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16. Abstract

This research report summarizes the activities of a research project intended to identify and quantify appropriate operational and safety performance measures that can be used for investigating access management treatments. Specifically, the research had three objectives: 1) assess the state-of-the-practice relative to performance measures that are applicable to access management and identify existing and/or new measures—particularly measures that can capture the safety benefits of access management treatments, 2) perform micro-simulation using the identified measures on two selected case study corridors and on three theoretical corridors to demonstrate the application of the measures, and 3) develop guidance for applying the performance measures for evaluating roadway improvements that include access management treatments (e.g., raised medians, driveway consolidation) and incorporating them into the transportation planning process.

The research will be useful to practitioners as it identifies desirable input and output characteristics for individuals searching for a micro-simulation tool to use for assessing the impacts of access management. It also identifies surrogate safety measures related to time-to-collision (TTC), and incorporates them into a micro-simulation model (VISSIM) as a demonstration of how both safety and operational impacts might be investigated in the same software package. Generally, the results appear intuitive—particularly at lower volumes and for the theoretical corridors.

The research report also discusses how the safety measures can be incorporated into the traditional transportation planning process. It also cautions that corridor improvements are very case specific and illustrates how micro-simulation, when calibrated appropriately to field conditions, provides a tool to estimate the effects of combined corridor characteristics. Finally, the research report concludes with future research needs that can enhance the state-of-the-practice in this area.

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IDENTIFYING AND QUANTIFYING OPERATIONAL AND SAFETY PERFORMANCE MEASURES FOR ACCESS MANAGEMENT: MICRO-SIMULATION RESULTS

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ABSTRACT

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The research report also discusses how the safety measures can be incorporated into the traditional transportation planning process. It also cautions that corridor improvements are very case specific and illustrates how micro-simulation, when calibrated appropriately to field conditions, provides a tool to estimate the effects of combined corridor characteristics. Finally, the research report concludes with future research needs that can enhance the state-of-the-practice in this area.

EXECUTIVE SUMMARY

INTRODUCTION

Access management techniques (e.g., median treatments, driveway consolidation, auxiliary lanes, signal spacing, etc.) are proven methods for improving traffic flow, safety, and protecting the initial public investment in the transportation infrastructure. However, to date there is no standard method for quantifying the “level,” whether satisfactory or unsatisfactory, of access management improvements along a corridor. There are no specific performance measures that directly capture the myriad of operational and safety-related impacts of access management techniques—particularly in a commercial off-the-shelf (COTS) software that can be used to evaluate roadway improvements that include access management.

It is hypothesized that “tracking” the acceleration and deceleration characteristics of individual vehicles can be used as a surrogate measure of the extent of conflict (i.e., relative safety) along a given corridor. For example, a measure that relates to the individual acceleration characteristics per mile or per hour would allow measurement of the conflicts, and therefore relative safety, along a corridor. This report describes research that investigates these possibilities.

PROJECT OBJECTIVES

To satisfy the needs highlighted in the paragraphs above, the primary objectives of this research effort were to:

1. Assess the state-of-the-practice relative to performance measures that are applicable to access management and identify existing and/or new measures—particularly measures that can capture the safety benefits of access management treatments.

2. Perform micro-simulation using the identified measures on two selected case study corridors and on three theoretical corridors to demonstrate the application of the measures.

3. Develop guidance for applying the performance measures for evaluating roadway improvements that include access management treatments and incorporating them into the transportation planning process.

METHODOLOGY AND PROCEDURE

Researchers identified and performed the tasks described on the following pages to satisfy the objectives above.

Conduct State-of-the-Practice Literature Review

This task was performed to satisfy the first objective of the research. This objective is to investigate performance measures that are applicable to access management—particularly those that may be used as surrogate measures of safety. Less discussion is provided on typical operational performance measures (travel time, speed, and delay) because they are generally well understood and implemented into transportation analysis software currently. Rather, the literature focuses on providing an overview of access management treatments, the use of micro-simulation tools for investigating access management, necessary model characteristics when selecting a micro-simulation tool, and how safety analysis might be incorporated into the micro-simulation environment.

The section that discusses how micro-simulation might incorporate safety analysis includes a discussion of measures identified in the literature that hold promise as surrogate measures of safety for roadway improvements in the micro-simulation environment. The time-to-collision (TTC) measure is initially identified and defined in that section (Section 2.4).

Develop Analysis Procedure and Perform Necessary Data Collection

This task included the development of the analysis procedure and collection of necessary data. A simultaneous effort funded by the Texas Department of Transportation (TxDOT) provided data from two corridors in the state of Texas that were used in the micro-simulation. The available data included traffic volumes, signal timings, geometric conditions, and turning volumes. In addition to the two case study corridors, the research team developed “theoretical corridors” to further test the TTC measure as a surrogate for safety in the micro-simulation environment.

Perform Micro-simulation

The micro-simulation was performed as part of this task. Micro-simulation was performed on the two selected case study locations as well as on the three theoretical corridors.

The researchers developed a subroutine within a micro-simulation model that computed TTC statistics in “real-time” as the model was running. Therefore, safety (with TTC as a surrogate) and operational (travel time, speed and delay) information were both obtained in the same software package.

Identify Methods to Incorporate Methodology into Transportation Planning Process

The work documented in this report clearly demonstrates the promise of incorporating surrogate safety measures into the micro-simulation environment. The report takes the findings and observations from the analysis, and describes how they may be incorporated into the transportation planning process as part of this task.

Prepare Final Report

The final task in the completion of this project was the preparation of this deliverable that documents the research need, literature review, procedures, case studies, findings, conclusions, and recommendations.

CASE STUDY CORRIDORS AND THEORETICAL CORRIDORS

Texas Avenue Corridor (Bryan, Texas)

The first corridor investigated was a 5-lane major arterial with a continuous two-way, left-turn lane (TWLTL). The major traffic generators along this section of roadway included fast-food restaurants, a drug store, a bank, office buildings, and a shopping center anchored by a large video store. Various retail and commercial developments also exist along this section. Currently, a TWLTL serves as the median treatment along this section of Texas Avenue. This corridor has a signal density of 3.0 signals per mile. The average daily traffic (ADT) along the 0.66-mile corridor was approximately 18,000.

A conflict point analysis was performed along this corridor as well as investigating the implementation of raised medians along the corridor with U-turns at selected locations. Micro-simulation was performed in Verkehr in Städten Simulation (VISSIM) (Traffic in Cities-Simulation), and traffic volumes were increased to investigate congested conditions.

Broadway Avenue Corridor (Tyler, Texas)

The second case study corridor is along Broadway Avenue (US 69) between Loop 323 and Chimney Rock Drive in Tyler, Texas. This road currently has three through lanes in each direction, a TWLTL, and a signal density of 4.1 signals per mile. Adjacent land uses include residential, office, commercial, and retail; however, there are no single-family residential driveways intersecting Broadway Avenue. The ADT is approximately 24,000 along the 1.47-mile corridor.

As with the Texas Avenue corridor, a conflict point analysis was performed along this corridor as well as investigating the implementation of raised medians along the corridor with U-turns at selected locations (two different options for raised median locations were investigated). Micro-simulation was performed in VISSIM, and traffic volumes were increased to investigate congested conditions.

Theoretical Corridors

While the actual case study locations were valuable in assessing the operational and safety impacts of access management treatments, additional theoretical scenarios were also simulated. Three 1-mile theoretical corridors incorporating access management treatments such as raised median installation and driveway consolidation were investigated for different traffic volumes.

The three theoretical corridors range from Scenario #1 with a TWLTL and very few driveways to Scenario #3 with a raised median and several driveways. The three scenarios were analyzed over a range of ADTs, varying numbers of lanes and driveways, and differing median treatments. All three scenarios have a signal density of 2.0 signals per mile (two signals at ½-mile spacing).

As with the two case study corridors, researchers performed a micro-simulation of the travel time, delay, speed, and the surrogate safety measures (TTC-related) on each theoretical corridor.

FINDINGS

Summary of Case Study Findings

Table S-1 illustrates the characteristics and results for both of the case study corridors. It provides a comparison among the different geometric characteristics, conflict point reductions, changes in operational measures (travel time, speed), and TTC measures.

The percent reduction in conflict points, and all the measures, are calculated as the difference after converting from a TWLTL to a raised median. The two corridors show the same percent reduction in conflict points. (See Chapter 3 for more details). The percent difference in travel time, speed, and TTC values varies for each corridor. The percent change in travel time varies between the two corridors. On the Texas Avenue corridor, travel time decreases 11 percent for the proposed raised median future condition with an ADT of ~21,800 and 38 percent for the future ADT of ~48,000 scenario, while the travel time on the Tyler corridor increases with the raised median. The travel time for the future condition (~48,000 ADT) increases 57 percent when the TWLTL is converted into a raised median on the Tyler case study. It is hypothesized that the more circuitous travel and increased U-turn traffic along the Broadway Avenue corridor cause the raised median treatment to have slightly longer travel times. The high U-turn traffic is due to the relatively large median opening spacing along Broadway Avenue (500 to 1,500 feet in Option B) particularly next to a large retail area. Decreased spacing of the median openings is hypothesized to increase the speeds by reducing/distributing U-turns more efficiently though this was not investigated in this study. However, even the relatively small speed decreases identified here are hypothesized as offset by the reduction in the number of conflict points with a raised median installation.

The TTC harmonic mean along the Texas Avenue corridor reduces 8 percent, while the TTC4 increases. These measures would indicate that the raised median produces increased acceleration characteristics, which is counter-intuitive. As described in Section 4.1.2, for this case study it appears that there is a need to isolate the TTC tool to include only the corridor segment of interest rather than including vehicular interactions that occur before the travel time data collection points. The fact that travel time results and TTC estimates were collected at different locations is hypothesized to be the cause of some of the counter-intuitive results. Similar findings result along the Broadway Avenue corridor.

Table S-1. Summary of Case Study Micro-simulation Results.

Case Study	Location	Corridor Length (miles)	Signal per Mile / Access Points per Mile[1]	Median Opening Spacing (feet)[2]	Number of Lanes each Direction[3]	Land Uses	Percent Reduction in Conflict Points[4]	Estimated Existing ADT[5]	Estimated Future ADT[6]	Future Percent Difference in Travel Time[2]	Future Actual Difference in Speed (mph)	Percent Difference in TTC Harmonic Mean[4,7] (seconds)	Future Actual Difference in TTC4[4,8]	Future Actual Difference in TTC10[4]
Texas Avenue	Bryan, Texas	0.66	3.0 / 91	660 to 1,320	2	Retail, University	-60	18,200	21,800	-11	2 (increase)	< 1	-0.2	-0.9
									48,000	-38	7 (increase)	-8	0.6	-0.3
Broadway Avenue	Tyler, Texas	1.47	4.1 / 46	500 to 1,500	3	Commercial, Retail	-54	24,400	29,300	2	<1 (decrease)	-7	-0.13	0.3
									48,000	57	5 (decrease)	-3	-0.32	1.5

[1] Access point density includes both directions and includes driveways, streets, and signalized intersections.

[2] Median opening spacing is the range for the raised median alternative with the most openings. Two alternatives were investigated along Broadway.

[3] The Texas Avenue corridor was not widened in the micro-simulation because VISSIM allows vehicles to perform U-turns with two lanes, and this study was intended to investigate the differences between the TWLTL and the raised median. From a practical perspective, flared intersections and slightly widened mid-block location(s) would facilitate the U-turns.

[4] The percent difference values are derived from the conversion from a TWLTL to a raised median. Negative values imply a decrease when converting to the raised median. These differences are based upon the weighted average of at least three micro-simulation runs.

[5] Estimated from road tubes or videotapes. The ADTs are estimated by assuming a K and D factor to apply to the observed peak-hour volume.

[6] The lower ADT value is a 20 percent increase over existing conditions. This represents an approximate 2 percent increase over 10 years. The higher ADT value was run to estimate higher-volume conditions. The ADTs are estimated by assuming a K and D factor to apply to the observed peak hour volume.

[7] TTC4: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds.

[8] TTC10: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds.

Along Broadway Avenue in Tyler, the travel time increased 2 percent (<1 mph decrease) when the raised median was installed at the lower ADT level (29,300). At the higher ADT level of 48,000, there was a 57 percent increase in travel time with the raised median. This equates to a 5 mph decrease in speed. The TTC harmonic mean for Broadway Avenue decreases in both future scenarios. The TTC4 also decreases in both scenarios. The TTC10 both increase when the TWLTL is converted to a raised median.

Summary of Theoretical Corridor Findings

Table S-2 presents a summary of the theoretical corridor micro-simulation results for the operational measures as well as the TTC measures. As in the case studies, the first observation is that the number of conflict points decreases with the installation of a raised median. This was shown in Chapter 3 in more detail. This decrease occurs even when the number of driveways increases from 18 in Scenario #1 to 84 in Scenario #2. The number of conflict points for both the 5- and 7-lane options for Scenario #2 was reduced by 70 percent with the installation of a raised median. This large reduction is accompanied by an increase in travel time with the raised median from 2 to 31 percent for the 5-lane option and from 8 to 44 percent for the 7-lane option.

The Scenario #3 results show a 75 percent reduction in the number of conflict points with the installation of a raised median, along with a 1 to 22 percent increase in travel time. The differences in travel time reflect the range in travel times as the ADT increases. The actual reduction in speed is, on average, approximately 3 mph when a raised median replaces a TWLTL across all of the conditions investigated.

The TTC harmonic mean typically increases, particularly for the 7-lane cross sections. For the ~48,000 ADT of Scenario #3, the TTC harmonic mean was only 1 second different (2 percent). Intuitively, the TTC4 and TTC10 values were typically lower with the raised median, or the same as, the condition with a TWLTL. These results are intuitive for the theoretical corridors and appear to show promise for the use of the TTC measures as a surrogate for safety in the micro-simulation environment. Sections 4.1.2 (Bryan, Texas, case study), 4.2.2 (Tyler, Texas, case study), and 4.3.2 (theoretical corridors) discuss further some of the improvements that could be made to the TTC tool in the micro-simulation environment.

CONCLUSIONS AND RECOMMENDATIONS

Desirable Input and Output Characteristics for Micro-simulation Tools Used to Evaluate Access Management Improvements

Micro-simulation is a useful and effective tool for evaluating transportation improvements provided the user understands the model and calibrates the model to field conditions. This report describes access management improvements and how they can be evaluated in the micro-simulation environment. Researchers identified key input and output characteristics (Section 2.3) that an analyst should look for when shopping for a micro-simulation tool that will be used to assess access management improvements.

Table S-2. Summary of Theoretical Corridor Micro-simulation Results.

Theoretical Corridor	Median Treatment[1]	Number of Lanes in Each Direction	Percent Difference in Conflict Points[2]	Number of Driveways	Driveway Spacing (feet)	Raised Median Opening Spacing (feet)	Estimated Future ADT[3]	Future Percent Difference in Travel Time[2]	Future Actual Difference (decrease) in Speed (mph)	Percent Difference in TTC Harmonic Mean[2] (seconds)	Future Actual Difference in TTC4[2,4]	Future Actual Difference in TTC10[2,5]
Scenario #1	TWLTL	2	Not Applicable	18	660	660	18,000 to 28,000	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Scenario #2	TWLTL	2	-70	42	330	660	18,000	2	<1	26	0.0	2.3
							23,000	6	2	-31	0.03	4.8
	Raised						28,000	31	8	85	-0.10	-6.9
	TWLTL	3	-70	42	330	660	18,000	8	2	20	0.04	-1.5
							23,000	8	2	14	0.0	0.0
	Raised						28,000	11	3	65	-0.03	-4.2
							48,000	44	9	129	-0.8	-8.0
Scenario #3	TWLTL	3	-75	84	165	660	18,000	6	2	10	-0.02	-0.2
							23,000	1	<1	8	-0.02	-0.2
							28,000	2	<1	15	0.0	-1.1
	Raised						33,000	7	2	8	-0.04	-0.5
							38,000	22	6	21	-0.05	-1.4
							48,000	10	3	-2	-0.02	0.7

[1] Scenario #1 can be considered as both a TWLTL and a raised median because, due to the driveway spacing, there is no change in the conflict points and turning locations.

[2] The percent difference values are from the conversion from a TWLTL to a raised median. Negative values imply a decrease when converting to the raised median. These differences are based upon the weighted average of at least three micro-simulation runs.

[3] The ADTs are estimated by assuming a K and D factor to apply to the observed peak-hour volume.

[4] TTC4: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds.

[5] TTC10: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds.

Micro-simulation tools do have steep learning curves to thoroughly understand their traffic flow theory and underlying computation methods. It is critical for the analyst to understand these characteristics prior to use.

Both Operational and Safety Performance Measures Are Important for Access Management

Nearly all transportation improvements assess both mobility and safety improvements. Traditional mobility measures include travel time, delay, and speed, and these measures are readily obtained from field studies and/or micro-simulation. The research also identified key measures based upon car-following theory that appear promising as surrogate measures of safety (Section 2.4). These measures relate to the time-to-collision of two vehicles. This is the time it would take for vehicles to collide given their current vectors (speed and direction). These measures where then investigated and quantified along case study corridors and theoretical corridors.

Promising Results for Incorporating TTC Measures into Micro-simulation

The research tested the incorporation of surrogate measures of safety (TTC-related measures) into the micro-simulation (VISSIM) environment. A program was written to compute the micro-simulation measures in “real-time” while the VISSIM model was running (Section 3.2). The model uses the vehicle trajectories of following vehicles. Potential angle-collisions were not considered in this initial software development, just potential “rear-end” collisions. The preliminary results on two case study corridors and three theoretical corridors are promising, particularly at lower traffic volumes. Researchers investigated the case study corridors, and theoretical corridors examined the conversion from TWLTL median treatments to raised median treatments. Driveway density was also investigated.

There were large reductions in the number of conflict points along the corridors investigated in this research when incorporating access management treatments, and the TTC measures appear to show promise in how they reflect the relative improved safety along the corridors. Generally, the TTC harmonic mean increased, TTC4 decreased, and TTC10 decreased when converting to raised medians (particularly for relatively uncongested conditions and along the theoretical corridors). While there is still a better understanding needed of what the specific values of the TTC output may mean (i.e., there are no standard values for what is “good” or “bad” for a given condition), the results appear useful for relative comparisons across transportation alternatives that include access management with some minimal additional calibration and testing.

Because the TTC measures capture acceleration characteristics inherently, they are anticipated to be useful for investigating many types of geometric design improvements beyond just access management improvements.

While there are some needed improvements necessary to improve the program and computation of the TTC within the micro-simulation environment (see Section 5.2), the preliminary results are promising.

Signal Timing Improvements Always Provide Corridor Improvements

Transportation agencies are always seeking cost-effective solutions to improve the transportation system while utilizing taxpayer dollars wisely. On all of the case study corridors and theoretical corridors investigated in this research, simply optimizing the signal timings always resulted in mobility improvement along the corridor.

Safety and Operational Access Management Performance Measures Can Be Incorporated into the Traditional Transportation Planning Process

This research report discussed how surrogate measures of safety could be incorporated into the traditional transportation planning process in the same way as traditional mobility measures (Section 4.7). In time, given target values for the TTC measures, transportation planning analyses might also incorporate safety measures into demand management (4-step) models as well.

Case Specific Corridor Results: Use Caution When Transferring Results to Other Corridors

Different results were found along both case study corridors due to local conditions. For the conversion of a TWLTL to a raised median along the Bryan, Texas, corridor, there was as much as a 7 mph increase in speed along the corridor with the installation of the raised median while along the Tyler, Texas, corridor there was a 5 mph decrease in speed at the ~48,000 ADT level. The corridors did contain relatively long median opening spacings—as much as 1,500 feet on the Tyler, Texas, corridor. Relatively long median opening spacings occurred adjacent to a retail shopping area, which, when congested, substantially increased the number of U-turning vehicles and the subsequent weaving that must occur from the U-turn lanes to desired driveways, thus slowing through movements.

It is more important to note that all corridors are different. They contain various corridor characteristics including travel demand, origins-destinations of travel, driver behavior, and geometric elements to name a few. Therefore, it is important to use caution when transferring results from one corridor to another. When calibrated to field conditions, micro-simulation provides a tool that can estimate the effects of the combination of these different corridor characteristics.

FUTURE WORK

Calibrate TTC Results to Crash Data

There is a need to calibrate/compare the TTC results to corridors on which actual crash data have been collected to identify the correlation of the micro-simulation TTC results to field crash information.

Investigate Case Studies with Closer Median Opening Spacings

There is a need to investigate case study locations with closer median opening spacings than those investigated here. Along the Tyler, Texas, corridor, the median opening spacings were as long as 1,500 feet, while along the Bryan, Texas, corridor, the median opening spacings were as long as 1,320 feet (Table 4-4). There is a corridor-specific optimal location of median openings based upon corridor specific characteristics to optimize speed while increasing safety and only limited conditions could be investigated in this report.

Expand TTC Program to Angle Crashes

The program developed to operate using the VISSIM vehicle trajectory data uses only "rear-end" crashes in this initial version. Therefore, it only considers two following vehicles. There is a need to expand the software to include angle crashes between vehicles.

Incorporate Distribution of TTC Values

Distribution information about the TTC measures would be valuable to compute. While the program does keep the mode of the TTC values for a given run, standard deviation information would be equally valuable to identify the variability in the average TTC for a given alternative—a potentially equally important measure for investigating potential collision severity.

Isolate TTC Computations to the Segments of Interest

In the current versions of the program developed for this analysis, researchers collected the speed information along the corridor itself based upon the travel time of vehicles traversing the entire corridor, while the TTC computations are performed on all vehicles in the micro-simulation. Therefore, the TTC measure includes the interactions of all vehicles in the system and in the micro-simulation (i.e., those vehicle interactions along the roadway and those that are occurring on parcels along the roadway—entering the roadway). Further, the TTC computations would include all vehicle interactions that occur prior to the vehicles getting to the travel time data collection points along the roadway. Therefore, when comparing speeds (travel times) to the TTC measures computed for this report, they are based upon different "groups" of vehicles.

There is a need to isolate the computation of the TTC measures to just the segment(s) of the corridor of particular interest where the travel time data collection points are located.

Define TTC Values

There is a need to establish reasonable ranges for the TTC. Control sites/conditions would be needed to identify the "normal" (baseline) value of a TTC. For example, are the values of 1 or 2 percent for TTC4 "average" or "low"?

Further Investigate TTC "Cutoff" Values

This report used the TTC4 and TTC10 values as appropriate TTC thresholds. This was based upon experiences noted in the literature and professional judgment. There is a need to further investigate whether these thresholds are appropriate or if values between TTC4 and TTC10 may be relevant for some operational situations. Investigating the variability on the TTC values (Section 5.2.4) would assist in this task.

Perform More Micro-simulation Runs on More Case Study Corridors—Particularly Under Congested Conditions

Given the numerous needs outlined above, there is a need to perform more micro-simulation runs on different geometric and operational conditions. Due to the variability of traffic as conditions become more congested, there is a particular need to perform more runs under congested conditions.

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LIST OF ACRONYMS

AASHTO:	Association of State Highway and Transportation Officials
ADT:	Average daily traffic
AIMSUN:	Advanced Interactive Microscopic Simulation for Urban and Non-Urban Networks
CORSIM:	Corridor Simulation
COTS:	Commercial off-the-shelf
CP:	Collection point
DDHV:	Directional design hour volume
DeltaS:	Maximum relative speed of the vehicles
DR:	Deceleration rate
FHWA:	Federal Highway Administration
FRESIM:	Freeway Simulation
ITE:	Institute of Transportation Engineers
MaxS:	Maximum speed of the two vehicles
NCHRP:	National Cooperative Highway Research Program
NETSIM:	Network Simulation
PARAMICS:	Parallel Microscopic Simulation
PET:	Postencroachment time
RM:	Raised median
RMO:	Raised median opening
TRB:	Transportation Research Board
TTC:	Time-to-collision
TTC10:	Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds
TTC4:	Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds
TWLTL:	Two-way, left-turn lane
TxDOT:	Texas Department of Transportation
VISSIM:	Verkehr in Städten Simulation (Traffic in Cities-Simulation)

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CHAPTER 1

INTRODUCTION

Access management techniques (e.g., median treatments, driveway consolidation, auxiliary lanes, signal spacing, etc.) are proven methods for improving traffic flow, safety, and protecting the initial public investment in the transportation infrastructure. However, to date there is no standard method for quantifying the “level,” whether satisfactory or unsatisfactory, of access management improvements along a corridor. There are no specific performance measures that directly capture the myriad of operational and safety-related impacts of access management techniques—particularly in a commercial off-the-shelf (COTS) software that can be used to evaluate roadway improvements that include access management.

It is hypothesized that “tracking” the acceleration and deceleration characteristics of individual vehicles can be used as a surrogate measure of the extent of conflict (i.e., relative safety) along a given corridor. For example, a measure that relates to the individual acceleration characteristics per mile or per hour would allow measurement of the conflicts, and therefore relative safety, along a corridor. This report describes research that investigates these possibilities.

1.1 PROJECT OBJECTIVES

To satisfy the needs highlighted previously in this chapter, the primary objectives of this research effort were to:

1. Assess the state-of-the-practice relative to performance measures that are applicable to access management and identify existing and/or new measures—particularly measures that can capture the safety benefits of access management treatments.

2. Perform micro-simulation using the identified measures on two selected case study corridors and on three theoretical corridors to demonstrate the application of the measures.

3. Develop guidance for applying the performance measures for evaluating roadway improvements that include access management treatments and incorporating them into the transportation planning process.

1.2 WORK PLAN

Researchers identified and performed the tasks described below to satisfy the objectives above.

1.2.1 Conduct State-of-the-Practice Literature Review

This task was performed to satisfy the first objective of the research. This objective is to investigate performance measures that are applicable to access management—particularly those that can be used as surrogate measures of safety. Less discussion is provided on typical operational performance measures (travel time, speed and delay) because they are generally well understood and implemented into transportation analysis software currently. Rather, the literature focuses on providing an overview of access management treatments, the use of micro-simulation tools for investigating access management, necessary model characteristics when selecting a micro-simulation tool, and how safety analysis might be incorporated into the micro-simulation environment.

The section that discusses how micro-simulation might incorporate safety analysis includes a discussion of measures identified in the literature that hold promise as surrogate measures of safety for roadway improvements in the micro-simulation environment. The time-to-collision measure is initially identified and defined in that section (Section 2.4).

1.2.2 Develop Analysis Procedure and Perform Necessary Data Collection

This task included the development of the analysis procedure and collection of necessary data. A simultaneous effort funded by the Texas Department of Transportation provided data from two corridors in the state of Texas that were used in the micro-simulation. The available data included traffic volumes, signal timings, geometric conditions and turning volumes. In addition to the two case study corridors, the research team developed “theoretical corridors” to further test the TTC measure as a surrogate for safety in the micro-simulation environment.

1.2.3 Perform Micro-simulation

The micro-simulation was performed as part of this task. Micro-simulation was performed on the two selected case study locations as well as on the three theoretical corridors.

The researchers developed a subroutine within a micro-simulation model that computed TTC statistics in “real-time” as the model was running. Therefore, safety (with TTC as a surrogate) and operational (travel time, speed, and delay) information were both obtained in the same software package.

1.2.4 Identify Methods to Incorporate Methodology into Transportation Planning Process

The work documented in this report clearly demonstrates the promise of incorporating surrogate safety measures into the micro-simulation environment. The report takes the findings and observations from the analysis, and describes how they may be incorporated into the transportation planning process as part of this task.

1.2.5 Prepare Final Report

The final task in the completion of this project was the preparation of this deliverable that documents the research need, literature review, procedures, case studies, findings, conclusions, and recommendations.

1.3 REPORT ORGANIZATION

This report is organized into a summary, five chapters, and a references section as described below.

- **Executive Summary:** This summary provides an overview of the research and results. It is intended to be a "stand-alone" summary.
- **Chapter 1, Introduction:** This chapter presents an introduction to the research topic, project objectives, work plan, and this report organization.
- **Chapter 2, Literature Review:** This chapter presents the results of the state-of-the-practice literature review.
- **Chapter 3, Micro-simulation Model Selection, Analysis Procedure, and Case Studies:** This chapter describes the micro-simulation model selection, the procedure for the analysis, and the corridors selected for analysis.
- **Chapter 4, Micro-simulation Findings:** This chapter presents the research findings, which include the quantitative results of the micro-simulation as well as observations related to using the micro-simulation model for evaluating the transportation improvements that include access management techniques.
- **Chapter 5, Conclusions, Recommendations, and Future Work:** This chapter describes the recommendations and discussion related to the findings in the report. This chapter also includes future research needs.
- **References:** This section lists the references used in the report.

