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## Abstract
Researchers used a state-of-the-art modeling methodology to analyze traffic congestion in and around IH 35 in Central Texas. The goal was to look at the big picture of travel patterns and congestion on the IH 35 main lane corridor. A base model of the adopted Capital Area Metropolitan Planning Organization’s plan was converted to a simulation-based dynamic traffic assignment model capable of analyzing traffic operations on a time-dependent basis. The dynamic traffic assignment model developed is one of the most comprehensive tolling models in the country. Researchers used a combination of static, time-dependent, and congestive-responsive tolling strategies for various corridors in the Austin metropolitan area. Multiple scenarios were modeled and built off the base model developed under Rider 42. Strategies modeled included time-dependent pricing, reversible lanes, ramp metering, en-route diversion, and demand management in various combinations to determine the best approach to address oversaturated networks.

## Key Words
Active Transportation, Demand Management, Dynamic Traffic Assignment, Multi-Resolution Modeling

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Active Transportation and Demand Management Texas Test Bed

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LIST OF FIGURES

Figure 1. Fastest Growing Cities in the United States (2012–2013) ............................................. 3
Figure 2. IH 35 Congestion—Austin 2013 .................................................................................... 4
Figure 3. Travel Diaries Assignment for Successive Simulated Years ....................................... 10
Figure 4. DYNAMIT-R Estimation and Prediction Structure (19) .................................................. 11
Figure 5. Outlined Scenarios ......................................................................................................... 13
Figure 6. CAMPO Metropolitan Transportation Plan – 2035 ..................................................... 14
Figure 7. Scenario 2B Modeled Assumptions ............................................................................. 15
Figure 8. Scenario 2C Modeled Assumptions ............................................................................. 16
Figure 9. Scenario 2D Modeled Assumptions ............................................................................. 17
Figure 10. Scenario 2E Modeled Assumptions .......................................................................... 18
Figure 11. Reversible Lanes ........................................................................................................ 19
Figure 12. DTA Components of Congestive-Responsive Tolling ............................................... 20
Figure 13. Ramp Metering Concept ............................................................................................. 21
Figure 14. Comparison of Total Hourly Auto-Vehicle Trips for 2035 CAMPO Network .......... 23
Figure 15. Congestion Warning Example .................................................................................... 24
Figure 16. Heat Diagram – Example ........................................................................................... 25
Figure 17. Base – Heat Diagrams ................................................................................................ 26
Figure 18. Scenario 2B – Heat Diagrams .................................................................................... 27
Figure 19. Scenario 2C – Heat Diagrams .................................................................................... 28
Figure 20. Scenario 2D – Heat Diagrams .................................................................................... 29
Figure 21. Scenario 2E – Heat Diagrams .................................................................................... 30
Figure 22. Vehicle-Hours Traveled ............................................................................................. 31
Figure 23. Vehicle-Miles Traveled .............................................................................................. 31
Figure 24. Total Delay .................................................................................................................. 32
Figure 25. Average Travel Time .................................................................................................. 32
Figure 26. Average Distance Traveled ....................................................................................... 33
Figure 27. Average Delay ............................................................................................................. 33
Figure 28: Travel Time ................................................................................................................ 34

LIST OF TABLES

Table 1. Travel Time Scenarios .................................................................................................... 34
Table 2. Travel Time Comparison – AM Peak Period ................................................................. 35
Table 3. Percent Difference – AM Peak Period .......................................................................... 35
Table 4. Travel Time Comparison – PM Peak Period ................................................................. 35
Table 5. Percent Difference – PM Peak Period .......................................................................... 35
EXECUTIVE SUMMARY

As urban sprawl becomes more prevalent, increased congestion issues become more of a regional issue, not just an inner city issue. Commuters routinely experience significantly longer travel times as they traverse through these urban corridors, resulting in increased fuel consumption, lost productivity, and extended delays. With funding shortfalls, state departments of transportation and local governments typically need several billion dollars more just to maintain current congestion levels. Cost, land consumption, neighborhood impacts, environmental concerns, and other factors serve as barriers to capacity expansion. In addition, fiscally constrained designated improvement projects in an urban area are often not enough to address the growing congestion problems, and transportation professionals realize that free-flow conditions during peak periods are simply unattainable. Therefore, an aggressive transportation operations and travel demand approach is needed to assess all potential mitigation strategies to supplement added capacity.

Active transportation and demand management (ATDM) is one such approach to mitigate escalating congestion problems. ATDM is the dynamic management, control, and influence of traffic flow and travel demand on a transportation system. Under an ATDM approach, the transportation system is constantly monitored, traffic flow is managed, and driver behavior is influenced to achieve operational objectives. These objectives include reduced emissions, improved safety and reducing or eliminating breakdown conditions. In order to analyze which ATDM strategies are most effective in a congested urban environment, it is necessary to utilize tools that will enable users to evaluate potential benefits.

For this study, researchers used a simulation-based modeling methodology to analyze various active transportation and demand management strategies including reversible lanes, pricing, ramp metering and pre-trip and en-route information. All modeled scenarios are built off of the adopted Capital Area Metropolitan Planning Organization (CAMPO) 2035 model, and each subsequent scenario is built off the previous. Reversible lanes doubled the capacity for directional flow during peak periods and help reduce travel time from the Austin downtown core to Round Rock by more than 50 percent when compared to the base model. However, reversible lanes do penalize the non-peak flow direction. Time-dependent pricing on the reversible lanes helps keep the facility from becoming oversaturated during heavy congestion periods.

Ramp metering is a promising active traffic management strategy but care must be taken when deploying this type of traffic control in areas of oversaturation as this could cause a spillback shockwave. Modeled results showed queue spillback on entrance ramps in and around the Round Rock area, causing further congestion. When space is available, adding dual metered entrance ramps can help alleviate spillback onto frontage roads by doubling the storage capacity.

