Development and Application of a Mobility Monitoring Process and Guidebook for Small to Medium-sized Communities

by

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ABSTRACT
Transportation professionals in growing small- to medium-sized communities (SMSCs) struggle with congestion issues. SMSCs are defined as communities with a population less than 200,000. Extensive resources and literature are dedicated to measuring, monitoring and improving large urban area congestion, but resources are scarce for SMSCs. Guidance is needed for SMSCs practitioners to better identify, measure, and alleviate congestion before the problems escalate.

This paper discusses the results of a research project sponsored by the Texas Department of Transportation (TxDOT). The project's primary objective was to develop and test a framework suitable for monitoring mobility in SMSCs. Practitioners including state DOT staff and staff of their partnering agencies (e.g., metropolitan planning organizations [MPOs], municipalities, and counties) interested in mobility monitoring in SMSCs will find the research products valuable resources.

This paper first highlights key points gleaned from the available literature. Performance measures are presented and discussed. Second, the paper presents the development of a six-step mobility monitoring framework and its application in two SMSCs. The framework was developed to be user-friendly. The mobility monitoring process was conducted in Bryan/College Station, Texas and Huntsville, Texas. Third, the paper discusses methods to communicate results to a wide audience. Several graphical techniques are presented and discussed, including intraday directional traffic volumes and travel rate indices within a corridor. Fourth, the paper highlights available resources to assist practitioners performing mobility monitoring in SMSCs. Finally, the authors summarize general conclusions and future research needs.

INTRODUCTION

Transportation professionals in growing small- to medium-sized communities (SMSCs) struggle with congestion issues. SMSCs are defined as communities with a population less than 200,000. Congestion in these communities is often highest along state highways that also serve major local travel functions. There are extensive resources and literature dedicated to measuring, monitoring and improving large urban area congestion, but resources are scarce for SMSCs. There is a need for guidance for SMSCs practitioners to better identify, measure, and alleviate congestion before the problems escalate. Potential solutions and performance measure targets necessarily are much different for smaller communities than those identified in the literature for urban areas.

This paper discusses work performed on a research project sponsored by the Texas Department of Transportation (TxDOT). That project's objective was to develop and test a framework for mobility monitoring in SMSCs, including economical (low-cost) monitoring techniques, and present a typical range of improvements applicable to SMSCs. The project produced a guidebook that "walks" users through key considerations of each framework step. The guidebook, and associated materials, developed from this research will be valuable to practitioners including state DOT staff and their partnering agencies, including metropolitan planning organizations (MPOs), municipalities, and counties interested in mobility monitoring in SMSCs.

The four objectives of this paper are to:

1. highlight select findings of an extensive mobility monitoring literature review with special emphasis to the SMSC application;
2. present the development of a mobility monitoring framework and its application in two SMSCs, including cost estimates;
3. discuss methods to communicate SMSC mobility monitoring results to a wide audience; and
4. highlight available resources to assist practitioners performing mobility monitoring in SMSCs.

The reader is directed to the project's final report (*1*) and guidebook (*2*) for additional information not presented here.

Defining Congestion and Congestion Trends

Definitions of congestion vary. Title 23, Part 500, Section 500.109 of the Transportation Equity Act for the 21st Century (TEA 21) provides a qualitative definition of congestion as "*the level at which transportation system performance is no longer acceptable due to traffic interference.*" A more technical definition is "*the inability to reach a destination in a satisfactory time due to slow travel speeds*" (*3*). However, congestion is best defined through the eyes of the delayed—what constitutes congestion in one location may be different in another location.

Nationally, congestion has increased significantly over the last 20 years. The Texas Transportation Institute's (TTI) annual Urban Mobility Report (*4*) monitors congestion in 85 metropolitan areas in the United States by population size. This report estimates total delay in 1982 was 0.8 billion person-hours compared to an estimated 4.2 billion person-hours in 2005. The report also documents that in 238 SMSCs (population between 50,000 and 250,000), total delay increased from 33 million person-hours in 1982 to 277 million person-hours in 2005. The total cost (2005 dollars) of congestion in these areas increased from $575 million to $4.7 billion from 1982 to 2005.

Congestion Performance Measures

There are a variety of congestion performance measures. Traditional measures of congestion include the volume-to-capacity ratio (V/C) and level-of-service (LOS). Historically, the evaluation of infrastructure projects was performed with volume and capacity data. Traffic volume and roadway capacity based measures do work well for some applications, but they do have limitations. They tend to be "engineering-based" and are difficult to communicate to the general public. Multimodal mobility analysis is important, and such measures are good for counting vehicles, but not persons.

Alternatively, the National Cooperative Highway Research Program Report (NCHRP) 398, *Quantifying Congestion* indicates that travel time based measures are more flexible, and more useful for a broad range of uses and audiences (*5*,*6*). They are far easier to communicate to the public. Many metropolitan planning organizations (MPOs) and states have adopted travel time based measures.

Table 1 presents both individual and areawide travel time based mobility and reliability measures as defined and described in TTI's *The Keys to Estimating Mobility in Urban Areas* (*3*). Measures such as travel time, speed, delay, and travel rate index (see travel time index and associated footnote in Table 1) are likely the most applicable for mobility monitoring needs in SMSCs.

A recent study by ICF Consulting investigated the innovative practices of various congestion management systems (CMSs) for the New York State Association of MPOs (*7*). Areas over 200,000 in population are required to have a congestion management process, previously called a "congestion management system," in place to manage congestion and improve mobility of traffic, people, and goods. The study identified several MPOs that used more traditional measures of V/C and LOS, as well as several MPOs that augment traditional count data with travel demand model data to estimate vehicle-hours of delay or person-hours of delay, and excess delay computations. Table 2 provides a selected summary of MPOs cited in the ICF Consulting work, and others found in the literature (*8-13*), and the measures these MPOs (or local agencies) are using that go beyond the traditional V/C and LOS-based congestion measures. Table 2 provides a good sampling of how selected transportation agencies are supplementing traditional V/C and LOS-based congestion measures with travel time based measures.

Typical Causes of Congestion

An FHWA report (*14*) notes seven root causes for urban congestion, including 1) physical bottlenecks, 2) traffic incidents, 3) work zones, 4) weather, 5) traffic control devices, 6) special events, and 7) fluctuations in normal traffic.

These factors also cause congestion in SMSCs. Typical examples of physical bottlenecks (item #1 above) in SMSCs include increasing highway traffic volumes, increased trucks, and new businesses needing truck deliveries from the street where roadway capacity is limited. Another example is the "classic case" of large "big box" retailers (e.g., Wal-Mart, Home Depot, Lowe's) developing and opening prior to adequate infrastructure being built. In SMSCs, this "classic case" begins with the fact that many people wish to remain outside of the city to maintain their rural living conditions and quality of life. As smaller communities grow and increase their population, their demographic characteristics surpass thresholds that then attract the attention of, and will sustain, these bigger developments.

