61.52%	80.97%	50.95%	44.04%	54.30%	44.32%	60.50%
West Bound	AM	27.12	-0.10	-	0.02	2.15	-3.40	26.69	0.01	1.07	15.09	0.58
		26.17%	-22.28%	-	0.10%	22.80%	-13.22%	25.86%	26.51%	22.87%	27.04%	19.81%
	PM	70.26	1.10	-	44.43	12.65	53.93	70.26	0.02	2.20	16.30	1.24
		46.61%	67.75%	-	63.66%	56.79%	60.26%	46.61%	36.07%	35.84%	26.34%	32.17%
	MD	41.02	0.33	-	15.12	3.31	18.29	41.02	0.02	1.37	13.18	0.76
		32.91%	31.74%	-	34.39%	23.47%	31.74%	32.91%	28.73%	26.01%	23.31%	22.71%

Table A-19: Savings Table for Trinity. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
East Bound	AM	51.41	2.43	-2.93	49.90	34.68	60.28	51.51	0.01	2.04	15.60	1.29
		28.76%	67.81%	-25.56%	56.83%	72.55%	47.68%	28.85%	21.60%	28.12%	21.91%	28.39%
	PM	44.75	1.48	-4.40	43.53	31.58	59.93	45.06	0.01	1.73	15.25	1.02
		26.25%	63.91%	-41.76%	54.44%	62.63%	51.74%	26.46%	18.23%	25.17%	21.13%	24.48%
	MD	-1.94	0.27	-0.88	-2.27	-9.19	13.02	-1.73	0.00	0.71	7.31	0.77
		-1.35%	18.49%	-6.96%	-4.32%	-47.22%	13.59%	-1.21%	3.69%	11.27%	11.41%	18.83%
West Bound	AM	10.56	0.65	-0.22	10.88	25.93	6.96	10.56	0.00	0.57	8.34	0.26
		6.81%	33.95%	-1.60%	16.84%	56.27%	7.37%	6.82%	7.13%	8.03%	10.75%	5.61%
	PM	28.41	0.65	-2.66	28.61	29.57	29.50	28.51	0.01	1.46	17.29	0.89
		18.21%	38.02%	-20.69%	43.58%	70.73%	30.54%	18.32%	15.97%	20.94%	23.24%	20.00%
	MD	9.28	0.54	-1.02	8.62	-2.82	21.17	9.49	0.00	0.60	5.04	0.48
		6.53%	30.00%	-8.00%	16.95%	-19.88%	22.60%	6.70%	3.09%	8.94%	7.52%	10.52%

Table A-20: Savings Table for Turtle Creek. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	14.66	-0.36	0.02	42.47	9.29	90.58	95.68	0.00	-0.01	-2.87	-0.22
		10.01%	-39.71%	0.06%	65.93%	33.04%	81.42%	65.71%	-0.46%	-0.18%	-5.28%	-6.52%
	PM	-1.62	-0.02	-0.04	36.14	-0.57	102.27	58.79	0.00	-0.07	-0.68	-0.04
		-0.86%	-1.15%	-0.21%	33.08%	-1.15%	62.15%	31.11%	-1.01%	-1.00%	-1.08%	-0.94%
	MD	1.15	0.18	-0.44	35.38	2.07	91.61	76.04	0.00	-0.03	-0.43	-0.05
		0.89%	32.11%	-1.69%	69.60%	22.61%	89.29%	58.89%	-0.04%	-0.59%	-0.80%	-1.45%
South Bound	AM	-17.17	-1.29	5.18	13.95	-3.14	55.57	56.98	-0.01	-1.96	-15.51	-1.89
		-16.03%	-	16.44%	52.96%	-	90.92%	53.67%	-25.78%	-50.94%	-37.63%	-88.40%
	PM	-2.36	-0.03	0.13	34.64	-0.53	78.10	68.01	0.00	-0.11	-1.02	-0.07
		-1.47%	-1.47%	0.54%	42.61%	-1.47%	64.23%	42.45%	-1.47%	-1.47%	-1.47%	-1.47%
	MD	3.38	0.55	2.44	17.16	5.59	4.46	39.40	0.00	0.09	0.78	0.00
		2.04%	27.12%	9.11%	28.03%	15.67%	10.17%	29.49%	1.60%	1.22%	1.10%	-0.09%

Table A-21: Savings Table for US 377. (All Values are Per Mile and are obtained by Dividing the Value by the Corridor Length.)

Direction	Travel Period	Measured Travel Time (seconds)	Number of Stops	Average Speed (miles per hour)	Delay (seconds)	Time ≤ 0 mph (seconds)	Time ≤ 35 mph (seconds)	Time ≤ 55 mph (seconds)	Fuel (gallons)	HC (grams)	CO (grams)	NOx (grams)
North Bound	AM	21.18	0.39	-0.60	20.05	14.04	24.05	18.11	0.01	1.00	9.56	0.69
		16.69%	43.77%	-18.31%	41.77%	55.12%	37.02%	14.75%	10.46%	19.63%	16.06%	23.09%
	PM	39.67	0.81	-0.53	39.59	23.67	47.48	39.73	0.01	1.24	8.22	0.69
		27.54%	62.95%	-15.72%	60.28%	65.80%	55.99%	28.07%	14.44%	22.09%	13.07%	21.16%
	MD	9.12	0.20	-0.44	7.45	2.48	10.04	10.86	0.00	0.28	-0.16	0.21
		7.62%	22.38%	-13.05%	18.61%	13.10%	17.86%	9.19%	1.58%	5.77%	-0.29%	7.08%
South Bound	AM	45.19	0.73	-1.10	44.43	27.18	53.79	47.79	0.01	1.49	11.00	0.85
		31.45%	66.01%	-35.53%	67.36%	72.59%	64.27%	34.33%	15.61%	26.80%	17.34%	26.73%
	PM	16.65	0.60	-0.70	16.92	6.05	21.75	14.00	0.00	0.90	6.13	0.72
		11.79%	48.37%	-21.91%	27.06%	17.51%	26.84%	10.19%	7.92%	15.61%	9.43%	20.97%
	MD	16.86	0.60	-0.45	16.77	8.24	21.47	12.69	0.00	0.63	3.61	0.43
		13.67%	57.46%	-13.05%	37.59%	32.40%	35.81%	10.89%	8.42%	12.41%	6.06%	14.22%

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