The telecommuting strategy helped reduce the home-based to work trips by more than 200,000. This scenario assumes that approximately 15 percent of all home-based work (HBW) trips are eliminated to reflect increases in telecommuting. HBW work trips were categorized into three main trip purposes: HBW Direct, HBW Strategic, and HBW Complex. When telecommuting is combined with optional congestion detour and built off previous modeled scenarios, measures-of-effectiveness are maximized.
Integrating both active transportation and demand management had the biggest bang in terms of travel time savings and speed improvements. Final model results showed that the combination of both active transportation and demand management may provide more benefits to specific corridors as opposed to the transportation system as a whole.
The area around the Texas capital saw the fastest population growth in the United States in 2013, according to Census Bureau estimates. San Marcos, Cedar Park, and Georgetown—all located within 30 miles of Austin—ranked among the top 10 of the most rapidly growing US cities with populations of 50,000 or more. Austin itself gained more people (nearly 21,000) than any other city with fewer than 1 million residents. Home to the University of Texas at Austin and state government offices, Austin has a population of 885,400 as of July 1, 2013. As a whole, Texas had the most month-to-month job gains than any other state with a jobless rate of 5.2 percent, which is lower than the national rate of 6.3 percent [1]. The state capital, however, is struggling to maintain core transportation infrastructure, and commuting times from surrounding communities like Round Rock to downtown Austin typically run more than 45 minutes to an hour during peak periods. There is no agreement on what should be done to help alleviate the travel time dilemma. Figure 1 shows that 3 of the top 10 fastest growing cities in the United States are located around Austin, Texas. According to the Texas A&M Transportation Institute’s (TTI’s) 2012 Urban Mobility Report, Austin ranks 32 in terms of travel delay. Commuters spend nearly 40 million combined hours of total delay in their vehicles each year with a total congestion cost of $810 million in what is considered a large urban area. That equates to approximately 44 hours of yearly delay per auto commuter and a congestion cost of $930/vehicle [2].

![Fastest Growing Cities With Populations > 50,000](image)

**Figure 1. Fastest Growing Cities in the United States (2012–2013).**

The long-range plan for the Austin Metropolitan area, the 2035 CAMPO transportation plan has no large-scale capital improvement strategies for IH 35 through Central Texas. Current ongoing

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1 Large urban areas- over 1 million and less than 3 million
initiatives by the Texas Department of Transportation (TxDOT), the Central Texas Regional Mobility Authority (CTRMA), and the City of Austin are focused on short- and mid-term improvement strategies that address existing and near-term congestion problems. At the same time, decision makers have expressed a need for examination of long-term solutions for IH 35, which include ideas and concepts that have been discussed under previous studies but not fully explored [3].

**Problem: What Is the Long-Term Strategy for IH 35 Congestion?**

In 2012, TTI began to study the long-term needs for IH 35 in Austin. As part of the Mobility Investment Priorities (MIP) project, TTI worked with various stakeholders in the region to assess an interim improvement concept including a future transportation system through the heart of Central Texas. During that time, the stakeholders of the region expressed a need to examine the long-term options for IH 35, which considered various concepts that had been discussed in theory under previous studies but not fully explored.

![Figure 2. IH 35 Congestion—Austin 2013.](source: Jim Lyle – Texas A&M Transportation Institute)

The MIP project designated a “Central Texas Working Group,” which was composed of various agencies across the region including the TxDOT Austin District, City of Austin, CAMPO, CTRMA, Capital Metro, Greater Austin Chamber of Commerce, Downtown Austin Alliance, Movability Austin, TTI, and chaired by State Senator Kirk Watson. Results from the modeling effort conducted under the MIP project analyzed multiple common beliefs to the public including:
- Capital improvement projects including roadway and transit construction can eliminate IH 35 congestion.
- Diverting truck traffic from IH 35 to SH 130 is a major cause of congestion.
- The majority of pass-through traffic causes most of the congestion problems along IH 35 in Central Texas.

While the MIP modeling effort was able to dispel some of these myths (e.g., majority of congestion is caused by daily commuters), one large underlying problem remained. The congestion in the future (2035) is expected to worsen exponentially. The afternoon peak hour travel time from downtown Austin to Round Rock will routinely exceed two-hours. While multiple strategies were analyzed during the MIP project, no single scenario examined was able to help relieve the critical hot spots along IH 35. This study is geared to supplement and build upon the analyses already conducted using both active transportation and demand management strategies. TTI used the most promising alternative (Scenario 2B), which included the construction of express lanes (1 lane in each direction) along IH 35 from SH 45N to SH 45S.
LITERATURE REVIEW

Background

ATDM is one approach to mitigate escalating congestion problems. ATDM is the dynamic management, control, and influence of traffic flow and travel demand on a transportation system. Under an ATDM approach, the transportation system is constantly monitored, traffic flow is managed, and driver behavior is influenced to achieve operational objectives. These objectives include reduced emissions, improved safety, and reducing or eliminating breakdown conditions. This literature review examines several existing active traffic and demand management strategies that would be applicable to a congested urban environment.

Further focus is placed on literature discussing simulation-based modeling and demand management, as dynamic traffic assignment (DTA) is being used to model the demand management strategies. DTA has the ability to capture dynamic interactions between travelers and the transportation network. This includes the interaction of vehicle movements at arterial intersections, especially turning movements or turn prohibitions, or restrictions to facilities based on traveler type, such as high-occupancy vehicle (HOV) and High Occupancy Toll (HOT) lanes and truck restrictions. Network capabilities can be divided into four categories: capacity, traffic control, pricing, and evacuation modeling [4].

Active Traffic Management

Active traffic management (ATM) as defined by the Federal Highway Administration is the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing and predicted conditions by maximizing the effectiveness and efficiency of the facility. It increases throughput and safety through the use of integrated systems with new technology including the automation of dynamic deployment to optimize performance quickly and without delay that occurs when operators need to deploy operational strategies manually. ATM approaches focus on influencing travel behavior with respect to lane/facility choices and operations.