Causes of congestion certainly vary by city size. Congestion itself certainly is relative by city size, and the potential solutions and performance measure targets necessarily are much different for smaller communities than for large urban areas. How a community locally defines congestion, and how it assesses its transportation system performance, are key elements for how it chooses to both monitor and address congestion. To capture typical congestion causes, the guidebook (*2*) describes the typical time periods to consider monitoring in SMSCs including morning and evening peak periods, off-peak period, lunch hour, weekends, and special events.

Communicating Monitoring Results

Careful consideration is needed to choose the proper method for communicating mobility monitoring results. Three types of audiences will use the information reported from the monitoring system:

1. The *public*, which does not possess basic mobility monitoring technical knowledge, needs other means to inform them. Information might be designed for lower technical comprehension levels and/or a wide array of tools used;
2. *Elected officials and MPO policy boards* may understand some technical issues, but they prefer to receive explanations in laymen's terms. Like the public, this group would prefer to receive information with measures to which they are easily able to relate (e.g., travel time or speed); and
3. The *technical practitioners* are able to understand and use more advanced reporting techniques.

TTI research (*3*) suggests various graphical illustrations be used. Graphical presentation should relate both spatial (place) and temporal (time) performance depending upon the initial goals and objectives of the monitoring efforts. Experience from the Washington Department of Transportation highlights the following points to effectively engage the audiences identified above: 1) tell a story, 2) engage the reader, 3) make it visual, and 4) make it brief (*15*).

RESEARCH PROCEDURE

After an extensive literature review, the next major task of the project was to develop the mobility monitoring framework. The framework development is described in the next section of this paper. The framework is intended to provide insight on how mobility monitoring can be used to establish local community congestion targets and establish baseline conditions for a continued mobility monitoring effort. The framework ultimately is flexible for adaptation to any size SMSC and to their available resources.

After developing the framework, researchers applied it to two communities. The results of these applications are later described. Because communicating mobility monitoring results is of the utmost importance, special attention was made to presentation methods of the results. Therefore, several examples are provided in this paper.

Researchers also performed a survey of Texas SMSCs seeking their input on congestion growth, causes, locations, and other aspects to obtain insight to the extent and location of congestion. The results of the survey are documented in detail in the full report (*1*).

A Project Monitoring Committee (PMC) that included state DOT, municipal, and MPO representation provided valuable input to the research team. This committee helped guide the development of the project's technical products.

FRAMEWORK DEVELOPMENT

The primary objective of this research was to develop a mobility monitoring framework. Practitioners must consider many elements to ensure successful on-going monitoring. Building from the available literature, and the experiences of the authors in the area of mobility monitoring, researchers developed a six-step framework that would guide the user through the appropriate steps that must be included in a mobility monitoring process applied by SMSCs. The six-step framework is:

1. Identify the needs and opportunities.
2. Create a monitoring plan.
3. Monitor the system.
4. Analyze the data.
5. Package and distribute the results.
6. Move forward with improvements and continue monitoring.

The steps are simplified intentionally for ease of recollection. The key was making the framework easily understood and implemented. To this end, graphic artists developed the rendering of the framework shown in Figure 1. This “1-pager” highlights important considerations within each step of the framework. The PMC found the active nature of this handout very effective for both promoting this research and the practitioner’s implementation of a mobility monitoring process, and it became a supplement in the guidebook.

FRAMEWORK APPLICATION

The framework was applied to two communities. The applications provided opportunities to determine typical needs/uses of a mobility monitoring process within a SMSC, identify the subsequently appropriate performance measures, collect appropriate data (e.g., travel time runs and traffic counts to satisfy local mobility goals/concerns) on selected corridors, perform data analysis, and develop methods to communicate results to different users better. These initial applications will provide the foundation for continued mobility monitoring in these communities.

Community Selection

Researchers, with PMC input, selected two communities to apply the monitoring framework. A “small-sized” and a “medium-sized” community were selected. The intent was to select a location without an MPO present, and one with an MPO present. The medium-sized community selected was Bryan-College Station, Texas (B-CS). This area has a population of approximately 160,000. It includes two cities (Bryan and College Station), a large university, and has an MPO present. The B-CS area is experiencing many of the typical “growing pains” of a medium-sized community that is beginning to experience spot congestion as residential and commercial developments outpace infrastructure allocation.

Huntsville, Texas was selected as the small-sized community. It has a population of approximately 35,000 and does not currently have an MPO. Huntsville is also home to a university, and is experiencing congestion along corridors in the downtown area that have limited right-of-way.

Data Collection

Researchers met with local representatives from each community to identify congested corridors. Researchers developed community-specific data collection plans based upon the feedback in each meeting.

The local practitioners identified the importance of using travel time-based measures. Researchers identified 12 corridors for travel time data collection in B-CS and two corridors in Huntsville. Researchers also identified locations for directional volume counts. There were 61 traffic count locations in B-CS and 10 in Huntsville. A stopped delay study was planned for B-CS. All data were collected between March 20, 2007 and April 17, 2007.

Travel Time Data Collection

The transportation professionals in B-CS and Huntsville suggested travel time measures would be valuable for providing congestion information to drivers. While neither of the communities have any technical congestion definitions in place that are used to "trigger" transportation improvements, each group recognized that travel time would be a good measure for a monitoring program.

Table 3 summarizes the corridors monitored. Characteristics of each corridor include termini, study length, and the number of test vehicles used for the travel time data collection.

Travel time runs were performed during the morning peak period (7:00-9:00 a.m.), off peak (9:00-10:00 a.m.) and afternoon peak (4:00-6:00 p.m.). These relatively larger timeframes for a SMSC more than cover the peak period, and will be useful when continued monitoring allows the local practitioners the ability to recognize how the peak period grows in duration.

SMSCs would likely use low-cost techniques like test vehicles in the traffic stream for travel time data collection. Numerous locations have successfully used GPS technology for travel time data collection. Through continued mobility monitoring, the initial costs of GPS travel time data collection can be justified. The initial costs are typically justified for the ease of data collection, data reduction, and report preparation. For these reasons, GPS equipment and a laptop computer were used to collect the travel time data.

Because GPS equipment is portable, it provides flexibility of which vehicle(s) can be used for the data collection. Individuals simply take the GPS equipment (including laptop) with them to perform travel time runs. For on-going SMSC mobility monitoring, this lends the opportunity for existing staff of the local transportation agencies to assist in the travel time data collection to reduce costs.

For most of the corridors, three to five data collection vehicles were sufficient to provide six runs in the time period of interest to satisfy a 90 percent confidence level for segments with three to six signals per mile per the Federal Highway Administration's *Travel Time Data Collection Handbook* (*16*). As an example, when five vehicles were used, three vehicles started at the end of the corridor in the peak direction, and two vehicles started in the off-peak direction. Vehicles ran continuously in a circuit. When two vehicles would queue at an endpoint, the second vehicle waited two to three minutes before beginning the next run. The wait time was dependent on the length of the corridor. Researchers also developed data collection forms for the drivers. Before and after each run, the drivers used these forms to record the run number and any observations about the run.

