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Analysis of Tolling on I-35 in Austin to Reduce Congestion

CE392 – FINAL REPORT

Archit Arora, Dan Kinn, Patrick Mannon, Wei-Hsiang Huang

Contents

CE392 Project Abstract

(as submitted on October 29, 2015)

Project Description

Our group will analyze the impact a toll would have on I-35 to divert through traffic around Austin on TX-130 rather than through Austin on I-35.

Main Data Needs

Our primary data needs include:

- Link flows on I-35 and TX-130 between Buda and Georgetown, to give us the current flow on each link.
    - Note: we have link flows, but we do not have link flows as a function of time of day. Time of day link flows will be critical, as the plan yields its benefits during rush hour.
- Link travel times on I-35 and TX-130, to enable us to calculate total system travel time and the amount of time saved if tolls were used on I-35. Link travel times are available; however, we do not know if they exist as a function of time of day. It may be possible to use Google Maps or similar mapping technologies to estimate travel times as a function of the time of day.
- Toll prices and revenue
    - Toll prices should be easily attained. Revenue can be located through publicly available information or estimated via link flow * toll price.

Assumptions

We will need to make the following simplifying assumptions

- Small tolls on I-35 will not significantly alter route choices through the city (not on the highway).
- Drivers will make rational decisions based on drive time and toll costs.

INTRODUCTION

Purpose

The purpose of this report is to analyze the impact of a toll on I-35 to divert through traffic around Austin on TX-130 instead of through Austin on I-35.

Specific questions we seek to address include:

- Could tolling on I-35 instead of TX-130 reduce total system travel time during peak morning traffic hours?
- What toll on I-35 would be appropriate to compensate for lost toll revenue on TX-130?
- What impact would the toll on I-35 have on traffic flows on I-35 and TX-130?

This is an important issue for the Texas Department of Transportation as congestion on I-35 through Austin has increased with the population growth, and the highway is expected to become more congested over the next decade[1]. Since central Austin has been fully developed, expanding current capacity through the city is difficult and costly. Alternative approaches, including incentivizing traffic to go around the city, should be explored to alleviate current and future congestion. **Figure 1** shows a map of the roads of interest.

It is important to note that for drivers with destinations or origins in downtown Austin, using TX-130 is not a feasible option since it does not take drivers near downtown. However, drivers traveling north-south across Austin have a choice between I-35 and TX-130, and our analysis explores the impact changing the current tolling system has on their route choice, and how this affects Austin traffic as a whole.

Current Status

Our project focuses on two major north-south routes in the Austin network. Interstate 35 runs through central Austin and is the main route for traffic entering downtown Austin from the north or south. Texas 130 is a state highway constructed by private investors and first opened as a toll road in 2006[2]. The route extends from Georgetown, TX in the north to Seguin, TX on the south; however, this project focuses only on the portion from Buda, TX to Georgetown, TX.

Interstate 35 is the more direct route between these two points, with a total distance of 51 miles between the north and south ends of interest for this study. TX-130 is 9 miles longer at a total distance of 60 miles.

Current Traffic Flows

Since I-35 is the main north-south route through downtown Austin, it receives considerably more traffic than TX-130. The Texas Department of Transportation's *Central Texas Turnpike System 2014 Traffic & Revenue Study* displays traffic counts at several cross-sections of I-35 and TX-130 (see **Figure 2**). At each cross section, traffic on I-35 is considerably higher than on TX-130.

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[1] Stantec Consulting Services Inc. *Central Texas Turnpike System 2014 Traffic & Revenue Study*. Rep. Texas Department of Transportation, 30 Dec. 2014. Web. 20 Nov. 2015.

[2] *SH130 Toll*. SH 130 Concession Company, LLC, 2013. Web.

For example, on the north end near Georgetown, I-35 has 148,765 vehicles per weekday on average, whereas TX-130 has only 18,453 vehicles, a multiple of 8.06x. Closer to downtown Austin, I-35 has 239,743 vehicles compared with 28,454 vehicles for TX-130 (8.43X), and on the southern side of the city I-35 average weekday traffic is 187,007 vehicles versus 18,630 vehicles for TX-130 (10.04X).

The traffic disparity has an impact on travel times during peak morning hours. Travel time data from Google Maps shows that traveling from on from Buda to Georgetown at 7:00am on a Tuesday morning takes 45-100 minutes on I-35, compared with 50-60 minutes on TX-130. This indicates that TX-130 is a much more reliable route for travelers going across the city, and likely has a lower average time than I-35. Data from other weekdays reflects similar conclusions (see **Figure 3** and **Figure 4**). Traveling in the opposite direction yields similar results, as reflected in **Figures 5 and 6**.

Current Tolling System

There is currently a toll charged on TX-130 and no toll charged on I-35. This is primarily because TX-130 is a relatively new highway constructed from private investors, and the tolls collected go toward paying back this investment. Interstate 35, on the other hand, is a federal highway and does not charge tolls. This creates a strong disincentive for vehicles to use TX-130 instead of I-35 when traveling across Austin.

Tolls are collected on TX-130 using the TxTag automated tolling systems. Cars and trucks passing through the toll points have a tag on their car scanned, and the toll is charged to their account. Vehicles that do not have a tag receive a bill in the mail (charged at a higher rate to account for the higher administrative costs). The toll is designed so that vehicles that travel a longer distance on TX-130 pay a higher toll. Further, trucks and other heavy vehicles pay a higher toll than cars as they lead to more roadway damage.

Vehicles generally pay a toll when they enter or exit the highway, as well as when they pass through plazas that are scattered across TX-130. Typical exit/entrance ramp tolls are $0.47 - $0.75 for cars, and the plazas are between $1.04 and $1.75. A car traveling the entire length of TX-130 between Georgetown and Buda would pay $8.04 each time it traverses the route. A six-axle truck pays an even higher rate of $24.12. This route is 60 miles long, making an average rate for cars of $0.13 per mile for cars and $0.40 for six-axle vehicles. This gives drivers who have a choice between I-35 and TX-130 a tremendous incentive to use I-35, even though it has higher travel times during peak hours.

ASSUMPTIONS

The primary purpose of this project is to analyze the impact of imposing tolls on I-35: whether tolled I-35 would encourage drivers to divert through traffic around Austin on TX-130 rather than through Austin on I-35. The key assumptions we made in our analysis are highlighted below.

Drivers Value Their Time Equally, at Ten Dollars per Hour

The key assumption concerns how drivers value their time. In this project, it is a highly critical factor that every driver value his/her time in the same manner. The main idea of this project is to investigate how adding toll on I-35 affects the congestion. When drivers plan routes, they would consider whether to include toll roads as part of their paths to reduce the travel time. In this project, we define the value of time for drivers as the "toll factor". If drivers value their time unequally, it will lead the project to add different weights to drivers' response to toll factors. Although in reality drivers have different economic values for their time, deriving individual time values is an unmanageable task; therefore, for our analysis, we assumed that drivers value their time equally.

After consulting with the reputable Dr. Stephen Boyles, the toll factor was set at $10.00 per hour, which is a little bit higher than the minimum hourly wage in Texas of $7.25. If we were to increase (decrease) this time factor, vehicles would have more (less) incentive to seek alternate routes around toll roads.