Adaptive Ramp Metering

This strategy consists of deploying traffic signals on ramps to dynamically regulate the rate vehicles enter the freeway. This in turn smooths the flow of traffic onto the mainline, allowing efficient use of existing freeway capacity. Adaptive ramp metering uses traffic responsive or adaptive algorithms that can optimize either local or system-wide conditions [5].

Dynamic Shoulder Lanes

This strategy allows for the use of the shoulder as a travel lane, also known as hard shoulder running, based on congestion levels during periods of heavy congestion and in response to incidents or other conditions as warranted during non-peak periods. In an ATDM approach, real-time and anticipated congestion levels are used to determine the need for using a shoulder lane as a regular or special purpose travel lane, and the operation of the dynamic shoulder lane is managed continuously [6].
Variable Speed Limits

A variable speed limit (VSL) system allows traffic agencies to change posted speed limits as a response to varying conditions such as congestion, accidents, severe weather, work zones, etc. VSLs often use traffic speed and volume detection, weather and road information to determine the optimal speeds at which drivers should be traveling. The ideal speeds are posted with the objective of homogenizing traffic flow and/or improving safety on specific roadway segments. Furthermore, VSLs are often implemented in conjunction with intelligent transportation systems to let drivers know the cause of a speed reduction in the area [7].

Active Demand Management

Active Demand Management (ADM) is one aspect of ATDM that builds upon traditional travel demand models (TDM) efforts, which traditionally focus on influencing mode choice, route choice, and time choices. Similarly, ADM uses technology and real-time information to influence these same factors dynamically[8]. ADM strategies can involve several specific objectives: eliminating a trip completely (as in telecommuting), changing travel times, and redirecting routes or affected mode shifts for single occupancy vehicles (SOV) to other higher occupancy or lower impact modes. Demand management strategies that would be applicable in a congested urban environment include departure time adjustments/peak spreading, dynamic pricing, telecommuting, and land use.

Departure Time Adjustments/Peak Spreading

One effort to actively reduce peak period travel involved dynamic pricing of congested locations and time periods in the Netherlands. Called rush hour avoidance or spitsmijden in Dutch, financial incentives were offered to participants to avoid a particular congested roadway at the morning rush (7:30 a.m. to 9:30 a.m.). Participants were provided with transponders for their car, and results showed that the approximately $4 influenced half of participants to change their travel; some changed mode but most chose to change their time of departure.

Ettema et al. present a micro-simulation model that accounts for departure time variation and choice by individual travelers given travel time uncertainty. Travelers in the model incorporate learning and adaptation processes into an individual mental model of traffic conditions to make decisions about departure time for routine trips. This individual traveler component is combined with a micro-simulation model of the transportation system that determines the effects of individual trip decisions on system characteristics. The simulated travel time from the latter is fed back into the individual’s mental models and may lead to adjustments in behavior. The approach incorporated mean travel time information and travel time variance in the traveler’s mental model. This learning and adaptation procedure applied to a case study illustrated its potential to predict responses to congestion (in terms of departure time decisions of individuals). This type of learning and adaptation is applicable to a non-stationary environment such as one characterized by changed travel conditions in which all travelers face a new uncertain situation (i.e., introduction of road pricing). The research used the SIASPARAMICS microscopic traffic simulator and an individual mental model of travel conditions updated each day with new trip information [9].
Dynamic Pricing

The first implementation of dynamic congestion pricing was undertaken on HOT lanes on IH 15 in San Diego. Fees could be adjusted every 6 minutes; loop detectors in the pavement determined if the state-mandated Level of Service C was being met and a system computer could change the fee. The IH 15 project in San Diego, California, demonstrated that the dynamic pricing mechanism maintained LOS C in 99 percent of time periods and that dynamic pricing per trip can lead to the redistribution of traffic away from the middle of the peak period [10].

Yang et al. describe a general and widely applicable dynamic distance-based pricing strategy for managed toll lanes. This pricing model can be used to undertake “a comparison of the pricing strategies under different objectives”[11].

Another study presents a simulation-based framework for modeling Advanced Traffic Management Systems and Advanced Traveler Information Systems. Sundaram at al. present a model framework that is capable of capturing day-to-day and within-day dynamics of travelers and demonstrate its potential to model and evaluate traffic management scenarios such as HOT/HOV lane conversion and traveler behavior in response to information. It could also be applied to HOV, HOT, congestion pricing, and other demand management tools [12].

Uber®, a technology-enabled transportation service, is an app-based car service that links drivers and passengers. Uber tracks ride-request locations, follows weather-forecast data and manually follow special events that could affect travel demand. Uber then uses these data to implement dynamic pricing, which they call surge pricing, where fares increase if high demand is predicted. Higher prices increase the supply of drivers and alleviate demand by raising the cost to customers. The prediction algorithm is updated with daily updates on how accurately demand was predicted throughout a city. Rates vary by city, by rental type, and by day and time [13]. The surge pricing was devised as a simple economic solution to an imbalance between supply and demand that would occur at certain times, for instance at 3 a.m. on a Saturday night—where drivers would punch-out leaving late-night travelers with unfulfilled requests [14].

Dynamic Fare Reduction

Dynamic fare reduction is a strategy in which the cost of a transit service or system is reduced in a particular corridor during periods of congestion or delay. Fares are communicated in real-time to the public through general channels including the transit website or personalized messages to subscribers. Real-time feeds on highway congestion or transit usage can be used to dynamically monitor and adjust the fare changes.

Telecommuting

Demand management strategies aimed at encouraging telecommuting can include targeted outreach and technical assistance for local employers intended to induce alternative work arrangements such as telecommuting, flexible schedules, and compressed work weeks [15].