CHAPTER 2

LITERATURE REVIEW

2.1 ACCESS MANAGEMENT TREATMENT OVERVIEW

According to the Transportation Research Board's (TRB's) *Access Management Manual*, access management is "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway. It also involves roadway design applications, such as median treatments and auxiliary lanes, and the appropriate spacing of traffic signals. The purpose of access management is to provide vehicular access to land development in a manner that preserves the safety and efficiency of the transportation system" (*1*).

Access management techniques address traffic flow operations and safety through the reduction of vehicular conflict points. Access management is a tool to positively affect motorists in terms of safety, capacity, and speed while providing an advantage to adjacent land uses (*2*,*3*). It does so by providing various land uses proper access (*4*).

There is a delicate balance when implementing access management treatments. There should be a trade-off between maximizing through traffic movement and proper access to adjacent land uses. This balance depends on the roadway's function and the user (*5*). National Cooperative Highway Research Program (NCHRP) Report 420, *Impacts of Access Management Techniques*, provides insight into eight techniques, which are most commonly used to improve operations and safety. These eight techniques consist of 1) traffic signal spacing, 2) unsignalized access spacing, 3) corner clearance criteria, 4) median alternatives, 5) left-turn lanes, 6) U-turns as alternatives to direct left turns, 7) access separation at interchanges, and 8) frontage roads. NCHRP Report 420 provides a state-of-the-practice review of the available information on access management techniques and their effectiveness (*2*).

One technique when addressing access management is traffic signal frequency and uniformity. Studies show that an increase in the amount of signalized intersections leads to an increase in delays and collisions (*2*,*3*). Of the eight access management techniques examined in NCHRP 420, spacing of signalized intersections had the highest correlation with vehicle crash rates. The space required between signalized intersections depends on roadway speed and geometry, signal cycle lengths, signal offsets, and signal phasing. Intersections with higher speeds and longer cycle lengths require a greater distance between signals than intersections with lower speeds and shorter cycle lengths to maintain signal progression. Increasing frequency of traffic signals causes greater delay.

For example, from Table 2-1, travel time increases 16 percent when signalized intersections increase from two to four signals per mile. On a related note, an article in the *ITE Journal* notes that one easy and cost-efficient method to ease traffic flow and increase safety is to simply optimize existing traffic signals. Optimizing signal timing, cycle length, offset, and phasing provides maximum vehicle movement along the corridor by reducing the frequency of stops (*6*). In turn, the reduction of stop frequency improves safety. The advantage of optimizing signal timings has been demonstrated in recent research performed at the Texas Transportation Institute on access management impacts. In this report, both case study corridors examined indicated substantial improvements in travel time and delay by merely optimizing existing signal timings (*7*). The research highlights the significant corridor improvement that can be achieved with relatively low-cost improvements.

Table 2-1. Estimated Effect of Signal Density on Corridor Travel Times (Reference *2*).

Signals Per Mile	Percent Increase in Travel Times (Two Signals Per Mile as Base)
3.0	9
4.0	16
5.0	23
6.0	29
7.0	34
8.0	39

Not only is the frequency of signalized intersections an important part of access management, unsignalized intersections (driveways and cross streets) have similar safety and operational impacts because more driveways introduce additional conflict points along the corridor. Similar to signalized intersections, corridors with a high frequency of driveways and cross streets have increased traffic flow interferences and subsequently higher crash rates (*3*,*8*,*9*,*10*). A safety study analyzing 37,500 crashes from 240 roadway segments in various states found a 4 percent increase in crash rates for every additional access point per mile (*2*). Other studies have found that spacing driveways further apart increases traffic flow by reducing conflict points, creating longer recovery distances, and creates space for turn lanes. It is estimated on divided highways each additional conflict point can reduce speeds by 0.25 mph. This speed reduction is observed up to 10 mph for 40 access points per mile (see Table 2-2) (*2*).

Table 2-2. Relationship Between Access Density and Free-flow Speed Reduction (Reference *2*).

Access Points Per Mile	Reduction in Free-flow Speed (mph)
0	0.0
10	2.5
20	5.0
30	7.5

Driveway and signal density, number of lanes, lane widths, median treatment types, raised median openings spacing, traffic volumes, and turn lanes are all different operational and geometric variables that cause different safety and delay impacts on roadways. However, even under ideal operational and geometric conditions, an increase in the number of driveways equates to an increase in crash rates (see Figure 2-1) (*2*,*9*). Similar findings have been found in Texas (*7*,*11*) Research indicates that too many driveways can impede traffic flow by creating friction along the corridor. On the other hand, in extreme cases, research indicates that too few driveways along a corridor may also slow down traffic flow. This could occur under high volume conditions when an abundant amount of traffic stays on the roadway because there are limited locations to access their destinations. It could create backups at the access points because all the vehicles are using the limited access points (*8*). There is a delicate balance between granting enough access to adjacent land while not impacting through traffic. Therefore, the space between driveways and signalized or unsignalized intersections is a critical concern.

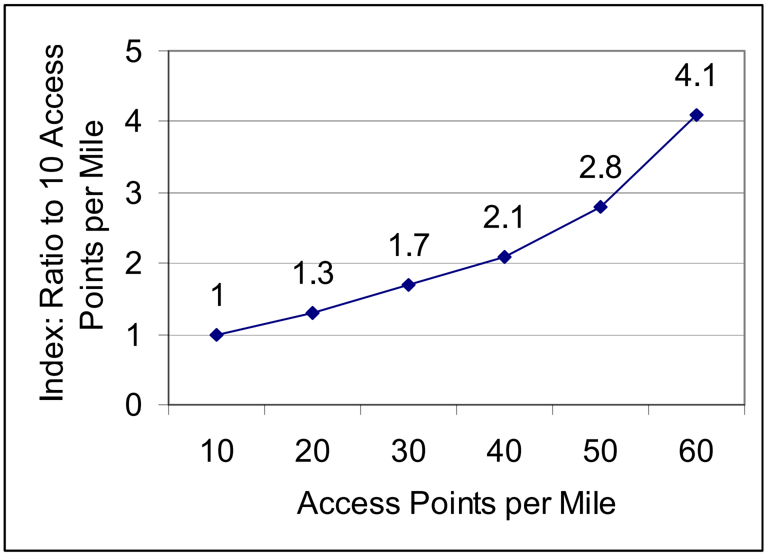


Figure 2-1. Relationship between Access Points per Mile and Crash Rate Index (Reference *2*).

Corner clearance is the distance between driveways and intersections. The American Association of State Highway and Transportation Official's (AASHTO's) *A Policy on Geometric Design of Highways and Streets* ("Green Book") indicates that an intersection's functional area, which extends the length of auxiliary lanes, should be clear of driveways (*12*). As with other access point spacing, there is a link between the spacing of driveways/intersections and crash rates. Again, the number of conflict points increases when access points are closely spaced together, whether it is driveways or cross streets. If a driveway is too close to an intersection, it may cause confusion to through traffic regarding which access point the turning vehicle will use. Insufficient distances from driveways to intersections can make left turns at the intersections difficult, and left turns into the driveway may cause queuing into the intersection. The minimum corner clearance should be derived from geometric considerations, green signal cycles, and the roadway speed limit. In general, guidelines and/or regulations need to be established before development of adjacent parcels. Simple design alterations of the intersection and corner property might also solve this issue. Some design techniques would include locating driveways on side streets, at the far end of the property, consolidating driveways with neighboring properties, or placing a raised median at the intersection (i.e., making the driveway "right-in, right-out").

Installing median alternatives is another way to provide safety and operational benefits to drivers. *NCHRP Report 420* identifies the following median alternatives: installing a two-way left-turn lane (TWLTL) on an undivided roadway, installing a raised median on an undivided roadway, and converting a TWLTL into a raised median (*2*). The addition of a median treatment to any roadway improves safety and delay by removing left-turning vehicles from the path of through traffic. Studies have found that installing a TWLTL on an undivided roadway can substantially improve safety as well. A reduction in the total number of crashes was seen in 90 percent of the cases with an average reduction of approximately 33 percent. Crash rates were also reduced with the installation of a non-traversable median on an undivided roadway. This was found in both directional and full left-turn median openings (*2*). By physically separating opposing traffic, it eliminates head-on collisions, controls left turns, and reduces the amount of conflict points.

Turn bay length is an important element of raised median success. If the length is too short it will not remove all the necessary vehicles from through traffic, which causes queuing into the through traffic lanes. In cases where left turns need to be controlled, a non-traversable median can be installed to replace the TWLTL. As with the installation of a non-traversable median to an undivided roadway, the conversion reduces the number of conflict points by reducing the number of turn locations. Non-traversable medians have a higher safety record than a TWLTL. Adding a TWLTL to an existing undivided roadway will also provide some safety and congestion benefits. Figure 2-2 shows the relationship of safety at different traffic volumes for roadways that are undivided. NCHRP 395 and a related ITE Journal article provide insight into when to convert based upon operational and crash analysis (*13*,*14*).

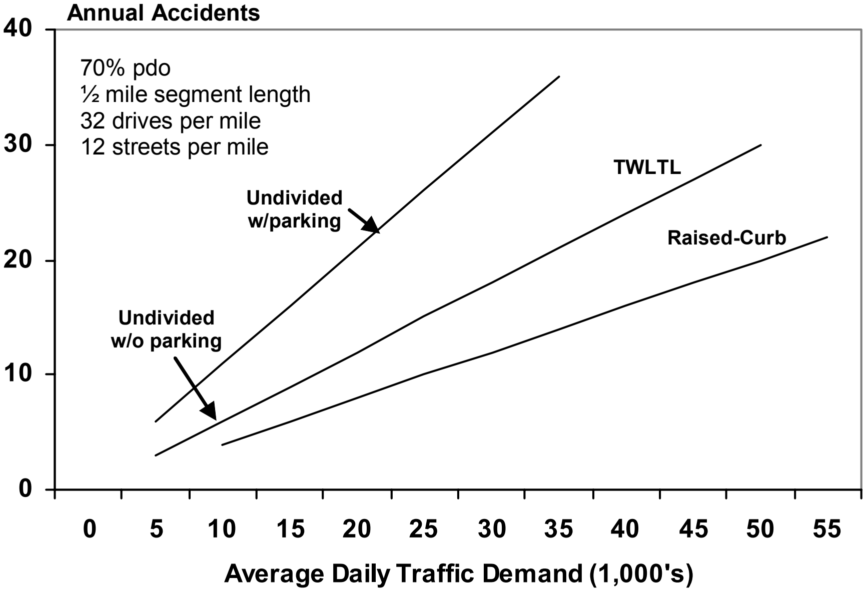


Figure 2-2. Relationship of ADT and Annual Crashes (Reference *13*).

Many states are beginning to realize the benefits of prohibiting left turns at intersections and driveways due to the reduction of conflict points and increased safety. A recent study included a survey of the 50 states regarding the prohibition of left turns. Of the 25 states that responded, only six states had some type of policy or guidelines for restricting left turns, seven states had completed studies on the effects of left-turn prohibition, and eight had some type of design guidelines for restricting or accommodating deterred traffic (*4*).

U-turns at mid-block locations, U-turns at intersections, the Michigan "U," and jug-handles are commonly used techniques to reroute traffic in the opposite direction to account for turn restrictions. Some locations provide dual left-turn lanes at intersections allocating the inner lane for U-turns only. Studies have shown a decrease in crash rates in locations where full left turns were restricted with the installation of raised medians (*7*,*15*).

Cities can use different access management techniques to reduce the number of conflict points along corridors. The overall benefits from reducing conflict points are improved safety and improved traffic flow. Research has proven that corridors with relatively few conflict points have smoother traffic operations and increased safety compared to corridors with a greater amount of conflict points.

This section of the literature provided an overview of key access management principles and treatments. The Transportation Research Board (TRB) Access Management Committee maintains an Internet site that includes more information and numerous references that may also be of interest to the reader (*16*). The next section of this chapter discusses the use of micro-simulation for measuring access management impacts.

2.2 MICRO-SIMULATION TOOLS FOR ACCESS MANAGEMENT

Micro-simulation is one method frequently used to analyze the benefits of access management. Transportation micro-simulation programs include traffic models that include car-following theory, lane changing operations, and gap acceptance rules to imitate real-world roadway networks (*17*,*18*). Micro-simulation can be used to develop new systems and optimize their effectiveness. Many of these impacts, such as pollution emission, are often difficult to measure in the field (*17*). Micro-simulation programs focus on individual vehicle characteristics to evaluate speed and location.

Simulation models can be macroscopic or mesoscopic. Macroscopic models generally work best for large traffic networks covering larger areas. Mesoscopic models have aspects of both micro- and macro-simulation models (*19*,*20*). Because of micro-simulation's capabilities, it is often used to evaluate access management techniques (*21*). Traffic simulations can provide a detailed comparison of roadways with and without access management treatments and illustrate safety issues (*22*). Animation is another benefit in using simulation to observe operations of different access management techniques. The user is able to visually compare influences of different designs. They allow the user to identify impacts both spatially and temporally at the individual vehicle level. There are several different micro-simulation programs. Identified below are some widely used micro-simulation programs (*18*,*23*,*24*):

- Advanced Interactive Microscopic Simulation for Urban and Non-Urban Networks (AIMSUN): The AIMSUN traffic program is a microscopic model developed by the Universitat Politecnica de Catalunya and Transport Simulation Systems in Barcelona, Spain. It is used to simulate new traffic systems and policies. AIMSUN can also be used to model all urban traffic networks individually or in combination with each other. Vehicle delay time modifies the gap acceptance time for that vehicle.

- Corridor Simulation (CORSIM): CORSIM is a traffic simulation model developed by the Federal Highway Administration (FHWA). It embodies two other computer models—Network Simulation (NETSIM) and Freeway Simulation (FRESIM). CORSIM simulates the traffic and traffic control conditions of a network over a period of time. CORSIM can be used for a wide range of applications.

- INTEGRATION: The name "INTEGRATION" is derived from the program's ability to integrate a number of unique capabilities. First, it integrates traffic assignment and microscopic simulation. Second, the program integrates freeway and arterial modeling within a single logic. It originated from a mesoscopic model base.

- Parallel Microscopic Simulation (PARAMICS): Paramics is another popular microscopic tool that can be used for modeling transportation alternatives. Paramics was originally developed by the Edinburgh Parallel Computing Centre located at the University of Edinburgh and SIAS Limited.

- Verkehr in Städten Simulation (Traffic in Cities-Simulation) (VISSIM): VISSIM is a microscopic traffic simulation model developed by the University of Karlsruhe, in Germany. VISSIM simulates all transportation models such as vehicles, transit, bicycle, and pedestrian traffic flow.

2.3 SELECTING A MICRO-SIMULATION TOOL FOR ACCESS MANAGEMENT IMPROVEMENTS

This section describes desirable characteristics for selecting a micro-simulation model for evaluating roadway improvements that include access management. Many of these characteristics are documented elsewhere (*20*) and repeated here for the interested reader.

Micro-simulation tools allow for detailed analysis of traffic systems and have great potential for analyzing corridors with access management improvements. They implicitly account for the stochastic nature of the transportation system and can provide both temporal and spatial information down to the individual vehicle level. As well, this information can be aggregated to provide information at any spatial or temporal level. There are several elements that should be considered when selecting a micro-simulation tool for evaluating access management strategies. These elements are categorized as belonging to either the input or output characteristics of the micro-simulation model. The following sections briefly describe some of these factors as they relate to micro-simulation needs when investigating access management improvements.

2.3.1 Input Characteristics

Analyzing access management strategies requires that a micro-simulation tool include the opportunity to input the complex conditions that must be considered when evaluating access management improvements. The ability for the micro-simulation model to manage geometric inputs is clearly important when evaluating access management techniques because access management strategies often include changes in roadway geometry. It is imperative that the model allows for locating driveways in their environment to scale. There must also be the ability to include acceleration or deceleration lanes (common access management techniques) in combination with these driveways. Turning radii and lane width are also important geometric factors that are necessary in the roadway network.

The micro-simulation tool must also have the ability to handle numerous operational inputs that affect traffic flow. These include gap acceptance, speed, and acceleration characteristics. Typically, the micro-simulation model should allow for these parameters to be input into the model. Empirical or theoretical speed and acceleration distributions should also be input items. Accurate traffic signal simulation is also an important element for a micro-simulation tool because signal spacing is an important access management treatment. In addition, accurate traffic signal operations and traffic progression are required if micro-simulation tools are to be used successfully. Because the success of traffic signal treatments depends on proper timings, it is important that the simulation package, 1) has traffic signal optimization routines, or 2) allows for the importation of traffic signal data to be input from external traffic signal software.

It is important that traffic operation effects (i.e., reduction in delay and/or travel time) be solely attributed to the transportation improvements made to a given corridor and not due to changes in traffic operations along the corridor (i.e., weaving). Therefore, it is imperative that users have complete control of the network demand. Control of the network demand can be accomplished by providing a method to input origin-destination pairs and paths or exclusively handle routing decisions of vehicles so that changes between simulation runs and alternatives do not include the influences of weaving maneuvers. For example, it can be readily shown that different origin-destination matrices, which result in the same link volumes, can result in travel time estimates that are over 20 percent different. In the case of the VISSIM micro-simulation package, origin-destination pairs and paths may be modeled through the use of dynamic assignment. Without dynamic assignment, the user supplies static routes for simulated vehicles (i.e., the drivers in the simulation have no choice of which way to go from their origin to their destination).

Finally, the analyst must understand the underlying theory behind the micro-simulation model, and the model must also be calibrated to field conditions. The underlying theory will affect driver behavior, vehicle type characteristics, and traffic flow within the context of the other input parameters. Generally, there are input parameters within the model that can be adjusted to better reflect field conditions. Recent research has found that calibration within CORSIM 5.0 results in a reduction in error relative to measured volumes from 11 percent to 0.5 percent, and in CORSIM 4.32 the error was found to reduce from 28 to 5 percent between the default parameter and calibrated results (*25*). Therefore, calibration to field data is important when using micro-simulation tools rather than relying upon the default values.

2.3.2 Output Characteristics

Considering the output characteristics necessary for a micro-simulation tool used for evaluating access management techniques is also important. For access management applications, the analysis requires the ability to analyze the system at any level of spatial or temporal detail. In particular, this is required at the individual level to provide for both disaggregate and aggregate analyses. Output is necessary for different locations (spatially) along the corridor where access management treatments are being evaluated. For example, signalized and unsignalized intersection and/or raised median openings may be locations where traffic operations are of particular interest. Temporal output that allows investigation of traffic operations through time is also necessary as it allows the analyst to investigate platooning, queuing, and other time-based operations. Micro-simulation allows for this investigation at the individual vehicle level.

It is also beneficial if the micro-simulation software provides an animation feature to allow the analyst to watch the simulation run to provide a visual check of consistency and to ensure there are no suspicious movements in the network (e.g., vehicles colliding). Further, animation abilities are valuable for graphically illustrating the operation and impacts of corridors after access management techniques have been implemented. The ability to perform animation in three dimensions is valuable in simulating and presenting alternatives involving access management elements (*26*).

2.4 INCORPORATING SAFETY ANAYLSIS INTO MICRO-SIMULATION

Studies have related traffic flow parameters to safety, and it is generally well known that particular parameters, such as speed variation, certainly influence roadway safety. Traffic operations can be modeled, while safety analyses are often done with crash data. There is a need for methods that incorporate safety surrogates into the micro-simulation environment to further enrich transportation improvement analyses that include access management treatments. This section describes the typical limitations and difficulties with using crash reports for safety analysis and describes surrogate methods for safety analysis.

Collecting crash reports from agencies is one way to identify crash rates and estimate future rates. There are, however, many well-documented reasons that crash records should be used cautiously to estimate crash rates. Solely relying on crash reports as a safety predictor for different access management treatments may not involve the full extent of safety impacts. One reason is that crashes can be avoided by drivers. For example, drivers could slam on their brakes and swerve to miss a potential crash. Therefore, a crash is avoided, but there is certainly a potential conflict. In addition, crashes can be rare events, making their statistics difficult to use in predicting success or failure of geometric improvements. The number of crash events is very small in comparison with the exposed population of events, producing very small probabilities of occurrence, which, in turn, can be difficult to extrapolate or predict. Taber stated: “while it is attractive to measure crash likelihood based on historical information, previous discussion has shown predictions are not usually that statistically significant because of the random nature of reported crashes” (*3*).

Not all crashes are reported to the authorities—a trend that is intensified by changes in crash report thresholds. Different agencies having different levels required for reporting collisions causes difficulty. Some drivers do not want to report a crash because they do not want their insurance rates to increase. In some states, reports are not filed if the collision occurred on private property (*15*,*27*,*28*). Even those crashes that get reported create reason for concern.

Some problems occur with the documentation itself and some involve the record system. Research has found that on average there are 1 to 2.2 errors per crash record (*28*). These are just inconsistencies found from the crash report to the crash record on file. Errors are also found in the crash location. When drivers fill out a report, they occasionally misjudge distances and/or misspell street names creating an unknown crash location. More detail is needed in the reports to provide sufficient data to determine the cause of collision (*15*,*27*,*28*).

Many alternative safety measures can be used instead of, or in combination with, crash reports. In 1967, Perkins and Harris proposed a traffic conflict concept as a substitute for crash data (*29*). They desired a method to replace the scarce, unavailable, or unsatisfactory crash reports with a method to define traffic events or incidences that occur frequently, can be observed, and are related to crashes. A traffic conflict is an observable situation in which two or more road users approach each other at a given time to the extent that if there is no change in movement they risk colliding (*30*,*31*). Traffic conflict points have a potential crash situation leading to an evasive action such as breaking or swerving (*32*).

There have been a variety of observation methods developed to measure traffic conflicts. These methods can be categorized into subjective and objective. Subjective methods include considerable judgment by the observer and are criticized by some because the grading of severity of the evasive action can vary greatly from one observer to another (*33*,*34*).

To supplement field studies, or when field studies are not possible, and/or cannot provide the required accuracy, micro-simulations are used as surrogate measures for safety (*20*,*33*,*34*). Gettman and Head list five surrogate measures that are frequently used for safety indicators: time-to-collision, postencroachment time (PET), initial deceleration rate (DR), maximum speed of the two vehicles (MaxS), and maximum relative speed of the vehicles (DeltaS) (*33*,*34*). They identify the first three as measures for conflict severity, and MaxS and DeltaS as measures for severity of possible conflicts (*33*,*34*). TTC has been proposed as the primary measure for conflict severity (*33*). On the other hand, some researchers believe that TTC can predict the collisions, but it cannot necessarily determine severity because speed is not included. They state that the deceleration rate is a better indicator of severity than TTC (*33*). Table 2-3 provides a summary of these surrogate measures.

Over the years, TTC is the one method researchers have proven effective as a surrogate for safety. In 1972, John Hayward introduced the TTC concept. He noticed, while watching traffic videos, that when a possible incident was about to occur, vehicles would maneuver around the situation causing a "near miss." Near misses are defined as traffic incidents where a vehicle must react to a potential conflict quickly to avoid a collision. Initially, this "near miss" idea was thought of as a surrogate measure for safety. However, it never became a crash predictor because of its highly dependent nature on the observer to determine near miss situations. The calculated TTC concept slowly evolved from the observed near miss theory. This evolution quantified the near miss theory (*35*).

Table 2-3. Summary of Surrogate Safety Measures.

Measure	Acronym	Surrogate	Description
Time-to-Collision	TTC	Conflict Severity	Time it would take for a vehicle to collide into another if they continue at the same speed without trying to avoid each other (*18*,*19*,*21*,*30*,*32*,*33*).
Postencroachment Time	PET	Conflict Severity	Time between the first vehicle and following vehicle to cross the avoided conflict location (*18*,*32*).
Deceleration Rate	DR	Conflict Severity	Rate at which a vehicle decelerates to evade a potential collision with another vehicle (*18*,*32*).
Maximum speed of the two vehicles	MaxS	Severity of Possible Conflicts	Calculated by first calculating the maximum speed of each vehicle. Then each of those speeds is compared to determine the maximum speed (*18*,*32*).
Maximum relative speed of the two vehicles	DeltaS	Severity of Possible Conflicts	Calculated as the difference in velocity for every time slice during the time of the conflict event. The maximum value of the time slices is recorded as DeltaS (*18*,*32*).

A TTC value at any instant is defined as the time that remains until a collision between two vehicles would have occurred if the collision course and relative speed difference had been maintained. TTC can be calculated at any time slice by dividing the distance between two vehicles by the speed difference of the vehicles (*21*,*31*,*33*,*34*). If two vehicles will not collide at any time, the TTC value is infinite (i.e., if a lead vehicle is accelerating away from a following vehicle). If two vehicles can collide at some time, the TTC value is finite and decreasing with time. The minimum TTC reached, as the vehicles approach on the collision course, is taken as the critical measurement in estimating conflict severity (*32*). There needs to be a positive speed difference between vehicles for the TTC to be significant. A negative speed difference indicates the vehicles are not on a collision course. Higher TTC values tend to indicate low collision risk, while lower TTC values equate to potentially unsafe situations (*21*,*31*,*33*,*34*). A suitable threshold is needed to differentiate between safe and unsafe circumstances. Depending on the researcher and the research area, typical threshold values can range between 1 and 4 seconds (*21*,*31*).

2.5 CONCLUDING REMARKS

Access management is one way to increase traffic movement and roadway safety. The numerous access management techniques described in this chapter all reduce and/or manage the number of conflict points along a corridor. This is an essential part of achieving the goal for safer and less congested roadways. When conflict points are removed, the likelihood of vehicle collisions decreases.

Many different micro-simulation programs are available to investigate roadway improvements and access management strategies. Micro-simulation tools allow the user to visually examine the corridor while producing output results that indicate how different access management techniques performed. This chapter identified desirable input and output characteristics for selecting a micro-simulation model for investigating access management alternatives (Section 2.3). It would appear that most micro-simulation tools are capable of producing safety indicators—as long as there is a way to obtain the individual time-step vectors and locations.

Of the many surrogate safety measures available, TTC appears to be particularly promising. This is due to its ability to estimate the extent of conflict for the alternative being investigated because the measure inherently includes the acceleration characteristics of individual vehicles and their interactions. Roadway improvements that incorporate access management should improve traffic flow and subsequently reduce "stop-and-go" traffic and improve the average TTC for the given alternative.

Micro-simulation also allows the user to perform visual observation, and it can provide precise TTC calculations in sub-second time steps. The ability to include typical traffic operations characteristics (e.g., travel time, speed, delay) and safety evaluations (e.g., TTC) in one software package (micro-simulation) would allow analysts to theoretically assess operations and safety more efficiently.

CHAPTER 3

MICRO-SIMULATION MODEL SELECTION, ANALYSIS PROCEDURE, AND CASE STUDIES

This chapter describes the selection of the micro-simulation tool VISSIM to evaluate operational and safety impacts of access management in one software tool. This chapter also describes the selected case studies and theoretical corridors as well as detail on how the time-to-collision analysis was performed.

3.1 SELECTION OF MICRO-SIMULATION TOOL

3.1.1 Selection of VISSIM

Section 2.3 of this report described key input and output characteristics that one should look for when selecting a micro-simulation tool for evaluating roadway improvements that include access management. The input and output characteristics identified in that section were largely identified as part of this research. They were documented in a prior conference paper based on the experiences of this research (*21*).

VISSIM is a microscopic, time step, and behavior-based model developed to simulate urban traffic and transit operations (*36*). Researchers chose this modeling tool for its unique ability to simulate specific complex multiple-conflict points and dynamics associated with the two-way left-turn lane (TWLTL) arterial environment. VISSIM also satisfies the input and output characteristics identified in Section 2.3 of this report. The research team used the model to quantify the performance measures of travel time, speed, delay and TTC along the study corridors. The research team also had experience with the VISSIM model from previous research. Because micro-simulation models have fairly steep learning curves, using the research team's prior experience was beneficial. It should be noted that any number of micro-simulation models could likely have been used, but for the reasons presented in this section, the research team chose to use the VISSIM model.