Demand is Constant

Since the purpose of this project is to discuss the traffic assignment problem (TAP) between Buda and Georgetown and the OD matrix of each node is obtained, we treat our simulation as a fixed demand network, which means that the demand on each route is inelastic. Even though using elastic demand might provide a more accurate view of the impacts of imposing tolls on I-35, it is difficult to accurately calibrate the demand functions across the entire network. Consequently, we treat our demand as constant.

Drivers Behave Rationally and Select Their Routes Based Solely on Cost

The factors that are involved in decision-making process of drivers in route selection are crucial. Congestion is determined by the choices drivers make: where drivers start and end their trip, what time the drivers prefer to travel, how often trips are taken. These choices depend on congestion – drivers may choose routes or departure times to avoid congestion. Congestion and drivers choices are connected. In order to understand how tolls impact travelers' route choices, assumptions in behavior of drivers is essential. Assuming cost is the significant factor in routes selections for all drivers, then the travel time and the toll charged on a route become important factors in routes selection. As such, we assume that cost is the only consideration in drivers' route selection is made.

Toll Payment Rate and Car/Truck Ratio Remains the Same

To estimate the current toll revenue on TX-130, the toll rate of vehicles needs to be identified. We assumed in our model that all vehicles are charged at the same rate. The absolute amount of cars and trucks on highways are unknown. By keeping the ratio of amount of cars to amount of trucks the same, we can omit the dependence between car or truck drivers when it comes to route selection. This means that the car drivers would not change their route due to the numbers of truck drivers who are already on the highway and vice versa. When the ratio of number of cars to number of trucks remains the same, while conducting toll simulations on I-35, we can estimate the total toll revenue on I-35 without knowing the true proportion of different kinds of vehicles. Hence, in this project, we keep the ratio of cars to trucks unchanged.

The time period for simulation is during peak hour

One of the main ideas of this project is to understand how adding tolls on I-35 affects congestion on I-35. The time period of data we obtained is during the morning peak hour of an unknown day. By using this actual data, we assume that the data of volume we have represents the typical daily volume on each link during morning peak hour. Therefore, by using this data obtained from morning peak hour, we assume the traffic assignment results of simulation are also in peak hour.

METHODOLOGY

The process of investigating the addition of tolls to I-35 underwent many phases. These steps can be broadly categorized into first fulfilling the project's data requirements and the actual analysis of the proposed changes to the system.

Fulfilling Data Requirements

The data requirements for the toll project were two-fold: an Austin traffic system network and information on the current real-world Austin traffic system.

Austin Traffic Network

First and foremost, a network of the roadway system was necessary before moving forward. Dr. Boyles provided four files containing Austin network data including those most important to the project: nodes, equilibrium flows, and an OD matrix. Before continuing with any analysis or investigation of tolls, the nodes composing I-35 and TX-130 (referred to as highway nodes) needed to be identified. Unfortunately, the nodes seemed to be ordered horizontally based on latitude, meaning no easily identifiable pattern of highway nodes existed and they had to be determined manually.

A cleverer means of identifying the highway nodes may exist but the following method is what was used in order to move forward with the project. First, a graphical representation of the network was created by plotting the nodes in Matlab. While giving an idea of the geographic layout of the nodes, this initial plot did not provide a usable representation as it connected the nodes numerically, instead of based on actual links. As a workaround, an adjacency matrix was formed for the nodes and used to add the appropriate links to the graph. A plot of the full Austin network can be seen in **Figure 7**. The Austin network contained 7,466 nodes and 18,710 links, with 1,117 of the nodes serving as zones in the OD matrix.

To find the highway nodes, a real map of Austin was compared to the network, in an attempt to line up I-35 and TX-130 between the two representations. Additionally, the latitude and longitude of real highway intersections were used to find their corresponding nodes in the network. Two major issues with this method had to be resolved. First, the large number of nodes and links led to a crowded graph, making individual nodes difficult to identify. Second, the coordinates of nodes in the graph did not exactly match up with those of their real-world counterpart intersections.

The solution consisted of limiting the number of nodes and links showing on the graph at one time by only showing links with large capacity as well as their start and end nodes. From the network files, links connecting highway nodes had a higher capacity than most others. This greatly reduced the number of nodes and links on the network but identifying individual nodes was still cumbersome. The graph was further partitioned into regions based on the nodes' coordinates. This final breakdown provided a feasible amount of nodes to handle at one time.

The process of identifying highway nodes from this reduced graph is as follows. First, use latitude and longitude coordinates in combination with the appearance of the connecting links in the graph to identify a single node in either I-35 or TX-130, depending on which is currently being identified. Once one node has been found, move along the links connecting to that node to find other nodes in the highway. Then, simply continue along the path until the end of the road is reached. Through this process, all nodes and links making up I-35 and TX-130 were identified. **Figure 8** shows the Austin network with the highway nodes highlighted in black.

Real-World Austin Traffic System

The second facet of the project's data requirements consisted of information about the real-world Austin traffic system. The flow and approximate travel times were found for both I-35 and TX-130 during the peak usage hours from the Texas Department of Transportation and Google maps, respectively. I-35 has approximately eight times as much flow as TX-130, supporting the need to shift traffic between the two routes as the project investigates. Additionally, information on the current tolling system was required, such as where and how much tolls are charged. Much of this information was collected from the TxTag webpage[3] and the Texas Department of Transportation's toll calculator[4]. These webpages allowed for the identification of tolling locations on TX-130.

Analyzing Effects of I-35 Toll

Once the highway nodes and links had been identified, the analysis of tolling I-35 could begin in earnest. First, an estimated toll revenue for TX-130 was calculated and compared to the hypothetical amount. Then the necessary toll rate on I-35 was hypothesized within an order of magnitude and trials were conducted to fine tune the rate. To conduct any trial with added or modified tolls, it was necessary to solve for user equilibrium, performed using Algorithm B.

Revenue and Toll Rates

The revenue from TX-130 was found by applying the peak flows from TXDOT to the roadway and calculating the total tolls gathered based on the current system rates. An estimate of the TX-130 revenue was also calculated by adding tolls to links in the Austin network modeled after the real system. Charges were added to links corresponding to tolled entrance ramps and plazas. This estimated value was then compared to the revenue determined by the real peak flow to validate the tolling approach and setup.

After the revenue for TX-130 had been determined, adding the appropriate tolls to I-35 served as the next step. As a reminder, the goal of the project lies in tolling I-35 to shift traffic towards

[3] *Austin Area Toll Roads.* Texas Department of Transportation, 2015. Web.
[4] *Toll Calculator.* Texas Department of Transportation, 2015. Web.

TX-130 while maintaining the revenue at its current level. Therefore any tolls added to I-35 must generate revenue at least equal to the current amount raised by TX-130. To determine an approximate value for the appropriate I-35 toll value, the route length of the two highways, baseline flows, and estimated TX-130 revenue were first used to hypothesize the correct order of magnitude. Then, trials at varying I-35 toll rates were conducted in order to fine tune the rate towards an appropriate amount.