Travel Time Run Data Reduction and Summary Statistics
The travel time run data were analyzed with software that segments the second-by-second GPS data into link speed and travel time data. Researchers performed analysis of average travel time conditions for each segment. The off-peak travel time runs allowed calculation of the travel rate index (peak travel time divided by the off-peak travel time). To avoid any "speedy" cars through the corridor, the denominator of the travel rate index calculations use the 15^{th} percentile free-flow travel time from the off-peak period. Researchers compared different free-flow speed values for the denominator.

Researchers performed nearly 1,200 travel time runs. Table 4 provides summary statistics on the number of travel time runs in B-CS and Huntsville. Note that the morning period is three hours, including one hour of "free-flow" conditions, and the afternoon period is two hours.

Traffic Counts
Average daily traffic (ADT) was collected at select locations in each corridor to provide a baseline of the amount of traffic. Delay was estimated by multiplying the number of vehicles (traffic counts) by the difference in actual travel time and free-flow travel time. *K* and *D* factors, the peak-hour factor (PHF), and directional daily volumes were also computed for each location. In SMSCs, simple increases in these traffic characteristics can provide the first indication of congestion.

Stopped Delay Study
The travel time runs provide travel time information between key checkpoints (e.g., intersections) for mobility monitoring. However, mobility monitoring between these points does not necessarily provide the door-to-door travel time of trips (e.g., commuting) that might be of particular interest. Because trips typically include "summing" up the travel times along several links and intersections, there is a need to include traffic control delay at intersections too.

The research team wanted to demonstrate how corridor travel time runs could be combined with a stopped delay study to develop a trip travel time estimate along a corridor of interest. Therefore, the research team performed a stopped delay study at a relatively congested intersection in College Station, Texas. The stopped delay study provides a method for estimating the seconds per vehicle for the turning maneuvers. This estimate can then be added to the link travel time estimates to estimate total trip travel times.

In SMSCs, such intersection studies are very important. Simply optimizing signal timings is a common and effective improvement. Mobility monitoring can identify candidate locations.

STUDY COSTS
This research included an extensive data collection effort. The data collection included travel time runs, traffic counts, and a stopped delay study. The travel time data collection was the most costly. Table 5 shows the costs for the equipment, wages and mileage, preparation and oversight, and data reduction for the travel time data collection. The total cost was approximately $36,000. This equates to approximately $31 per travel time run ($35,600 divided by 1,156 runs). The actual cost was a little less because the authors already had academic licenses for the necessary software. Costs were also reduced because there were many students available for data collection. Local agency transportation officials were interested in the data

collection and volunteered to perform some travel time data collection runs, which reduced costs further.

There are several items to note that made the cost of the data collection relatively higher than it could be in practice. These considerations are included here to provide additional guidance to practitioners and researchers interested in performing similar studies:

- Use Existing Staff: The authors performed the data collection with full-time TTI staff or students. In practice, the cost could be reduced by using existing staff from area transportation agencies who could perform the monitoring in the course of their normal work duties and/or commute patterns (i.e., without the need to hire additional staff or outsource the work).
- Spread the Monitoring over Several Days: The authors performed the data collection on one corridor per day. In actuality, the data collection could be spread over several days for one corridor, reducing the cost, particularly if existing staff performed travel time runs on their commute routes.
- Perform the Minimum Number of Runs: The 1,200 runs collected here represent far more than were necessary according to the FHWA *Travel Time Data Collection Handbook*. Extra runs were collected to ensure adequate sample size (particularly for the baseline conditions), field-test the technology, and ensure the framework was adequate. To satisfy a 90 percent confidence level for segments with three to six signals per mile, approximately six runs per time period would be needed (i.e., 3 time periods [morning peak, off-peak, and afternoon peak] x 2 directions x 14 corridors x 6 runs required = 504 runs).
- Use Existing Equipment: Practitioners and researchers probably have some laptops or office computers available. If only two vehicles are instrumented, and two laptops and an office computer are already available, the “equipment and software” cost in Table 5 is reduced below $3,000.
- Use the Manual Method: Practitioners in SMSCs may initially be intimidated by using GPS-equipped vehicles for the data collection. Manual methods can certainly be used to lower initial data collection costs. (Note that over time, GPS-equipped data collection becomes more cost-effective. This was investigated by the authors and is described in detail in the full report [*1*]).

To further assist practitioners and researchers interested in performing travel time data collection, the authors document unit costs and an example for all costs, including calculations, for each method—manual, distance measuring instrument, GPS with laptop computer, and GPS without laptop computer in the full report (*1*). The full report also includes a CD with a spreadsheet-based calculator to estimate costs for specific data collection efforts.

The authors estimate that collecting traffic volume data at all 71 count locations cost approximately $3,000. This estimate does not include the counters themselves, only the time to identify count locations, installation with two people, data reduction, and mileage. Most agencies performing traffic counts would either own the counters, or would rely on counts performed by another local agency; therefore, the cost of collecting the data is more meaningful than the counter cost. The stopped delay study cost approximately $1,500. This estimate includes time for the full-time staff and students who collected the data in the field, form development, and determining the study scope. The data collection was performed for one turning movement in the morning, and one turning movement in the afternoon.

COMMUNICATING ANALYSES RESULTS

The application of the framework in both B-CS and Huntsville provided the researchers the opportunity to "field test" and revise the mobility monitoring framework. The guidebook developed by the research team provide much more detail than can be provided in this paper (*2*). In the guidebook, users "walk" through each step of the framework using questions, when possible, to prod the reader down the correct paths in their analysis and presentation of the results.

Ultimately, the key to successful mobility monitoring is communicating the results effectively. Researchers investigated numerous presentation methods to communicate mobility changes for SMSCs. Those that follow are only selected examples. The full report (*1*) and guidebook (*2*) cover more topical communication elements with examples including: maps, tables, scale plots, visualization techniques, use of color and scale, speed profiles, and time-space diagrams. The guidebook goes into significant detail about how to analyze and summarize the data.

Directional Traffic Characteristics and Capacity Measures

Figure 2 shows directional volumes through the typical work day. The traffic demand is highest in the westbound direction in the morning period, reversing demand in the afternoon. Here a measure of congestion defined as the percent of the day operating at 50 percent of the capacity of the roadway is presented. A manual procedure for estimating this target is provided in the full research report and guidebook (*1*,*2*). For SMSCs, this measure can be valuable to identify how many locations exceed this target each year, and on-going monitoring (i.e., year-to-year) can investigate changes in this measure. Traffic characteristics for this count location are also included in the graphic. With further augmentation of Figure 2, one can overlay speeds from the travel time runs onto the directional volume. The general public may relate better to speeds, and such a graphic helps to convey the speed-flow-density relationship to a nontechnical audience. The authors produced examples of such graphics as part of the research.

Daily and Historical Volume Trends

Current year daily traffic is shown in Figure 3a. Traffic count locations are shown in relation to major cross streets on the corridor. The figure also separates volumes by direction of travel. The graphic is kept relatively simple—no repeating axis values on each graph. Keeping the graphic simple directs the reader's attention to the data and is less distracting.

