APPLYING SUSTAINABLE TRANSPORTATION IN TEXAS

J Zietsman, T Ramani, L Quadrifoglio* and W Knowles**

Texas Transportation Institute, College Station, Texas – 77843, USA
*Texas A&M University, College Station, Texas- 77843, USA
** Texas Department of Transportation, Austin, Texas-78701, USA

ABSTRACT

The aim of this project was to develop a performance-measurement based approach for the Texas Department of Transportation (TxDOT) to evaluate and enhance the relative sustainability of transportation projects. TxDOT's strategic plan contains five goals (reduce congestion, improve safety, increase economic opportunity, preserve the value of transportation assets, and improve air quality), each of which need to be addressed to improve the sustainability of the transportation system. This project uses a multi-criteria decision making (MCDM) approach for the sustainability evaluation, which requires the development of appropriate performance measures, which are evaluated and aggregated into a composite indicator of sustainability. The focus of the project was on the transportation corridor level and focused on the highway mode of transportation. As part of the project a user-friendly analysis tool in the form of a spreadsheet-based calculator was developed that can quantify the selected performance measures and apply the sustainability enhancement methodology. Several case studies were performed using the methodology and applying the analysis tool. Finally, it is demonstrated how the methodology is being integrated into TxDOT's planning process.

INTRODUCTION

In the United States, there is an increasing interest in sustainability among state-level transportation agencies. However, the goals of sustainable transportation are rarely addressed adequately and on a consistent basis within these agencies. For sustainable transportation to be successfully implemented it is essential that the concepts are adequately understood, quantified, and applied (Zietsman and Rilett, 2002). The process of performance measurement has direct application in this area because it makes it possible to measure progress toward sustainability goals objectively and consistently. To facilitate this process for state DOTs there is a need for the development of a practical and easy to use analysis framework and methodology based on performance measures.

The overall goal of this study was to develop a performance-measurement based approach for the Texas Department of Transportation (TxDOT) to evaluate and enhance the relative sustainability of transportation projects. The specific objectives were to develop sustainable transportation performance measures for the Texas Department of Transportation's (TxDOT's) strategic goals, develop a methodology for TxDOT to evaluate these measures during the planning process, and thereby promote a more sustainable transportation system. The methodology was designed to be applicable at the level of a highway corridor.

The project objectives were achieved by the following steps:

- Develop a framework assessing sustainability using performance measures.
- Identify sustainable transportation performance measures and a methodology for evaluating these measures for a specific highway section.
- Develop a user-friendly analysis tool based on the methodology and performance measures.
- Perform pilot applications of the analysis tool for selected highway corridors.

It is anticipated that the concepts and principles developed under this study can be applied to other state DOTs and transportation agencies. This paper summarizes the findings from the study and discusses how the findings can be integrated into agency practice.

SUSTAINABLE TRANSPORTATION

While the term sustainable development is fairly new, some principles associated with it date back to the 18th century. The term sustainable development was first used by the World Conservation Strategy (WCS) in 1980 (World Bank, 1996). Since then the concept has spread across the world and has found global prominence by having it designated as a global mission through two key United Nations Conferences held in 1992 and 2002, respectively.

Numerous authors have provided definitions for sustainable development and sustainable transportation. These definitions are mostly based on the one developed by the Brundlandt Commission, namely that "*sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*"(Bruntdland, 1987). In general, sustainability emphasizes the integrated nature of human activities and the need to coordinate decisions among different sectors, groups and jurisdictions. In addition, sustainability is largely defined through impacts of the system on the economy, environment, and general social well-being, generally referred to as the three dimensions of sustainability.