Vu and Vandebona developed a “user equilibrium model with elastic demand” to model the influence of telecommuting on traffic flow patterns. However, this model is not dynamic, but can
be used to estimate the effects of telecommuting on travel time, vehicle miles traveled (VMT), air pollution, and noise pollution [16].

Land Use

In an integrated ATM project in the Puget Sound region of Washington State, TDM strategies are being incorporated including the identification of significant origin and destination areas including major employment centers and other major generators called “Growth and Transportation Efficiency Centers.” This type of data is important for urban planning but also as an input for developing more accurate and up-to-date OD matrices.

Huynh et al. (2014) present an agent-based model that simulates the interactions between population growth, transport demands, and urban land use, and may be used for analysis of long-term impacts of transport and land use scenarios. The model incorporates TRANSIMS traffic data to inform the travel time of each modeled trip and traffic density on the roads. The model aims to explicitly simulate interactions between population growth, traffic demand, and the relocation of households over time. The model includes a synthetic population, residential relocation choice, perceived livability, travel diaries, traffic micro-simulation, and transport mode choice.

Household Travel Survey (HTS) data were used to assign trip sequences to the synthetic population by matching household characteristics and then randomly assigning the travel diary of individuals in an HTS household to a synthetic household. Algorithms were designed to determine activity type, activity location, and to reassign travel diaries for successive years (given the assumption that household composition changes over time). Figure 3 shows this last process. Travel mode choice was assigned using the results of the TRANSIM traffic simulation (representing travel time) and individual income (a proxy for perception of value of time). The model was found to realistically reflect the HTS results and traffic congestion (as observed on Google® Maps) [17].
Predictive Traveler Behavior

Predictive travel information includes real-time and historical transportation data to anticipate upcoming conditions, and then relay this information to travelers both pre-trip and en-route in hopes of influencing travel choices. This type of information can be disseminated via various dynamic messaging tools including dynamic messaging signs, trip planning tools, targeted phone messages, etc. [18].

Many communities have undertaken efforts to provide real-time or predictive travel information to travelers on the road. Examples include Messaging Infrastructure for Travel Time Estimates to a Network of Signs (MITTENS) and 511 Traffic in the San Francisco Bay Area. 511 Traffic provides real-time and predictive trip information on roadway, rideshare, transit, and bike conditions via the internet, mobile phones, and broadcast media. Developer resources can be found at http://511.org/developer-resources.asp.

Several types of models can be used to simulate traffic and traveler behavior at various levels of detail. Burghout provides a detailed review of simulation model types used to analyze the performance of traffic infrastructure, the behavior of travelers, and in combination, the use of information to influence the driver’s behavior. Mesoscopic model DynaMIT has been developed to simulate and predict the effects of real-time traffic information given to drivers. Figure 2 presents the estimation and prediction structure of one model, DYNAMIT-R [19].
Figure 4. DYNAMIT-R Estimation and Prediction Structure (19).
Toledo et al. calibrate and validate the MITSIMLab micro-simulation model by comparing traffic flows, travel times, and queue lengths from simulated results with corresponding observed measurements from Stockholm, Sweden. This model was developed to evaluate ATMS and ATIS at an operational level and can be used to model driver response to real-time traffic information. Researchers found that simulated flows, travel times, and queues corresponded well with data observed [20].

Ciari reviewed 16 years of historical travel diary surveys to generate a scenario for a micro-simulation model scenario predicting travel in Switzerland in 2030. Dynamic Network Assignment-Simulation Model for Advanced Road Telematics (DYNASMART) is a discrete time mesoscopic simulation model designed to model traffic pattern and evaluates overall network performance under real-time information systems. UCI has also been enhancing the features of DYNASMART for the real-time analysis of advanced transportation management systems as a core model of the UCI test bed [21].

Several DTA systems have and are being developed to simulate real-time traffic conditions. Milkovits et al. discuss DynaMIT 2.0, a DTA system that integrates real-time sensor information (21). However, the application was combined with a static OD rather than an activity framework or mode choice.

Dynamic Ridesharing

A strategy that uses technology such as smart phones, internet, and social networks to connect travelers for short-notice, one-time shared rides. This dynamic ridesharing/carpooling can reduce the number of vehicles on congested roadways.

Ghoseiri et al. present research to develop an optimization algorithm for real-time rideshare matching. This dynamic rideshare matching optimization model collects traveler and driver information continuously over time and maximizes total assignments of shared rides within a given time frame [22].

Herbawi and Weber outline a similar optimization model that is shown to be able to solve the ride matching problem within reasonable time windows. This model is static, however, using a snapshot of riders and drivers as an input; extending the algorithm to be dynamic itself is mentioned as a future opportunity [23].
**APPRAOCH**

The modeling approach for assessing traffic congestion in and around IH 35 in Central Texas was aimed at analyzing the overall big picture of travel patterns and congestion on the corridor. A base model of the adopted CAMPO 2035 plan was converted to a simulation-based DTA model and was used as the foundation for all supplemental scenarios. Figure 5 outlines and summarizes the scenarios examined for this study.

**Base**

The 2035 CAMPO-adopted planned network was used as the basis for comparison to other scenarios. It includes no additional auto or truck capacity along IH 35 between SH 45N and SH 45S. Based on the level of congestion anticipated for the 2035 forecasted horizon year, several roadways within the Austin metropolitan area would be considered managed lane facilities. Therefore, sections of Loop 1 (MoPac), US 183N, and US 183S will be operated with some sort of dynamic pricing. Hence, these facilities were assumed to be dynamically tolled. SH 45 and SH 130 were tolled using fixed static toll rates as outlined in the CAMPO 2035 plan. Figure 6 depicts the 2035 regional roadway system for Central Texas.
Figure 6. CAMPO Metropolitan Transportation Plan – 2035.
**Scenario 2B—Express Lanes**

Scenario 2B is derived from the base scenario but includes express lanes running parallel to the IH 35 general purpose main lanes. It is assumed that there is one lane in each direction and stretches from SH 45N to SH 45S with intermediate access points along the corridor. This scenario assumes that all vehicle classes (SOV, HOV, and truck) are tolled on the IH 35 managed lanes. Figure 7 shows the tolling assumptions made on the network. Types of tolling methods used include static, time-of-day, and congestive-responsive. All subsequent modeled tolling scenarios are based off of Scenario 2B.