Historical traffic volumes are shown in Figure 3b. In this example, TxDOT collected annual counts on each end of the corridor. TxDOT counts the locations between the corridor ends every five years. Showing data gaps are acceptable here. The viewer can still identify useful trends in the data; however, trends are more evident and stronger conclusions made when data gaps are minimized. This data presentation style is useful in SMSCs where identifying even small changes in volume is important and necessary.

Link-based Measurements

Figure 4 is an example of a link-based travel rate index for a corridor that provides several packets of information. First, along the x-axis, the reader understands the physical aspects of the roadway—its width, distance between cross streets, traffic signal density, and land uses that may impact corridor travel. The worst mobility conditions are shown with one thick line ("longest measurement") and the median conditions ("middle measurement"), where half of the test vehicle drivers experienced higher or lower travel rates, are shown with a thinner line. Finally, a summary box to the right provides the reader with select travel rate index values for a few long segments within the corridor.

Optimizing signals is often a common low-cost mobility improvement for SMSCs. The "spikes" in Figure 4 indicate possible locations where signal timing improvements may improve mobility.

AVAILABLE RESOURCES

The *Guidebook for Mobility Monitoring in Small to Medium-Sized Communities: A How-To Guide* (*2*) was created as part of this project. The guidebook steps the user through all of the mobility monitoring framework steps.

Several additional resources are included in the guidebook. While the guidebook is intended for a technical audience, a companion document in the guidebook (*A Guide for Monitoring Mobility in Small to Medium-Sized Communities*) provides information on mobility monitoring to a broader audience that may not be interested in the level of detail shown in the guidebook. A tri-fold pamphlet is also included to provide additional information to interested citizens. The tri-fold is entitled *Frustrated by Big City Congestion in Your Community?: We're Working to Improve Your Standard of Driving.* The pocket at the end of the guidebook also includes the framework overview shown in Figure 1.

There is an interactive compact disc (CD) at the end of the guidebook. The CD includes two PowerPoint® presentations—one to a technical and one to a nontechnical audience about how to implement mobility monitoring in SMSCs using the framework and techniques identified throughout this report and the guidebook itself. The CD includes an interactive presentation of a case study that allows the user to "drill" forward and backward through the steps of the framework and how they are addressed in the example case study. The CD provides links to additional resources available through the Internet, the research reports generated by this project, and electronic (PDF) versions of the guidebook, companion document, tri-fold, and one-page overview.

CONCLUSIONS, DISCUSSION, AND FUTURE WORK

This paper provides a summary of the development and application of a process for performing on-going mobility monitoring in SMSC. The research project developed, tested, and updated the framework through data collection in two communities. The bullets below highlight the major conclusions and resources available as a result of this work.

The following bullets highlight the key observations from the literature review.

- Congestion is best defined through the eyes of the delayed—what constitutes congestion in one location may be different in another location.
- Congestion in many SMSCs is growing.
- Congestion measures should be developed only after an examination of the uses and audiences to be served, the full consideration of program goals and objectives, and the nature of likely solutions.

- Travel time based congestion measures are more flexible and more useful for a broad range of uses and audiences.
- Many metropolitan planning organizations (MPOs) use travel time based congestion measures to supplement traditional measures.
- SMSCs would likely use low-cost techniques like test vehicles in the traffic stream for travel time data collection. It is likely that with continued mobility monitoring, the initial costs of GPS travel time data collection are justified. Numerous locations have successfully used GPS technology, and the initial costs of GPS are likely justified for the ease of data collection, reduction, and report preparation, especially when mobility monitoring will be performed on an on-going basis.
- Using existing staff for travel time data collection can reduce costs in SMSCs.
- Funding on-going mobility monitoring might be possible through existing or increased taxing sources or transportation-based revenue sources. Though there are legislative and practical hurdles to using these sources, they do provide possibilities.
- Typical congestion improvements in SMSCs will include signal improvements, intersection improvements, construction of additional travel lanes, and access management.

The following are selected conclusions based upon the framework, case studies, and data sources.

- A six-step framework was developed, tested and refined. A technical guidebook, and companion document for nontechnical audiences, was developed to guide readers through the main steps of the mobility monitoring framework and call attention to issues, considerations and important questions as they develop and implement an on-going monitoring process.
- Researchers performed data collection at two case study locations—one with an MPO present and one without an MPO present, which demonstrates the applicability of the process to a range of community sizes.
- Researchers successfully demonstrated the methods for, and importance of, collecting traffic count data, travel time data, and intersection studies.

The following are selected highlights of the data reduction, analysis, and results.

- "X% of the working day capacity" was introduced as a reasonable threshold at count locations (Figure 2), and it can be adjusted in subsequent monitoring efforts as more data become available. Changes in this measure and typical traffic operation characteristics (ADT, PHF, *K* factor, *D* factor) can be good measures of congestion changes in smaller communities, and illustrating these values spatially on a map can assist in presenting and understanding these changes.
- Graphics such as Figure 2 through Figure 4 provide a much more appealing and understandable way to present traffic count data over time and travel rate index information that is far more understandable than simple tables.
- Stopped delay studies can be used to provide travel time information through intersections along trips where travel time is of interest.
- The success of any on-going mobility monitoring is contingent upon effective communication of the results. Researchers developed several unique ways to report changes in mobility that can be effective for presentation to technical and nontechnical audiences in SMSCs.

- PowerPoint® presentations were developed to communicate the research results and available resources to technical and nontechnical audiences. An interactive CD included in the guidebook includes PowerPoint® slides to interactively guide interested users through the framework.

Researchers identified the following additional research needs.

- Testing the overall mobility monitoring measures, methods, and process in more SMSCs to provide additional opportunity to refine the framework and guidance further, and to develop and share additional examples that demonstrate the benefits of a mobility monitoring process in SMSCs.
- Further evaluation of the advantages and disadvantages of different types of travel time data collection techniques. Generally for a multi-year (annual) monitoring program, GPS methods do require the highest initial cost but then become the lowest labor cost methods in subsequent years. Although the manual method has the lowest initial cost, its labor costs are roughly 50 percent greater each subsequent monitoring year over GPS methods. There is a need to build an improved knowledge base of the advantages/disadvantages of each travel time data collection technique with actual SMSC monitoring efforts.

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REFERENCES

1. Eisele, W.L., J.A. Crawford, and R. Stensrud. "Measures, Methods, and Application of a Mobility Monitoring Process for Small to Medium-Sized Communities." Texas Transportation Institute. Report 0-5571-1. College Station, Texas. December 2007. Available: http://tti.tamu.edu.

2. Eisele, W.L. and J.A. Crawford. "Guidebook for Mobility Monitoring in Small to Medium-Sized Communities: A How-to Guide." Texas Transportation Institute. Report 0-5571-P1. College Station, Texas. February 2008. Available: http://tti.tamu.edu.