Sustainable transportation can be seen as an expression of sustainable development in the transportation sector, and transportation system effectiveness is an additional criterion that needs to be considered (Litman, 2005). Another conceptualization of transportation sustainability measures it according to system effectiveness and efficiency, and the impacts of the system on the natural environment (Jeon and Amekudzi, 2005). In the light of these discussions and the nature of TxDOT's business, researchers and key TxDOT staff agreed that sustainable transportation for the purpose of this study be defined as: "*the provision of safe, effective, and efficient access and mobility into the future while considering the economic, social, and environmental needs of society."*

PERFORMANCE MEASUREMENT

Application of Performance Measures

Performance measures are broadly used for simplification, quantification, and communication of data. They translate data and statistics into succinct information that is readily understood. Performance measures are typically aligned with strategic goals and objectives to ensure that these goals and objectives are met. A comprehensive performance measurement system would include measurements of the condition, trends over time, and can provide the basis for informed decision making.

Traditionally the focus in performance measurement in transportation has been on the more operational and quantifiable objectives (transportation system perspective) as opposed to the broad encompassing nature of sustainability (which also includes qualitative measures). Measures for sustainability require that system measures be integrated with environmental, social, and economic measures to ensure that all the aspects of sustainability are addressed. The identification of appropriate performance measures is a very important task because poor performance measures can lead to poor decisions and outcomes. It is also very important to develop performance measures that are understood by a broad audience.

Selection of Decision-Making Method

The transportation planning process involves the evaluation of a discrete set of alternatives with respect to different and often conflicting objectives (Giuliano, 1985). The aims of the transportation planning processes thus can be viewed as a multi-criteria decision problem. Several methods have been developed to assess the relative importance of projects or plans based on the multi-criteria analysis. The most common multi-criteria decision-making techniques used for transportation decision making are the multi-attribute utility theory, analytical hierarchy process, and the outranking method. For this application the Multi-Attribute Utility Theory (MAUT) approach was selected because it is a simple and intuitive approach to decision making (Olson, 1996). The application of the MAUT to the particular analysis framework is discussed in further detail in the next section.

DEFINING PERFORMANCE MEASURES AND ANALYSIS FRAMEWORK

Selection of Performance Measures

TxDOT's strategic plan for 2009-2013 contains the following mission statement "*we will provide, safe, efficient and effective means for the movement of people and goods throughout the state, facilitating trade and economic opportunity"* (Texas Department of Transportation, 2009). TxDOT's vision is to *"…deliver a 21st century, multi-modal transportation system that will improve the quality of life for Texas citizens and increase the competitive position for Texas industry*." TxDOT's specific goals identified to address the vision and mission are:

- reduce congestion;
- enhance safety;
- expand economic opportunity;
- improve air quality; and
- preserve the value of transportation assets.

These five goals address the three dimensions of sustainable transportation — economic development, environmental stewardship, and social equity— to a certain extent and the key to this project was to develop a set of performance measures that reflected sustainability concerns within the scope of the strategic planning goals. As discussed earlier, the measures were developed to be relevant to highway corridors.

A workshop was held with key TxDOT staff to identify appropriate performance measures. To further explain how the selected measures related to concepts of sustainability, "sustainability-related objectives" were defined under each of the strategic goals, and performance measures were then formulated for each. The performance measures were selected to make use of readily available data, as well as satisfy the general requirements of a good and robust performance measure. Zietsman et al. (2008) also presents a discussion of this research and the performance measures developed at an earlier stage of the project. Table 1 shows the goals with the corresponding objectives and final performance measures used in this research.

TABLE 1 Selected Performance Measures

TxDOT Goal	Sustainability-Related Objective	Performance Measure
Reduce congestion	Improve mobility on highways	Travel time index
	Improve reliability of highway travel	Buffer index
Enhance safety	Reduce crash rates and crash risk	Annual severe crashes per kilometer
	Improve traffic incident detection and response	Percentage lane kilometers under traffic monitoring/surveillance
Expand economic opportunity	Optimize land use mix for development potential	Land use balance
	Improve road-based freight movement	Truck throughput efficiency
Increase the value of transportation assets	Maintain existing highway system quality	Average pavement condition score
	Reduce cost and impact of highway capacity expansion	Capacity addition within available right of way
	Leverage non-traditional funding sources for highways	Cost recovery from alternative sources
	Increase use of alternatives to single-occupant automobile travel	Proportion of non-single-occupant travel
Improve air quality	Reduce adverse human health impacts and comply with ambient air quality standards	Air quality index
	Reduce greenhouse gas emissions	Daily CO_2 emissions