VISSIM is an ideal tool for modeling changes from a TWLTL to a raised median (a common access management roadway improvement) because of its dynamic routing system. When a route is removed (i.e., a left-turn movement is eliminated when a raised median is installed), VISSIM causes the vehicle to automatically find the next shortest route, which is the next median opening. VISSIM can also animate the simulation. Therefore, the user can visually identify any problems occurring in the model and check the model for accuracy. This visual animation is also an informative tool that the public can easily see and understand.

Although VISSIM is a good modeling tool, it cannot optimize signal timing. Whenever traffic volumes or roadway geometrics change, the user must optimize signal timing, allowing maximum flow of vehicles through the intersection. Comparing the incremental benefits of various alternatives is more accurate when all the scenarios have optimized signal timing.

3.1.2 VISSIM Inputs and Coding

The first step in creating the model was gathering the necessary data. Generally, the research team obtained an aerial photograph of the case study corridors for use as the background in VISSIM. The research team found that opening VISSIM with the background in place slowed the simulation. Researchers manually collected the necessary geometrics such as lane configurations, lane widths, driveway widths, distance between driveways, and lengths of dedicated lanes. They also collected traffic volumes on the mainlanes and turning movement counts at signalized intersections and driveways along the corridor. These counts were taken during the noon and evening peak hours. Researchers also obtained signal timing for the signalized intersections on the corridor. Finally, the team completed travel time runs using the floating-car method in both directions on the corridor during the peak hour (*37*). The data collected during the travel time runs were used in the calibration process to ensure that the VISSIM model was operating in a similar manner to the travel time run data collected in the field.

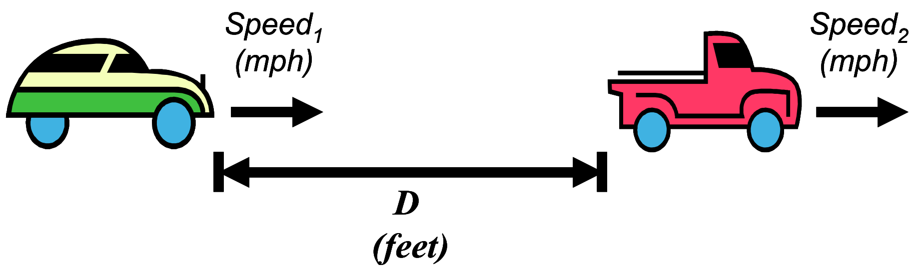
Research team members input the gathered information into VISSIM, which was a tedious task. For a new user, entering these data can be a very time-consuming process. However, as the user becomes more familiar with the software, this stage of the modeling procedure becomes easier and less time consuming.

3.1.3 VISSIM Testing and Calibrating

Once the VISSIM model was completed, it was tested and calibrated. Researchers reviewed the on-screen animation and model outputs to determine the model's accuracy in simulating field operations. The user then viewed the on-screen animation to check the realism of queue lengths. Computer operators then compared the travel time outputs to those collected with the field travel time runs. Speed distributions were calibrated slightly (when necessary) to ensure that the VISSIM model's travel times were similar to the floating-car travel time data collected in the field.

3.2 TIME-TO-COLLISION ANALYSIS IN VISSIM

Time-to-collision was identified in the state-of-the-practice literature review as a promising surrogate measure for safety in the micro-simulation environment. As previously described, a TTC value at any instant is defined as the time that remains until a collision between two vehicles would occur if the collision course and relative speed difference are maintained, and it can be calculated as the distance between the vehicles divided by the speed difference between the vehicles. See Figure 3-1 for a graphic illustration that demonstrates a car traveling at 30 mph at a distance of 100 feet behind a truck traveling at 15 mph, which results in a TTC of 4.5 seconds.



$$\text{Time-to-collision (seconds)} = \frac{D \times 3{,}600}{(Speed_1 - Speed_2) \times 5{,}280}$$

Example:

$$\text{Time-to-collision (seconds)} = \frac{\text{100 feet} \times \text{3,600 seconds/hour}}{(\text{30 mph} - \text{15 mph}) \times \text{5,280 feet/mile}} = \text{4.5 seconds}$$

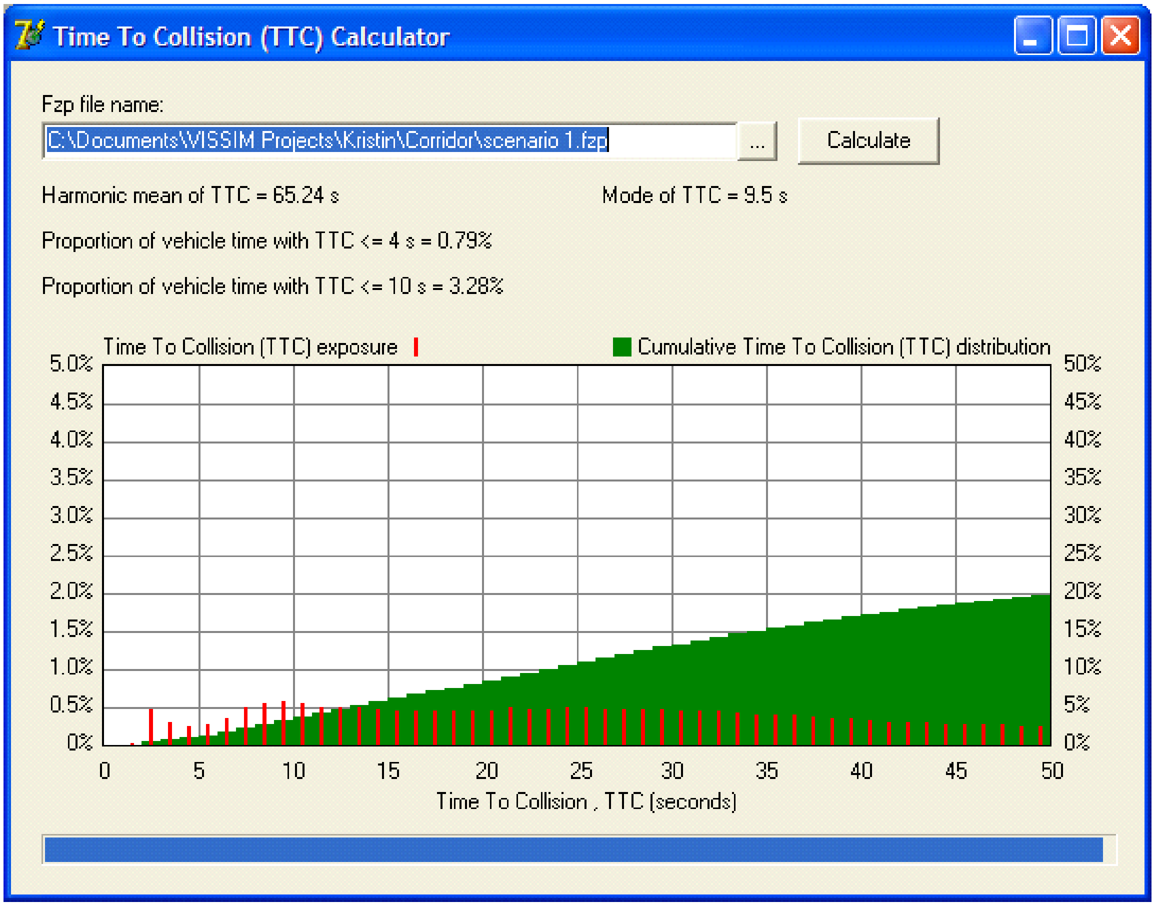
Figure 3-1. Illustration of Time-to-Collision Concept.

The TTC is only meaningful if a positive speed difference exists between the vehicles. It is generally assumed that higher TTC values indicate safer situations, and that safety-critical situations are characterized by small TTC values. By choosing an appropriate threshold TTC value, it is possible to distinguish between relatively safe and safety-critical encounters. A percentage of the TTCs under a certain time in seconds for the micro-simulation can be used as a surrogate for safety. The intent is that the TTC would identify the stop-and-go acceleration characteristics that might be present for different transportation alternatives—allowing them to be compared from a safety perspective.

TTI researchers developed a computer program using the Borland Delphi software that would post-process the *.fzp output file from VISSIM for TTC computations. The *.fzp file is the VISSIM vehicle record file, and it includes vehicle location and speed information at whatever time step is used by the analyst.

When using micro-simulation to determine TTC values, it should be taken into account that simulated drivers are “perfect” in that they do not suffer from inattentiveness, misjudgments, and errors that result in many crashes in real life. Consequently, the assumption can be made that a slightly higher threshold TTC value has to be used in micro-simulation in order to account for the “perfect” drivers in the simulation. For this reason, a threshold TTC value of 4.0 seconds was chosen for the analysis. A value of 10 seconds was used as an “upper end” value for relative comparisons between alternatives as well.

Figure 3-2 shows a snapshot from the screen as the TTC program was running in VISSIM. The graph shows that approximately 0.79 percent of the travel time on the network is spent at TTC values less than 4.0 seconds. By comparing the percentage of time spent below TTC threshold as well as the general shape of the TTC distribution between different access management alternatives, it may be possible to compare their relative safety performances. It should be noted that the harmonic mean of the TTC is computed to ensure that the average value of the TTC is not skewed by the large number of TTC values that are relatively very large. For this reason, the harmonic mean of the TTC is used in the computations. It should be further noted that only following vehicles are included in the TTC calculations in the current version of the software. A future version of the software will include TTC values between conflicting vehicles at angles. The process appears to be promising, and it was applied to the case studies and theoretical corridors.



Fzp file name: C:\Documents\VISSIM Projects\Kristin\Corridor\scenario 1.fzp

Harmonic mean of TTC = 65.24 s

Mode of TTC = 9.5 s

Proportion of vehicle time with TTC <= 4 s = 0.79%

Proportion of vehicle time with TTC <= 10 s = 3.28%

Figure 3-2. Time-to-Collision Calculator Developed to Operate within VISSIM (Reference *21*).

It should be noted that each simulation run provides an estimate of the performance measures computed (TTC, travel time, delay). Therefore, it is necessary to run each simulation several times and then average the results. Due to the number of different alternatives investigated (driveway densities, traffic volumes, etc.), three runs were usually performed for each scenario investigated due to budgetary constraints.

Throughout this report, the abbreviation TTC4 is used to represent "the proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds." Likewise, the abbreviation TTC10 is used to "represent the proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds."

3.3 ANALYSIS METHODOLOGY OF CASE STUDIES AND THEORETICAL CORRIDORS

3.3.1 Texas Avenue Corridor (Bryan, Texas)

General Description. The Texas Avenue study corridor is a 5-lane major arterial with a continuous TWLTL. The major traffic generators along this section of Texas Avenue include fast-food restaurants, a drug store, a bank, office buildings, and a shopping center anchored by a large video store. Various retail and commercial developments also exist along this section. Currently, a TWLTL serves as the median treatment along this section of Texas Avenue. This corridor has a signal density of 3.0 signals per mile. Figure 3-3 shows the Texas Avenue study site between the two arrows. The northbound view of the Texas Avenue corridor is shown in Figure 3-4 from the Villa Maria signalized intersection. Figure 3-5 shows the TWLTL along Texas Avenue with the Villa Maria intersection in the background.

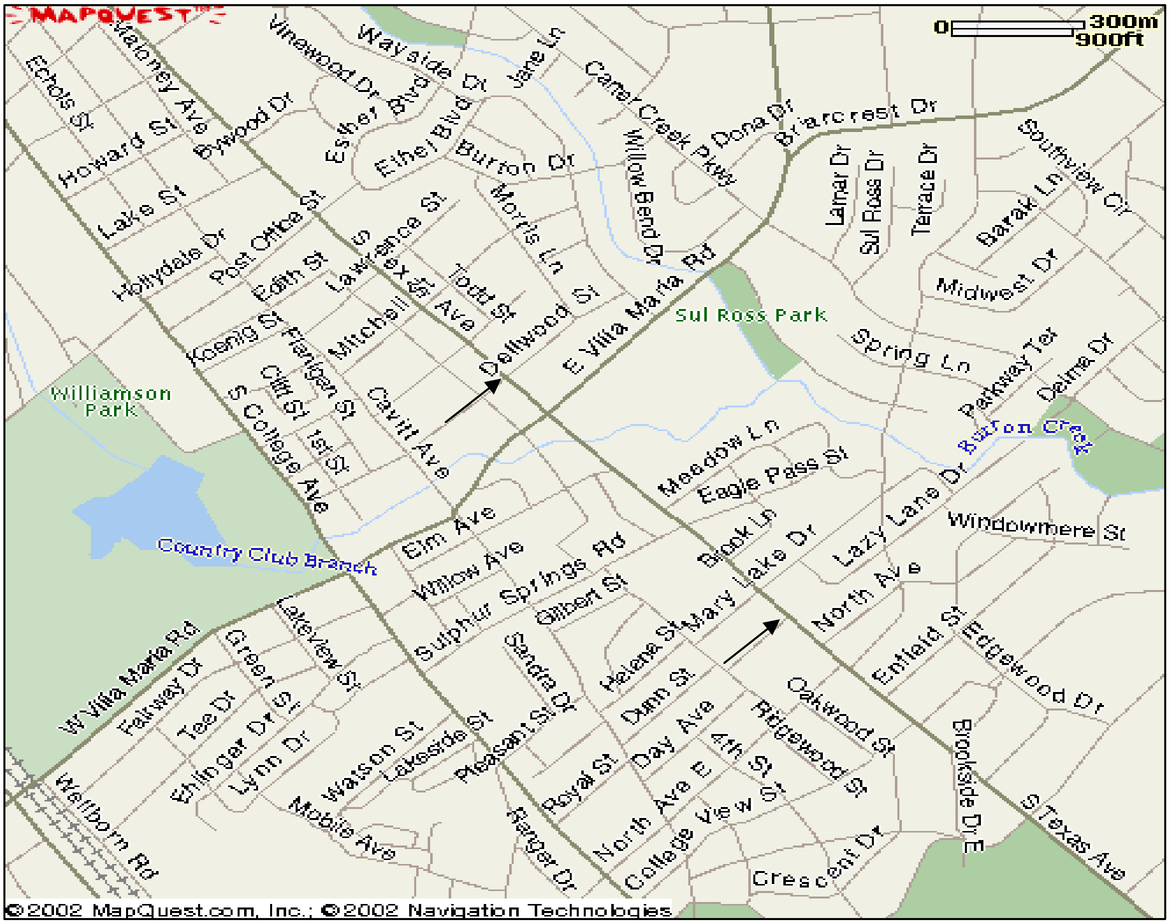


Figure 3-3. Texas Avenue Study Site in Bryan, Texas, Used for Operational Analysis (Map Provided by MapQuest.com, Inc.).

Figure 3-4. Texas Avenue Facing North from Villa Maria.

Figure 3-5. Texas Avenue Facing North with Villa Maria in the Background.

Data Collection. Researchers collected traffic volume data on Texas Avenue between Dunn Street and Dellwood Street in March and April of 2002. They also collected average daily traffic data on Texas Avenue at two locations using tube counters located south of Dunn Street and north of Dellwood Street. The estimated ADT from loop counts at two locations on Texas Avenue north and south of Villa Maria was approximately 18,200 and 16,600, respectively. Researchers collected noon and evening turning movement counts at the intersections of Texas Avenue and Villa Maria Road and Texas Avenue and Sulphur Springs/Eagle Pass Road. They also collected turning movement counts at all of the driveways between Dunn Street and Dellwood Street. Researchers videotaped traffic on the corridor and later reduced the data to obtain specific counts.

Traffic Demand. Researchers evaluated existing and proposed conditions using existing traffic volumes. The noon peak hour consisted of the highest mainlane and driveway traffic volumes; therefore, the team used the noon peak-hour volumes for the operational analysis.

For the raised median condition, VISSIM automatically rerouted existing traffic volumes to alternate routes to their destinations. For example, a left-turning motorist from a driveway that was prohibited by the installation of the raised median would turn right and make a U-turn at the first median opening.

Vehicle Conflict Points. As part of related research (*7*), researchers conducted an evaluation of vehicle conflict points for existing TWLTL and raised median conditions. The existing condition on Texas Avenue consists of a 5-lane arterial with a TWLTL. At the intersections of Texas Avenue with Villa Maria Road and Eagle Pass/Sulphur Springs Road, the TWLTL transitions to a conventional left-turn lane.

Previous national research suggests that a TWLTL providing access to numerous driveways can be a safety problem due to the numerous conflict points (*2*,*13*). Table 3-1 presents an estimate of the number of existing conflict points based on the type and number of intersections and driveways on Texas Avenue between Dunn Street and Dellwood Street.

The raised median alternative consists of a raised median between Dunn Street and Dellwood Street with full median openings north of Dellwood Street, between Villa Maria Road and Sulphur Springs Road, at Sulphur Springs Road, and at Dunn Street. Table 3-2 summarizes the estimated number of conflict points for the raised median alternative. The raised median reduces the number of potential conflicts from 756 to 297, a reduction of approximately 60 percent.

Analysis Conditions. Researchers used VISSIM to model the following: (1) existing TWLTL condition, (2) optimized existing condition, (3) existing with a raised median, (4) future (higher volume) condition with a raised median, (5) future condition (higher volume) with the current TWLTL along Texas Avenue (6) future with a raised median, and (7) future TWLTL at 48,000 ADT. The following sections describe the details of the seven conditions. The VISSIM model evaluated travel time and delay along the Texas Avenue corridor under each of the seven conditions.

Table 3-1. Texas Avenue Existing TWLTL Condition Conflict Points.

Roadway Section Type[1]	Number of Intersection[2] Types along Study Corridor	Conflict Points per Intersection	Number of Lanes[3]	Total Conflict Points
T-Intersection (TWLTL)	40	13	5	520
T-Intersection (RM)	0	2	5	0
T-Intersection (RMO)	0	11	5	0
RMO only	0	5	5	0
Dellwood Intersection	1	46	5	46
Villa Maria Intersection	1	52	5	52
Sulphur Springs Intersection	1	46	5	46
Mary Lake Intersection	1	46	5	46
Dunn Intersection	1	46	5	46
Total				

[1] TWLTL = two-way left-turn-lane. RM = raised median. RMO = raised median opening.
[2] Intersections include both public streets and private driveways.
[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.
Note: Some rows were kept at zero for consistency and comparison between Tables 3-1 and 3-2.

Table 3-2. Texas Avenue Raised Median Condition Conflict Points.

Roadway Section Type[1]	Number of Intersection[2] Types along Study Corridor	Conflict Points per Intersection	Number of Lanes[3]	Total Conflict Points
T-Intersection (TWLTL)	0	13	5	0
T-Intersection (RM)	38	2	5	76
T-Intersection (RMO)	4	11	5	44
RMO only	1	5	5	5
Dellwood Intersection	1	4	5	4
Villa Maria Intersection	1	52	5	52
Sulphur Springs Intersection	1	56	5	56
Mary Lake Intersection	1	4	5	4
Dunn Intersection	1	56	5	56
Total				297

[1] TWLTL = two-way left-turn-lane. RM = raised median. RMO = raised median opening.
[2] Intersections include both public streets and private driveways.
[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.
Note: Some rows were kept at zero for consistency and comparison across between Tables 3-1 and 3-2.

1. Existing Condition. Texas Avenue is a 5-lane arterial roadway with a TWLTL as the center lane. The corridor is 0.66 miles in length with an ADT of approximately 18,200 north of Villa Maria and approximately 16,600 south of Villa Maria. The driveway density is 40 and 50 driveways per mile on the east and west side of Texas Avenue, respectively. The current signal timings were collected from the City of Bryan and used in this model. Figure 3-6 shows the approximate location of streets and driveways.

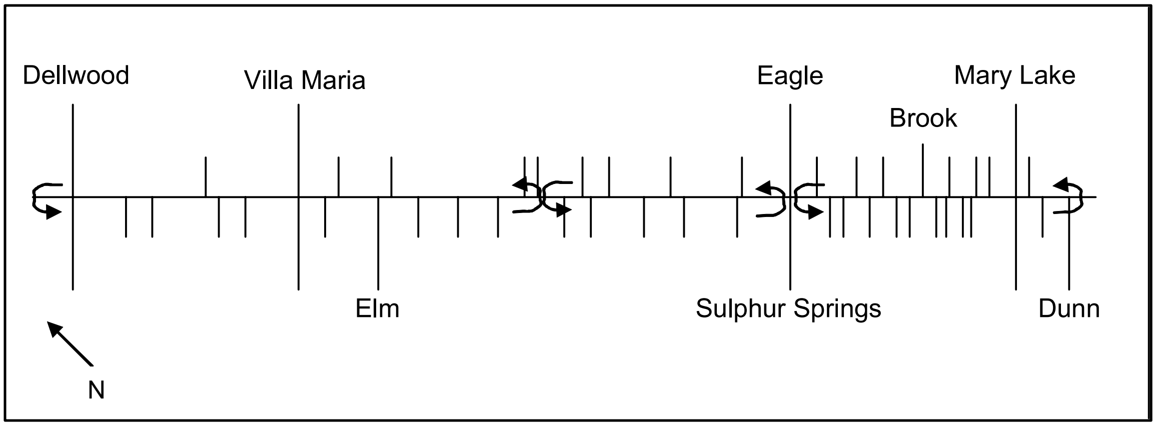


Figure 3-6. Schematic to Illustrate Approximate Driveway, Street, and U-turn Locations for Operational Scenarios.

2. Optimized Existing Condition. In the optimized condition, the existing geometry on Texas Avenue remains the same, but signal timing at the two signalized intersections on the corridor was optimized using SYNCHRO, a signal optimization software.
3. Proposed Condition with a Raised Median. In this proposed condition, a raised median replaces the TWLTL. U-turn median openings range in spacing from 690 to 1,320 feet. U-turns are allowed at the median openings north and south of Villa Maria Road and at the intersection of Texas Avenue and Sulphur Springs Road. The U-turn locations are approximated in Figure 3-6. Because of the existing high traffic volumes at the intersection of Texas Avenue and Villa Maria Road, U-turns are not allowed at this intersection. U-turns are rerouted to median openings located north and south of Villa Maria Road. Signal timing was also optimized in the proposed condition.
4. Proposed Future Condition with a Raised Median. Researchers increased the traffic volume along Texas Avenue to analyze how Texas Avenue may operate in the future. Traffic volume was increased by 20 percent, which equates to approximately 2 percent per year for 10 years to yield 21,800 vehicles per day north of Villa Maria and 19,900 vehicles per day south of Villa Maria. The increase resulted in approximately 400 additional vehicles on Texas Avenue during the peak hour. The future condition was analyzed for the 5-lane cross section with a center raised median. The high traffic volume at the intersection of Texas Avenue and Villa Maria Road required mitigation to allow traffic flow through the intersection. Therefore, dual left-turn lanes were added on the south, east, and west approaches to the

intersection. Dual left-turn lanes are currently present on the north approach. Signal timing was also optimized in both of the future conditions. Median spacing is the same as for analysis #3.

5. Future Condition with a TWLTL. This condition is the same as #4 except that a TWLTL replaces the raised median.
6. Proposed Future with a Raised Median. This condition is the same as option #4 approximately 48,000 ADT.
7. Future TWLTL. This condition is the same as option #5, but the ADT is increased to approximately 48,000 ADT.

Analysis Procedure. The research team conducted travel time, delay, and TTC analyses to create the existing and proposed conditions along Texas Avenue. The VISSIM model then evaluated travel time and delay along the Texas Avenue corridor under each of the seven conditions listed above. Three simulations of each scenario were performed, each using a different random number seed. The random number seed was constant for a given replication across each of the alternatives. The random number seed was varied across replications to randomize the micro-simulation. VISSIM generated three travel time and delay estimates for each corridor scenario.

Travel time and delay were two measures analyzed in this study. Travel time estimates were generated for both northbound and southbound vehicles for the entire corridor, by placing a travel time measurement location where the analysis started and stopped as vehicles crossed these points. Traveling northbound, a beginning travel time measurement "bar" was placed before the Dunn Street intersection and an ending travel time measurement bar was placed after the Dellwood Street intersection. This distance of 0.66 miles is somewhat longer than the study corridor length. The bars were located to ensure that vehicles were "created" upstream prior to reaching the analysis zone of the corridor. The travel time measurement bars were placed in the same locations in the southbound direction, with the start before the Dellwood Street intersection and the end after the Dunn Street intersection. Floating-car travel time runs during the noon peak hour provided data to compare with VISSIM for calibration purposes. During this time, research team members traveled the corridor six times in each direction. The average travel times from the floating-car runs were comparable to the VISSIM travel times; however, the speed distributions in VISSIM were calibrated to match the field travel time data.

3.3.2 Broadway Avenue (US 69) Corridor (Tyler, Texas)

General Description. The second case study corridor is located along Broadway Avenue (US 69) between Loop 323 and Chimney Rock Drive in Tyler, Texas. This road currently has three through lanes in each direction, a TWLTL, and a signal density of 4.1 signals per mile. Adjacent land uses include residential, office, commercial, and retail; however, there are no single-family residential driveways intersecting Broadway Avenue. The study site is shown between the arrows in Figure 3-7. Figures 3-8 and 3-9 show the three lanes in each direction and the TWLTL along with the mix of land uses along the corridor.

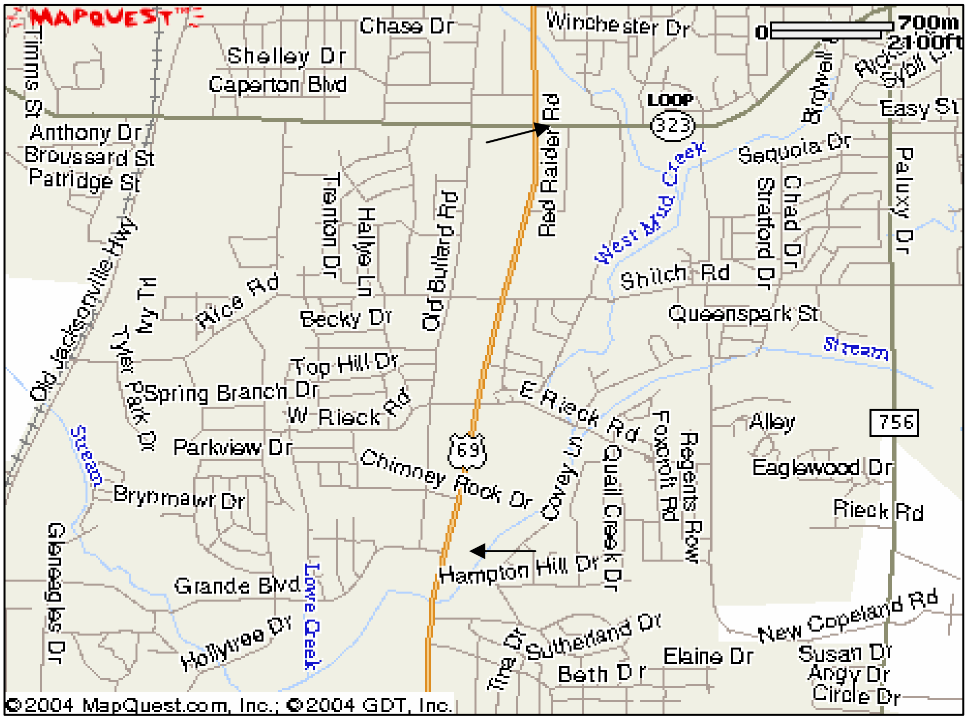


Figure 3-7. Broadway Avenue Study Site in Tyler, Texas, Used for Operational Analysis (Map Provided by MapQuest.com, Inc.).

Figure 3-8. Broadway Avenue Facing North to Chimney Rock Signalized Intersection.

Figure 3-9. Broadway Avenue Facing South at Chimney Rock Signalized Intersection.

Traffic Operations Analysis. The corridor is 1.47 miles from Grande Boulevard to Loop 323. In a similar manner as the Texas Avenue corridor, the existing condition, optimized existing condition, two different proposed median opening options, and future proposed traffic volumes were investigated. The subsequent sections describe the data collection, traffic demand, and analysis procedures.

Data Collection. The research team collected traffic volume data on Broadway Avenue from Grande Boulevard to Loop 323 using videotapes from a 1999 project. The videotapes included all turning and through movements at every street and driveway intersection from 12:00 p.m. to 1:00 p.m. (noon peak period) and from 5:00 p.m. to 6:00 p.m. (evening peak period). To assist in the analysis, researchers organized the data into turning movement counts at each driveway and through and turning movement counts at each signalized and un-signalized intersection. Corridor geometrics were recently collected.