3. Schrank, D.L., W.L. Eisele and T.J. Lomax. *The Keys to Estimating Mobility in Urban Areas: Applying Definitions and Measures that Everyone Understands.* FHWA Pooled Fund Study SPR 3(049). Texas Transportation Institute: College Station, Texas. Second Edition, May 2005. Available: http://mobility.tamu.edu/resources/.

4. Schrank, D.L. and T.J. Lomax. *The 2007 Urban Mobility Report.* Texas Transportation Institute: College Station, Texas. September 2007. Available: http://mobility.tamu.edu/ums/report/.

5. Lomax, T.J., S.M. Turner, G.A. Shunk, H.S. Levinson, R.H. Pratt, P.N. Bay, G.B. Douglas. *Quantifying Congestion, Volume 1, Final Report*, NCHRP Report 398, Volume 1, Final Report. Transportation Research Board, National Research Council, Washington, D.C., 1997. Available: http://trb.org/TRB/publications/Publications.asp.

6. Lomax, T.J., S.M. Turner, G.A. Shunk, H.S. Levinson, R.H. Pratt, P.N. Bay, G.B. Douglas. *Quantifying Congestion, Volume 2, User's Guide*, NCHRP Report 398, Volume 2, User's Guide. Transportation Research Board, National Research Council, Washington, D.C., 1997. Available: http://trb.org/TRB/publications/Publications.asp.

7. *Congestion Management Systems: Innovative Practices.* Prepared for New York State Association of MPOs. Performed by ICF consulting. August 2005. Available: www.nysmpos.org/sci/cms/NYSMPO_SCI_CMS_TASK1-REPORT.pdf.

8. *Congestion Management System Report—Spring 2004.* Prepared by Carter-Burgess. Prepared for Hidalgo County Metropolitan Planning Organization. McAllen, Texas, August 2004. Available: http://www.lrgvdc.org/mpo_studies.html.

9. Schrank, D.L, T.J. Lomax and T. Baker. *Mobility in Grand Junction.* Sponsored by the Colorado Department of Transportation. Performed by the Texas Transportation Institute. College Station, Texas, June 2001. Available: http://mobility.tamu.edu/resources/.

10. Travel Time and Speed-Based Performance Measures Study: Technical Analysis for the Travel Model Update and Revalidation Project. Prepared for City of Lincoln-Lancaster County Planning Department. Prepared by Olsson Associates and Cambridge Systematics. March 1999.

11. *Traffic Studies and Evaluations for Lincoln's Arterial Street System: Interim Report.* Prepared by Meyer, Mohaddes Associates, Inc. and The Schemmer Associates, Inc. TSA Project #398201. January 1999.

12. Guindon. M. E. "2002 Congestion Management Report: Travel Time and Delay Study." In *Proceedings of the 9th National Conference on Transportation Planning for Small and Medium-sized Communities.* Colorado Springs, Colorado. September 2004.

13. 2002-2003 MAG *Regional Travel Time and Travel Speed Study.* Prepared by Carter-Burgess, Traffic Research and Analysis, Inc., and Dr. Darcy Bullock. Prepared for Maricopa Association of Governments. April 2004. Available: http://www.mag.maricopa.gov/display.cms.

14. *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation.* Produced by Cambridge Systematics with Texas Transportation Institute. Sponsored by Federal Highway Administration, Washington, DC. September 1, 2005. Available: http://ops.fhwa.dot.gov/congestion_report/congestion_report_05.pdf.

15. *Reader-Friendly Document Tool Kit.* Washington Department of Transportation, Olympia. Washington, June 2005. Available: http://www.wsdot.wa.gov/Environment/ReaderFriendly.htm.

16. Turner, S.M., W.L. Eisele, R. Benz, and D. Holdener. *Travel Time Data Collection Handbook.* Prepared by Texas Transportation Institute. Sponsored by Federal Highway Administration. Report No. FHWA-PL-98-035. Washington, D.C., March 1998. Available: http://tti.tamu.edu/inside/hdv/ama/its_data/tt_book.stm.

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TABLE 1 Travel Time Based Mobility Measures (Adapted from Reference *3*)

INDIVIDUAL MEASURES[1]	
Delay per Traveler[2]	$$\begin{matrix}\text{Delay per}\\ \text{Traveler}\\ (\text{annual hours})\end{matrix} = \frac{\left(\begin{matrix}\text{Actual}\\ \text{Travel Time}\\ (\text{minutes})\end{matrix} - \begin{matrix}\text{FFS or PSL}\\ \text{Travel Time}\\ (\text{minutes})\end{matrix}\right) \times \begin{matrix}\text{Vehicle Volume}\\ (\text{vehicles})\end{matrix} \times \begin{matrix}\text{Vehicle Occupancy}\\ (\text{persons/vehicle})\end{matrix} \times \frac{\text{250 weekdays}}{\text{year}} \times \frac{\text{hour}}{\text{60 minutes}}}{\begin{matrix}\text{Vehicle Volume}\\ (\text{vehicles})\end{matrix} \times \begin{matrix}\text{Vehicle Occupancy}\\ (\text{persons/vehicle})\end{matrix}}$$
Travel Time	$$\begin{matrix}\text{Travel Time}\\ (\text{person – minutes})\end{matrix} = \begin{matrix}\text{Actual Travel Rate}\\ (\text{minutes per mile})\end{matrix} \times \begin{matrix}\text{Length}\\ (\text{miles})\end{matrix} \times \begin{matrix}\text{Vehicle Volume}\\ (\text{vehicles})\end{matrix} \times \begin{matrix}\text{Vehicle Occupancy}\\ (\text{persons/vehicles})\end{matrix}$$
Travel Time Index[3,4]	$$\text{Travel Time Index} = \frac{\begin{matrix}\text{Actual Travel Rate}\\ (\text{minutes per mile})\end{matrix}}{\begin{matrix}\text{FFS or PSL Travel Rate}\\ (\text{minutes per mile})\end{matrix}}$$
Buffer Index[3]	$$\text{Buffer Index}(\%) = \left[\frac{\begin{matrix}\text{95th Percentile Travel Time}\\ (\text{minutes})\end{matrix} - \begin{matrix}\text{Average Travel Time}\\ (\text{minutes})\end{matrix}}{\begin{matrix}\text{Average Travel Time}\\ (\text{minutes})\end{matrix}}\right] \times 100\%$$
Planning Time Index[3]	$$\begin{matrix}\text{Planning Time Index}\\ (\text{no units})\end{matrix} = \frac{\begin{matrix}95^{th}\ \text{Percentile Travel Time}\\ (\text{minutes})\end{matrix}}{\begin{matrix}\text{FFS or PSL Travel Time}\\ (\text{minutes})\end{matrix}}$$
AREA MOBILITY MEASURES[1]	
Total Delay	$$\begin{matrix}\text{Total Segment Delay}\\ (\text{person-minutes})\end{matrix} = \left[\begin{matrix}\text{Actual}\\ \text{Travel Time}\\ (\text{minutes})\end{matrix} - \begin{matrix}\text{FFS or PSL}\\ \text{Travel Time}\\ (\text{minutes})\end{matrix}\right] \times \begin{matrix}\text{Vehicle Volume}\\ (\text{vehicles})\end{matrix} \times \begin{matrix}\text{Vehicle Occupancy}\\ (\text{persons/vehicle})\end{matrix}$$
Congested Travel	$$\begin{matrix}\text{Congested Travel}\\ (\text{vehicle-miles})\end{matrix} = \sum\left(\begin{matrix}\text{Congested}\\ \text{Segment Length}\\ (\text{miles})\end{matrix} \times \begin{matrix}\text{Vehicle Volume}\\ (\text{vehicles})\end{matrix}\right)$$
Percent of Congested Travel	$$\begin{matrix}\text{Percent}\\ \text{of}\\ \text{Congested}\\ \text{Travel}\end{matrix} = \left[\frac{\sum_{i=1}^{m}\left(\left(\begin{matrix}\text{Actual}\\ \text{Travel}\\ \text{Time}_i\\ (\text{minutes})\end{matrix} - \begin{matrix}\text{FFS or PSL}\\ \text{Travel}\\ \text{Time}_i\\ (\text{minutes})\end{matrix}\right) \times \left(\begin{matrix}\text{Vehicle}\\ \text{Volume}_i\\ (\text{vehicles})\end{matrix} \times \begin{matrix}\text{Vehicle}\\ \text{Occupancy}_i\\ (\text{persons/vehicle})\end{matrix}\right)\right)_{\text{Each congested segment}}}{\sum_{i=1}^{n}\left(\begin{matrix}\text{Actual Travel Rate}_i\\ (\text{minutes per mile})\end{matrix} \times \begin{matrix}\text{Length}_i\\ (\text{miles})\end{matrix} \times \begin{matrix}\text{Vehicle}\\ \text{Volume}_i\\ (\text{vehicles})\end{matrix} \times \begin{matrix}\text{Vehicle}\\ \text{Occupancy}_i\\ (\text{persons/vehicle})\end{matrix}\right)_{\text{All segments}}}\right] \times 100$$
Congested Roadway	$$\begin{matrix}\text{Congested Roadway}\\ (\text{miles})\end{matrix} = \sum \begin{matrix}\text{Congested Segment}\\ \text{Lengths (miles)}\end{matrix}$$
Accessibility	$$\begin{matrix}\text{Accessibility}\\ (\text{opportunities})\end{matrix} = \begin{matrix}\sum \text{Objective Fulfillment Opportunities}\\ (\text{e.g., jobs}),\text{ where}\\ \text{Travel Time} \le \text{Target Travel Time}\end{matrix}$$