Toll Rate Trials

The states tested consists of the current state, an I-35 test case, and the proposed case for adding tolls to I-35. In the current state, tolls have been added to TX-130 and not I-35 in order to mimic the system as it exists in real life. In the test case, a toll rate of $0.10 was added to each link of I-35 in an attempt to limit the range of appropriate toll values. Finally, the proposed case adds $0.02 to each I-35 link. Tolls were only added to either I-35 or TX-130, never both at once. When a toll was added to I-35, it took the form of a small uniform rate on each link. This tolling strategy was used because the current tolls on TX-130 are designed to cost drivers a constant rate per mile travelled. Therefore, the tolls added to I-35 try to mimic the real method.

Toll per link can be thought of in terms of number of nodes per mile. There are approximately two nodes per mile. I-35 is around 50 miles, so in total we have 100 nodes for people going from north to south. Effective maximum toll any traveler pays from going north to south or vice versa would be 100 times $0.02 which equals $2.00. In contrast, current maximum toll on TX-130 is $7.00. So, this implementation of $0.02 toll is realistic.

A toll rate trial consists of adding or modifying tolls on the network and then solving for user equilibrium. In this analysis, Algorithm B was used to determine the user equilibrium flows, total system travel time (TSTT), and shortest path travel time (SPTT). In order to add tolls to the network, a toll factor is necessary to convert the monetary value of the toll to time units so it can be factored into the time calculations. In the analysis of I-35 tolls, a toll factor of $10.00 per hour was assumed. This means drivers value an hour of their time at $10.00. Because the flows are calculated by Algorithm B in units of flow per minute, the toll factor is converted to $0.17 per minute.

The Algorithm B code provided by Dr. Boyles was used to determine user equilibrium. The code was modified slightly to accommodate the toll trials. The termination criteria was changed to 10^{-6} in order for the trials to terminate in under an hour. Additional alterations include saving the equilibrium flows, TSTT, and SPTT. These outputs are then used to determine the final metrics: TSTT, toll revenue, total flow on each highway, and ratio of flow between I-35 and TX-130.

Metrics

The results of these trials were analyzed in terms of the metrics mentioned in the methodology description. These consist of TSTT, toll revenue, total flow, and the ratio of flow on highways.

- **Total system travel time** provides a measure the magnitude of the effect of the implementation of tolls. An increase in TSTT means the trial's toll setup leads to a higher total travel time in the system and therefore a driver's average travel time also increases.
- **Toll revenue** is analyzed to verify that the implementation of tolls on I-35 and removal of tolls from TX-130 achieves at least as much toll revenues as before. Otherwise the change would not be feasible from the perspective of return on investment. The toll

revenue is calculated by taking the dot product of the flow vector and the vector of link toll rates.

- **Total flow** indicates how the flow changes on I-35 and TX-130 before and after the implementation of the proposed change in tolls. If the toll led to the desired effect of reducing congestion, I-35's total flow will decrease. Total flow is found by taking the sum of flow of all links on a specific highway.
- **Ratio of flow on highways** is a similar metric to total flow but gives a clearer picture of the shift of people from I-35 relative to the people on TX-130. This metric is therefore more useful in deciding if the proposed model achieves decongestion of I-35. This ratio is found by dividing the I-35 total flow by the TX-130 total flow.

RESULTS

The results of the three trials have been broken down based on the four metrics. The outcome of all three trials can be seen in **Table 1**.

- **Total system travel time** decreased by 2,815.27 vehicle-minutes when a toll of $0.02 is implemented on I-35. This meets our primary target of reducing total system travel time. On the other hand, when $0.10 toll is implemented on I-35, TSTT increases because the toll implemented on I-35 is too high to have a significant adoption rate. These results are summarized in **Figure 9**.
- **Toll revenue** increased by $3,400 (5.8%) on shifting of tolls from TX-130 to I-35, which satisfies the condition of meeting the present toll revenue target (**Figure 10**).
- **Total flow** on I-35 decreased by 13,556 vehicles after implementing tolls on I-35 and the total flow on TX-130 increases by 11,538 vehicles upon the removal of tolls (**Figure 11**).
- **Ratio of flow on highways** Ratio of traffic on I-35 versus TX-130 decreases by approximately 3% after the proposed toll change (**Figure 12**).

CONCLUSIONS AND FUTURE WORK

When judged by only TSTT, the observed decrease of 2,815.27 vehicle-minutes is likely not significant enough to warrant the investment it would take to shift the tolls from TX-130 to I-35. This decrease is less than a 0.01% of TSTT, which indicates that shifting tolls did not greatly reduce the overall travel time of the system. On the other hand, when looking at the total flows of each highway, as well as the ratio between the two, a shift of traffic from I-35 to TX-130 can be observed. After tolls were added to I-35, its flow decreased by 13%, whereas flow on TX-130 increased by just over 11%. This suggests the desired shift took place and may meet the objective of reducing congestion on I-35. Therefore, it is concluded that the proposed addition of a $0.02 per link toll on I-35, while simultaneously removing tolls on TX-130, could be a possible solution to the issue of congestion on I-35 and lead to better utilization of TX-130.

Given the preliminary nature of this project as well as the assumptions made, the conclusions drawn here should only be used as an initial investigation into the issue. Further work must be done to fully determine the effectiveness of shifting tolls from TX-130 to I-35.

Trucks make up only 7-10% of the total daily traffic on I-35 in the Austin area. Therefore, even if all trucks from were removed the interstate, it would help, but not solve the congestion problem. Also, many commercial trucks using I-35 are making pickups and deliveries in the Austin area. Those truck drivers do not divert to SH-130 because their jobs require them to be along the I-35 corridor[5]. Considering truck traffic, in combination with cars, would lead to a more accurate portrayal of the system.

Despite being an interstate highway, the congestion problem along I-35 in the greater Austin area has a local cause. A recent study by the Texas A&M Transportation Institute shows that a majority of traffic on I-35 is "local," with home, work, school, and other trip destinations located within Hays, Travis, and Williamson counties[5]. Separating this local traffic from through traffic could lead to a more focused effort at shifting only the through traffic to TX-130 specifically via tolls, or even other means such as local discounts or passes of some sort.

Finally, relaxing some of the assumptions could lead to a more accurate model and analysis of changing the toll setup of the Austin network. This could be as simple as considering both two-axle and six-axle traffic by solving two separate TAPs and combining the link flows and toll revenue. Another possible route is to investigate the effects of shifted tolls during non-peak hours.

There are obviously many more paths to continue investigating the question of adding tolls to I-35 to reduce congestion, and based on the preliminary work of this project, shifting tolls from TX-130 to I-35 may be a viable option and further study could be worthwhile.

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[5] *My35*. Texas Department of Transportation, 2015. Web.