![Figure 7. Scenario 2B Modeled Assumptions.](image)

**Scenario 2C—Reversible Lanes + Pricing**

Similar to the previous scenario, Scenario 2C includes reversible lanes (also called contra flow lanes) instead of express lanes. This scenario assumes that there are two additional managed lanes that are not barrier separated. Traffic flow is directional so inbound traffic to the central
business district/University of Texas at Austin is allowed during the morning peak periods and is reversed during the afternoon peak periods. Researchers used a flat time-of-day toll rate of $10.00 per vehicle for all auto user classes while truck classes were charge $20.00 per vehicle during peak periods. To keep vehicles from entering the facility in the wrong direction, an inflated toll rate was used to restrict access and keep traffic flow directional.

![Figure 8. Scenario 2C Modeled Assumptions.](image)

**Scenario 2D—Reversible + Pricing + Ramp Metering**

Scenario 2D is built off of the previous scenario with the addition of ramp metering on the IH 35 general purpose lanes within the limits of the toll lanes. This type of access managed was aimed at restricting flow of vehicles onto the IH 35 main lanes and help prevent bottleneck break downs at ingress locations and keep traffic flowing during peak periods. Figure 9 highlights the approximate positions of ramp metered locations. Ramp metering was not employed in the central business district.
Scenario 2E is built off of the previous scenario and includes a change in demand management. This scenario assumes that approximately 15 percent of all home-based work trips are eliminated to reflect increases in telecommuting. HBW work trips are categorized into three main trip purposes: HBW Direct, HBW Strategic, and HBW Complex where the reduction was applied to the output from TRIPCAL5.\(^2\) This is applied to both SOV and HOV user classes. Truck demand was not modified or reduced in this scenario. Scenario 2E also includes en-route diversion due to congestion. Dynamic message signs are placed in strategic locations where a defined percentage of vehicles have the option to divert to an alternate route when congestion levels are displayed on the message sign as shown in Figure 10.

\(^2\) TRIPCAL5 is a multi-functional program developed by the TTI for estimating trip productions and attractions for multiple trip purposes.
Methodology

Researchers used an innovative multi-resolution modeling methodology to analyze all proposed scenarios, which included the use of both macroscopic (travel forecasting model) and mesoscopic (dynamic traffic assignment) modeling tools. The CAMPO five-county travel forecasting model was used as a starting point to derive region-wide demand for IH 35. A base scenario was run in the travel forecasting model to generate project trips for SOV, high occupancy vehicles (HOV2 and HOV3+), and trucks. Travel by other types of modes was generated in the travel forecasting tool but was not incorporated into the DTA model. The use of a DTA model was necessary due to several reasons. First, the DTA model incorporates both temporal and spatial aspects of modeling. In other words, the DTA model can simulate congestion conditions at any given location and point of time (e.g., it can simulate queuing). The DTA model also has a higher fidelity resolution and incorporates traffic signals/stop signs to mimic impedences on a transportation facility. In addition, the DTA model is also capacity constrained so it cannot generate more capacity on a roadway than its physical capacity (i.e., cannot have a volume-to-capacity ratio >1). Researchers used a variety of active transportation...
strategies incorporated with demand management to model multiple scenarios within the DTA model framework. The following sections outline the strategies employed.

**Reversible Lanes**

Reversing lanes (also referred to as contra flow lanes) reduce congestion for handling special event traffic, during morning and evening commuters when an accident blocks a lane, and when construction or maintenance activity is present on the road. Reversible traffic lanes add peak-direction capacity to a two-way road or freeway and decrease congestion by utilizing available lane capacity from the other off-peak direction [24]. In the context of this research, reversible lanes were used to add directional capacity on the freeway facility during peak period rush hours. From a modeling perspective, extremely inflated toll rates were used at ramp junction access locations to restrict directional flow. Figure 12 shows the reversible lane concept per peak period.

![Figure 11. Reversible Lanes.](image)

**Value Pricing**

Variable pricing refers to variable road tolls intended to reduce peak-period traffic volumes to optimal levels. Tolls can vary based on a fixed schedule (time-of-day), or they can be dynamic meaning that rates change depending on the level of congestion that exists at a particular time (congestive-responsive) [25]. Both types of value pricing were used in this project in addition to static tolls as defined by the CAMPO-adopted metropolitan transportation plan.

**Congestive-Responsive Pricing**

One of the most compelling reasons to use the DTA model was its ability to simulate congestive-responsive tolling.³ Researchers used this to model dynamic tolling across multiple tolling facilities in the region. Congestive-responsive tolling is simply a dynamic tolling algorithm governed by the speed on the managed lanes. During periods of light congestion, vehicles enter the toll lanes to reduce their overall travel time. As more vehicles enter the tolled facility, speeds on the managed lane begin to drop. When a user-defined threshold of minimum speed is reached, the tolling algorithm increases the toll rates to reduce the demand entering the facility. Toll rates

³ Algorithm develop by University of Arizona
are updated in 5-minute increments. Components of the congestive-responsive tolling include the pricing model, route choice model, and current network conditions as shown in Figure 12.