Traffic Demand. The traffic volume data revealed that the evening peak hour (5:00 p.m. to 6:00 p.m.) was the daily peak hour; therefore, this time period was used for the subsequent analysis.

For the proposed raised median conditions, existing traffic volumes were rerouted to alternative routes to reach their ultimate destination. For example, a left-turning motorist entering the corridor from a driveway or side street that was prohibited by the installation of the raised median would turn right and then make a U-turn at the first median opening. In some instances, where corner lots consisted of large left-turning volumes, traffic was rerouted to the side street, allowing vehicles to make a left turn at the signal instead of a U-turn at the first median opening in the direction opposite of desired travel. Signalized intersections with a left-turning volume of roughly 250 or greater received a second turn lane. Due to high southbound left-turning volumes at the Rieck Road signalized intersection, a dual turn lane was installed, allowing two lanes for left turns and U-turns from the inside lane.

The ADT was estimated for Broadway Avenue by dividing the directional design hour volume (DDHV) for each direction by an assumed K-factor (peak-hour proportion of daily traffic) of 0.135 and D-factor (directional distribution) (*38*). The D-factor for northbound traffic was 0.46, while for southbound traffic it was 0.54. The directional ADT was averaged to get the total ADT for the corridor. ADT for the current condition was approximately 24,000. The future condition contained a relatively higher ADT of approximately 29,400. When the videotaped data were collected in 1999, there was no signal at the Chimney Rock intersection. However, when the research team returned to the corridor to collect roadway geometrics such as lane widths and distance between driveways, a signal had been installed at Chimney Rock. For analysis proposes, the signal was omitted from the existing condition and the optimized existing condition. The signal was included for the proposed, future existing, and proposed future conditions.

Further, in 1999 and currently, Broadway Avenue northbound at Loop 323 has only two through lanes. Initial VISSIM runs showed bottlenecking at this intersection as vehicles merged into two lanes from three lanes. The resulting congestion backed up the rest of the corridor. For analysis purposes, researchers extended the third lane through the intersection for all scenarios, allowing traffic to run more smoothly and the analysis to focus on the raised median treatments.

Vehicle Conflict Points. A conflict point analysis was performed in a similar manner as the Texas Avenue case study. Researchers conducted an evaluation of vehicle conflict points for the existing condition compared to the two proposed raised median conditions.

The existing condition on Broadway Avenue consists of a 7-lane arterial with a TWLTL from Grande Boulevard to Loop 323. Table 3-3 presents an estimate of the existing conflict points based on the type and number of intersections and driveways on Broadway Avenue between Grande Boulevard and Loop 323. The existing condition contains 1,090 total conflict points.

The proposed raised median (Option A) condition consists of a raised median between Grande Boulevard and Loop 323 with full median openings at the signalized intersections—Grande Boulevard, Chimney Rock, Rieck, Rice/Shiloh, Independence, and Loop 323. Table 3-4 summarizes the estimated number of conflict points for the proposed raised median (Option A) condition. The proposed condition reduces the number of potential conflicts from 1,090 to 474, a reduction of approximately 57 percent. The substantial decrease in the number of conflict points can be seen by comparing the first two rows of data in Table 3-3 with those in Table 3-4. The predominant change in the total number of conflict points is a result of eliminating the numerous conflict points at the TWLTL driveways and replacing those with the raised median.

Table 3-3. Broadway Avenue (US 69) Existing TWLTL Condition Conflict Points.

Roadway Section Type[1]	Number of Intersection[2] Types along Study Corridor	Conflict Points per Intersection	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	56	13	7	728
T-Intersections RM (Driveways)	0	2	7	0
T-Intersections RMO (Driveways)	0	11	7	0
RMO Only	0	6	7	0
Directional RMO (Left in Only)	0	6	7	0
Grande Blvd Intersection	1	46	7	46
Chimney Rock Intersection	1	46	7	46
Rieck Intersection	1	46	7	46
Rice/Shiloh Intersection	1	62	7	62
Independence Intersection	1	46	7	46
Loop 323 Intersection	1	116	7	116
Total				1,090

[1] TWLTL = two-way left-turn-lane. RM = raised median. RMO = raised median opening.
[2] Intersections include both public streets and private driveways.
[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.
Note: Some rows were kept at zero for consistency and comparison across between Tables 3-3 through 3-5.

Table 3-4. Broadway Avenue (US 69) Proposed Raised Median Condition (Option A) Conflict Points.

Roadway Section Type[1]	Number of Intersection[2] Types along Study Corridor	Conflict Points per Intersection	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	0	13	7	0
T-Intersections RM (Driveways)	56	2	7	112
T-Intersections RMO (Driveways)	0	11	7	0
RMO Only	0	6	7	0
Directional RMO (Left in Only)	0	6	7	0
Grande Boulevard Intersection	1	46	7	46
Chimney Rock Intersection	1	46	7	46
Rieck Intersection	1	46	7	46
Rice/Shiloh Intersection	1	62	7	62
Independence Intersection	1	46	7	46
Loop 323 Intersection	1	116	7	116
Total				474

[1] TWLTL = two-way left-turn-lane. RM = raised median. RMO = raised median opening.
[2] Intersections include both public streets and private driveways.
[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.
Note: Some rows were kept at zero for consistency and comparison across between Tables 3-3 through 3-5.

The proposed raised median (Option B) condition consists of a raised median between Grande Boulevard and Loop 323 with full median openings at signalized intersections and at three mid-block locations. The first mid-block opening is located between Chimney Rock and Rieck; the second between Rieck and Rice/Shiloh at Mobile, a T-intersection; and the third between Independence and Loop 323 at the Broadway Square Mall main entrance. Table 3-5 summarizes the estimated number of conflict points for the proposed raised median Option B condition. The proposed raised median (Option B) reduces the number of potential conflicts from 1,090 to 501, a reduction of approximately 54 percent.

Table 3-5. Broadway Avenue (US 69) Proposed Raised Median Condition (Option B) Conflict Points.

Roadway Section Type[1]	Number of Intersection[2] Types along Study Corridor	Conflict Points per Intersection	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	0	13	7	0
T-Intersections RM (Driveways)	53	2	7	106
T-Intersections RMO (Driveways)	3	11	7	33
RMO Only	0	6	7	0
Directional RMO (Left in Only)	0	6	7	0
Grande Boulevard Intersection	1	46	7	46
Chimney Rock Intersection	1	46	7	46
Rieck Intersection	1	46	7	46
Rice/Shiloh Intersection	1	62	7	62
Independence Intersection	1	46	7	46
Loop 323 Intersection	1	116	7	116
Total				501

[1] TWLTL = two-way left-turn-lane. RM = raised median. RMO = raised median opening.
[2] Intersections include both public streets and private driveways.
[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.
Note: Some rows were kept at zero for consistency and comparison between Tables 3-3 through 3-5.

Analysis Procedure. The research team used VISSIM to model several conditions. The team modeled the existing condition, optimized existing condition, proposed raised median conditions with different raised median opening options (Options A and B), and proposed future raised median conditions with an increased volume. The future conditions are based on an approximate 2 percent increase in traffic volumes each year for 10 years. This equated to an estimated "future" volume of approximately 29,300. A future volume of approximately 48,000 was also investigated in the study to examine even higher congestion levels. The following sections describe the 10 conditions. VISSIM also evaluated the travel time and delay along the Broadway Avenue corridor under each of the seven conditions.

1. Existing Condition. Broadway Avenue is a 7-lane arterial roadway with a TWLTL as the center lane. The corridor is 1.47 miles in length and has 32 driveways on the west side and 24 on the east side. The driveway density remains the same throughout the proposed conditions where the raised median is added and when traffic volumes are increased. The existing signal timings were collected from the City of Tyler. Figure 3-10 shows the approximate location of streets and driveways.

2. Optimized Existing Condition. The optimized condition is the same as the existing condition, but the signal timing at the two signalized intersections on the corridor was optimized using SYNCHRO.

3. Proposed Condition with a Raised Median (Option A). In each of the proposed conditions (Option A and Option B), a raised median replaces the TWLTL. In Option A, full-median openings are located at the signalized intersections only to facilitate U-turns. The signalized intersections include Grande Boulevard, Chimney Rock (not included in existing condition), Rieck, Shiloh/Rice, Independence, and Loop 323.

4. Proposed Condition with a Raised Median (Option B). In Option B, full median openings are located at the signalized intersections, and three median openings are located at mid-block locations. The first mid-block opening is located at the Broadway Square Mall main entrance, which is also the south driveway for the French Quarter Shopping Center between Loop 323 and Independence. The second mid-block median opening is located at Mobile between Rice/Shiloh and Rieck Road, and the third is located at the driveway for Outback Steakhouse between Rieck Road and Chimney Rock.

5. Proposed Future Condition with a Raised Median (Option A). In the proposed future conditions the roadway geometry, driveway locations, and intersection locations do not change from the proposed conditions. For the future conditions, traffic volumes are increased by 20 percent, representing an approximate 2 percent per year increase over 10 years. The future Option A condition is similar to the proposed condition; full median openings are located at signalized intersections to allow U-turns.

6. Proposed Future Condition with a Raised Median (Option B). The future Option B condition is similar to the proposed Option B with full median openings at signalized intersections and also includes the 20 percent increase in traffic volume.

7. Future Condition with a TWLTL. This condition has the same roadway geometry as the existing condition with a 20 percent increase in vehicle traffic volume.

8. The same as option #5 but at approximately 48,000 ADT.

9. The same as option #6 but at approximately 48,000 ADT.

10. The same as option #7 but at approximately 48,000 ADT.

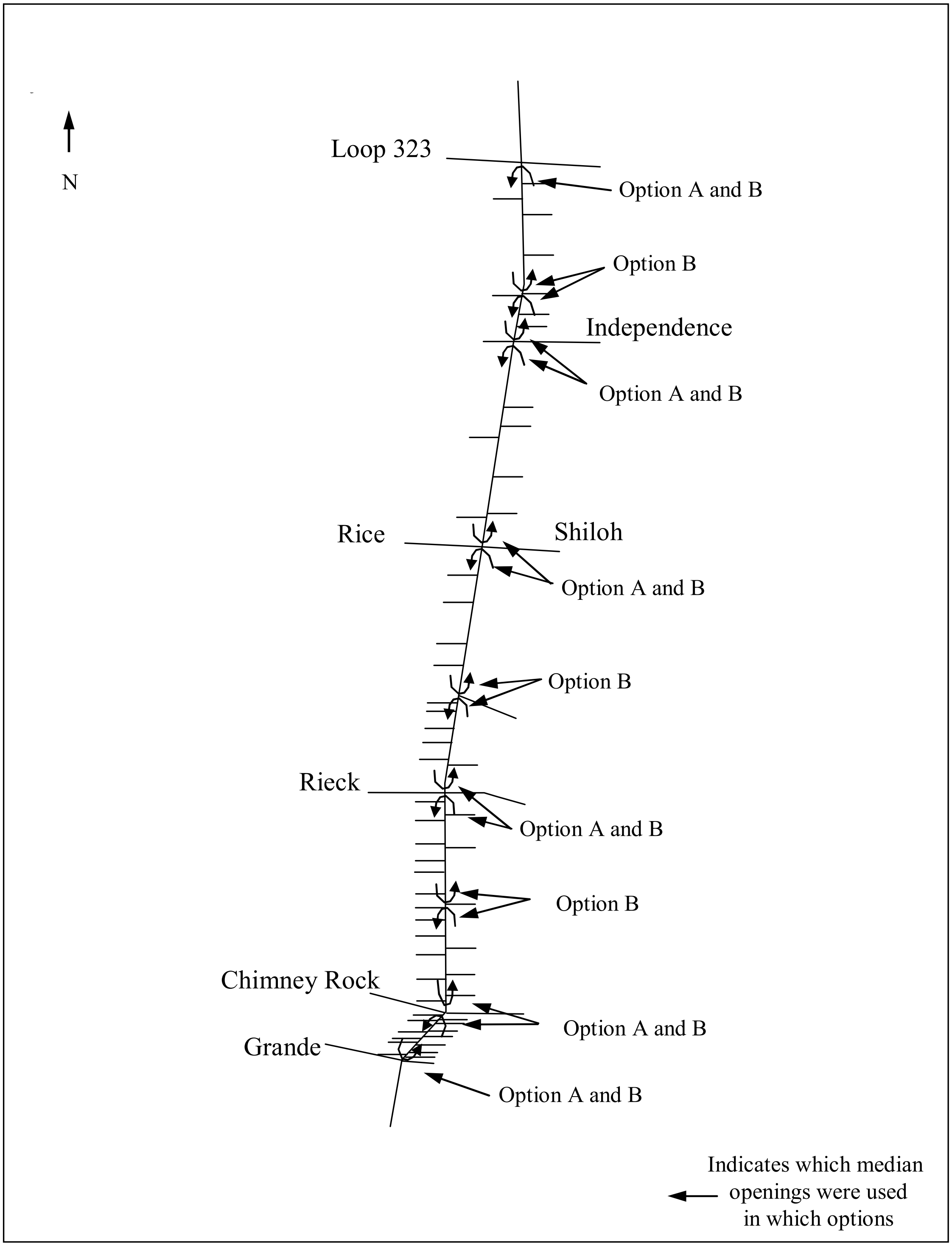


Figure 3-10. Schematic to Illustrate Approximate Driveway, Street, and U-turn Locations for Operational Scenarios.

3.3.3 Theoretical Corridors

While the actual case study locations presented here are valuable in assessing the operational and safety impacts of access management treatments, additional theoretical scenarios were also simulated. Three theoretical corridors incorporating access management treatments such as raised median installation and driveway consolidation were investigated for different traffic volumes.

General Description. The three theoretical corridors range from Scenario #1 with a TWLTL and very few driveways to Scenario #3 with a raised median and several driveways. The three scenarios were analyzed using differing ADTs, varying numbers of lanes and driveways, and differing median treatments. All three scenarios have a signal density of 2.0 signals per mile.

Traffic Operations Analysis. The research team performed a micro-simulation of the travel times, delay, and TTC on each theoretical corridor similar to the two case studies. Each theoretical corridor is 1 mile long. The following sections describe the data configuration and analysis procedures.

Data Configuration. The design of a theoretical corridor began with identifying typical land uses for the 1-mile corridor. The goal of the researchers was to design a realistic representation of a typical corridor. Some of the land uses included a drive-in bank, pharmacy/drugstore, fast-food with drive-through, and gas station. In Scenario #1, 18 driveways represented 18 parcels with varying land use types; some were used more than once. In Scenario #2, 42 driveways represented 42 parcels with repeating land uses. While Scenario #3 contained the same number of parcels as Scenario #2, with the same land uses, each parcel in Scenario #3 had two driveways, making a total of 84 driveways. In all scenarios there are an equal number of driveways on the north and south sides along the corridor, and the driveways lined up across the road. Once the land uses were identified, the researchers used the Institute of Transportation Engineers (ITE) *Trip Generation* manual to estimate the number of trips generated and the directional distribution (entering/exiting) of each particular land use (*39*). In Scenario #3, the trips generated were divided equally between the two driveways. The vehicles exiting all driveways in all scenarios were divided equally—50 percent left turning and 50 percent right turning. This was also true for all vehicles entering the driveways—50 percent enter from one direction, and the other 50 percent enter from the other direction.

Traffic Demand. Scenarios #1 and #2 evaluated ADT volumes of approximately 18,000, 23,000, 28,000, and 48,000. The research team added ADTs of approximately 33,000 and 38,000 to Scenario #3's evaluation. For a given ADT level and simulation run, the same number of vehicles entered the corridor from each end. The actual number of entering vehicles was calculated by estimating the DDHV, which was accomplished by multiplying the ADT by the K-factor (0.135) and the D-factor (0.5). The K-factor value was estimated for a suburban area (*38*), and the D-factor assumed an equal split of traffic from each direction.

For the raised median conditions, VISSIM automatically rerouted the existing traffic to its final destination using the shortest route. For example, a left-turning motorist exiting a driveway that was prohibited by the installation of the raised median would turn right and then make a U-turn at the first median opening.

Vehicle Conflict Points. Similar to the preceding case studies, researchers evaluated conflict points for Scenario #1 (with a TWLTL) and Scenarios #2 and #3 (with raised medians). The number of conflict points is based on the number of driveways and types of intersections.

Table 3-6 summarizes the number of conflict points for Scenario #1, which contains 18 driveways and two cross streets, with a driveway spacing of 660 feet. This distance is the same as the median opening spacings in the raised median options. For this reason, Scenario #1 can be interpreted as a TWLTL or a raised median. The total number of conflict points is 338.

Table 3-6. Theoretical Corridor Scenario #1 (5-lane TWLTL/RM) Conflict Points.

Roadway Section Type[1]	**Number of Intersection Types along Study Corridor**	**Conflict Points per Intersection[2]**	**Number of Lanes[3]**	**Total Conflict Points**
T-Intersections TWLTL (Driveways)	18	13	5	234
T-Intersections RM (Driveways)	0	2	5	0
Cross Street 1 Intersection	1	52	5	52
Cross Street 2 Intersection	1	52	5	52
Total				338

[1] TWLTL = two-way left-turn lane. RM = raised median.

[2] It is assumed that even though the driveways are directly across from one another, vehicles will not go straight from one driveway to the other.

[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.

Note: Some rows were kept at zero for consistency and comparison across Tables 3-6 to 3-12.

The total number of conflict points for Scenario #2 with a 5-lane TWLTL cross section is shown in Table 3-7. The total number of conflict points increased from Scenario #1 because the number of driveways increased from 18 to 42. The number of conflict points increased from 338 to 650, approximately 48 percent.

Table 3-7. Theoretical Corridor Scenario #2 (5-lane TWLTL) Conflict Points.

Roadway Section Type[1]	Number of Intersection Types along Study Corridor	Conflict Points per Intersection[2]	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	42	13	5	546
T-Intersections RM (Driveways)	0	2	5	0
Cross Street 1	1	52	5	52
Cross Street 2	1	52	5	52
Total				650

[1]TWLTL = two-way left-turn lane. RM = raised median.

[2]It is assumed that even though the driveways are directly across from one another, vehicles will not go straight from one driveway to the other.

[3]Number of lanes includes through lanes with a TWLTL or RM depending on the option.

Note: Some rows were kept at zero for consistency and comparison across Tables 3-6 to 3-12.

Table 3-8 presents Scenario #2 with a 7-lane TWLTL. The addition of one lane in each direction increased the number of conflict points even more than adding more driveways. The number of conflict points increased from 338 in Scenario #1 to 674, approximately 50 percent.

Table 3-8. Theoretical Corridor Scenario #2 (7-lane TWLTL) Conflict Points.

Roadway Section Type[1]	Number of Intersection Types along Study Corridor	Conflict Points per Intersection[2]	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	42	13	7	546
T-Intersections RM (Driveways)	0	2	7	0
Cross Street 1	1	64	7	64
Cross Street 2	1	64	7	64
Total				674

[1]TWLTL = two-way left-turn lane. RM = raised median.

[2]It is assumed that even though the driveways are directly across from one another, vehicles will not go straight from one driveway to the other.

[3]Number of lanes includes through lanes with a TWLTL or RM depending on the option.

Note: Some rows were kept at zero for consistency and comparison across Tables 3-6 to 3-12.

The theoretical corridor in Scenario #2 with a 5-lane RM is shown in Table 3-9. The number of conflict points dramatically decreased after the installation of a raised median, from 338 in Scenario #1 to 196, approximately 42 percent.

Table 3-9. Theoretical Corridor Scenario #2 (5-lane RM) Conflict Points.

Roadway Section Type[1]	Number of Intersection Types along Study Corridor	Conflict Points per Intersection[2]	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	0	13	5	0
T-Intersections RM (Driveways)	42	2	5	84
Cross Street 1	1	56	5	56
Cross Street 2	1	56	5	56
Total				196

[1] TWLTL = two-way left-turn lane. RM = raised median.

[2] It is assumed that even though the driveways are directly across from one another, vehicles will not go straight from one driveway to the other.

[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.

Note: Some rows were kept at zero for consistency and comparison across Tables 3-6 to 3-12.

The number of conflict points for Scenario #2 with a 7-lane RM is summarized in Table 3-10. The addition of one lane in each direction adds conflict points at the intersections, but installation of the raised median reduces the number of conflict points at driveways. The decrease in driveway conflict points decreases the total number of conflict points for the corridor from 338 in Scenario #1 to 216, approximately 36 percent.

Table 3-10. Theoretical Corridor Scenario #2 (7-lane RM) Conflict Points.

Roadway Section Type[1]	Number of Intersection Types along Study Corridor	Conflict Points per Intersection[2]	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	0	13	7	0
T-Intersections RM (Driveways)	42	2	7	84
Cross Street 1	1	66	7	66
Cross Street 2	1	66	7	66
Total				216

[1] TWLTL = two-way left-turn lane. RM = raised median.

[2] It is assumed that even though the driveways are directly across from one another, vehicles will not go straight from one driveway to the other.

[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.

Note: Some rows were kept at zero for consistency and comparison across Tables 3-6 to 3-12.

Table 3-11 presents the number of conflict points for Scenario #3 with a 7-lane TWLTL. Doubling the number of driveways along the corridor doubles the number of driveway conflict points. The total number of conflict points increased significantly from 338 in Scenario #1 to 1,220, approximately 70 percent.

Table 3-11. Theoretical Corridor Scenario #3 (7-lane TWLTL) Conflict Points.

Roadway Section Type[1]	Number of Intersection Types along Study Corridor	Conflict Points per Intersection[2]	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	84	13	7	1092
T-Intersections RM (Driveways)	0	2	7	0
Cross Street 1	1	64	7	64
Cross Street 2	1	64	7	64
Total				1220

[1] TWLTL = two-way left-turn lane. RM = raised median.

[2] It is assumed that even though the driveways are directly across from one another, vehicles will not go straight from one driveway to the other.

[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.

Note: Some rows were kept at zero for consistency and comparison across Tables 3-6 to 3-12.

Table 3-12 indicates the number of conflict points for Scenario #3 with a 7-lane RM. This scenario is an excellent example of how simply installing a raised median will dramatically decrease the number of conflict points. The number of conflict points decreased from 1,120 in Scenario #3 without a raised median to 300 with a raised median, a reduction of approximately 75 percent. The number of conflict points decreased from 338 in Scenario #1 to 300, approximately 11 percent.

Table 3-12. Theoretical Corridor Scenario #3 (7-lane RM) Conflict Points.

Roadway Section Type[1]	Number of Intersection Types along Study Corridor	Conflict Points per Intersection[2]	Number of Lanes[3]	Total Conflict Points
T-Intersections TWLTL (Driveways)	0	13	7	0
T-Intersections RM (Driveways)	84	2	7	168
Cross Street 1	1	66	7	66
Cross Street 2	1	66	7	66
Total				300

[1] TWLTL = two-way left-turn lane. RM = raised median.

[2] It is assumed that even though the driveways are directly across from one another, vehicles will not go straight from one driveway to the other.

[3] Number of lanes includes through lanes with a TWLTL or RM depending on the option.

Note: Some rows were kept at zero for consistency and comparison across Tables 3-6 to 3-12.

Analysis Procedure. The researchers used VISSIM to model the three scenarios, each having a few different options related to traffic volume and median treatment. The corridor's length and two cross streets remain the same throughout each scenario, and the signalized cross streets are placed 0.5 miles apart. The subsequent sections detail the three different scenarios and their varying options. The VISSIM model evaluated travel time and delay along the corridor under each of the scenarios.

- Scenario #1. Scenario #1 consists of a 5-lane TWLTL (or raised median). The driveways are spaced 660 feet apart, the same distance as the median openings. This spacing provides the same benefits of having a raised median. The 1.0-mile long corridor contains two cross streets (0.5 miles apart) and 18 driveways (660 feet apart), nine on each side directly across from one another (see Figure 3-11). This scenario was analyzed using ADTs of approximately 18,000, 23,000, and 28,000. Signal timing was optimized for every option using the different ADTs.

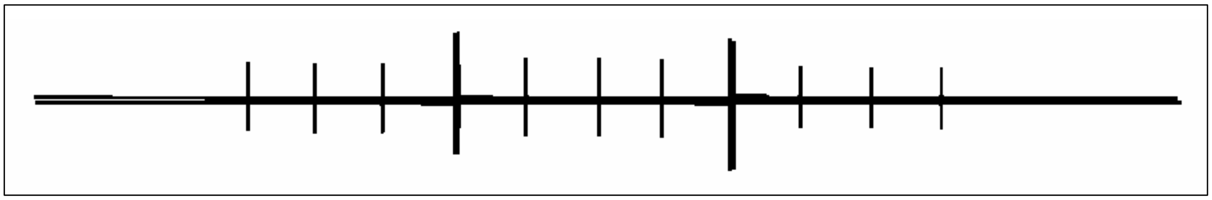


Figure 3-11. Schematic of Cross Streets and Driveway Locations for Scenario #1.

- Scenario #2. Scenario #2 consists of four different options: a 5-lane TWLTL and raised median and a 7-lane TWLTL and raised median. The geometry of Scenario #2 is similar to that of Scenario #1. However, in this scenario 24 driveways were added to the original 18, making a total of 42 driveways spaced 330 feet apart (see Figure 3-12). This scenario was analyzed using ADTs of approximately 18,000, 23,000, 28,000, and 48,000.

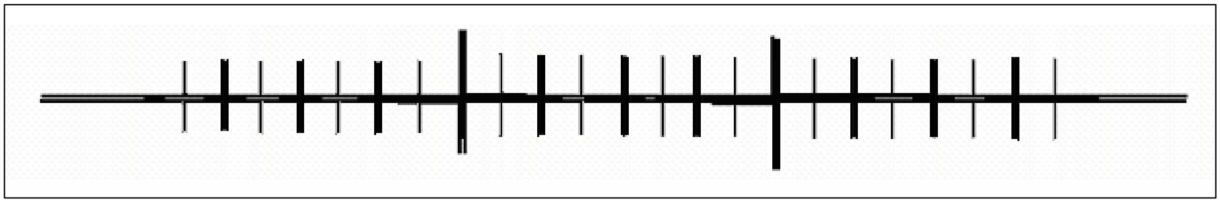


Figure 3-12. Schematic of Cross Streets and Driveway Locations for Scenario #2.

- Scenario #3. This scenario is a 7-lane corridor with a TWLTL in one option and a raised median in another option. The driveway density increases once again in this scenario, doubling from 42 to 84 and creating a driveway spacing of 165 feet (see Figure 3-13). For this scenario, the research team analyzed ADTs of approximately 18,000, 23,000, 28,000, 33,000, 38,000, and 48,000.

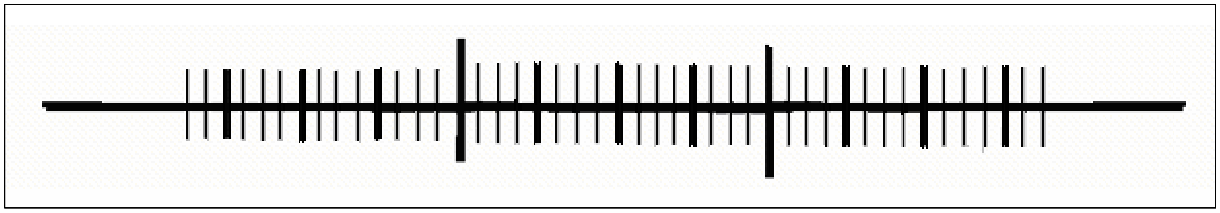


Figure 3-13. Schematic of Cross Streets and Driveway Locations for Scenario #3.

The research team analyzed travel time, vehicle speed, delay, and TTC at three locations along each corridor. Figure 3-14 shows the locations of data collection points (CPs) or travel time measurement "bars." For example, CP 1's beginning travel time measurement "bar" is on the west side, and the ending travel time measurement bar is on the east side. Collection points 1, 2, and 3 collect data in one direction, while CPs 4, 5, and 6 collect data at the same location but in the opposite direction. Collection points 1 and 4; 2 and 5; and 3 and 6 coincide, respectively, for opposite directions. Note that CPs 1 and 4 are located 0.25 miles from the end at the points where traffic enters the corridor. The distance between CP 1 and CP 4 is 1 mile. Collection points 2 and 5 are located just outside the cross street intersection and before a driveway. They are 0.55 miles (2,900 feet) apart. This placement focuses on signal effects on vehicle travel when compared to CPs 3 and 6, located just inside the cross street intersection and before a driveway. CPs 3 and 6 are 0.47 miles (2,500 feet) apart. Each scenario was run at least three times using different random seeds, then analyzed and compared to similar options to ensure they were similar enough to average and to estimate the performance measures.