TABLES AND FIGURES

Figure 1: Map of I-35 and TX-130 through Austin

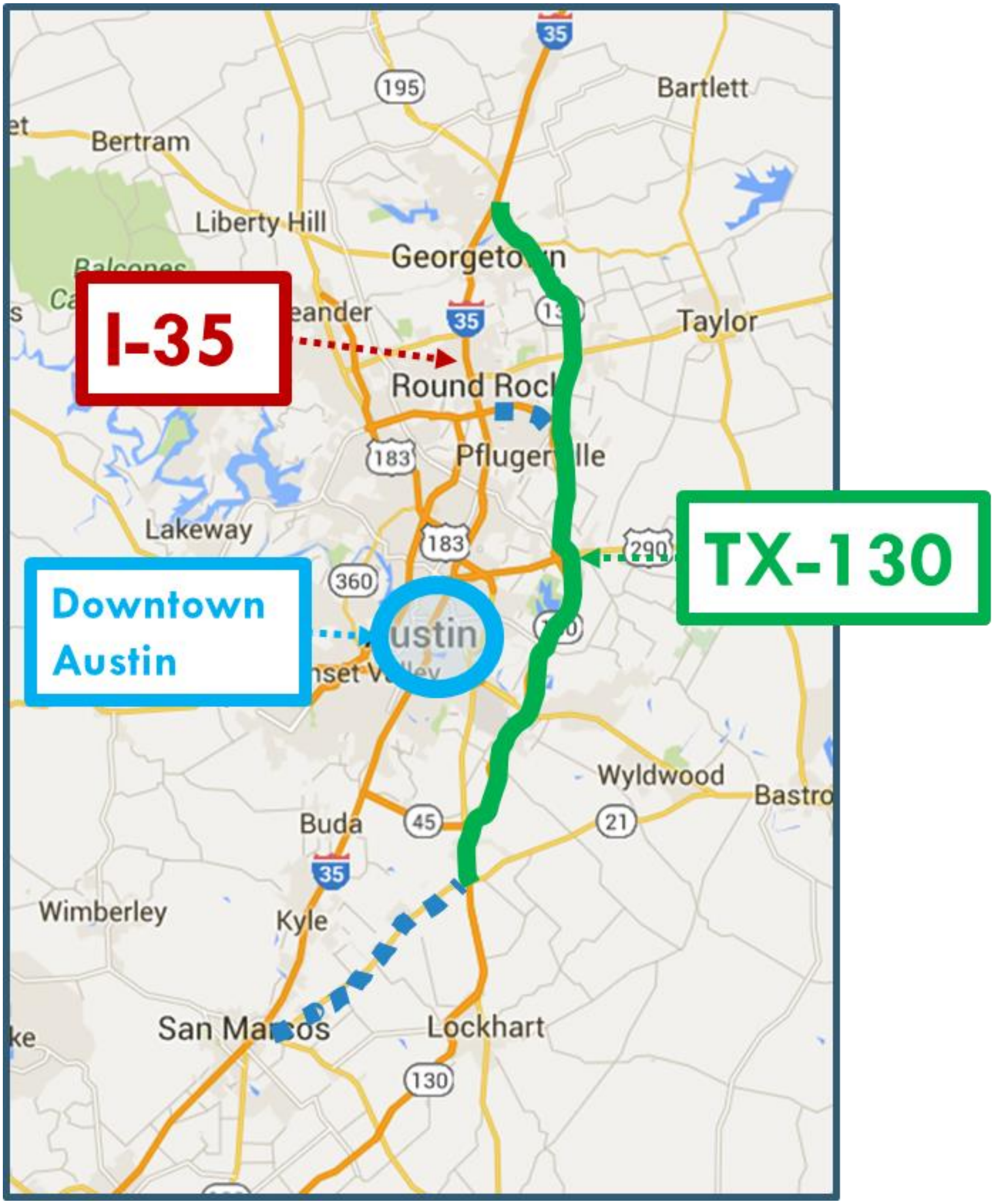
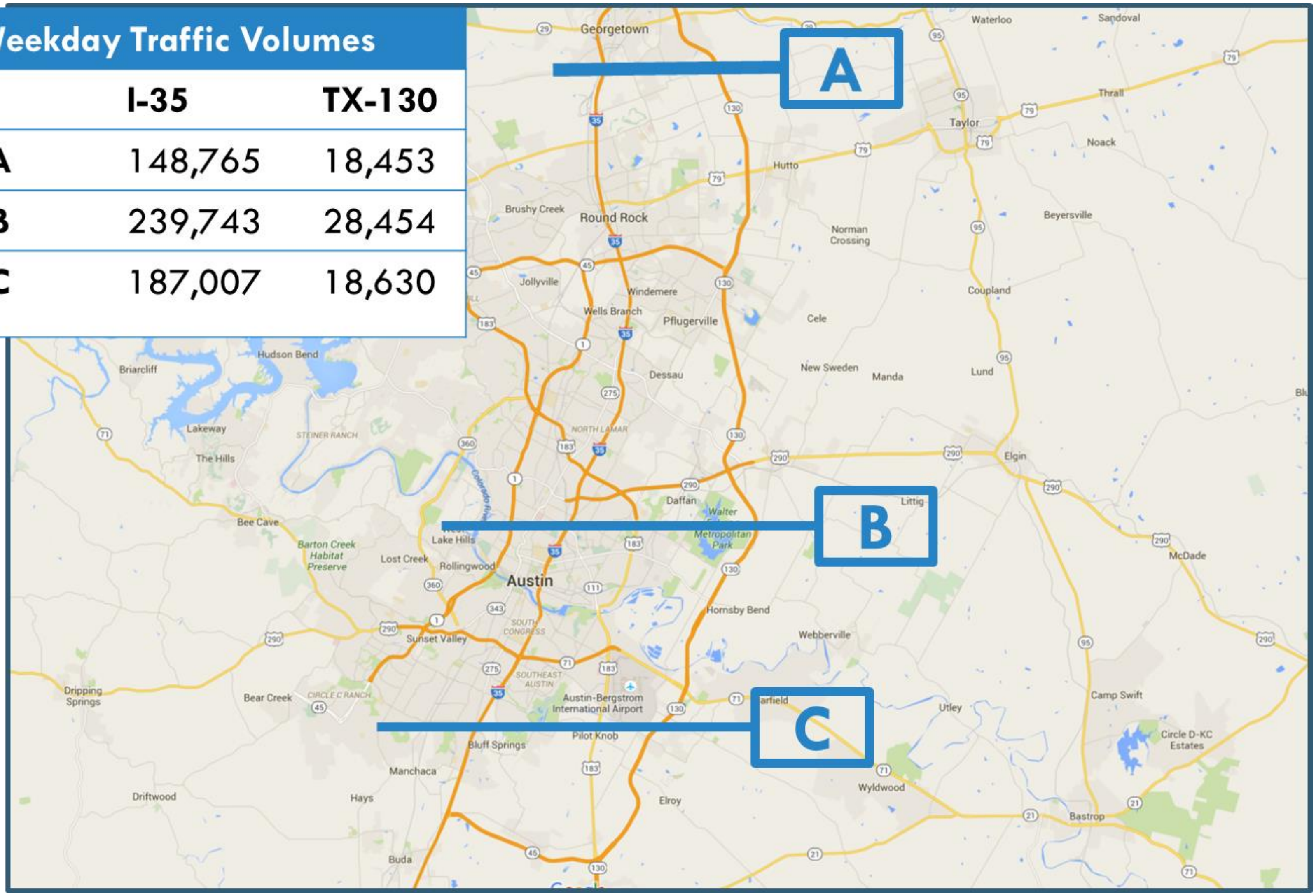