![Diagram of DTA Components of Congestive-Responsive Tolling](Image)

**Figure 12. DTA Components of Congestive-Responsive Tolling.**

The formulation of the congestive-responsive tolling algorithm is [26]:

\[
\begin{align*}
\text{max } Z &= \sum_{t \in T} \sum_{l \in L} k_t^l v(k_t^l) \\
\text{Subject to:} & \\
& v(k_t^l) \geq v_t^0, \quad \forall l \in L, t \in T \\
& \frac{d_l}{\delta y} \left( \frac{1}{v_t^0} - \frac{1}{v(k_t^l)} \right) \leq \pi, \quad \forall l \in L, t \in T \\
& \frac{d_l}{\delta y} \left( \frac{1}{v_t^0} - \frac{1}{v(k_t^l)} \right) \geq \pi - \varepsilon, \quad \forall l \in L, t \in T
\end{align*}
\]

where:

- \( k_t^l \): density of congestive-pricing segment \( l \) at time \( t \)
- \( v(k_t^l) \): speed of congestive-pricing segment \( l \) at time \( t \)
- \( v_t^0 \): required minimal operating speed inside HOT lane
- \( v_t^0 \): average speed on the general purpose lane
- \( d_l \): distance of the congestive-pricing segment \( l \)
- \( \pi_t^l \): toll rate for congestive-pricing segment \( l \) at time \( t \) (decision variable)
- \( \delta y \): value-of-time for vehicle type \( n \)
- \( \varepsilon \): threshold
The congestive-responsive tolling formulation is designed to maximize throughput in a dynamic user equilibrium framework while maintaining the target HOT operating speed threshold. It is based on how drivers would consider the tradeoff between tolled and non-tolled lanes considering the congestion levels and the designated value-of-time for each defined user class. The pricing calculation is based on an iterative process that is needed to reach a stable pricing solution [27].

**Time-of-Day Pricing**

Time-of-day pricing refers to toll rates that are adjusted based on specified time periods. Typically, toll rates are increased during peak periods and are then reduced when rush hour traffic has subsided. In the context of this modeling effort, time-of-day pricing was used on IH 35 express lanes and reversible lanes.

**Ramp Metering**

Several types of freeway metering exist. The most common technique to address freeway congestion is ramp metering. It limits the rate at which vehicles enter the freeway facility so that the downstream mainline capacity is not exceeded. Ramp metering redistributes the freeway demand over space and time. Excess demand is either stored on the ramp or diverted. The diverted vehicles may choose less traveled alternative routes with shorter experienced travel times. It helps in the dispersion of platoons of vehicles that are released from nearby signalized intersections. Turbulence is reduced in the merge zone by releasing a limited number of vehicles into the mainline traffic stream as shown in Figure 13 [28]. Metering rates range from 240 vehicles per hour to a practical maximum of 750 to 1000 vehicles per hour.

![Figure 13. Ramp Metering Concept.](image)

Ramp metering from a modeling perspective adjusts the on-ramp flow rates based on the flow and downstream capacity of mainline freeway lanes. The algorithm follows a logic first derived...
from Papageorgiou’s feedback control. ALINEA is based on a feedback structure and is derived by use of classical automatic control methods [29]. The procedure measures the flow on freeway mainline lanes downstream of the ramp and determines the remaining freeway capacity available based on occupancy values. The on-ramp flow capacity is then adjusted to meet the available capacity. The model formulation is [30]:

\[
\gamma_t = \gamma_{t-1} + \alpha(\beta - MDO)
\]  

**Eq. 2**

where:

- \( \gamma_t \): Ramp flow rate (veh/hr/lane) for the \( t^{th} \) period
- \( \gamma_{t-1} \): Ramp flow rate (veh/hr/lane) for the \((t-1)^{th}\) period
- \( MDO \): Measured downstream occupancy (percent time)
- \( \alpha \): Occupancy-to-flow conversion rate (veh/hr/lane/percent time)
- \( \beta \): Maximum freeway downstream occupancy (percent time)

\[
\gamma_t = \begin{cases} 
(Saturation flow rate (SFR) if \gamma_t \geq SFR) \\
700 \text{ veh per hour per lane if } \gamma_t < SFR
\end{cases}
\]

The term \((\beta - MDO)\) represents the downstream capacity available for entering vehicles. Therefore, the higher the \( \beta \) is, the more capacity is available for entering vehicles. The term \( \alpha \) may be regarded as a control factor, which controls the number of vehicles entering the freeway through the on-ramp. Therefore, the higher the \( \alpha \) is, the more vehicles are able to enter the freeway. For this study, researchers used a minimum discharge of 700 veh/hr/lane and a maximum discharge rate of 1000 veh/hr/lane.

**Telecommuting**

Telecommuting is a work arrangement in which employees do not commute to a central place of work and allows flexibility to employees who can perform work tasks remotely. This in turn allows employees to work from home or satellite location and eliminate their commute entirely [31]. The telecommuting strategy in the context of simulation modeling for this project represented a 10 percent level of reduced trips. Researchers used the 10 percent reduction factor for all SOV and HOV trips within the 5-county CAMPO modeled area. Figure 14 shows a comparison of the total hourly auto-vehicle trips with full demand versus a 10 percent reduction, which illustrates telecommuters who choose to work from home that day.
Dynamic message signs (DMS) are considered congestion warning messages that allow a specified percentage of DMS-responsive vehicles to evaluate the information displayed and divert if a better path exists. For this study, DMS signs were placed on IH 35 upstream of SH 45 junctions to allow diversion to the toll road. For this study, twenty percent of vehicles were allowed to evaluate and respond to the displayed information. Vehicles that do not evaluate the DMS information will keep their original paths. The premise is to determine whether vehicles from external IH 35 stations would be willing to divert to the toll facility and avoid peak hour congestion locations as shown in Figure 15.
Figure 15. Congestion Warning Example.
FINDINGS

Multiple scenarios were analyzed using both active transportation and demand management strategies. Results were post-processed using both tabular and graphical analyses. The following section outlines modeled results.