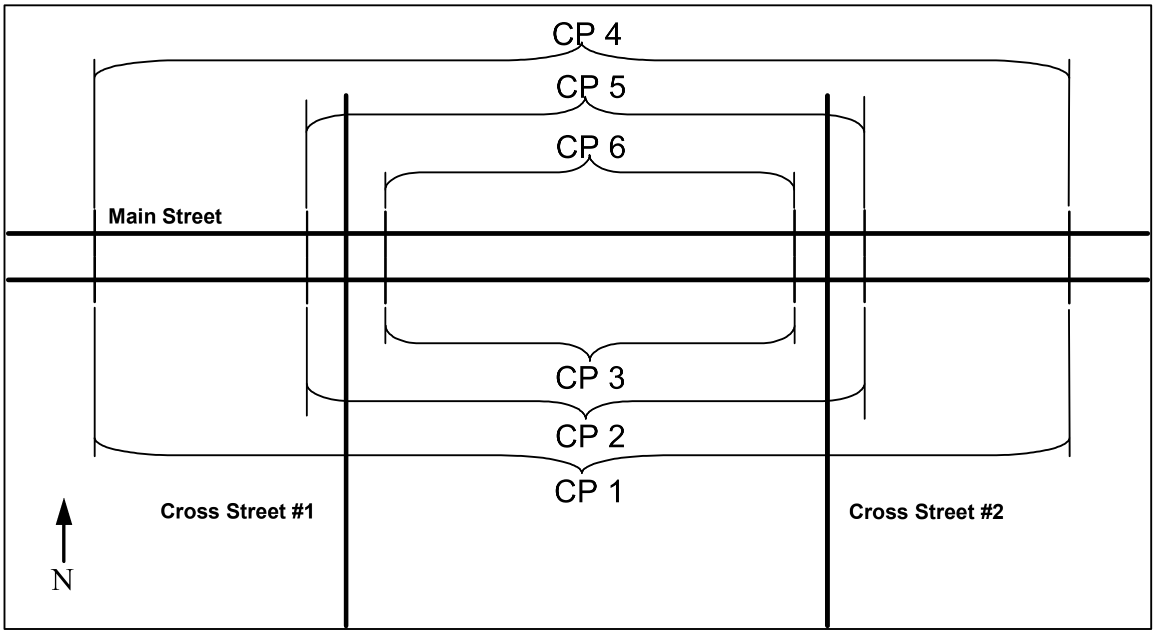


Figure 3-14. Collection Point Locations in VISSIM.

CHAPTER 4

MICRO-SIMULATION FINDINGS

This chapter describes the findings of the micro-simulation analysis on the Texas Avenue (Bryan, Texas) and Broadway Avenue (Tyler, Texas) corridors as well as theoretical corridors. Final sections of the chapter describe observations regarding the use of micro-simulation tools for analyzing roadway improvements that include access management alternatives, performance measures for micro-simulation, and including access management measures into the transportation planning process with emphasis on surrogate measures of safety.

4.1 TEXAS AVENUE CASE STUDY

4.1.1 Time-to-Collision Micro-simulation Results on the Texas Avenue Case Study

Table 4-1 summarizes the time-to-collision, travel time, delay, and speed micro-simulation findings for Texas Avenue in Bryan, Texas. By simply optimizing the signals in the existing TWLTL scenario (Scenario #2 compared to Scenario #1), the travel time and delay decrease by 8 percent and 23 percent, respectfully. The harmonic mean of the TTC decreased 8 seconds (19 percent). The TTC4 increased 0.2, and the TTC10 increased 1.7. Compared to the optimized existing TWLTL scenario, the proposed raised median had an increase in TTC harmonic mean of 18 seconds. Figure 4-1 illustrates how the TTC harmonic mean varies by median treatment and traffic volume. A decrease in TTC4 of 0.9 occurred when the raised median was installed for the existing condition. Figure 4-2 shows the existing condition as well as other ADT level changes in the TTC4. Figure 4-3 illustrates the TTC10 by ADT level. This trend is also identified at the approximately 21,800 and 48,000 ADT levels.

This case study appears to indicate that the TTC performance measures investigated here may be useful as surrogate measures of safety in the micro-simulation environment. In the existing conditions, and at the ~21,800 ADT, the harmonic mean (Figure 4-1) is higher in the alternative with the raised median as compared to the TWLTL, which is intuitive due to the improved traffic flow through the reduction of conflict points. It follows that the TTC4 (Figure 4-2) and TTC10 (Figure 4-3) indicate a higher percentage of conflict within the TWLTL environment. This is observed for the two lower ADT ranges. However, at the ~48,000 ADT, the results appear to reverse, and the raised median alternative appears to be providing more conflict with the measures investigated here. There is a lower TTC harmonic mean (Figure 4-1), and the TTC4 is higher with the raised median. Figures 4-4 to 4-6 provide some insights. They show the trends in travel time, delay, and speed, respectively, at each ADT level. Specifically, Figure 4-6 indicates that the average speed along the corridor increased from 12 to 19 mph with the installation of the raised median. Table 4-1 also shows this data. Increased speed along the corridor due to the raised median installation provides smoother traffic flow and would be hypothesized to translate into a smaller TTC4 (Figure 4-2) and higher harmonic mean of the TTC (Figure 4-1). It is hypothesized a higher harmonic mean of the TTC is not observed at ~48,000 ADT because the speed information was collected along the corridor itself based upon the travel time of vehicles traversing the entire corridor, while the TTC computations include vehicle interactions throughout the entire simulation area—including beyond the study corridor.

Table 4-1. Texas Avenue Micro-simulation Results.

Scenario[1]	ADT	TTC Harmonic Mean (seconds)	TCC4[2] (seconds)	TCC10[3] (seconds)	Weighted Average Travel Time (seconds)	Average Delay (seconds/ vehicle)	Average Speed (miles/ hour)	Number of Simulation Runs
1. Existing TWLTL	~18,200	42	2.5%	7.2%	109	24	22	3
2. Optimized Existing (TWLTL)	~18,200	34	2.7%	8.9%	101	18	24	3
3. Proposed (RM)	~18,200	52	1.8%	4.9%	108	24	22	3
4. Proposed Future (RM)	~21,800	48	1.8%	5.3%	113	28	21	3
5. Future (TWLTL)	~21,800	44	2.0%	6.2%	127	30	19	3
6. Future (RM)	~48,000	35	1.8%	7.4%	128	50	19	3
7. Future (TWLTL)	~48,000	38	1.2%	7.7%	207	83	12	3

[1] Scenarios are defined in Section 3.3.1 of the report. TWLTL = two-way left-turn lane, RM = raised median.

[2] TTC4: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds.

[3] TTC10: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds.

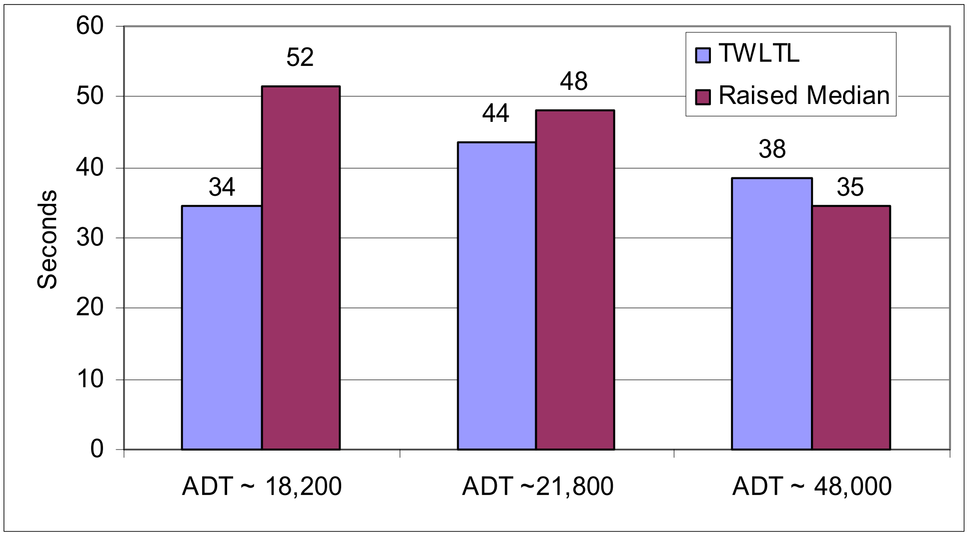


Figure 4-1. Harmonic Mean of TTC on Texas Avenue Corridor by ADT Level.

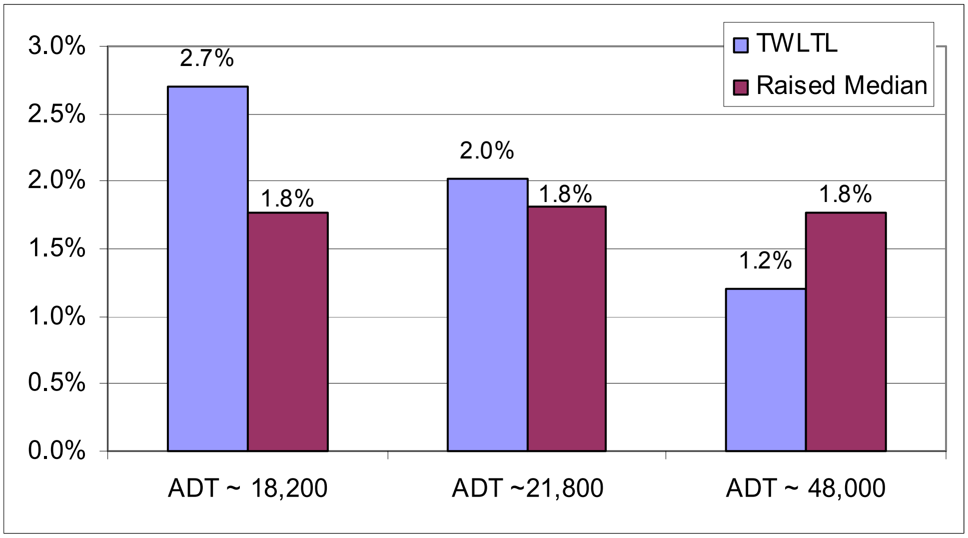


Figure 4-2. TTC4 on Texas Avenue Corridor by ADT Level.

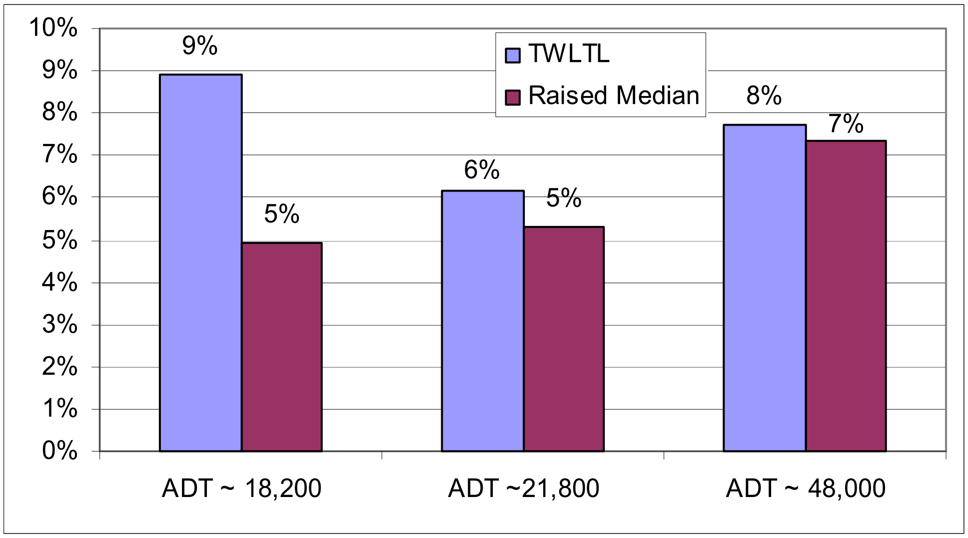


Figure 4-3. TTC10 along Texas Avenue by ADT Level.

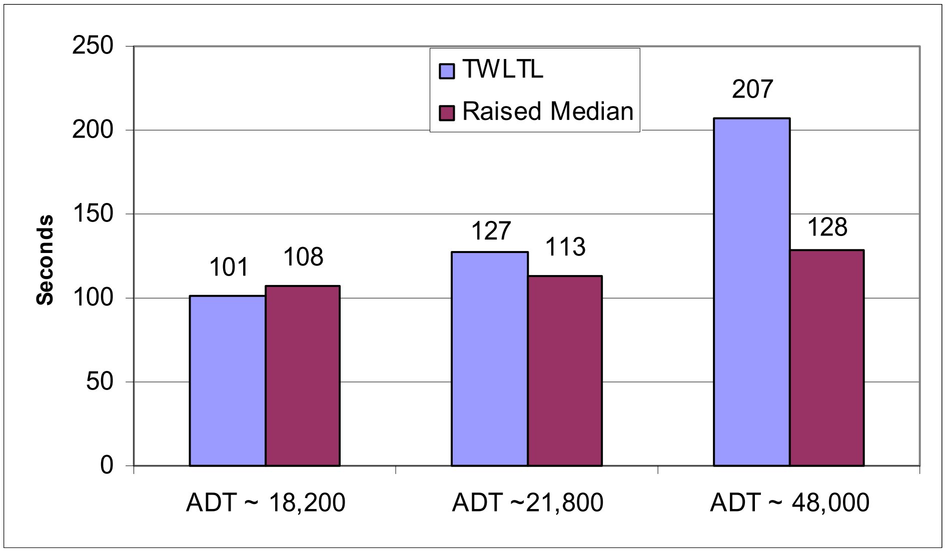


Figure 4-4. Weighted Corridor Travel Time by ADT Level for Texas Avenue.

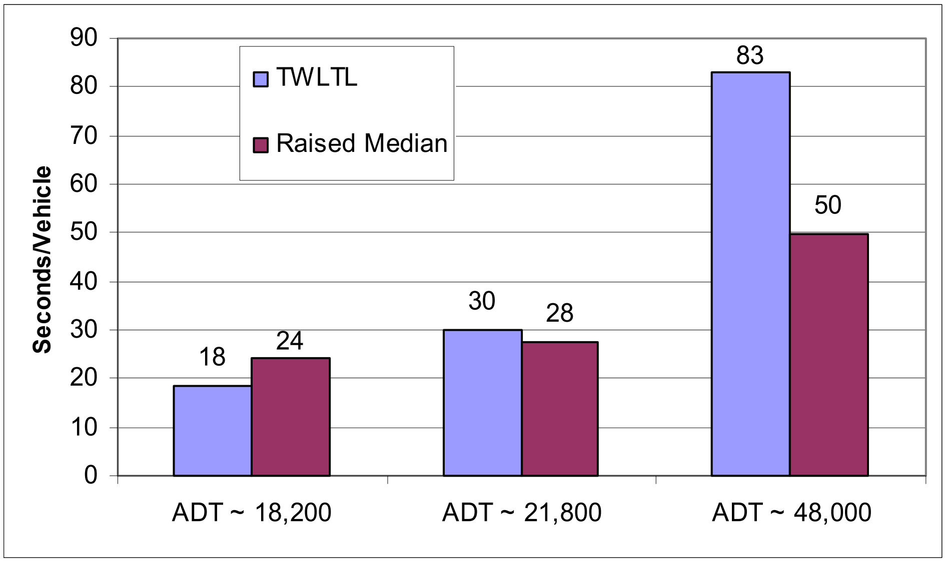


Figure 4-5. Daily Results by ADT Level for Texas Avenue.

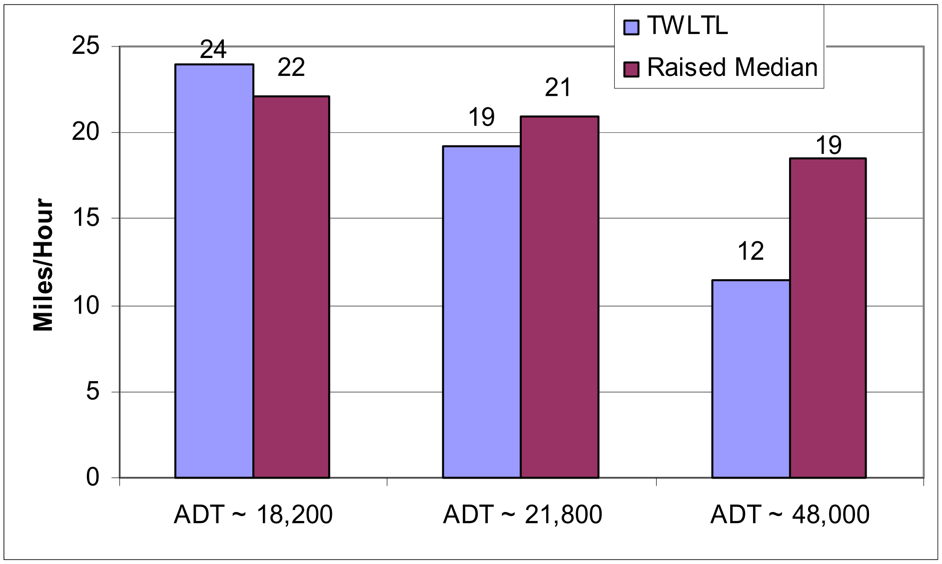


Figure 4-6. Speed Results by ADT Level for Texas Avenue.

The TTC measure is including the interaction of all vehicles in the system and in the micro-simulation (i.e., those vehicle interactions along the roadway and those that are occurring on parcels along the roadway—entering the roadway). Further, the TTC computations would include all vehicle interactions that occur prior to the vehicles getting to the travel time data collection points along the roadway. Under extremely congested conditions, there can be significant interactions, which is why the travel time data collection points are placed downstream of these locations so that the traffic flow can become relatively more stable and more representative of field conditions. It would appear that the TTC model developed here may require some further updates to separate these affects to ensure the TTC is being computed along the corridor of interest without influence from these vehicle interactions outside the primary area of study. Nonetheless, the TTC measures illustrated here appear to provide a promising method for assessing safety levels of transportation alternatives in the micro-simulation environment.

The interested reader can review work elsewhere for more information on the travel time, speed, and delay results along this test corridor (*7*,*11*).

4.1.2 Discussion of the Time-to-Collision Proof of Concept on the Texas Avenue Case Study Corridor

The results here begin to identify some interesting observations regarding the TTC in the proof of concept along the Texas Avenue corridor. The preliminary results appear to indicate that the TTC measures used for the analysis hold promise for identifying the relative safety of a corridor. It would appear that there is a need to isolate the tool to only the corridor segment of interest (rather than including vehicular interactions before the travel time data collection points). There is also a need to investigate different values of the TTC "cutoff." TTC4 and TTC10 were used here, but it might be more appropriate to investigate values between 4 and 10 seconds also. In addition, distribution information about the TTC would be valuable to keep in the analysis. While the program does keep the mode of the TTC values for a given run, standard deviation information would be equally valuable to identify the variability in the average TTC for a given alternative—a potentially equally important measure for investigating collision potential severity. There is also a need to calibrate/compare the TTC results to corridors on which actual crash data have been collected to identify the correlation of the micro-simulation TTC results to field crash information.

Though statistical differences were not analyzed here, irrespective it would appear that there is not a practical difference in some of the values experienced in this analysis—particularly in the harmonic mean of the TTC, TTC4, and TTC10 at the approximately 48,000 ADT level. Finally, there is a need to establish reasonable ranges for the TTC. Control sites/conditions would be needed to identify the "normal" (baseline) value of a TTC. For example, are the values of 1 or 2 percent "average" or "low"?

4.2 BROADWAY AVENUE CASE STUDY

4.2.1 Time-to-Collision Micro-simulation Results on the Broadway Avenue Case Study

Table 4-2 summarizes the time-to-collision, travel time, delay, and speed findings for Broadway Avenue in Tyler, Texas. The harmonic mean of the TTC for the existing condition was 38 seconds. Signal optimization on the existing corridor improved the TTC harmonic mean by 12 seconds (an increase of approximately 32 percent). The TTC4 decreased by 0.1, and the TTC10 decreased by 1.5. Improvements are also seen in travel time, delay, and speed. These findings suggest an improvement in traffic flow (reduced conflicts) with signal optimization. Figure 4-7 shows the harmonic mean of the TTC for the TWLTL options and with the installation of the raised median by ADT level. All values decrease, or are relatively similar, with the installation of the raised median. The raised median (Option B) had the largest decrease of 9 seconds (19 percent) at the ~24,000 ADT. At the ~29,300 and ~48,000 ADT, the difference in harmonic mean values becomes minimal between the TWLTL scenarios and the raised median scenarios.

The benefits of installing a raised median improved at higher ADTs in relation to TTC4 (Figure 4-8). It decreased 0.3 for both raised median options (A and B) at ~48,000 ADT. The results are somewhat more intuitive than those for the Texas Avenue case study as the TTC4 is greatly reduced at increasing ADT levels. This was hypothesized due to the improved traffic flow created by the raised median alternative.

However, the TTC10 increased at the highest ADT level (Figure 4-9). It is intuitive that at this higher congestion, there is nearly a ten-fold increase in the TTC10 percentages compared to the TTC4 values simply due to the increased vehicle interactions. The relative difference between the TWLTL and the raised median alternatives are not as extreme for the TTC10 (Figure 4-9) as those identified for the TTC4 (Figure 4-8). For investigating safe operations through a surrogate of acceleration characteristics, the TTC4 measure provides a more applicable measure, while the TTC10 measure provides a reasonableness check (i.e., are the TTC10 values much larger). It would be beneficial to investigate the distribution of values from TTC4 to TTC10.

Researchers also investigated the effects of the raised median on travel time, delay, and speed. Figure 4-10 shows the weighted corridor travel time for Broadway Avenue by ADT level. The travel time increased approximately 57 percent at the ~48,0000 ADT level. Negligible differences were observed at the ~24,400 and ~29,300 ADT levels. Figure 4-11 indicates that the average delay values (seconds/vehicle) at ~48,000 ADT are approximately double those of the lesser ADTs. Figure 4-12 indicates the changes in speed, and at the ~48,000 ADT, the speed decreases approximately 5 mph with the raised median installation.

Table 4-2. Broadway Avenue Case Study Micro-simulation Results.

Scenario[1]	ADT	TTC Harmonic Mean (Seconds)	TCC4[2] (seconds)	TCC10[3] (seconds)	Number of TTC Simulation Runs	Weighted Average Travel Time (seconds)	Average Delay (seconds/ vehicle)	Average Speed (miles/ hour)	Number of Operations Simulation Runs
1. Existing (TWLTL)	~24,400	38	0.4%	4.6%	3	264	32	20	3
2. Optimized Existing (TWLTL)	~24,400	50	0.3%	3.1%	3	176	18	30	3
3. Proposed RM (Option A)	~24,400	42	0.2%	3.0%	3	188	18	28	3
4. Proposed RM (Option B)	~24,400	40	0.3%	3.3%	3	183	16	29	3
5. Proposed Future RM (Option A)	~29,300	30	0.3%	5.6%	3	237	29	22	3
6. Proposed Future RM (Option B)	~29,300	29	0.4%	7.1%	3	231	24	23	3
7. Future Condition (TWLTL)	~29,300	31	0.5%	6.8%	3	226	25	24	3
8. Proposed Future RM (Option A)	~48,000	34	0.3%	8.3%	5	515	85	11	3
9. Proposed Future RM (Option B)	~48,000	33	0.3%	8.5%	5	509	82	11	3
10. Future Condition (TWLTL)	~48,000	34	0.6%	7.0%	5	325	64	16	3

[1] Scenarios are defined in Section 3.3.2 of the report. TWLTL = two-way left-turn lane; RM = raised median.

[2] TTC4: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds.

[3] TTC10: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds.

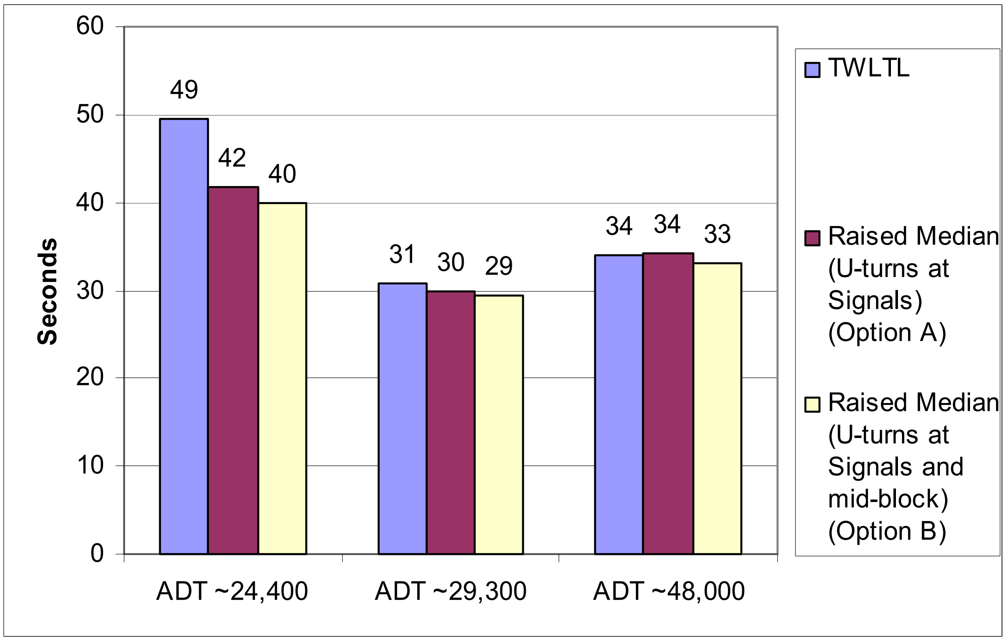


Figure 4-7. Harmonic Mean of TTC on Broadway Avenue Corridor by ADT Level.

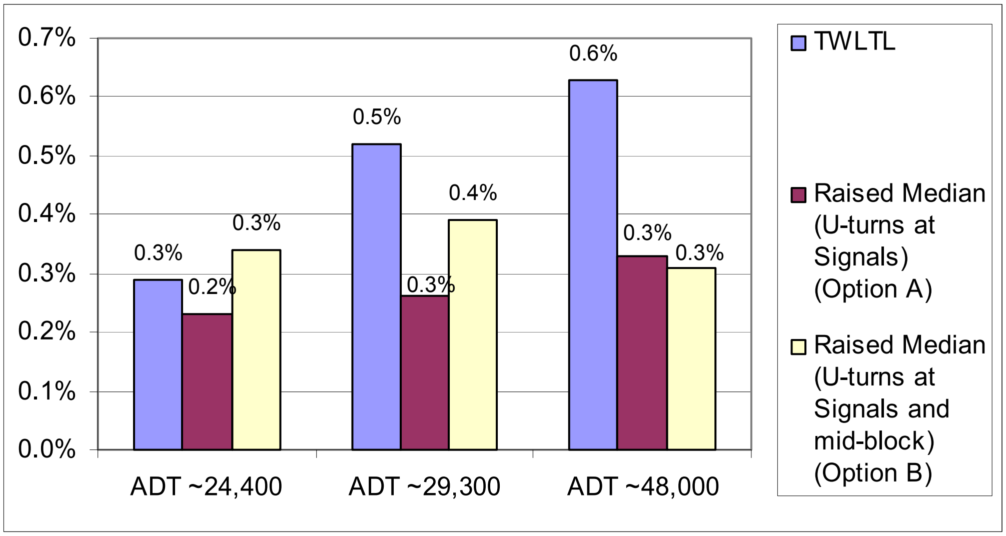


Figure 4-8. TTC4 on Broadway Avenue Corridor by ADT Level.