Figure 2: Weekday Traffic Flows on I-35 and TX-130



Weekday Traffic Volumes

	I-35	TX-130
A	148,765	18,453
B	239,743	28,454
C	187,007	18,630

Figure 3: Peak Morning Travel Times, Buda to Georgetown

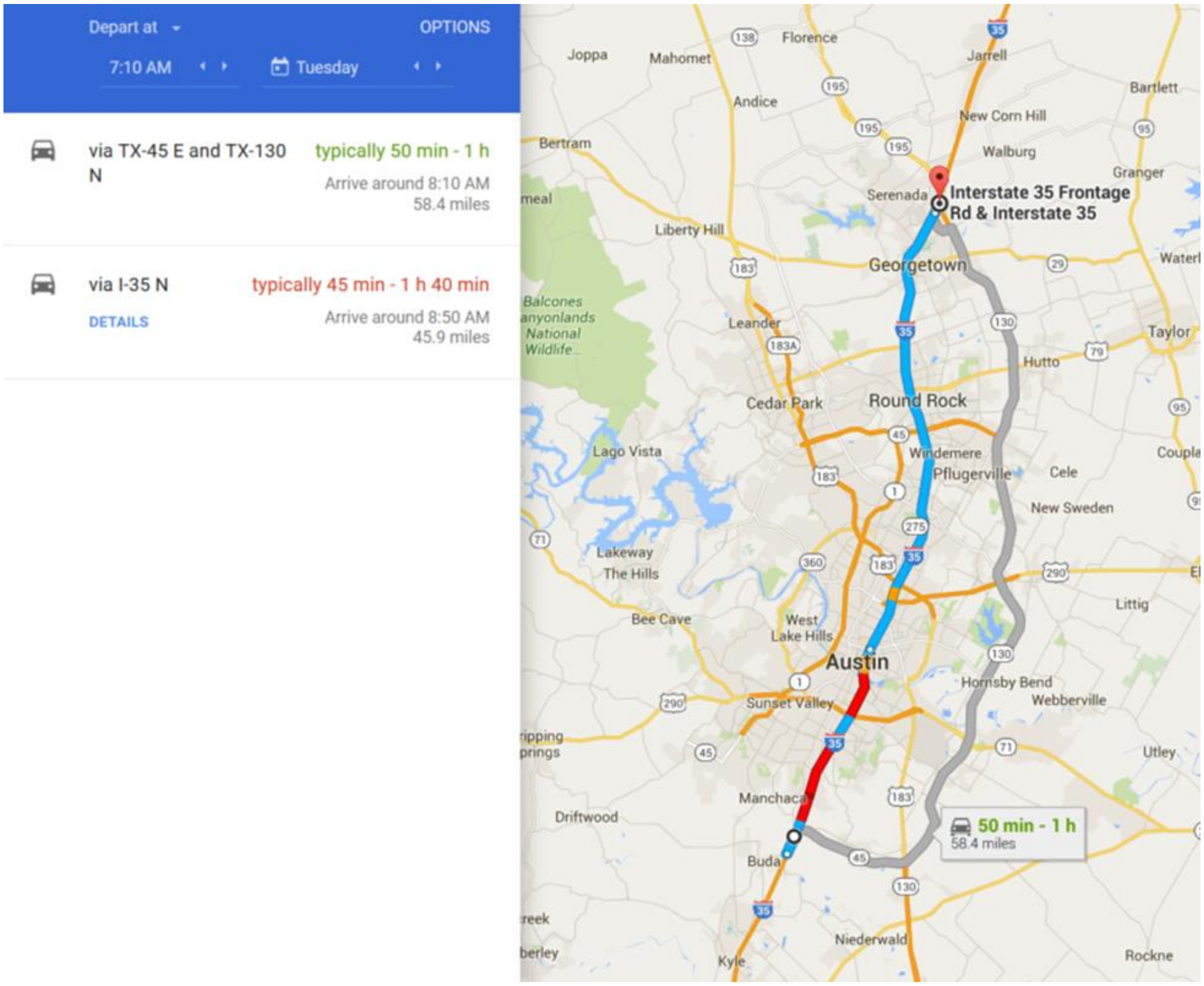


Figure 4: Maximum Weekday Travel Times, Buda to Georgetown

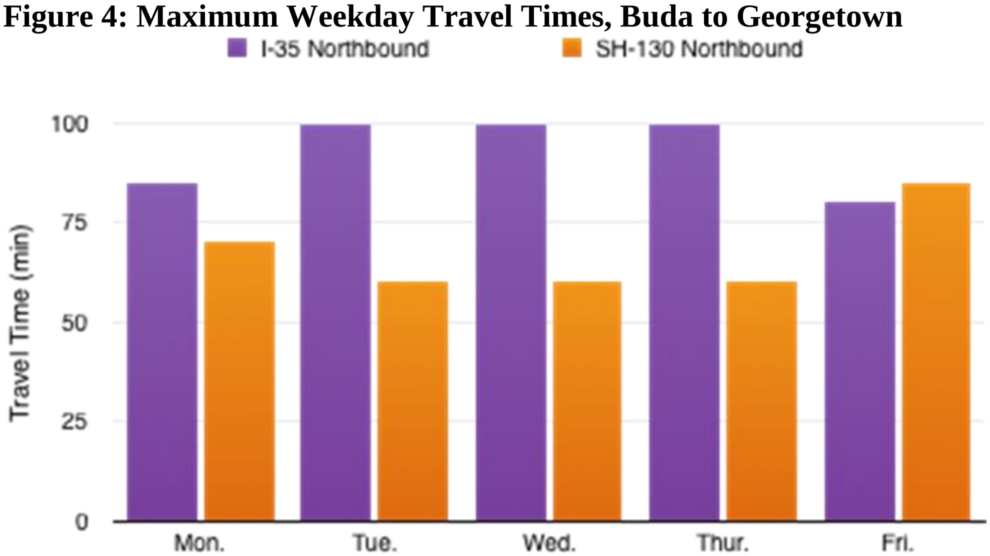