Speed Profile – IH 35

The 2035 adopted CAMPO plan was used as the basis for comparison for all subsequent modeled scenarios. It included no additional capacity for SOV, HOV, or trucks between SH 45N and SH 45S. All HOV\(^4\) facilities identified are assumed to be available for both auto HOV vehicles and bus transit usage. Loop 1 (MoPac), US 183N, and US 183S managed lane facilities are assumed to be operating with dynamic congestive-responsive tolling. Figure 16 through Figure 21, known as a time-space-speed diagram or heat diagram, depict the average operating speed throughout the IH 35 corridor in the southbound direction. The heat diagram is color coded so dark blue represents free flow speed (60 mph) while the yellows, oranges, and reds depict higher congestion locations where the average speed has dropped significantly up to stop-and-go conditions. The x-axis represents time throughout a 24-hour period while the y-axis represents location along the IH 35 corridor.

\(^4\) HOV facilities in the DTA model are assumed to be HOV3+.
Base model analysis shows heavy congestion southbound from Round Rock/Georgetown area all the way to the central business district of Austin during the morning peak period, which runs from approximately 7:30 a.m. past 11:00 a.m. In the afternoon, congestion and resulting speed reductions occur between Riverside Dr. and SH 45S. Afternoon peak hours last from approximately 3:00 p.m. to almost 10:00 p.m. at night. In the northbound direction, the heaviest congestion occurs in the afternoon from US 183 to Georgetown where speeds have dropped to 10 mph from 4:00 p.m. to past 10:00 p.m.

Figure 17. Base – Heat Diagrams.
Figure 18. Scenario 2B – Heat Diagrams.
Figure 19. Scenario 2C – Heat Diagrams.
Figure 20. Scenario 2D – Heat Diagrams.
Output of heat diagrams shows heavy congestion during both the morning and afternoon peak hours. When reversible lanes are introduced and doubling the capacity in each direction during peak hours, speeds improve dramatically. Scenario 2C showed vast improvement in average speeds in and around the Round Rock/Georgetown area along IH 35 in the northbound direction. Scenarios 2D and 2E also showed promising results when compared to the base model. In the southbound direction, Scenarios 2C and 2D showed the most improved speeds when compared to the base model.

**Mobility**

Multiple measures-of-effectiveness (MOEs) were calculated for all defined scenarios including vehicle-hours traveled (VHT), VMT, total delay, average travel time, average distance traveled,
and average delay. Scenario 2B had the lowest VHT at just over 2.2 million hours followed by Scenario 2E at 2.4 million hours. Scenario 2C performed the best in terms of total and average delay, while Scenario 2E had the least amount of VMT at just less than 70 million miles traveled. The following graphs outline all MOEs calculated.

![2035 CAMPO Scenario Comparison (VHT)](image)

**Figure 22. Vehicle-Hours Traveled.**

![2035 CAMPO Scenario Comparison (VMT)](image)

**Figure 23. Vehicle-Miles Traveled.**
Figure 24. Total Delay.

Figure 25. Average Travel Time.
Travel Times

Travel time is a key metric used when analyzing the level of performance on a freeway system. This metric considers the travel time derived using simulation-based DTA analysis. In this study, it did not consider people’s trips by walking, bicycling, or riding transit, only trips by auto and truck. However, due to the randomness in the generation of vehicles during each simulation hour, it was extremely difficult to find a trip originating in the same zone, departing approximately the same time, and destined for the same zone through all defined scenarios.
Therefore, it was necessary to utilize a script (travel time probe vehicle\textsuperscript{5}), which captures travel times along specified routes. One vehicle is generated every hour during the peak periods and travels through a user-defined route before reaching its destination. This provided researchers a more accurate depiction of travel times from specific origins and destinations. For this study, travel times were calculated from the pairs as shown in Table 1 and depicted in Figure 28.

\begin{table}[h]
\centering
\begin{tabular}{ |c|c|c|c|}
\hline
\textbf{IH 35 Northbound} & \textbf{IH 35 Southbound} \\
\hline
Buda to Central Business District (CBD) & Round Rock to CBD \\
\hline
CBD to Round Rock & CBD to Buda \\
\hline
South Hays County Line to North Williamson County Line & North Williamson County Line to South Hays County Line \\
\hline
\end{tabular}
\caption{Travel Time Scenarios.}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure28}
\caption{Travel Time}
\end{figure}

\textsuperscript{5} Script developed by the University of Arizona.
Travel times were tabulated for the morning peak period (7:00 a.m.) and afternoon peak period (6:00 p.m.) for the six scenarios defined in Table 1. From Round Rock to Austin CBD, Scenario 2B was the only scenario that had a reduction in travel time (−10 percent) while trips originating in Buda and destined for the CBD saw a −26 percent reduction in travel time. For the afternoon peak period, travel times from the CBD to Buda saw the biggest travel time savings from Scenarios 2D and 2E at 32 percent and 23 percent, respectively. The heaviest traffic congestion by far was from the CBD to Round Rock in afternoon peak period. All scenarios showed vast improvements when compared to the base model (see Table 2 through Table 5).

### Table 2. Travel Time Comparison – AM Peak Period.

<table>
<thead>
<tr>
<th>7:00 AM</th>
<th>Ext - Ext (SB)</th>
<th>RR - CBD (SB)</th>
<th>CBD - Buda (SB)</th>
<th>Ext - Ext (NB)</th>
<th>Buda - CBD (NB)</th>
<th>CBD - RR (NB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>178</td>
<td>27</td>
<td>19</td>
<td>221</td>
<td>29</td>
<td>21</td>
</tr>
<tr>
<td>SC2B</td>
<td>125</td>
<td>25</td>
<td>18</td>
<td>172</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>SC2C</td>
<td>141</td>
<td>30</td>
<td>21</td>
<td>140</td>
<td>41</td>
<td>22</td>
</tr>
<tr>
<td>SC2D</td>
<td>147</td>
<td>34</td>
<td>21</td>
<td>134</td>
<td>41</td>
<td>23</td>
</tr>
<tr>
<td>SC2F</td>
<td>145</td>
<td>36</td>
<td>20</td>
<td>140</td>
<td>38</td>
<td>23</td>
</tr>
</tbody>
</table>