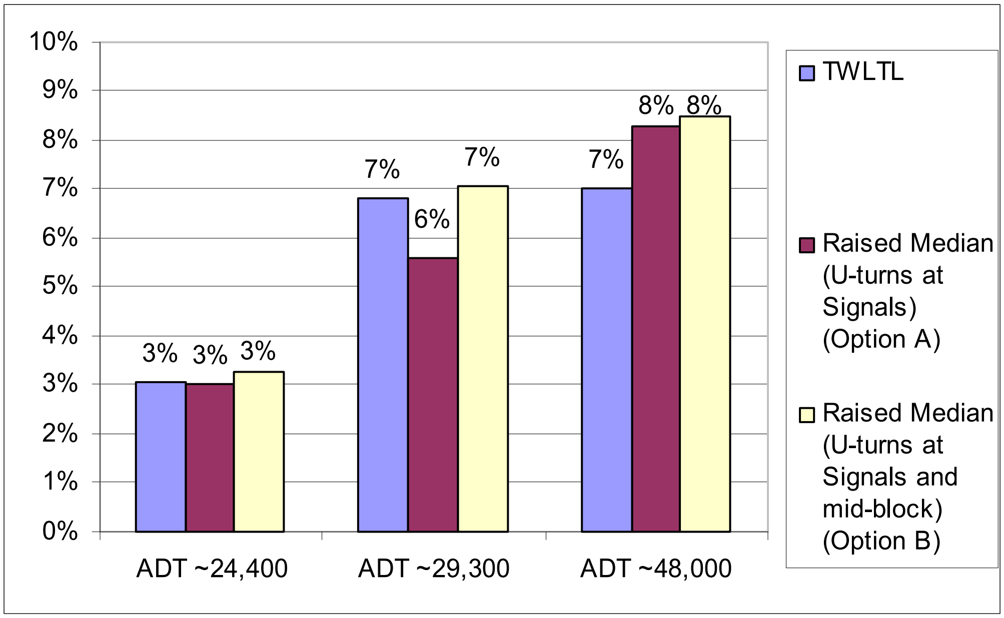


Figure 4-9. TTC10 on Broadway Avenue Corridor by ADT Level.

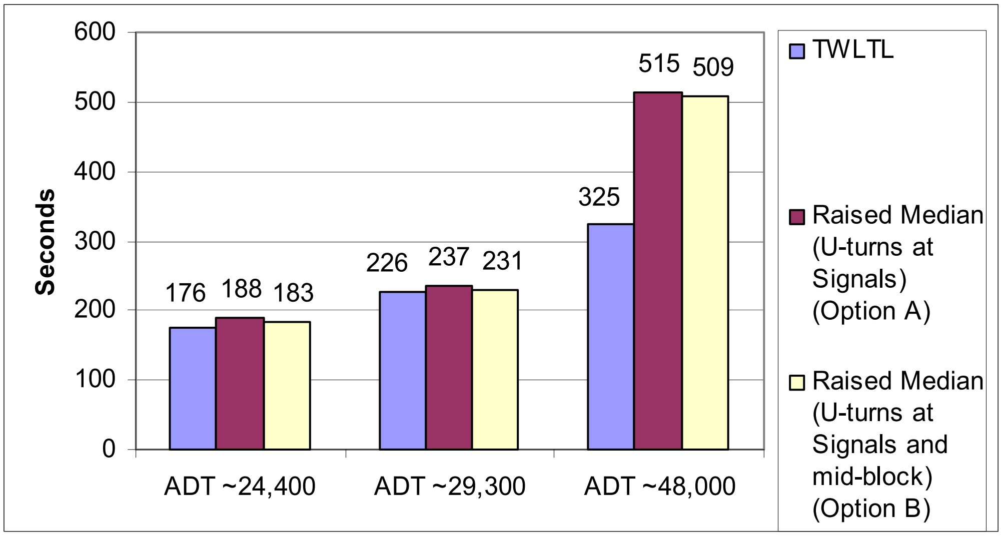


Figure 4-10. Weighted Corridor Travel Time for Broadway Avenue by ADT Level.

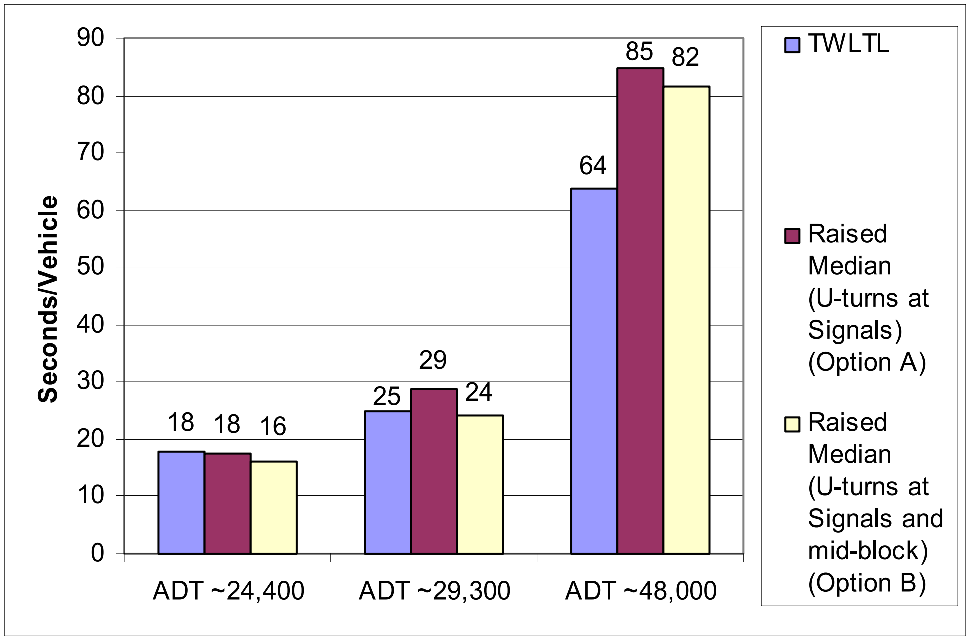


Figure 4-11. Delay Results by ADT Level for Broadway Avenue.

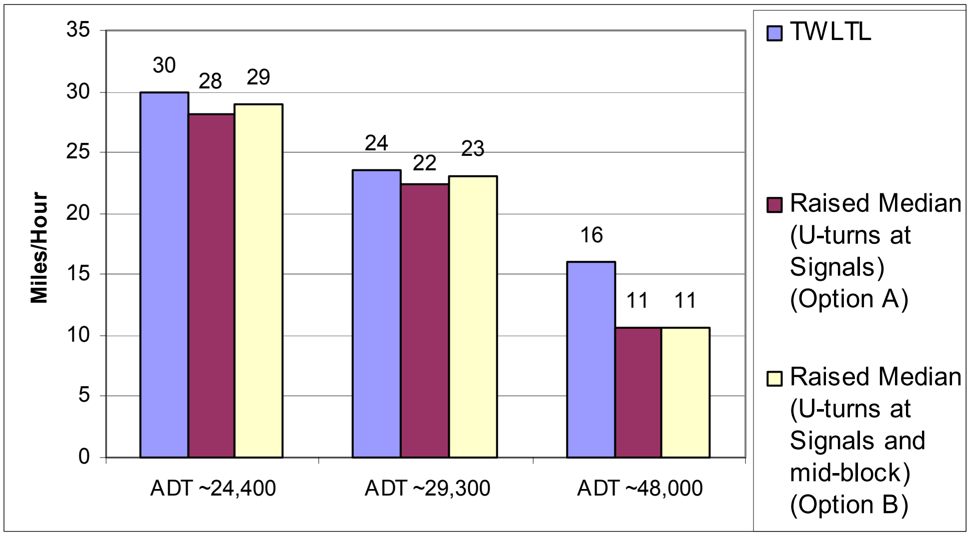


Figure 4-12. Speed Results by ADT Level for Broadway Avenue.

It should be noted that generally the more circuitous travel and increased U-turn traffic can cause the raised median treatment to have a slightly longer travel time (reduced speed) and slightly higher delay. The reader should further note that the travel time (and subsequent speed) computed along the case study corridors is based upon vehicles that traverse the entire corridor only. Their speeds can be reduced by increased numbers of vehicles at U-turn locations that may queue beyond the left-turn lanes. Also, with the relatively long distances between raised median openings (Figure 3-10) there are heavy U-turn movements that also increase weaving traffic, and may reduce speeds, particularly at higher volumes. It is hypothesized that by reducing the median opening spacing, the speed difference could be reduced, but available resources limited the ability to perform further analysis. However, it is hypothesized that the relatively small decreases in speed observed here are offset by the reduction in the number of conflict points and increased safety. Increased safety and small decreases in safety were also findings of work performed by the National Cooperative Highway Research Program (*2*,*13*). More specifically, along the Broadway Avenue corridor, the TTC4 values would appear to indicate the reduction in vehicle interactions along the corridor with the raised median (Figure 4-8).

The interested reader can review work elsewhere for more information on the travel time, speed, and delay results along this test corridor (*7*,*11*).

4.2.2 Discussion of the Time-to-Collision Proof of Concept on the Broadway Avenue Case Study Corridor

Additional insights into the TTC measure as a surrogate safety measure in the micro-simulation environment were obtained when investigating the Broadway Avenue case study. In addition to those items mentioned in Section 4.1.2 (observations from the Texas Avenue case study), researchers identified the fact that there is also more work necessary at the higher ADT levels (congested conditions) as it appears a better understanding is needed of what occurs when the corridors reach congestion (forced) flow. There is also a need for documenting values between the TTC4 and TTC10 that would likely provide a profile of the TTC distribution—particularly as congestion levels are increased.

4.3 THEORETICAL CORRIDORS

4.3.1 Time-to-Collision Micro-simulation Results on the Theoretical Corridors

Researchers conducted TTC, travel time, delay, and speed analysis for the three different theoretical scenarios defined in Chapter 3. The micro-simulation results are shown in Table 4-3. Analysis was performed comparing TWLTLs and raised medians for each corridor while increasing the ADTs, driveway density, and number of lanes.

Scenario #1 Analysis Results

ADT was the only characteristic that was altered within Scenario #1 conditions. Section 3.3.3 and Figure 3-11 describe and illustrate Scenario #1 in more detail. Scenario #1 includes 5-lane cross sections. Note that while it is not technically a 5-lane cross section for the raised median alternative, the naming convention is kept the same so there is no confusion when alternatives are later compared. In Scenario #1, as the ADT volume increased, the TTC harmonic mean decreased. When increasing the ADT from ~18,000 to ~23,000, the harmonic mean decreased 15 percent, and when the ADT increased to 28,000, the harmonic mean declined another 12 percent (Figure 4-13).

Table 4-3. Theoretical Corridors Micro-simulation Results.

Scenario[1]	ADT	TTC Harmonic Mean (Seconds)	TCC4[2] (seconds)	TCC10[3] (seconds)	Weighted Average Travel Time (seconds)	Average Delay (seconds/ vehicle)	Average Speed (miles/hour)	Number of Simulation Runs
#1 TWLTL/RM	~18,000	52	0.04%	7.6%	119	27	30	3
#1 TWLTL/RM	~23,000	45	0.19%	10.2%	118	25	31	3
#1 TWLTL/RM	~28,000	39	0.03%	10.5%	119	27	30	3
#2 TWLTL (5-Lane)	~18,000	42	0.02%	9.6%	128	35	28	3
#2 RM (5-Lane)	~18,000	53	0.02%	7.3%	131	38	28	3
#2 TWLTL (7-Lane)	~18,000	46	0.02%	8.2%	123	30	29	3
#2 RM (7-Lane)	~18,000	55	0.06%	6.7%	132	40	27	3
#2 TWLTL (5-Lane)	~23,000	52	0.02%	7.0%	124	31	29	3
#2 RM (5-Lane)	~23,000	36	0.05%	11.8%	132	39	27	3
#2 TWLTL (7-Lane)	~23,000	52	0.02%	6.8%	122	29	30	3
#2 RM (7-Lane)	~23,000	59	0.02%	6.8%	132	39	27	3
#2 TWLTL (5-Lane)	~28,000	33	0.12%	13.0%	117	24	31	3
#2 RM (5-Lane)	~28,000	61	0.02%	6.1%	153	60	24	3
#2 TWLTL (7-Lane)	~28,000	43	0.05%	9.2%	118	25	31	3
#2 RM (7-Lane)	~28,000	71	0.02%	5.0%	131	38	28	3
#2 TWLTL (7-Lane)	~48,000	34	0.81%	13.0%	115	22	31	3
#2 RM (7-Lane)	~48,000	78	0.02%	5.0%	166	72	22	3
#3 TWLTL (7-Lane)	~18,000	59	0.04%	5.9%	121	28	30	3
#3 RM (7-Lane)	~18,000	65	0.02%	5.7%	128	36	28	3
#3 TWLTL (7-Lane)	~23,000	61	0.04%	5.8%	122	29	30	3
#3 RM (7-Lane)	~23,000	66	0.02%	5.6%	123	30	29	3
#3 TWLTL (7-Lane)	~28,000	59	0.02%	6.3%	121	28	30	3
#3 RM (7-Lane)	~28,000	68	0.02%	5.2%	123	39	30	3
#3 TWLTL (7-Lane)	~33,000	53	0.07%	7.0%	115	22	31	3
#3 RM (7-Lane)	~33,000	57	0.03%	6.5%	122	30	29	3
#3 TWLTL (7-Lane)	~38,000	49	0.06%	7.9%	114	20	32	3
#3 RM (7-Lane)	~38,000	59	0.01%	6.5%	140	47	26	3
#3 TWLTL (7-Lane)	~48,000	57	0.05%	6.8%	115	22	31	3
#3 RM (7-Lane)	~48,000	56	0.03%	7.5%	126	34	29	3

[1] Scenarios are defined in Section 3.3.2 of the report. TWLTL = two-way left-turn lane; RM = raised median.

[2] TTC4: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds.

[3] TTC10: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds.

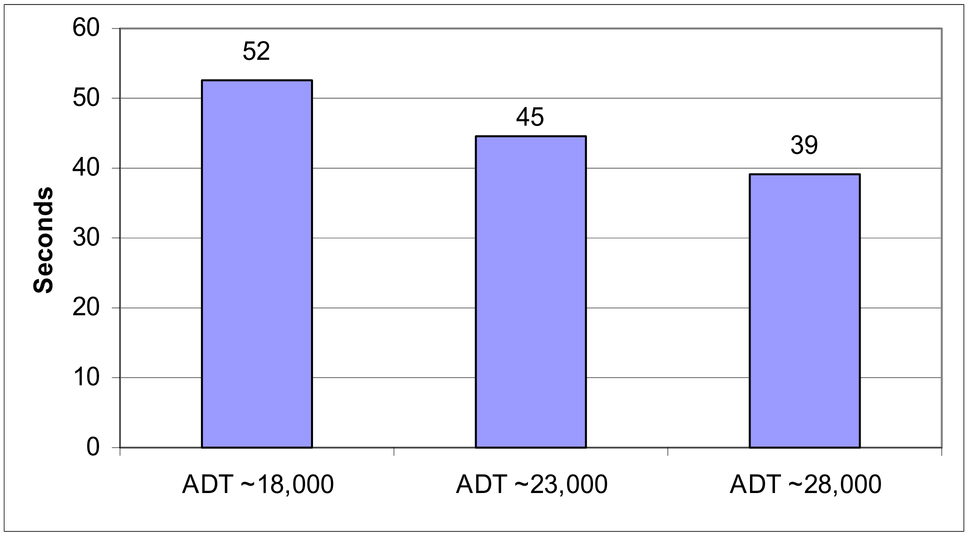


Figure 4-13. Scenario #1 TTC Harmonic Mean by ADT Level.

While the TTC harmonic mean decreased, the TTC4 was relatively constant and less than 0.25 percent for all ADT levels, indicating the relatively uncongested conditions. This is shown in Figure 4-14. Figure 4-15 illustrates that the TTC10 increases with increasing ADT. The weighted average travel time (Figure 4-16) and average delay (Figure 4-17) and speed (Figure 4-18) remained relatively constant for increasing ADT levels in Scenario #1, which is intuitive due to their relatively low congestion levels. Speeds for all of the Scenario #1 ADT levels are within 1 mph.

These results illustrate that the TTC measures are providing intuitive results, particularly at these lower congestion levels. Namely, the TTC harmonic mean reduces with increasing ADT (Figure 4-13), and the TTC10 increases with increasing ADT.

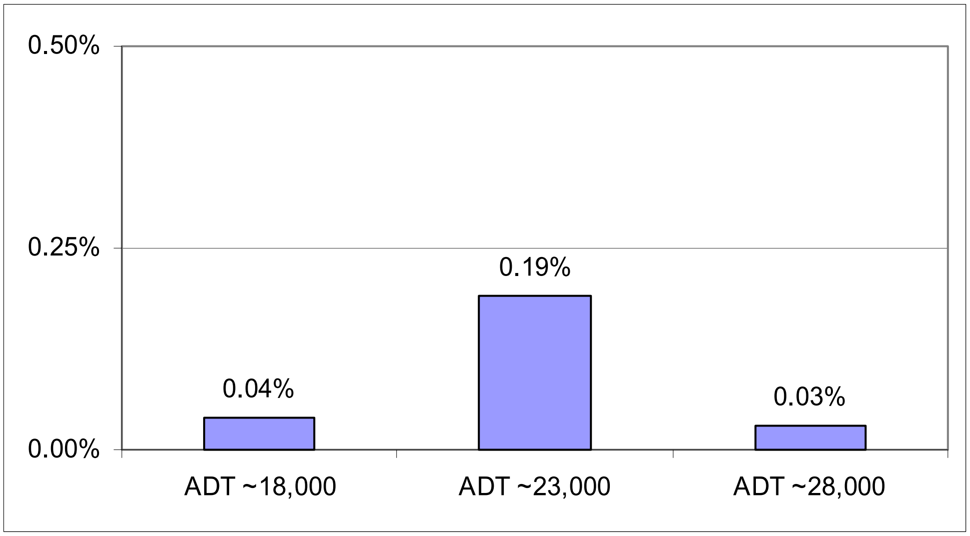


Figure 4-14. Scenario #1 TTC4 by ADT Level.

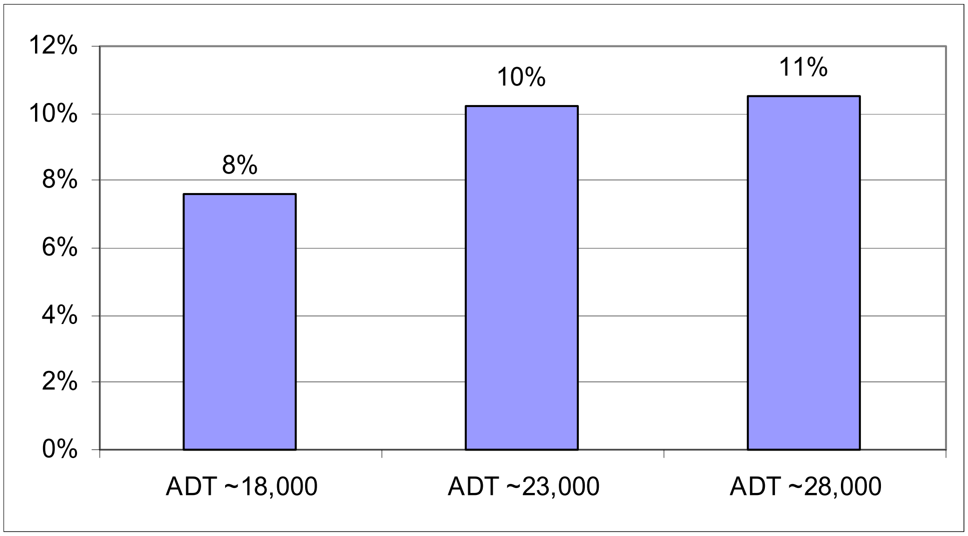


Figure 4-15. Scenario #1 TTC10 by ADT Level.

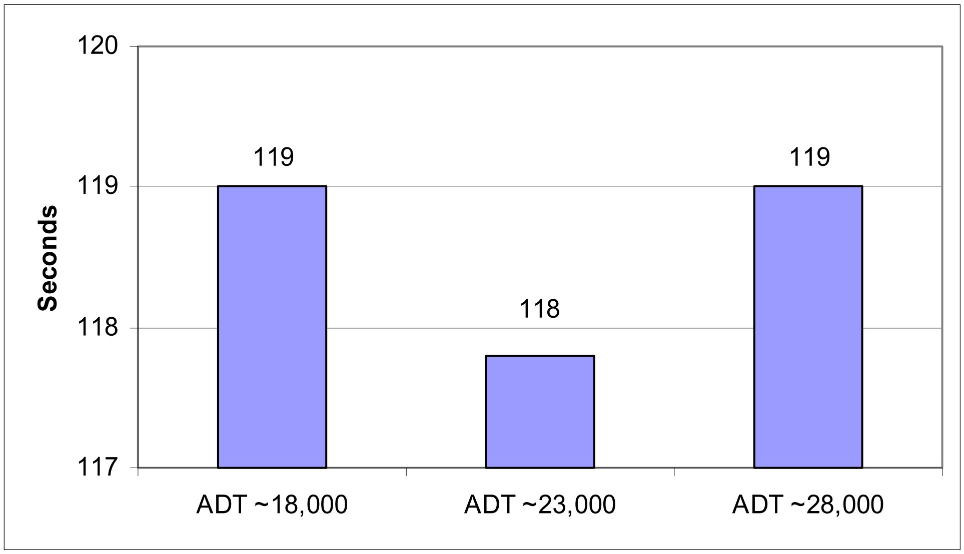


Figure 4-16. Weighted Corridor Travel Time for Scenario #1 by ADT Level.

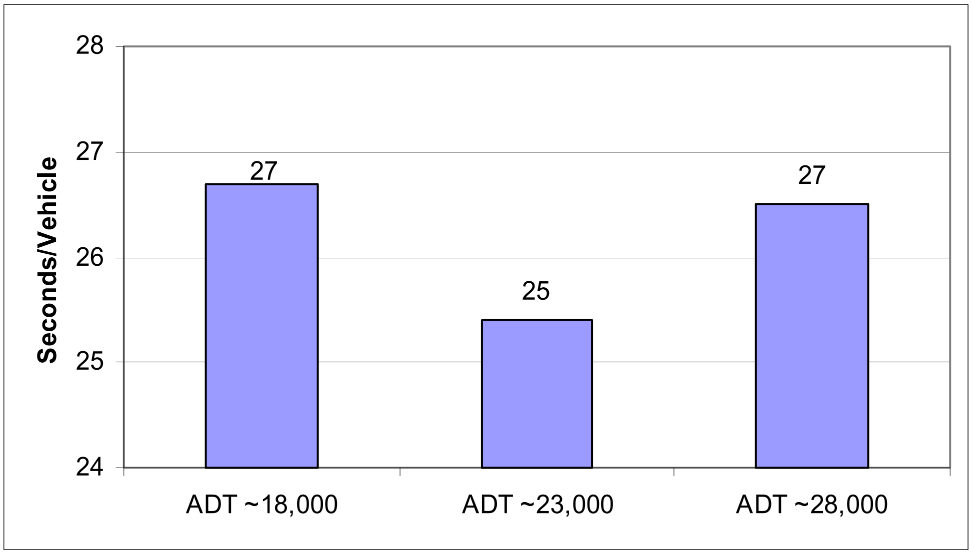


Figure 4-17. Scenario #1 Average Delay by ADT Level.

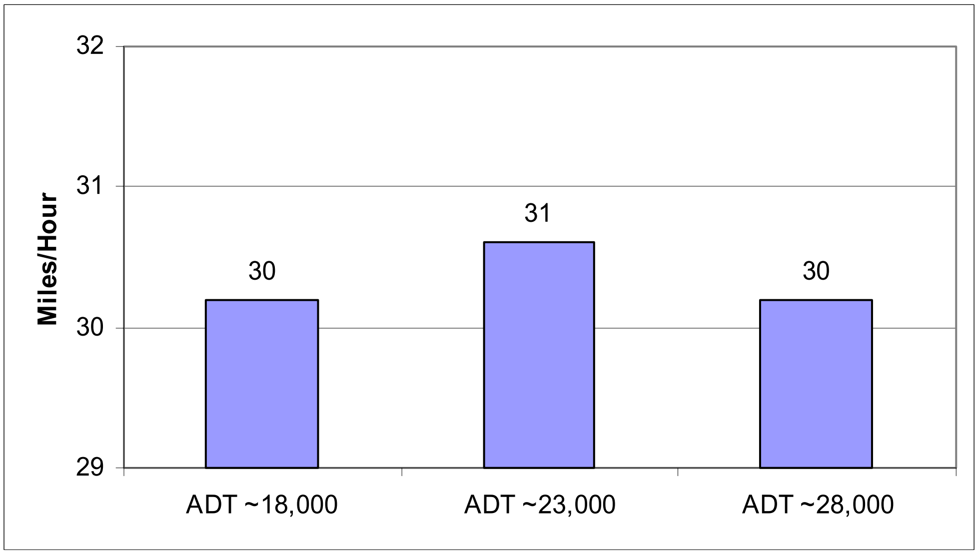


Figure 4-18. Speed by ADT Level for Scenario #1.

Scenario #2 Analysis Results

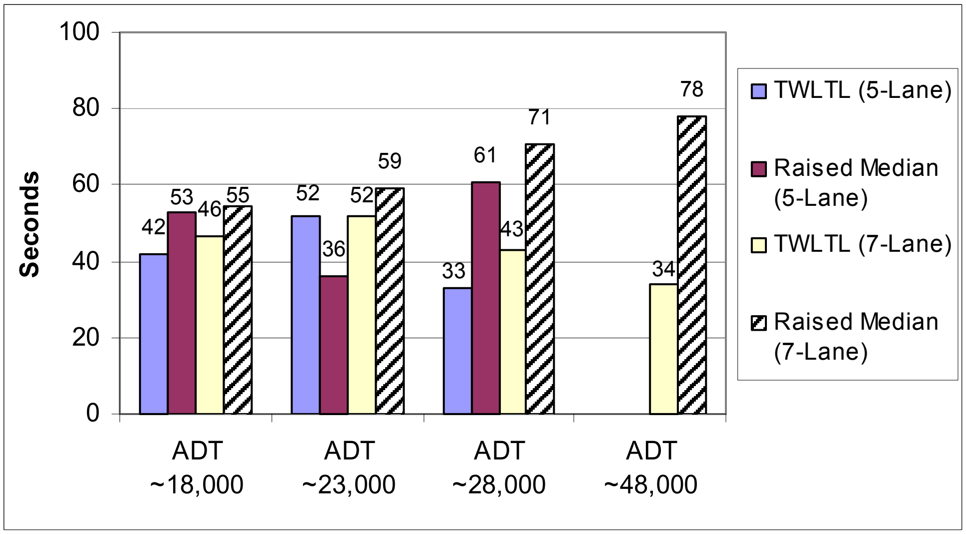
For Scenario #2, the number of lanes and ADT were varied. As described in Section 3.3.3 and shown in Figure 3-12, the number of driveways were increased from 18 to 42. As shown in Figure 4-19, the TTC harmonic mean typically increased with the raised median condition compared to the TWLTL. At the ~48,000 ADT, the TTC harmonic mean increased from 34 to 78 seconds (approximately 129 percent), which appears to indicate the improved flow of the raised median treatment. TTC4 values were relatively low (typically less than 0.25 percent (Figure 4-20). At the ~48,000 ADT, the TTC4 was 0.81 percent, which reduced to 0.02 percent with the raised median. In a similar manner, generally the same trends were found for TTC10 (Figure 4-21).

Figure 4-22 indicates that the weighted corridor travel time values generally increased when going from the TWLTL to the raised median. This increase was as much as 44 percent for the ~48,000 ADT 7-lane section. Figure 4-23 shows the delay results by ADT level for Scenario #2. Delay also increases in Scenario #2 with the raised median installation for all conditions (Figure 4-23). Finally, Figure 4-24 shows the speed results by ADT level for Scenario #2. Speed decreases range from less than 1 mph to 9 mph.

The results for Scenario #2 also indicate that the TTC measures appear to provide reasonable and intuitive results for increasing ADT levels and the installation of a raised median in place of a TWLTL. The results indicate reduced conflicts in terms of acceleration characteristics through the harmonic mean (Figure 4-19) and TTC4 (Figure 4-20). The more circuitous travel and weaving characteristics typically cause the reductions in speed and increases in delay, but they are hypothesized to be offset by the improvements in safety with raised median installation. The TTC measures and typical travel time, delay, and speed measures seem to support these conclusions for Scenario #2, and these findings support national research findings as well (*2*,*13*).