Figure 5: Peak Morning Travel Time, Georgetown to Buda

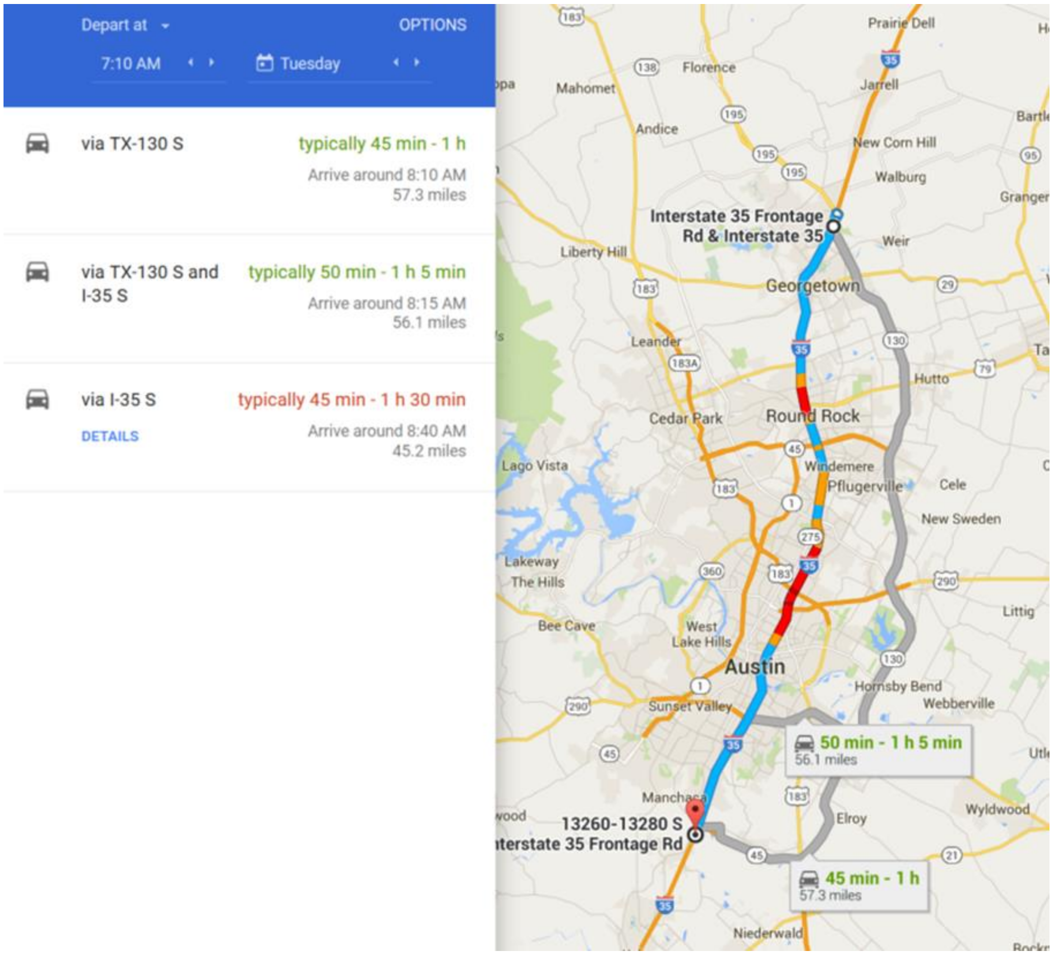


Figure 6: Maximum Weekday Travel Times, Georgetown to Buda

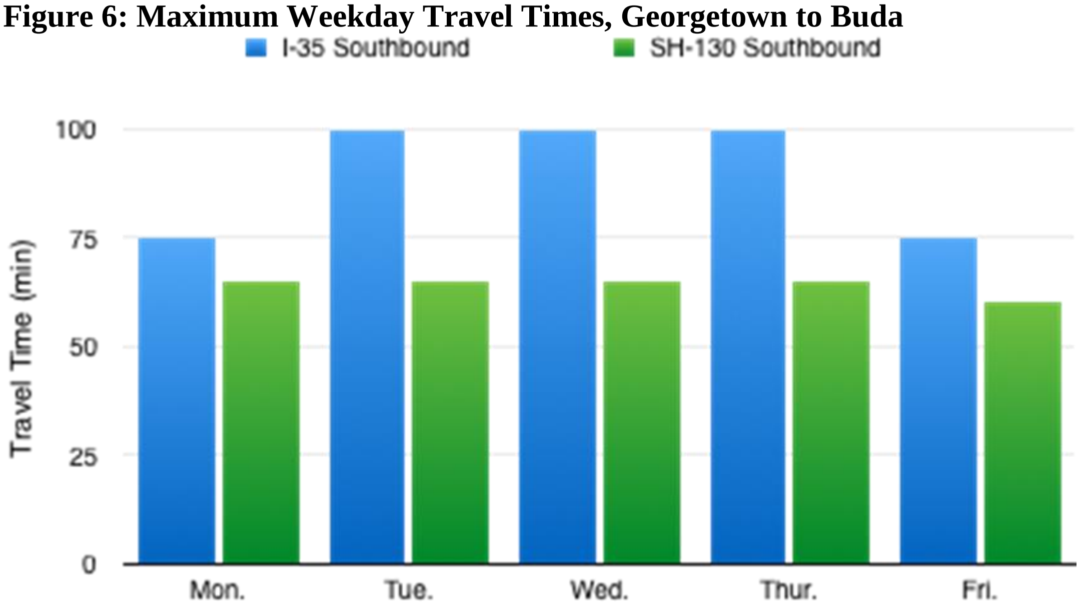


Figure 7: Austin Traffic Network Graph

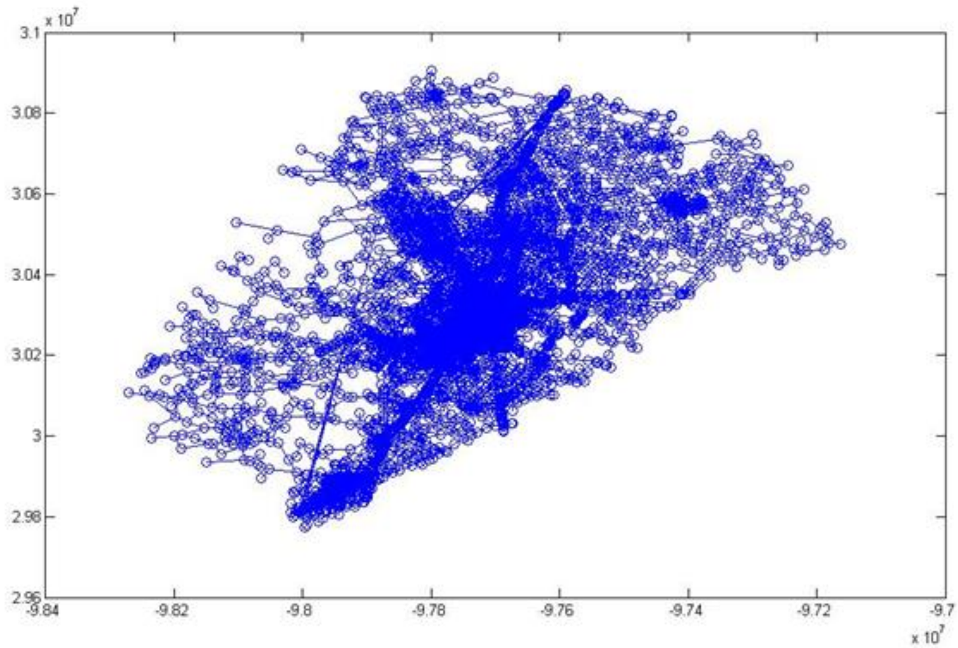