1 "Individual" measures are those measures that relate best to the individual traveler, whereas the "area" mobility measures are more applicable beyond the individual (e.g., corridor, area, or region). Some individual measures are useful at the area level when weighted by passenger-miles of travel (PMT) or vehicle-miles of travel (VMT).

2 As a practical matter, total delay (in person-minutes) is usually computed first (see definition in table), and is useful as an area mobility measure. The total delay is then converted to delay per traveler (in annual hours) as shown here by dividing the number of peak-period travelers. Note that the vehicle volumes multiplied by the vehicle occupancy do not, therefore, cancel out.

3 Can be computed as a weighted average of all sections using VMT or PMT.

4 Sometimes referred to as a "Travel Rate Index" when the data source does not include incident conditions (i.e., using non-continuous data such as test vehicles for travel time estimation).

Note: FFS = Free-flow speed, PSL = Posted speed limit. Where FFS or PSL occur in the equations above, typically the prevailing travel rate (or travel time) is used during light traffic (not to be lower than the travel time at the posted speed limit).

Note: The Buffer Index and Planning Time Index are reliability measures, which require continuous data sources to estimate. While most SMSCs may not have continuous data sources available, they should be aware of the importance of these reliability measures and seek ways to incorporate them in future mobility monitoring efforts.

TABLE 2 Characteristics of Selected MPOs and Other Transportation Agencies Using Travel Time Based Congestion Measures (Adapted from References *7-13*)

Transportation Agency Name / Location	Travel Time Based Measures Used	Additional Detail
Capital Area Metropolitan Planning Organization (regional MPO) Austin, TX	Went to travel-speed-related measures to identify congested locations. CAMPO has defined minimum acceptable speeds, based on roadway type and area (i.e., lower speeds are more acceptable in central business district).	Travel time based measures allow for multimodal analysis. Global positioning system (GPS)-enabled vehicles used to measure travel times using the floating car method. Intersection delay also investigated.
Greenville South Carolina MPO Greenville, SC	Percent of time at free-flow. Travel time surveys for 33 routes using GPS technology.	Roadways grouped into tiers based on congestion severity.
Pioneer Valley Planning Council (regional MPO) Springfield, MA	Travel time measures of delay and congestion indices.	Uses travel demand model to develop V/C ratios for all corridors, and supplements this with travel time runs.
Regional Transportation Commission (regional MPO) Southern Nevada Las Vegas, NV	V/C for initial identification of roadway congestion; also V/C or percent reduction in speed (intensity), number of hours congestion exceeds a given target (duration), number of persons or vehicles affected (extent), and reliability calculated based on crash rates.	Weights for the four components and a scoring process for each component were developed on a 0 to 100 scale to assist in the prioritization.
Rhode Island State Planning Council (statewide MPO) Providence, RI	Travel time measures include: percent under posted speed, incident clearance time, travel time index, delay reduction, delay cost, and percent of congested travel.	Analysis performed for three time periods: peak, off-peak, and seasonal.
Hidalgo County MPO Hidalgo County, Texas	Congestion index (same form as the travel time index).	MPO performs studies each year that are rotated seasonally to identify problem areas and provide improvement recommendations.
Colorado Department of Transportation Colorado (Statewide)	Travel rate index is the primary measure being used.	Using probe travel time data and traffic counts to compute travel rate index and travel time related measures. Study was initially done in Grand Junction, Colorado but measures and methods expanded statewide.
City of Lincoln Lincoln, Nebraska	Speed and travel time by link.	One study identified congestion problems and updated the travel demand model. A second study included a before-and-after assessment of signal timing improvements. Target speeds approximating LOS C were used.
Lexington Area MPO Lexington, Kentucky	Average speed and travel rate index.	Floating car runs were collected using GPS along primary corridors in the region to identify congested segments of the roadway network and for improvement prioritization.
Maricopa Association of Governments (regional MPO) Phoenix, Arizona	Travel time, speed, percent of posted speed and the congestion index (same form as the travel time index).	Primary study purpose was to calibrate and validate the regional planning model. Another purpose was to compare the current year's data with data from previous years to identify any congestion trends and identify candidate improvement locations.