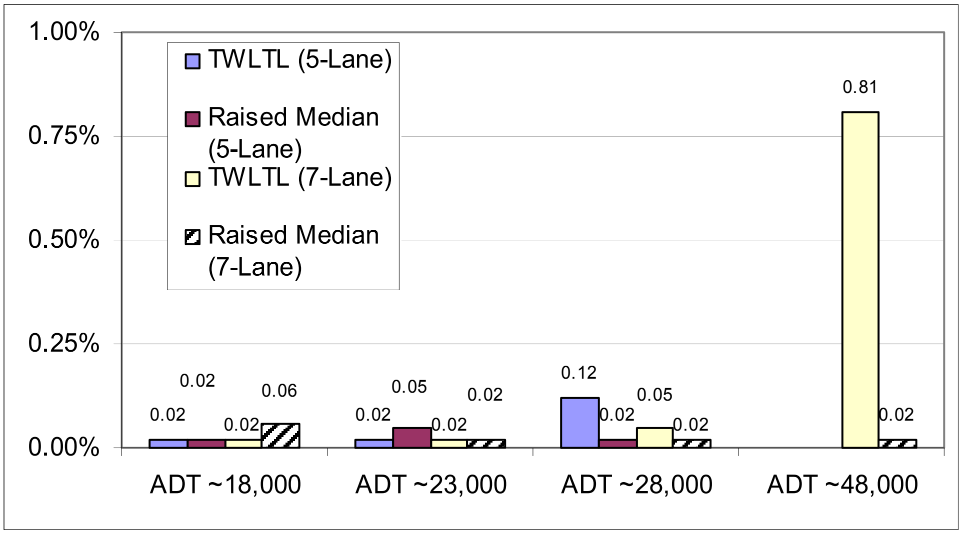
Scenario #3 Analysis Results

For Scenario #3, the number of lanes was kept at seven, the ADTs were varied, and the number of driveways were double the number in Scenario #2. Figure 3-13 and Section 3.3.3 of this report describe theoretical Scenario #3 in more detail. In Scenario #3, the TTC harmonic mean generally increased with the installation of a raised median from a TWLTL condition (Figure 4-25). Conversely, the TTC4 values go down when converting to a raised median from a TWLTL under all of the conditions investigated (Figure 4-26). At the highest ADT of ~48,000, the TTC4 reduces from 0.05 percent to 0.03 percent. All of the TTC4 values are 0.07 percent or less in Figure 4-26. The TTC10 values all generally decrease with the installation of the raised median as well (Figure 4-27). These results follow the same trend as the TTC4 values in Figure 4-26, though the TTC10 values decrease by smaller percentages. At an ADT of ~48,000, the TTC10 increases a negligible amount with the raised median alternative (from 6.8 percent to 7.5 percent).



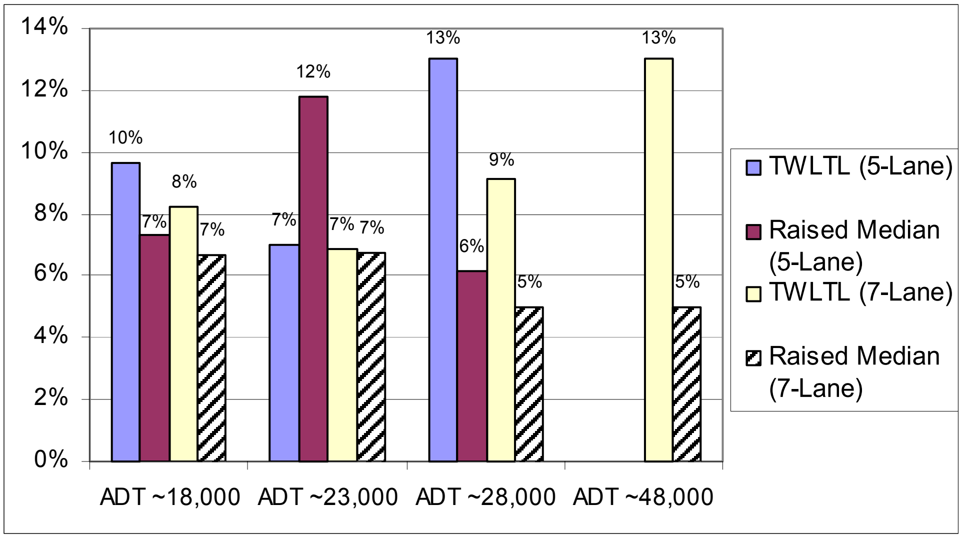
Note: The 5-lane cross section was not investigated at ADT ~48,000.

Figure 4-19. Scenario #2 TTC Harmonic Mean by ADT Level.



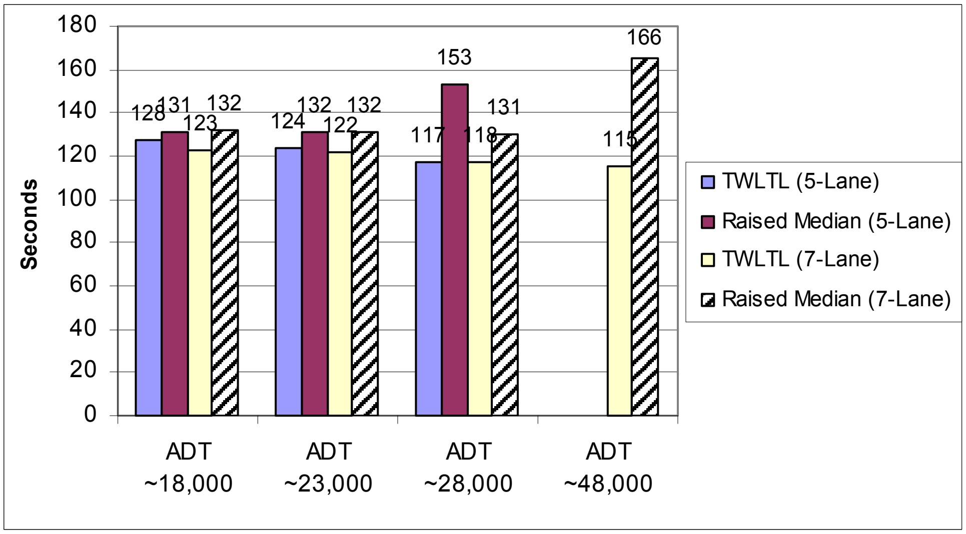
Note: The 5-lane cross section was not investigated at ADT ~48,000.

Figure 4-20. Scenario #2 TTC4 by ADT Level.



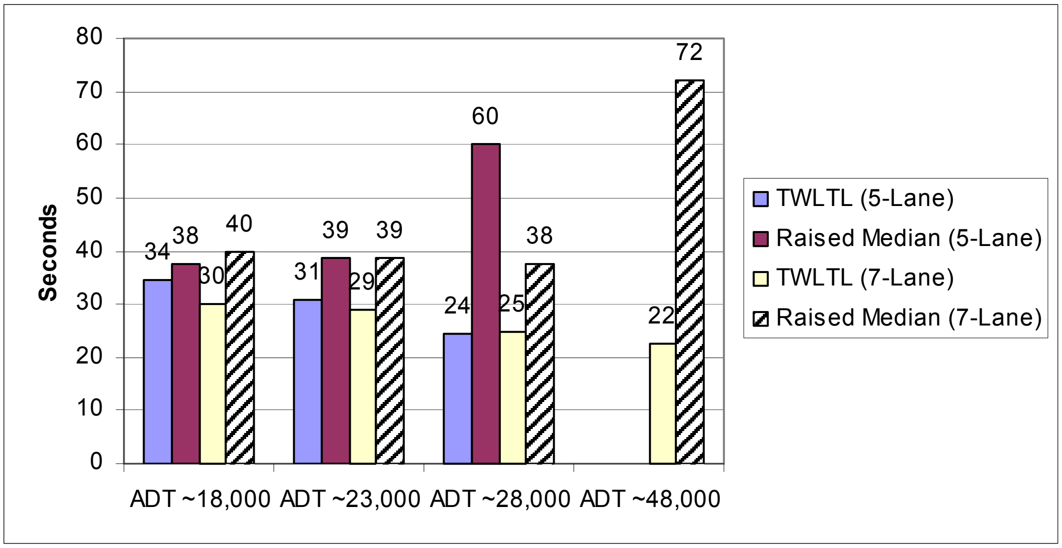
Note: The 5-lane cross section was not investigated at ADT ~48,000.

Figure 4-21. Scenario #2 TTC10 by ADT Level.



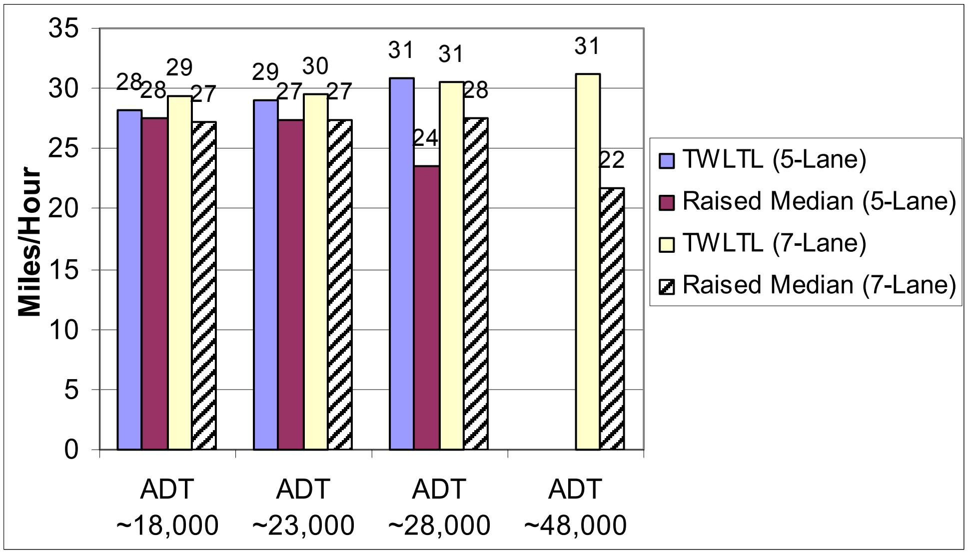
Note: The 5-lane cross section was not investigated at ADT ~48,000.

Figure 4-22. Scenario #2 Weighted Corridor Travel Time by ADT Level.



Note: The 5-lane cross section was not investigated at ADT ~48,000.

Figure 4-23. Scenario #2 Delay Results by ADT Level.



Note: The 5-lane cross section was not investigated at ADT ~48,000.

Figure 4-24. Scenario #2 Speed Results by ADT Level.

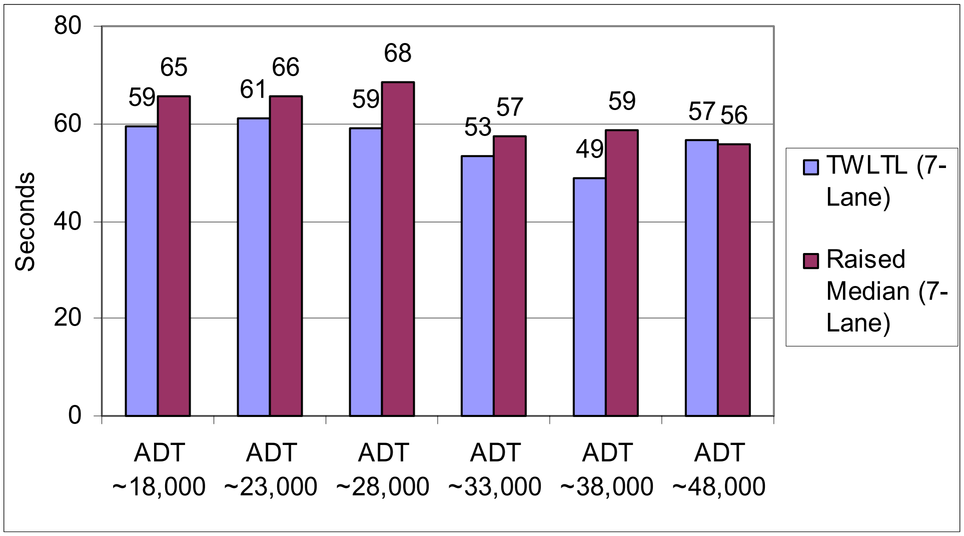


Figure 4-25. Scenario #3 Harmonic Mean by ADT Level.

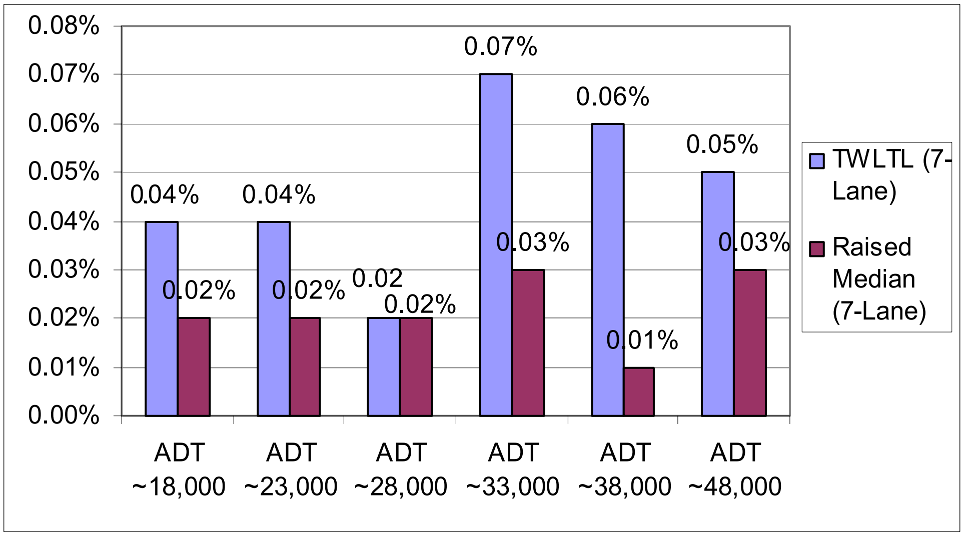


Figure 4-26. Scenario #3 TTC4 by ADT Level.

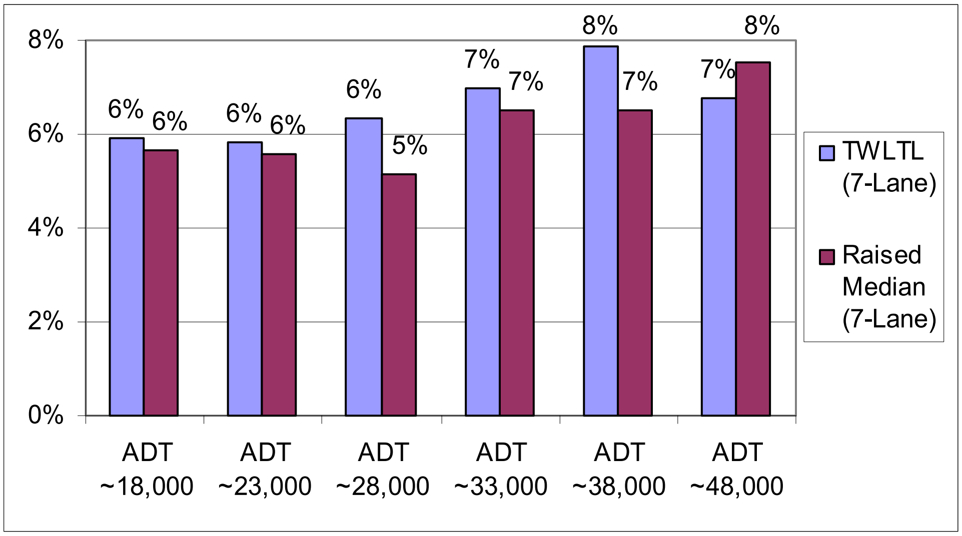


Figure 4-27. Scenario #3 TTC10 by ADT Level.

As with Scenario #2, travel time increases (Figure 4-28), delay increases (Figure 4-29), and speed decreases (Figure 4-30) when the raised median is installed. Speeds reduce from less than 1 mph to 6 mph. This result is slightly less than that experienced in Scenario #2. On average, the speed reduction when going from a TWLTL to a raised median averages approximately 3 mph across Scenarios #2 and #3. For a direct visual comparison, Figures 4-31 through 4-34 show the TTC harmonic mean, TTC4, TTC10, and speed, respectively, for Scenarios #2 and #3 on the same graph.

4.3.2 Discussion of the Time-to-Collision Proof of Concept on the Theoretical Corridors

The theoretical corridors were created to provide further investigation of the TTC surrogate measures under a range of ADTs, driveway density, number of lanes, and median treatments. Unlike some of the case study results, a majority of the results in the theoretical corridors were very intuitive. This included the increases in the TTC harmonic mean with a raised median compared to a TWLTL. Similarly, there were generally decreases in the TTC4 and TTC10, which is intuitive. Further, there was generally a small decrease in speed, which was, on average, approximately 3 mph for the theoretical scenarios. This result is consistent with national findings that have indicated there may be small increases in recurrent congestion due to the installation of a raised median over a TWLTL, but there will be an improvement in safety (*2*,*13*).

As first indicated in Section 4.1.2, there is a need to investigate further case studies to assist in establishing what "low" or "average" values of the TTC harmonic mean, TTC4 and TTC10. Certainly the measures look promising and could be readily adopted and used for relative comparisons between alternatives, but there is a need for a better understanding of the scale of the measures.

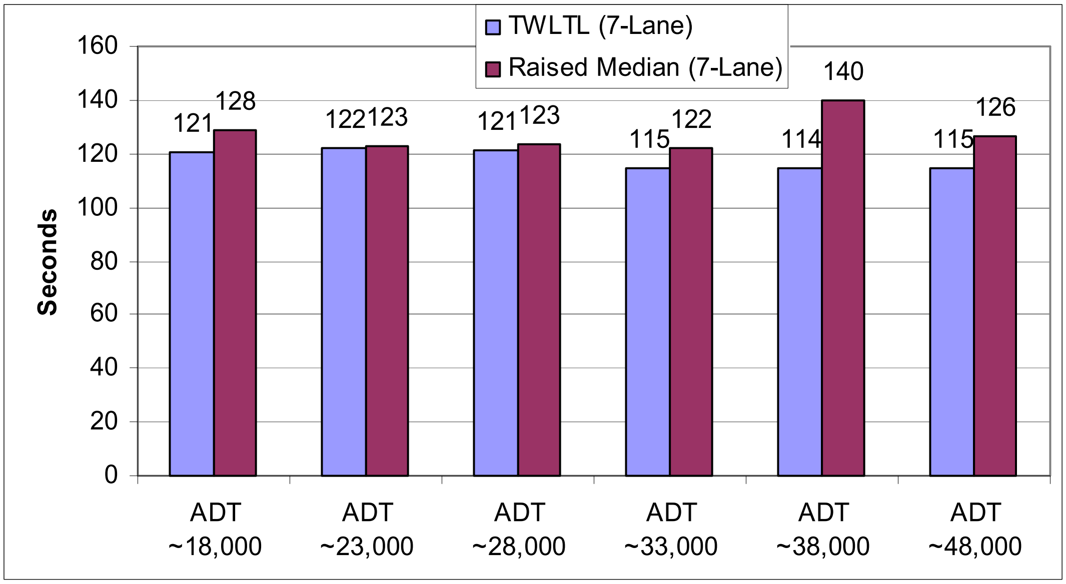


Figure 4-28. Weighted Corridor Travel Time for Scenario #3 by ADT Level.

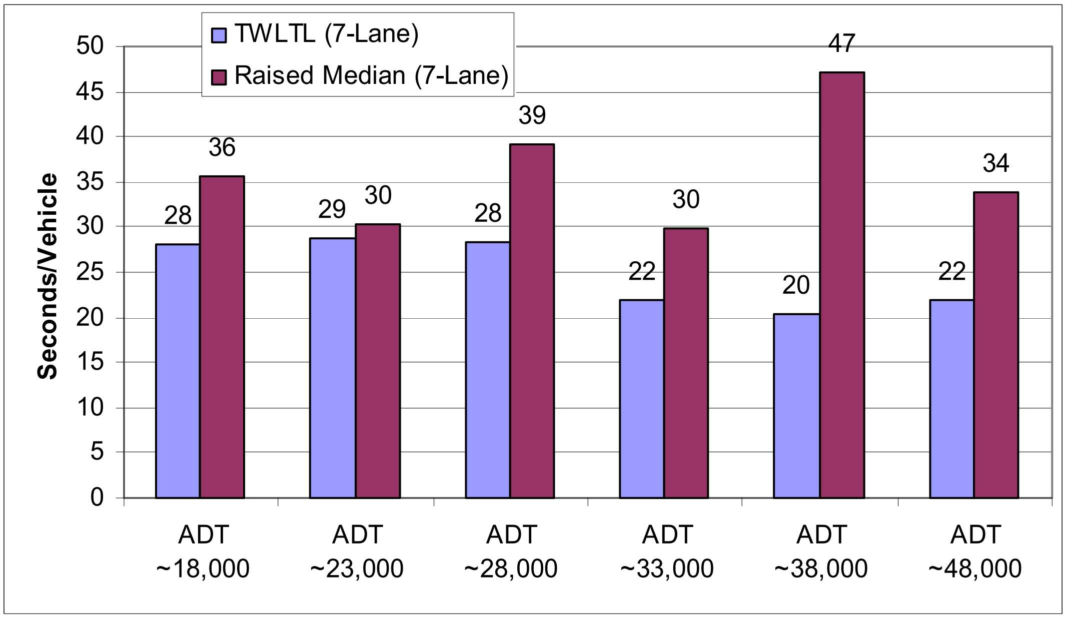


Figure 4-29. Delay Results by ADT Level for Scenario #3.

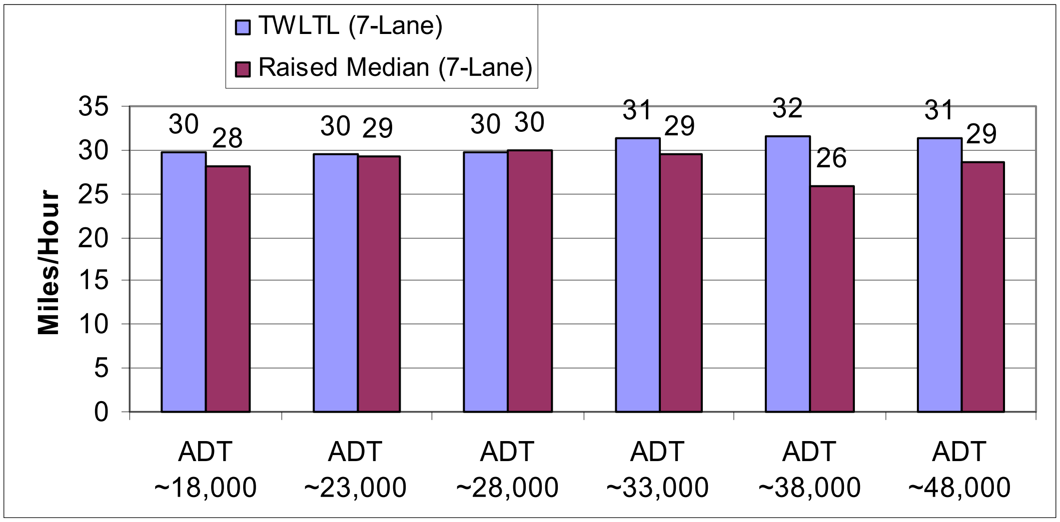


Figure 4-30. Speed Results by ADT Level for Scenario #3.

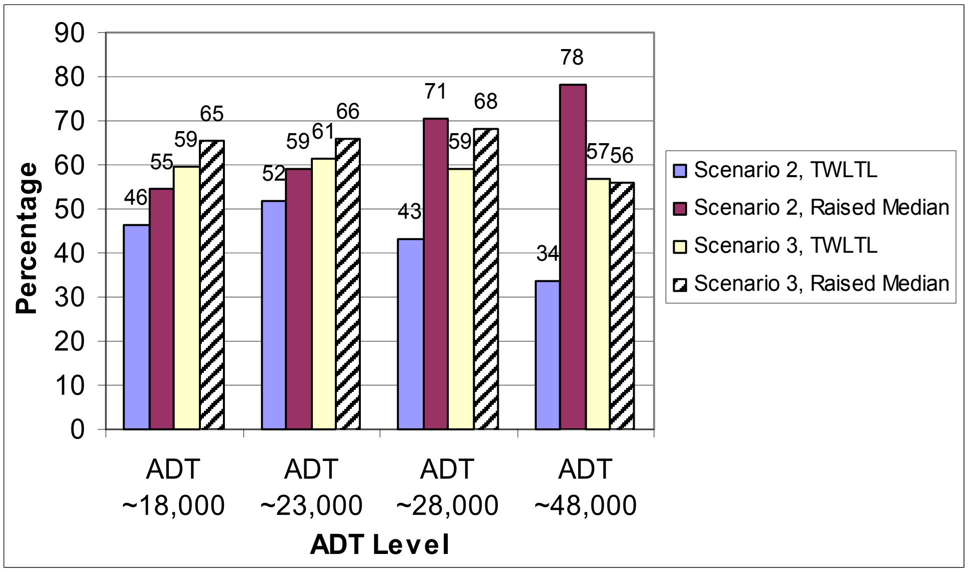


Figure 4-31. TTC Harmonic Mean by ADT Level for Scenarios #2 and #3 (7-Lane).

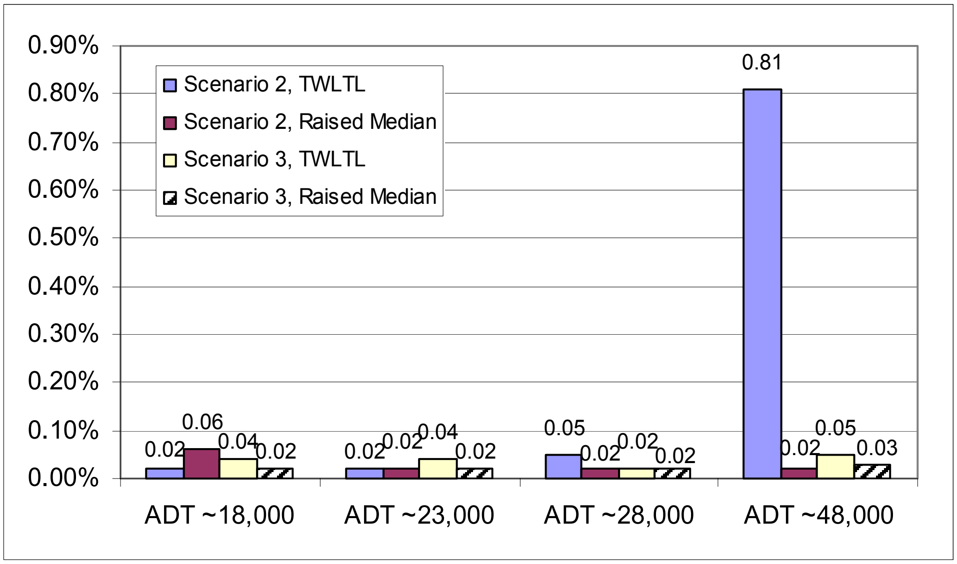


Figure 4-32. TTC4 by ADT Level for Scenarios #2 and #3 (7-Lane).

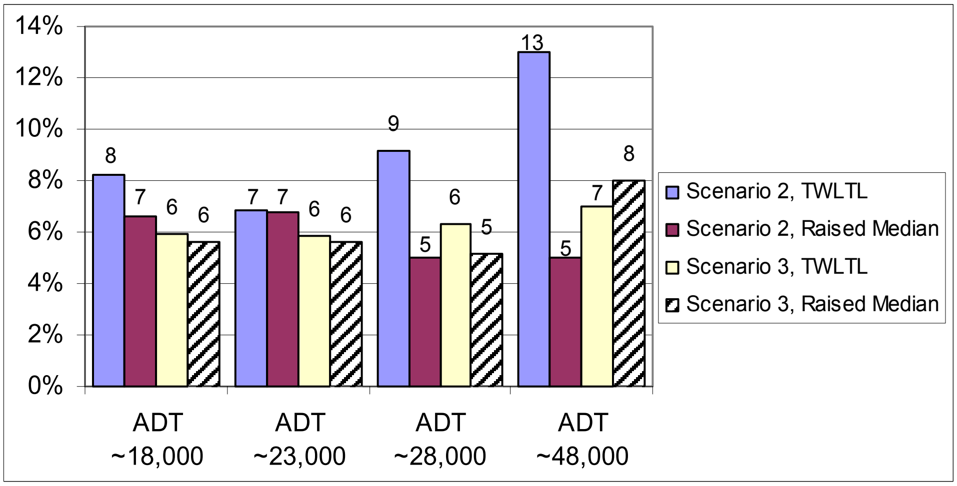


Figure 4-33. TTC10 by ADT Level for Scenarios #2 and #3 (7-Lane).