Figure 8: Austin Traffic Network Graph with Indicated Highway Nodes

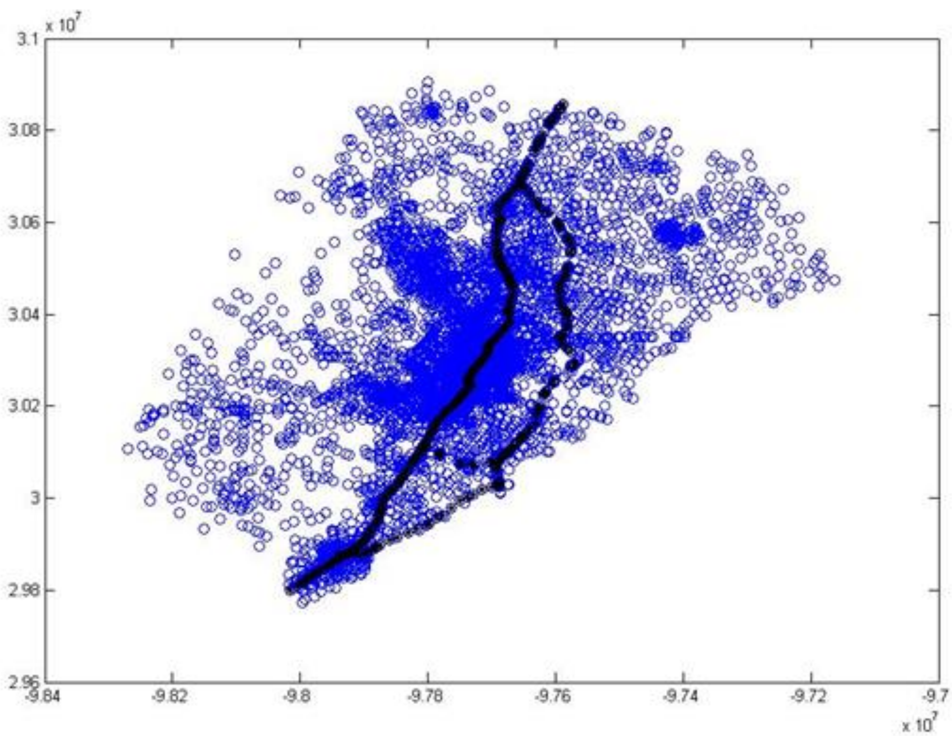


Figure 9: Total System Travel Time under Several Scenarios

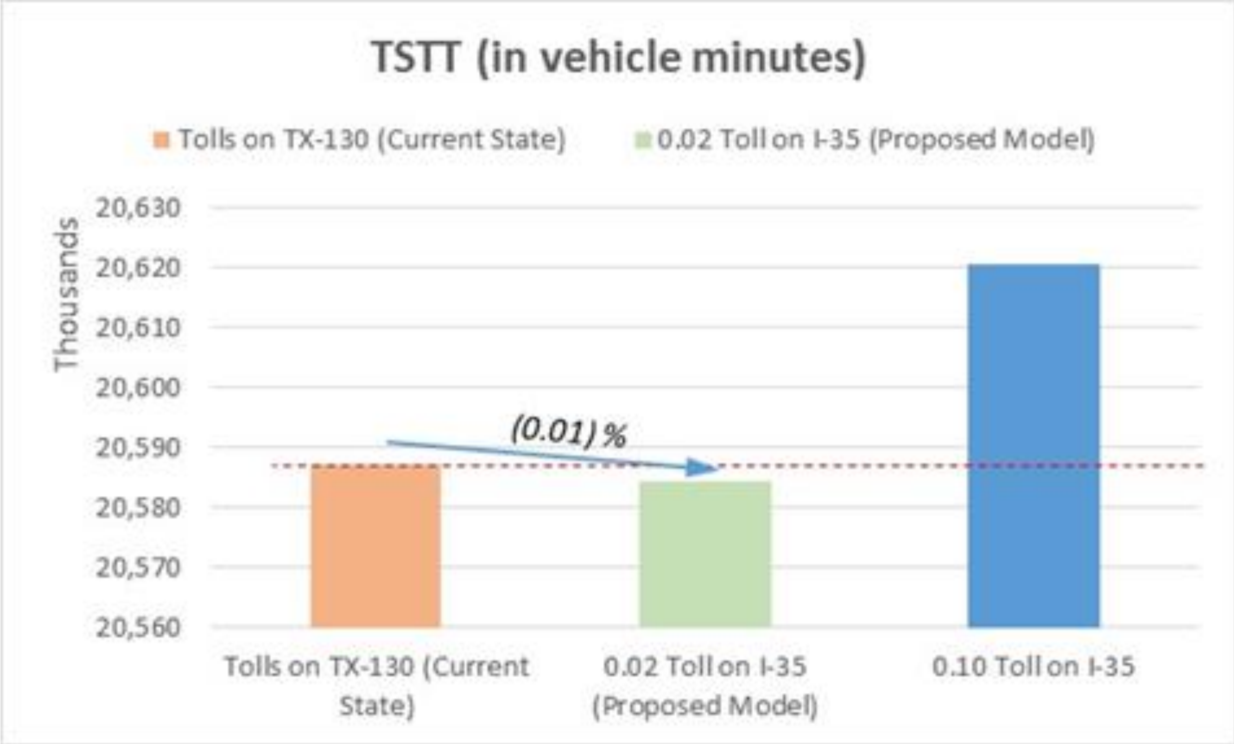


Figure 10: Toll Revenue under Several Scenarios

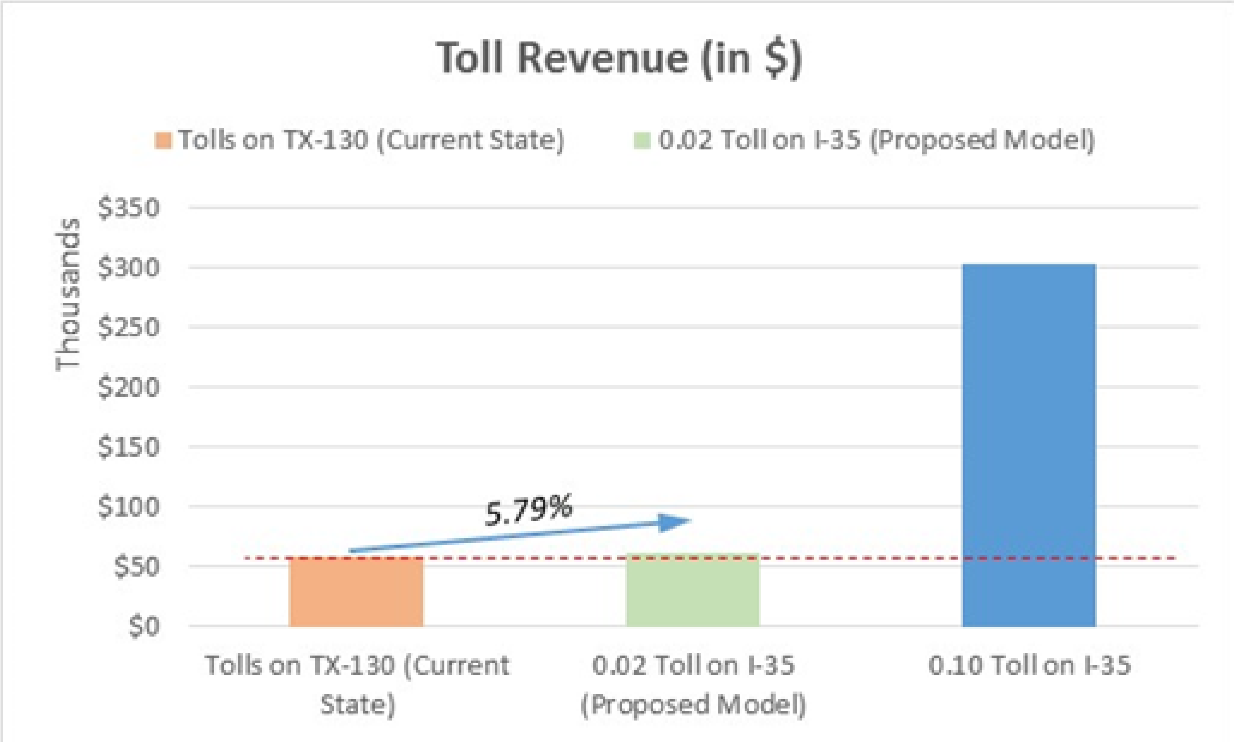
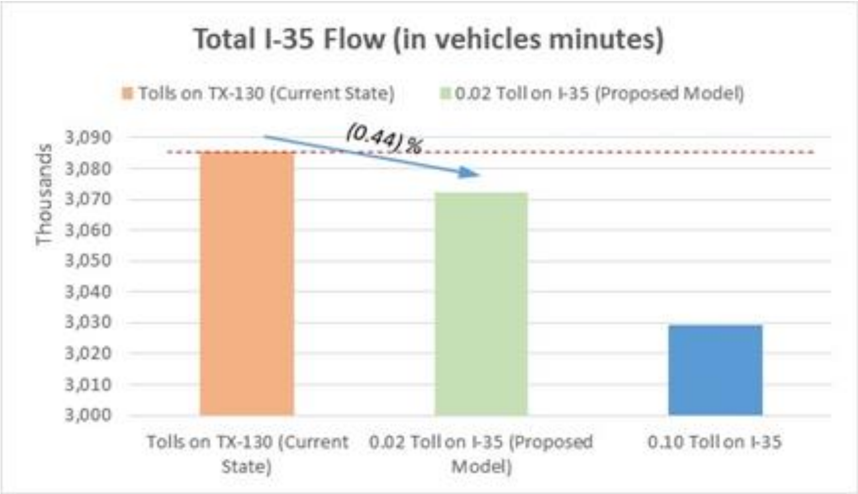