TABLE 3 Characteristics of Travel Time Run Corridors

Facility	Community	North / East Terminus	South / West Terminus	Length[1]	No. of Test Vehicles
FM 158 (Boonville Road)	Bryan	SH 30	SH 21	7.3	5
FM 1179 (Villa Maria/ Briarcrest)	Bryan	Steep Hollow	FM 2818	7.7	5
Villa Maria	Bryan	FM 158	FM 2818	4.0	4
29th Street	Bryan / College Station	Crosswalk west of Parker (west of tracks)	FM 60	4.5	5
Business SH 6 (Texas Avenue)	Bryan / College Station	SH 6	Deacon	14.8	5
FM 2818 (Harvey Mitchell Parkway)	Bryan / College Station	SH 21/San Jacinto	SH 6	11.6	3
FM 60 (University Drive)	Bryan / College Station	FM 158	Jones	8.3	5
SH 30 (Harvey Road)	Bryan / College Station	FM 158	Texas Avenue	4.1	5
Southwest Parkway	College Station	SH 6	FM 2154	3.1	5
Longmire Drive	College Station	FM 2818	Barron Road	3.0	3
Rock Prairie	College Station	William D. Fitch Parkway	FM 2154	5.0	5
FM 2154 (Wellborn Road)	Bryan / College Station	Villa Maria	Barron	8.2	5
SH 30 / US 190 (11th Street)	Huntsville	SH 19 Overpass	FM 1791	6.5	4
SH 75 (Sam Houston Avenue)	Huntsville	SH 30	SH 19 Overpass	3.0	4

[1]Length includes turnaround area at terminus of the corridor.

TABLE 4 Summary of Travel Time Run Statistics

Travel Time Summary Statistic	Morning Period (7 – 10 a.m.)	Afternoon Period (4 – 6 p.m.)
Bryan – College Station Corridors		
Total Number of Runs	603	360
Average Number of Runs (per direction)	25	15
Minimum Number of Runs (per direction)	11 (FM 2818)	8 (FM 2818)
Maximum Number of Runs (per direction)	42 (SH 30)	25 (Southwest Parkway)
Huntsville Corridors		
Total Number of Runs	115	78
Average Number of Runs (per direction)	29	20
Minimum Number of Runs (per direction)	23 (SH 30 / SH 190)	15 (SH 30 / SH 190)
Maximum Number of Runs (per direction)	35 (SH 75)	25 (SH 75)

TABLE 5 Costs for Travel Time Data Collection

Cost	Description	Total Amount (2007 Dollars)[1]
Equipment and Software	Five GPS units ($75 each); Laptop data collection software ($700 per laptop for 5 laptops); Five laptop computers ($600 each); Office data reduction software ($1,100); Office computer ($1,000); and Power invertors and clipboards ($265).	$9,300
Wages and Mileage	Time for students and full-time staff to perform travel time runs; and Mileage reimbursed at Internal Revenue Service allowable cost for personal vehicle (0.485 cents per mile).	$19,100
Preparation and Oversight	Route planning, data collection sheet preparation, test vehicle driver training, and supervision and management of data collection and analysis.	$5,200
Data Reduction	Reducing field data to travel time information.	$2,000
Total Travel Time Data Collection Cost =		$35,600

[1] See full report (*1*) for unit costs.

FIGURE 1 SMSCs framework for mobility monitoring.

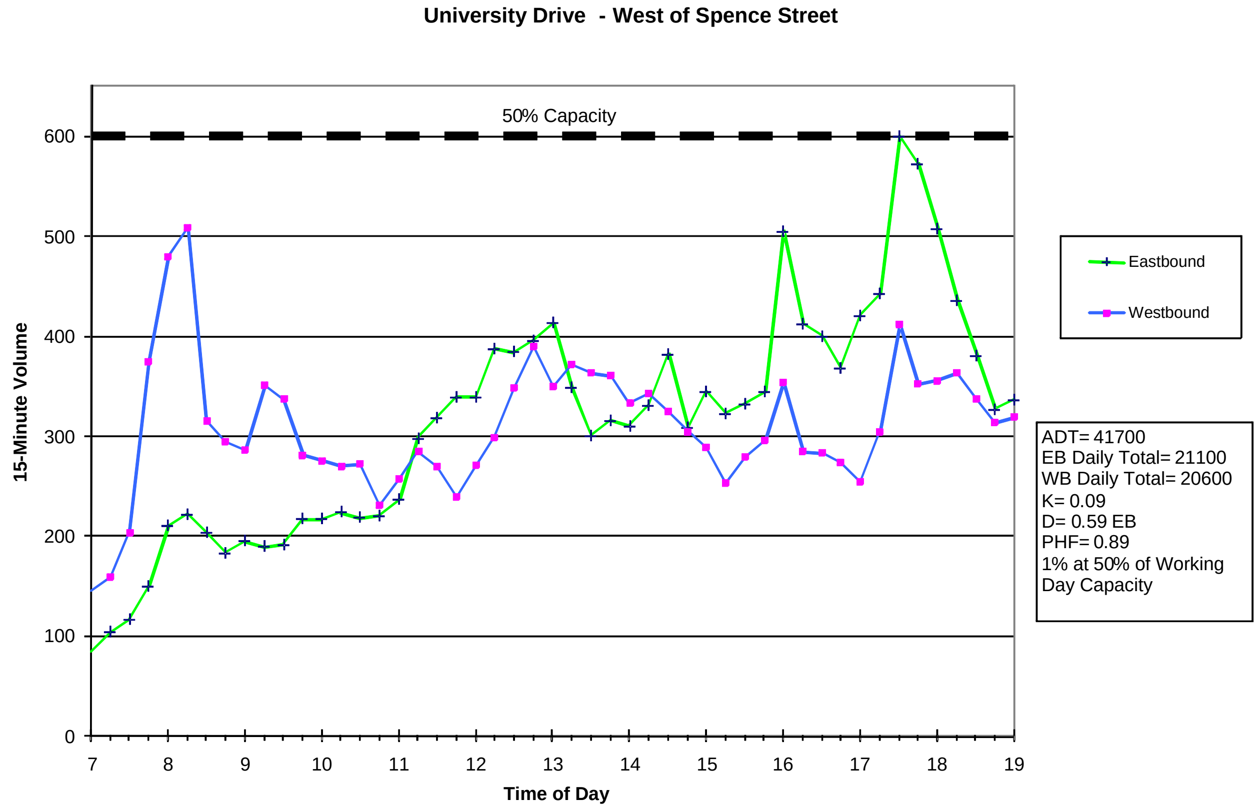
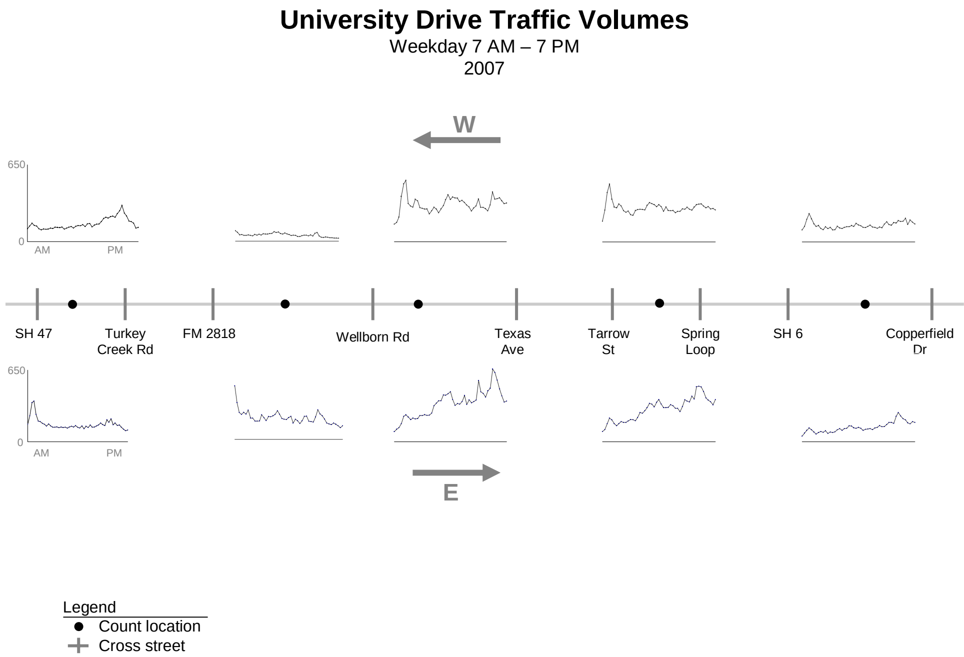
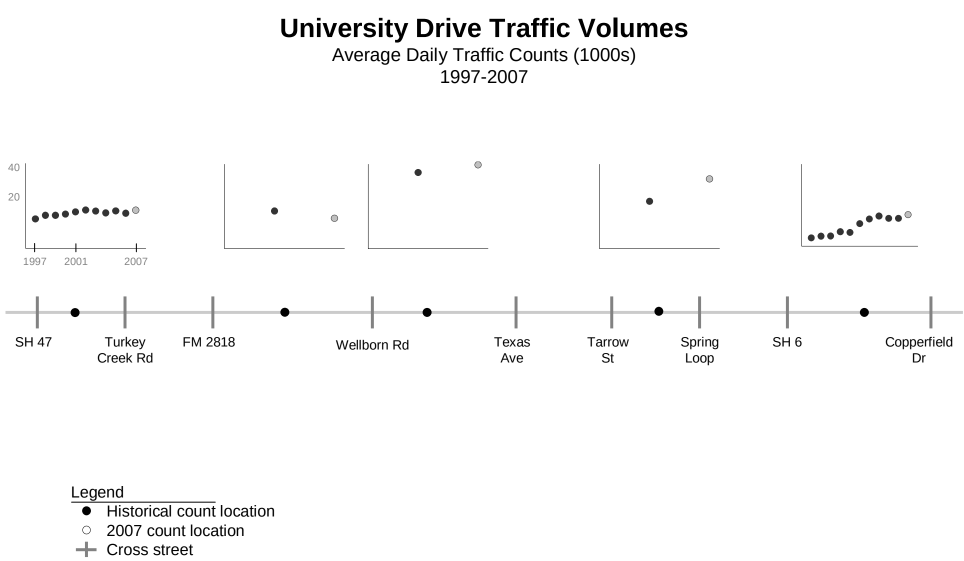