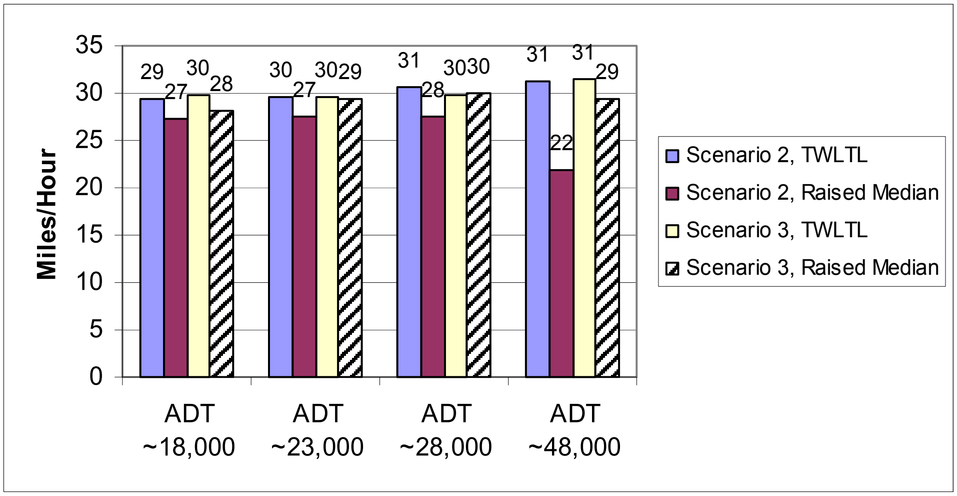


Figure 4-34. Speed by ADT Level for Scenarios #2 and #3 (7-Lane).

4.4 SUMMARY OF CASE STUDY AND THEORETICAL CORRIDOR FINDINGS

4.4.1 Summary of Case Study Findings

Table 4-4 illustrates the characteristics and results for both of the case study corridors. It provides a comparison among the different geometric characteristics, conflict point reductions, changes in operational measures (travel time, speed), and TTC measures.

The percent reduction in conflict points, and all the measures, are calculated as the difference after converting from a TWLTL to a raised median. The two corridors show the same percent reduction in conflict points. (See Chapter 3 for more details). The percent difference in travel time, speed, and TTC values vary for each corridor. The percent change in travel time varies between the two corridors. On the Texas Avenue corridor, travel time decreases 11 percent for the proposed raise median future condition with an ADT of ~21,800 and 38 percent for the future ADT of ~48,000 scenario, while the travel time on the Tyler corridor increases with the raised median. The travel time for the future condition (~48,000 ADT) increases 57 percent when the TWLTL is converted into a raised median on the Tyler case study. It is hypothesized that the more circuitous travel and increased U-turn traffic along the Broadway Avenue corridor cause the raised median treatment to have slightly longer travel times. The high U-turn traffic is due to the relatively large median opening spacing along Broadway Avenue (500 to 1,500 feet in Option B) particularly next to a large retail area. Decreased spacing of the median openings is hypothesized to increase the speeds by reducing/distributing U-turns more efficiently though this was not investigated in this study. However, even the relatively small speed decreases identified here are hypothesized as offset by the reduction in the number of conflict points with a raised median installation.

The TTC harmonic mean along the Texas Avenue corridor reduces 8 percent, while the TTC4 increases. These measures would indicate that the raised median produces increased acceleration characteristics, which is counter-intuitive. As described in Section 4.1.2, for this case study it appears that there is a need to isolate the TTC tool to include only the corridor segment of interest rather than including vehicular interactions that occur before the travel time data collection points. Similar findings result along the Broadway Avenue corridor.

Along Broadway Avenue in Tyler, the travel time increased 2 percent (<1 mph decrease) when the raised median was installed at the lower ADT level (29,300). At the higher ADT level of 48,000, there was a 57 percent increase in travel time with the raised median. This travel time difference equates to a 5 mph decrease in speed. The TTC harmonic mean for Broadway Avenue decreases in both future scenarios. The TTC4 also decreases in both scenarios. The TTC10 both increase when the TWLTL is converted to a raised median.

Table 4-4. Summary of Case Study Micro-simulation Results.

Case Study	Location	Corridor Length (miles)	Signal per Mile / Access Points per Mile[1]	Median Opening Spacing (feet)[2]	Number of Lanes each Direction[3]	Land Uses	Percent Reduction in Conflict Points[4]	Estimated Existing ADT[5]	Estimated Future ADT[6]	Future Percent Difference in Travel Time[2]	Future Actual Difference in Speed (mph)	Percent Difference in TTC Harmonic Mean[4,7] (seconds)	Future Actual Difference in TTC4[4,8]	Future Actual Difference in TTC10[4]
Texas Avenue	Bryan, Texas	0.66	3.0 / 91	660 to 1,320	2	Retail, University	-60	18,200	21,800	-11	2 (increase)	< 1	-0.2	-0.9
									48,000	-38	7 (increase)	-8	0.6	-0.3
Broadway Avenue	Tyler, Texas	1.47	4.1 / 46	500 to 1,500	3	Commercial, Retail	-54	24,400	29,300	2	<1 (decrease)	-7	-0.13	0.3
									48,000	57	5 (decrease)	-3	-0.32	1.5

[1] Access point density includes both directions and includes driveways, streets, and signalized intersections.

[2] Median opening spacing is the range for the raised median alternative with the most openings. Two alternatives were investigated along Broadway.

[3] The Texas Avenue corridor was not widened in the micro-simulation because VISSIM allows vehicles to perform U-turns with two lanes, and this study was intended to investigate the differences between the TWLTL and the raised median. From a practical perspective, flared intersections and slightly widened mid-block location(s) would facilitate the U-turns.

[4] The percent difference values are derived from the conversion from a TWLTL to a raised median. Negative values imply a decrease when converting to the raised median. These differences are based upon the weighted average of at least three micro-simulation runs.

[5] Estimated from road tubes or videotapes. The ADTs are estimated by assuming a K and D factor to apply to the observed peak-hour volume.

[6] The lower ADT value is a 20 percent increase over existing conditions. This represents an approximate 2 percent increase over 10 years. The higher ADT value was run to estimate higher-volume conditions. The ADTs are estimated by assuming a K and D factor to apply to the observed peak hour volume.

[7] TTC4: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds.

[8] TTC10: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds.

4.4.2 Summary of Theoretical Corridor Findings

Table 4-5 presents a summary of the theoretical corridor micro-simulation results for the operational measures as well as the TTC measures. As in the case studies, the first observation is that the number of conflict points decreases with the installation of a raised median. This was shown in Chapter 3 in more detail. This decrease occurs even when the number of driveways increases from 18 in Scenario #1 to 84 in Scenario #2. The number of conflict points for both the 5- and 7-lane options for Scenario #2 was reduced by 70 percent with the installation of a raised median. This large reduction is accompanied by an increase in travel times with the raised median from 2 to 31 percent for the 5-lane option and from 8 to 44 percent for the 7-lane option.

The Scenario #3 results show a 75 percent reduction in the number of conflict points with the installation of a raised median, along with a 1 to 22 percent increase in travel time. The differences in travel times reflect the range in travel times as the ADT increases. The actual reduction in speed is, on average, approximately 3 mph when a raised median replaces a TWLTL across all of the conditions investigated.

The TTC harmonic mean typically increases, particularly for the 7-lane cross sections. For the ~48,000 ADT of Scenario #3, the TTC harmonic mean was only 1 second different (2 percent). Intuitively, the TTC4 values were typically lower with the raised median, or the same as, the condition with a TWLTL. These results are intuitive for the theoretical corridors and appear to show promise for the use of the TTC measures as a surrogate for safety in the micro-simulation environment. Sections 4.1.2 (Bryan, Texas, case study), 4.2.2 (Tyler, Texas, case study), and 4.3.2 (theoretical corridors) discuss further some of the improvements that could be made to the TTC tool in the micro-simulation environment.

4.5 MICRO-SIMULATION MODEL USE FOR ACCESS MANAGEMENT

Micro-simulation models have become a valuable tool for assessing potential transportation improvements and analysis of alternatives. There are numerous commercially available tools. Some of these tools were introduced in Section 2.2 of this report. Of primary interest to a practitioner selecting a micro-simulation tool is ensuring that it provides the necessary input and output characteristics to perform the desired analysis. Section 2.3 of this report describes some of the desirable input and output characteristics for performing micro-simulation analysis on roadway improvements that include access management. This list of input and output characteristics was developed as part of this research project.

While the research team used VISSIM as the micro-simulation tool for this analysis, any number of tools could likely be used for the analysis. The VISSIM tool was selected in part because the research team was very familiar with the model due to it use in previous research projects. The model was also selected because of its ability to model TWLTL conditions as well as the fact that the model satisfies the desirable input and output characteristics listed in Section 2.3.

Table 4-5. Summary of Theoretical Corridor Micro-simulation Results.

Theoretical Corridor	Median Treatment[1]	Number of Lanes in Each Direction	Percent Difference in Conflict Points[2]	Number of Driveways	Driveway Spacing (feet)	Raised Median Opening Spacing (feet)	Estimated Future ADT[3]	Future Percent Difference in Travel Time[2]	Future Actual Difference (decrease) in Speed (mph)	Percent Difference in TTC Harmonic Mean[2] (seconds)	Future Actual Difference in TTC4[2,4]	Future Actual Difference in TTC10[2,5]
Scenario #1	TWLTL	2	Not Applicable	18	660	660	18,000 to 28,000	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Scenario #2	TWLTL	2	-70	42	330	660	18,000	2	<1	26	0.0	2.3
							23,000	6	2	-31	0.03	4.8
	Raised						28,000	31	8	85	-0.10	-6.9
	TWLTL	3	-70	42	330	660	18,000	8	2	20	0.04	-1.5
							23,000	8	2	14	0.0	0.0
	Raised						28,000	11	3	65	-0.03	-4.2
							48,000	44	9	129	-0.8	-8.0
Scenario #3	TWLTL	3	-75	84	165	660	18,000	6	2	10	-0.02	-0.2
							23,000	1	<1	8	-0.02	-0.2
							28,000	2	<1	15	0.0	-1.1
	Raised						33,000	7	2	8	-0.04	-0.5
							38,000	22	6	21	-0.05	-1.4
							48,000	10	3	-2	-0.02	0.7

[1] Scenario #1 can be considered as both a TWLTL and a raised median because, due to the driveway spacing, there is no change in the conflict points and turning locations.

[2] The percent difference values are from the conversion from a TWLTL to a raised median. Negative values imply a decrease when converting to the raised median. These differences are based upon the weighted average of at least three micro-simulation runs.

[3] The ADTs are estimated by assuming a K and D factor to apply to the observed peak-hour volume.

[4] TTC4: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 4 seconds.

[5] TTC10: Proportion (percentage) of rear-end vehicle time-to-collision values that are less than, or equal to, 10 seconds.

Micro-simulation tools will continue to provide a valuable analysis tool for evaluating transportation alternatives and roadway improvements. Access management is a package of proven roadway improvement techniques. The list of desirable input and output characteristics in Section 2.3 should be valuable to practitioners as a checklist for model selection.

4.6 PERFORMANCE MEASURES FOR ACCESS MANAGEMENT

Performance measures or measures of effectiveness (MOEs) are used for evaluating roadway improvements and performing alternative analysis. Typical operational performance measures include travel time, speed, and delay when evaluating networks or specific corridors. These performance measures are appropriate for investigating roadway improvements that include access management. These measures were used in the corridor analyses in this report.

While measures such as travel time, speed, and delay can readily assess operational impacts along a corridor or network (i.e., recurring congestion, roadway bottlenecks, signal progression), they do not provide a direct indication of safety along a corridor. In addition to operational improvements, safety improvements are often sought with roadway improvements. However, assessing the safety of transportation alternatives is often founded in evaluating crash records/reports. There are numerous potential problems with using crash data. It is often limited, unavailable, requires a great time to collect/reduce, and there are often questions about data accuracy. These issues are discussed in more detail in Section 2.4 of this report.

To alleviate the difficulty of relying on crash reports in all cases, this report performed a review of performance measures that can serve as surrogate measures of safety in the micro-simulation environment. Thus, analysts could theoretically use only one tool (micro-simulation) to get an assessment of operational and safety impacts for a given transportation alternative. This report investigated the use of time-to-collision measures (TTC harmonic mean, TTC4, TTC10) as surrogates of safety in the micro-simulation environment. The TTC measure appears to show great promise for use in micro-simulation as a surrogate for safety with the case studies and theoretical corridors evaluated in this report. Further research and development is needed on the TTC subroutine that was incorporated into VISSIM in the analysis documented in this report, but the early results documented in this report are promising.

Therefore, in addition to the traditional operational measures of travel time, speed, and delay, performance measures such as the TTC appear useful and promising for access management evaluation.

4.7 INCORPORATING ACCESS MANAGEMENT PERFORMANCE MEASURES INTO THE TRANSPORTATION PLANNING PROCESS

With the identification of TTC-related measures to incorporate safety impacts into the micro-simulation environment, the next step is to incorporate the use of the TTC (and related measures) into the transportation planning process.

Figure 4-35 illustrates how performance measurement is central to the traditional transportation planning process. The performance measures are directly related to the goals and objectives of the transportation system, data elements, system operations, analysis methods, and alternative improvement strategies. As indicated previously, typically there are goals/objectives related to improving operational performance (travel time, speed) as well as safety (crash reduction). Therefore, there is an opportunity for incorporating the surrogate performance measures for safety into the typical planning stages with relative ease, particularly if micro-simulation models can directly incorporate these measures/techniques.

There is a need to calibrate the TTC measures identified in this report (TTC harmonic mean, TTC4, TTC10) with field observations, which includes crash records. Ultimately, and theoretically, repeated calibration and increased case studies would provide a "baseline" on typical values for the TTC harmonic mean, TTC4, and TTC10 to define targets values (or even ranges) for different conditions and possibly even access management treatments. Such targets could ultimately provide acceptable values that are intuitive and readily understood. For example, at present a TTC4 value of 2.5 percent can be difficult to understand, but with increased field observations, the relative "improvement" of such a value may become more clear (i.e., as it is clear when a corridor speed improves from 35 mph to 45 mph). The use of the surrogate measures will be most useful for relative comparisons between alternatives prior to a clearer understanding of the meaning of exact values.

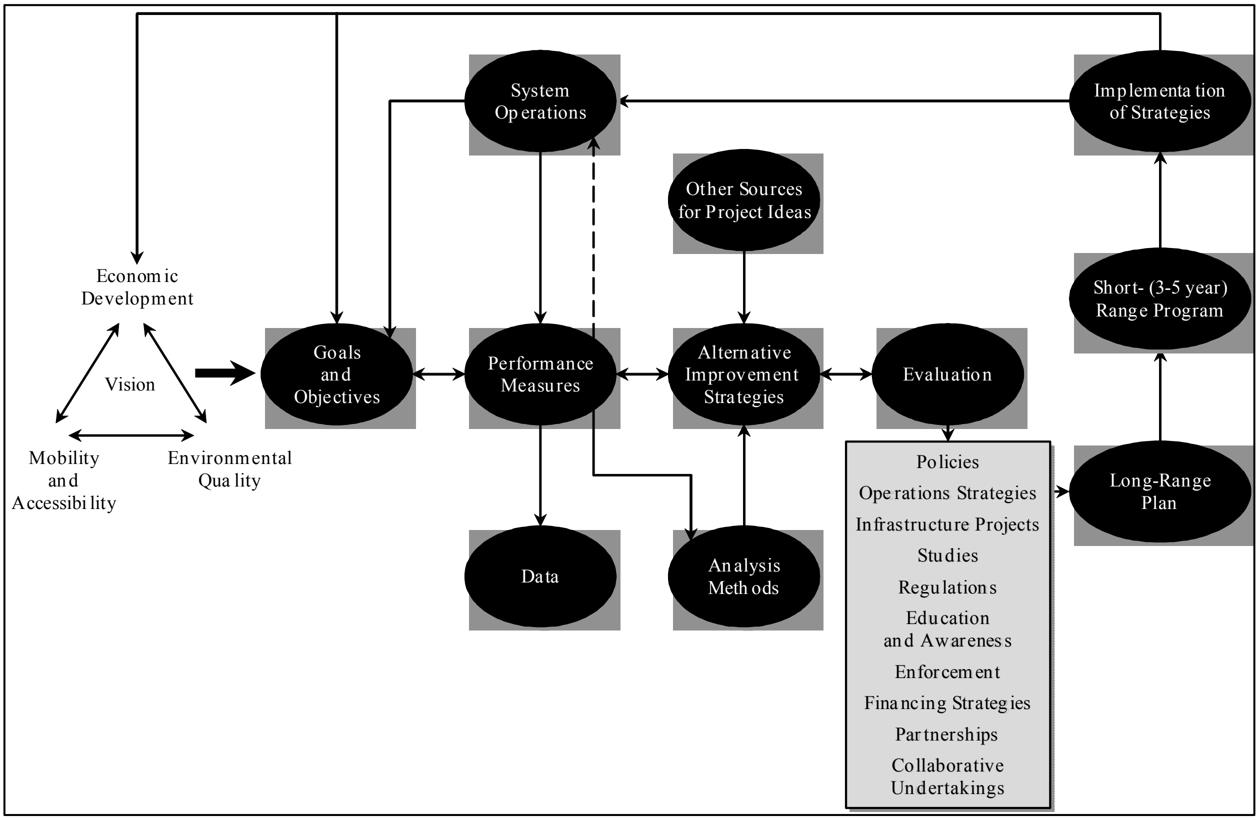


Figure 4-35. Performance Measurement in the Traditional Transportation Planning Process (Reference *40*).

In time, given target values for the TTC measures, transportation planning analyses could ultimately incorporate safety measures into demand management (4-step) models as well. Such models could consider safety as an additional component in addition to their traditional capacity and operational focus. Figure 4-36 shows the typical 4-step process (trip generation, trip distribution, modal split, and traffic assignment) and how they fit into the continuing urban transportation planning process. The 4-step process could benefit from safety measures being incorporated though it would be necessary for significant calibration to field conditions before such analyses would be practical.

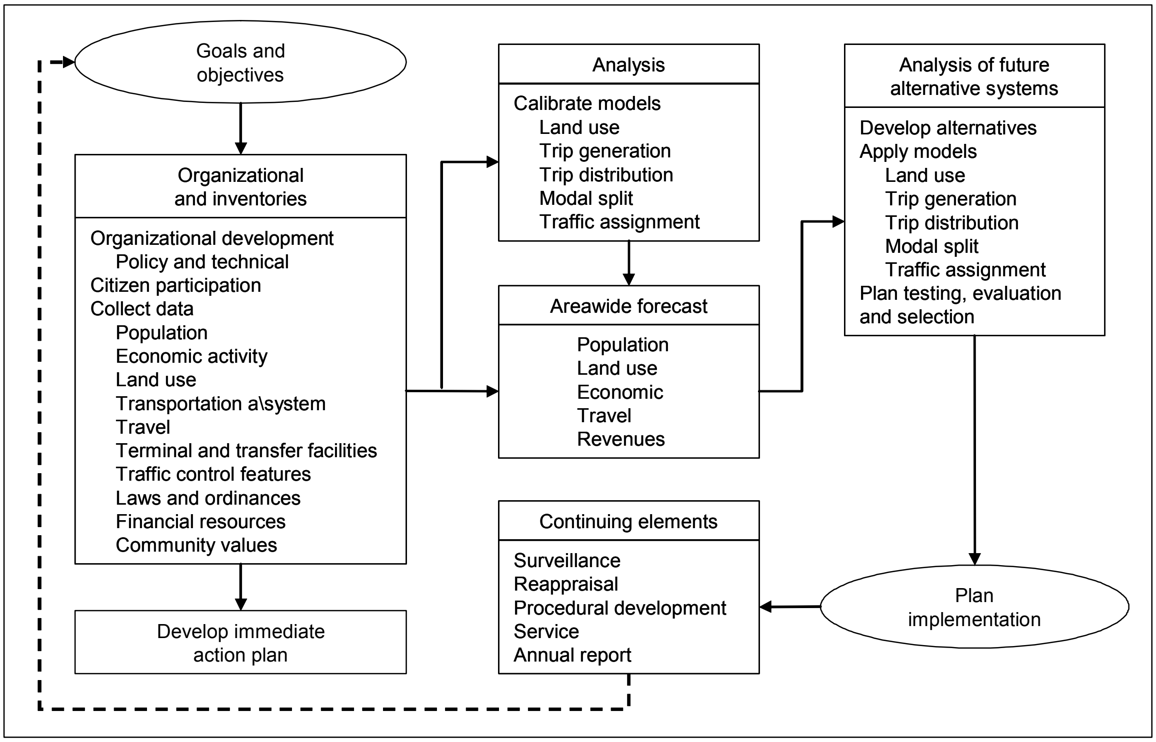


Figure 4-36. Illustration of the 4-Step Travel Demand Components within the Context of the Long-range Transportation Planning (Reference *41*).

CHAPTER 5

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORK

5.1 CONCLUSIONS AND RECOMMENDATIONS

5.1.1 Desirable Input and Output Characteristics for Micro-simulation Tools Used to Evaluate Access Management Improvements

Micro-simulation is a useful and effective tool for evaluating transportation improvements provided the user understands the model and calibrates the model to field conditions. This report describes access management improvements and how they can be evaluated in the micro-simulation environment. Researchers identified key input and output characteristics (Section 2.3) that an analyst should look for when shopping for a micro-simulation tool that will be used to assess access management improvements.

Micro-simulation tools do have steep learning curves to thoroughly understand their traffic flow theory and underlying computation methods, but it is critical for the analyst to understand these characteristics prior to use.

5.1.2 Both Operational and Safety Performance Measures Are Important for Access Management

Nearly all transportation improvements assess both mobility and safety improvements. Traditional mobility measures include travel time, delay, and speed, and these measures are readily obtained from field studies and/or micro-simulation. The research also identified key measures based upon car-following theory that appear promising as surrogate measures of safety (Section 2.4). These measures relate to the time-to-collision of two vehicles. This is the time it would take for vehicles to collide given their current vectors (speed and direction). These measures were then investigated and quantified along case study corridors and theoretical corridors.

5.1.3 Promising Results for Incorporating TTC Measures into Micro-simulation

The research tested the incorporation of surrogate measures of safety (TTC-related measures) into the micro-simulation (VISSIM) environment. A program was written to compute the micro-simulation measures in “real-time” while the VISSIM model was running (Section 3.2). The model uses the vehicle trajectories of following vehicles. Potential angle-collisions were not considered in this initial software development, just potential “rear-end” collisions. The preliminary results on two case study corridors and three theoretical corridors are promising, particularly at lower traffic volumes. Analysis of the case study corridors and theoretical corridors investigated the conversion from TWLTL median treatments to raised median treatments. Driveway density was also investigated.

There were large reductions in the number of conflict points along the corridors investigated in this research when incorporating access management treatments, and the TTC measures appear to show promise in how they reflect the relative improved safety along the corridors. Generally, the TTC harmonic mean increased, TTC4 decreased, and TTC10 decreased when converting to raised medians (particularly for relatively uncongested conditions and along the theoretical corridors). While there is still a better understanding needed of what the specific values of the TTC output may mean (i.e., there are no standard values for what is "good" or "bad" for a given condition), the results appear useful for relative comparisons across transportation alternatives that include access management with some minimal additional calibration and testing.

Because the TTC measures capture acceleration characteristics inherently, they are anticipated to be useful for investigating many types of geometric design improvements beyond just access management improvements.

While there are some needed improvements necessary to improve the program and computation of the TTC within the micro-simulation environment (see Section 5.2), the preliminary results are promising.

5.1.4 Signal Timing Improvements Always Provide Corridor Improvements

Transportation agencies are always seeking cost-effective solutions to improve the transportation system while utilizing taxpayer dollars wisely. On all of the case study corridors and theoretical corridors investigated in this research, simply optimizing the signal timings always resulted in mobility improvement along the corridor.

5.1.5 Safety and Operational Access Management Performance Measures Can Be Incorporated into the Traditional Transportation Planning Process

This research report discussed how surrogate measures of safety could be incorporated into the traditional transportation planning process in the same way as traditional mobility measures are used (Section 4.7). In time, given target values for the TTC measures, transportation planning analyses might also incorporate safety measures into demand management (4-step) models as well.

5.1.6 Case Specific Corridor Results: Use Caution When Transferring Results to Other Corridors

Researchers found different results along both case study corridors due to local conditions. For the conversion of a TWLTL to a raised median along the Bryan, Texas, corridor, there was as much as a 7 mph increase in speed along the corridor with the installation of the raised median while along the Tyler, Texas, corridor there was a 5 mph decrease in speed at the ~48,000 ADT level. The corridors did contain relatively long median opening spacings—as much as 1,500 feet on the Tyler, Texas, corridor. This large spacing occurred adjacent to a retail shopping area, which, when congested, substantially increased the number of U-turning vehicles and the subsequent weaving that must occur from the U-turn lanes to desired driveways, thus slowing through movements.

It is more important to note that all corridors are different. They contain various corridor characteristics including travel demand, origins-destinations of travel, driver behavior, and geometric elements to name a few. Therefore, it is important to use caution when transferring results from one corridor to another. When calibrated to field conditions, micro-simulation provides a tool that can estimate the effects of the combination of these different corridor characteristics.

5.2 FUTURE WORK

5.2.1 Calibrate TTC Results to Crash Data

There is a need to calibrate/compare the TTC results to corridors on which actual crash data have been collected to identify the correlation of the micro-simulation TTC results to field crash information.

5.2.2 Investigate Case Studies with Closer Median Opening Spacings

There is a need to investigate case study locations with closer median opening spacings than those investigated here. Along the Tyler, Texas, corridor, the median opening spacings were as long as 1,500 feet, while along the Bryan, Texas, corridor, the median opening spacings were as long as 1,320 feet (Table 4-4). There is a corridor-specific optimal location of median openings based upon corridor specific characteristics to optimize speed while increasing safety and only limited conditions could be investigated in this report.

5.2.3 Expand TTC Program to Angle Crashes

The program developed to operate using the VISSIM vehicle trajectory data only uses “rear-end” crashes in this initial version. Therefore, it considers only two following vehicles. There is a need to expand the software to include angle crashes between vehicles.

5.2.4 Incorporate Distribution of TTC Values

Distribution information about the TTC measures would be valuable to compute. While the program does keep the mode of the TTC values for a given run, standard deviation information would be equally valuable to identify the variability in the average TTC for a given alternative—a potentially equally important measure for investigating potential collision severity.

5.2.5 Isolate TTC Computations to the Segments of Interest

In the current versions of the program developed for this analysis, the researchers collected the speed information along the corridor itself based upon the travel time of vehicles traversing the entire corridor, while the TTC computations are performed on all vehicles in the micro-simulation. Therefore, the TTC measure includes the interactions of all vehicles in the system and in the micro-simulation (i.e., those vehicle interactions along the roadway and those that are occurring on parcels along the roadway—entering the roadway). Further, the TTC computations would include all vehicle interactions that occur prior to the vehicles getting to the travel time data collection points along the roadway. Therefore, when comparing speeds (travel times) to the TTC measures computed for this report, they are based upon different “groups” of vehicles.

There is a need to isolate the computation of the TTC measures to just the segment(s) of the corridor of particular interest where the travel time data collection points are located.

5.2.6 Define TTC Values

There is a need to establish reasonable ranges for the TTC. Control sites/conditions would be needed to identify the “normal” (baseline) value of a TTC. For example, are the values of 1 or 2 percent for TTC4 “average” or “low”?

5.2.7 Further Investigate TTC “Cutoff” Values

This report used the TTC4 and TTC10 values as appropriate TTC thresholds. This was based upon experiences noted in the literature and professional judgment. There is a need to further investigate whether these thresholds are appropriate or if values between TTC4 and TTC10 may be relevant for some operational situations. Investigating the variability on the TTC values (Section 5.2.4) would assist in this task.

5.2.8 Perform More Micro-simulation Runs on More Case Study Corridors—Particularly Under Congested Conditions

Given the numerous needs outlined above, there is a need to perform more micro-simulation runs on different geometric and operational conditions. Due to the variability of traffic as conditions become more congested, there is a particular need to perform more runs under congested conditions.

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