Figure 11: Vehicle Flow on I-35 and TX-130 under Several Scenarios



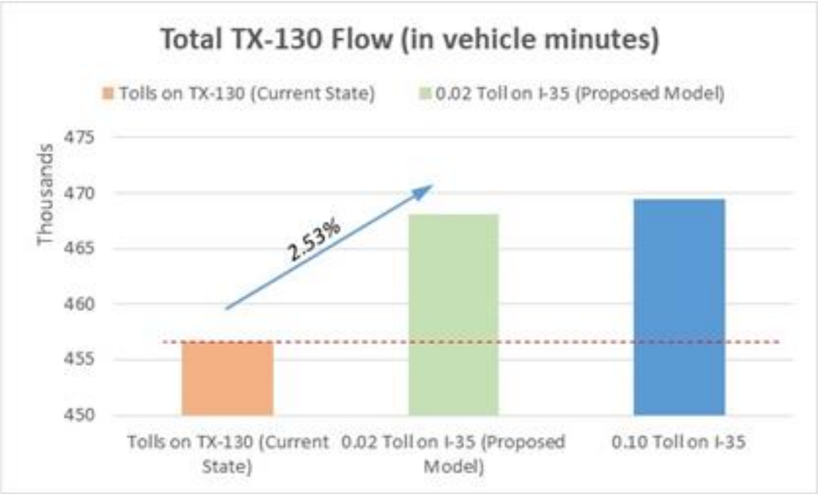


Figure 12: Traffic Ratio, I-35:TX-130, under Several Scenarios

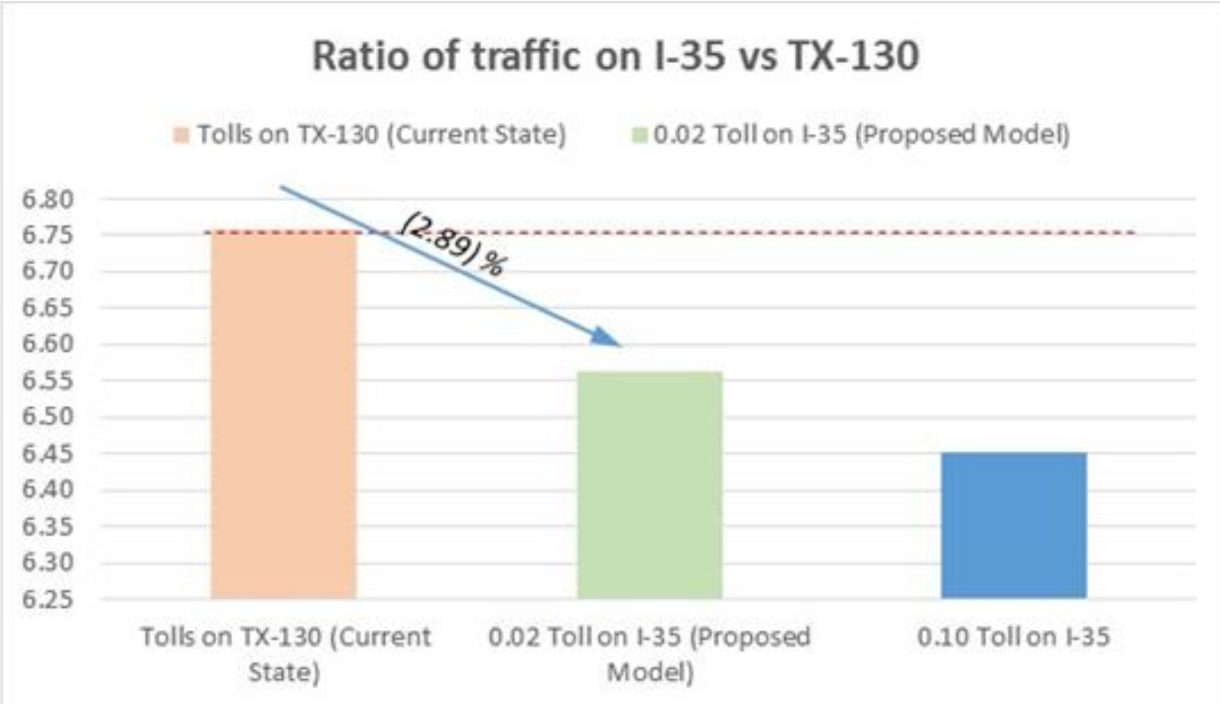


Table 1: Summary of Results

	Model Analysis				Test Case
	Tolls on TX-130 (Current State)	0.02 Toll on I-35 (Proposed Model)	% Change	Change	0.10 Toll on I-35
TSTT (in vehicle minutes)	20,587,037.56	20,584,222.29	-0.01%	-2,815.27	20,620,400.51
Toll Revenue (in $)	$58,079.16	$61,440.90	5.79%	3,361.74	$302,930.00
Total I-35 Flow (in vehicle minutes)	3,085,601	3,072,045	-0.44%	-13,556.26	3,029,300
Total TX-130 Flow (in vehicle minutes)	456,610	468,148	2.53%	11,538.12	469,500
Ratio of flow on highways I35/TX130	6.76	6.56	-2.89%	-0.20	6.45