FIGURE 2 Directional volume illustration including traffic characteristics and capacity target.



(a) Example of corridor current daily traffic volumes.



(b) Example of corridor volume trends.

FIGURE 3 Example of (a) corridor current daily traffic volumes, and (b) corridor volume trends.

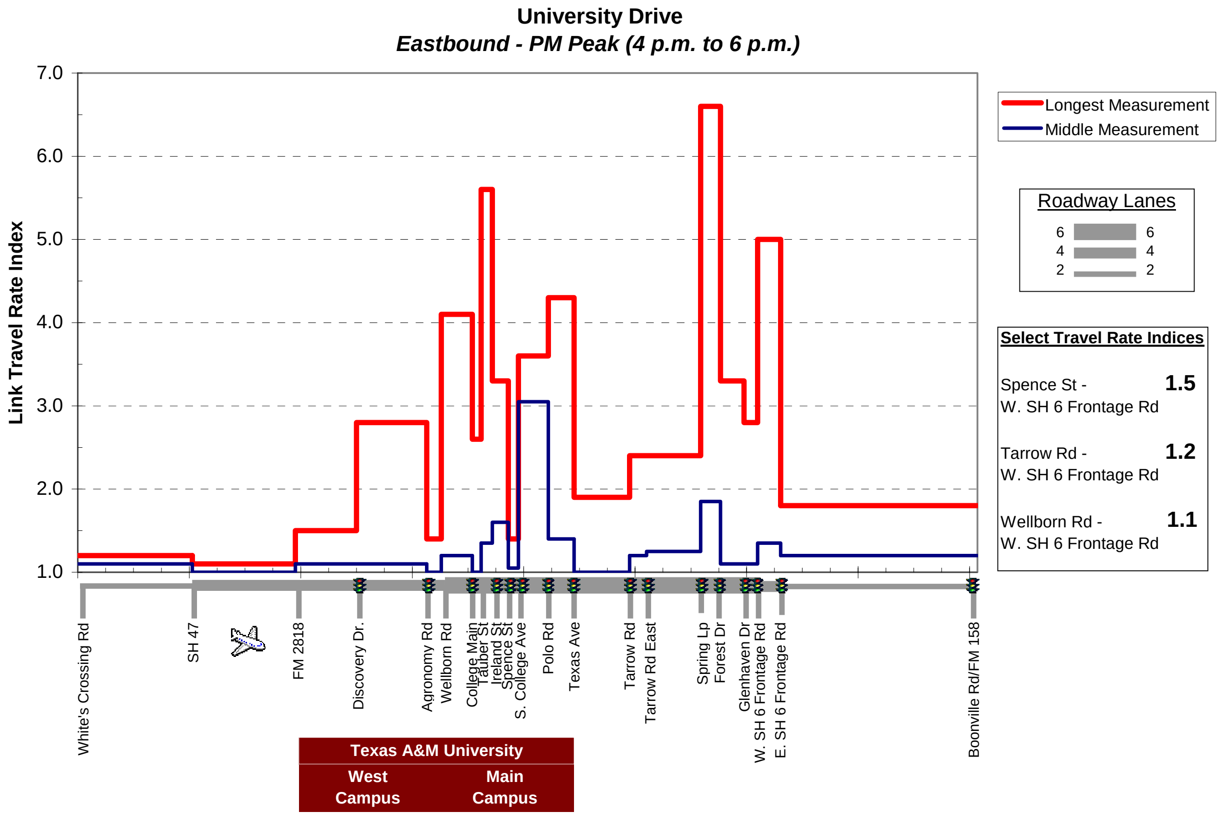


FIGURE 4 Illustration of link travel rate index along a corridor.