### Table 3. Percent Difference – AM Peak Period.

<table>
<thead>
<tr>
<th>7:00 AM</th>
<th>Ext - Ext (SB)</th>
<th>RR - CBD (SB)</th>
<th>CBD - Buda (SB)</th>
<th>Ext - Ext (NB)</th>
<th>Buda - CBD (NB)</th>
<th>CBD - RR (NB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>-29.71%</td>
<td>-10.47%</td>
<td>-2.10%</td>
<td>-22.30%</td>
<td>-26.34%</td>
<td>-2.41%</td>
</tr>
<tr>
<td>SC2B</td>
<td>-20.58%</td>
<td>9.85%</td>
<td>12.29%</td>
<td>-36.66%</td>
<td>38.96%</td>
<td>7.97%</td>
</tr>
<tr>
<td>SC2C</td>
<td>-17.21%</td>
<td>22.77%</td>
<td>12.15%</td>
<td>-39.58%</td>
<td>41.32%</td>
<td>11.83%</td>
</tr>
<tr>
<td>SC2D</td>
<td>-18.58%</td>
<td>30.29%</td>
<td>9.49%</td>
<td>-36.68%</td>
<td>31.41%</td>
<td>9.71%</td>
</tr>
</tbody>
</table>

### Table 4. Travel Time Comparison – PM Peak Period.

<table>
<thead>
<tr>
<th>6:00 PM</th>
<th>Ext - Ext (SB)</th>
<th>RR - CBD (SB)</th>
<th>CBD - Buda (SB)</th>
<th>Ext - Ext (NB)</th>
<th>Buda - CBD (NB)</th>
<th>CBD - RR (NB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>231</td>
<td>87</td>
<td>115</td>
<td>301</td>
<td>56</td>
<td>196</td>
</tr>
<tr>
<td>SC2B</td>
<td>155</td>
<td>89</td>
<td>113</td>
<td>310</td>
<td>19</td>
<td>167</td>
</tr>
<tr>
<td>SC2C</td>
<td>177</td>
<td>56</td>
<td>116</td>
<td>178</td>
<td>50</td>
<td>87</td>
</tr>
<tr>
<td>SC2D</td>
<td>170</td>
<td>86</td>
<td>78</td>
<td>217</td>
<td>60</td>
<td>121</td>
</tr>
<tr>
<td>SC2F</td>
<td>151</td>
<td>32</td>
<td>89</td>
<td>189</td>
<td>34</td>
<td>89</td>
</tr>
</tbody>
</table>

### Table 5. Percent Difference – PM Peak Period.

<table>
<thead>
<tr>
<th>6:00 PM</th>
<th>Ext - Ext (SB)</th>
<th>RR - CBD (SB)</th>
<th>CBD - Buda (SB)</th>
<th>Ext - Ext (NB)</th>
<th>Buda - CBD (NB)</th>
<th>CBD - RR (NB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>-32.74%</td>
<td>2.12%</td>
<td>-1.83%</td>
<td>2.99%</td>
<td>-66.92%</td>
<td>-14.84%</td>
</tr>
<tr>
<td>SC2B</td>
<td>-23.42%</td>
<td>-35.22%</td>
<td>0.56%</td>
<td>-40.75%</td>
<td>-11.48%</td>
<td>-55.47%</td>
</tr>
<tr>
<td>SC2C</td>
<td>-26.32%</td>
<td>-0.67%</td>
<td>-31.96%</td>
<td>-27.83%</td>
<td>7.87%</td>
<td>-38.46%</td>
</tr>
<tr>
<td>SC2D</td>
<td>-34.75%</td>
<td>-63.13%</td>
<td>-22.73%</td>
<td>-37.31%</td>
<td>-39.21%</td>
<td>-54.41%</td>
</tr>
</tbody>
</table>

35
CONCLUSIONS

This study concluded that both active transportation and demand management could provide added benefits for congested corridors. IH 35 in Central Texas was used as a case study to test an innovative modeling methodology to analyze various proposed corridor relief scenarios. Modeled results showed that contra flow lanes benefit the peak period flow of traffic by providing a mobility option not presently available (if lanes are managed to maintain level of performance) in addition to mobility improvements for the IH 35 general purpose lanes. Reversible lanes showed promise by doubling the added capacity during the peak flow while time-dependent pricing kept the managed lanes from becoming oversaturated. Ramp metering is a promising active traffic management strategy but care must be taken when deploying this type of traffic control in areas of oversaturation as this could cause a spillback shockwave. Modeled results showed queue spillback on entrance ramps in and around the Round Rock area, causing further congestion. When space is available, adding dual metered entrance ramps can help alleviate spillback onto frontage roads by doubling the storage capacity.

Demand management is crucial to the stability of the transportation network in the future. Active measures must be taken to utilize land use in the most efficient ways that can capitalize on the accessibility of SH 130 to the east. Diversion of vehicles that are merely pass-through trips can use the toll road where the speed limit was raised to 85 mph. This bypass around the city can provide incentives to drivers to use SH 130 and can help provide relief to IH 35. Behavioral changes include the ability to telecommute to work for many home-based trips, changes in departure times away from the peak periods, and changing the mindset of commuters by encouraging them to shop and work closer to home.

While this modeling effort did show promise in providing some congestion relief for IH 35, the long-term outlook demonstrates that Central Texas confronts a harsh impending reality should population and growth trend rates continue. Therefore, it will be necessary that all strategies include active traffic and demand management be further analyzed to explore all possibilities of congestion relief in the future.
REFERENCES

31. Williams, T., *Quantifying Transportation Improvement Strategies for the Austin Metropolitan Area*, 2013, Texas A&M Transportation Institute: Austin.