Given the constraints of restricting the evaluation to highway segments alone, it is felt that these measures are fairly comprehensive. By evaluating the measures for current as well as future conditions, another key aspect of sustainability – consideration of changes over time – can also be addressed. The following is a short description of each of the selected performance measures:

Travel Time Index

Travel time index is a measure that provides an idea of the magnitude of congestion (Lomax et al., 1997). It is a measure of the ratio of the peak hour travel time to the free-flow or off-peak travel time, and indicates how much longer travel takes due to congestion alone. In this study, the travel time index has been quantified as the ratio of peak hour travel time to travel time at the posted speed limit.

Buffer Index

The buffer index is an indicator of travel time reliability that provides an idea of the variation of observed travel times for a section of road over a period of time. In this study, the buffer index is obtained based on empirical relationships with the travel time index value.

Annual Number of Severe Crashes per Kilometer

The number of crashes is the most common indicator used to evaluate safety. However, it is generally expressed as a crash rate, i.e. number of crashes per million vehicle kilometers (km) of travel (VKT). From a sustainability evaluation perspective, however, the fact that the absolute number of crashes will increase based on increased VKT should be considered. Thus, a measure of crashes per km is used, allowing comparison of highway sections of differing length.

Percentage of Lane Kilometers under TMC Surveillance

Traffic Management Centers (TMCs) provide surveillance of the road system, which greatly enhances response times to incidents, thereby improving congestion and safety.

Land Use Balance

This measure is a formulation that examines a mix of land uses in a half-mile (0.8 km) zone along the highway section. The land area is classified into three categories: Residential, Commercial/Industrial, and Institutional/Public. The measure is formulated to have the highest values when all categories of land use are equally distributed and the lowest values when all the land uses are concentrated into one category. While this measure does not have economic implications alone, the presence of an adequate area devoted to commercial establishments ensures economic vitality. The proper balance with residential and other areas ensures a positive impact on accessibility as well.

Truck Throughput Efficiency

This measure is a reflection of truck volumes along the highway section, combined with the travel speeds on the links. The theory behind this measure is that the impact of having truck freight movement in terms of economic benefits needs to be checked against the possible reductions in travel speeds or existing low speeds along the corridor. Thus, a measure that looks at a combination of truck volumes and speeds as an output, rather than truck percentages is selected for this purpose.

Average Pavement Condition Score

TxDOT monitors the condition of the pavements in the road network by considering factors such as surface distress, rutting, and ride quality. The data for the entire network is collected in a Pavement Management Information System (PMIS), which combines these factors into a pavement condition score.

Capacity Expansion Possible within Available Right-of-Way

While having increased highway capacity could be beneficial from the standpoint of improving the value of the highway system, there are reasons why simply adding extra lanes is not completely sustainable. This measure addresses the issue by only considering expansion that is possible within existing right-of-way (ROW), which represents value addition at a lesser social, environmental, and economic cost than acquiring land solely for the purpose of highway construction.

Cost Recovery from Non-DOT Sources

The expenditure on a highway can be classified as the initial capital cost required for construction and the recurring (annual) cost for operation and maintenance (O&M). When some of these costs are contributed from sources external to the DOT, it can be considered a positive occurrence, as discussed previously. This performance measure is structured to consider the proportion of capital costs, as well as the proportion of the current annual O&M cost that is contributed from external sources. External sources are considered to include funds from local/municipal agencies, toll revenue recovered, or roads that are built or operated by the private sector.

Proportion of Non-Single-Occupant Travel

This measure evaluates the higher occupancies achieved by carpooling, use of bus transit or parallel rail facilities. This measure is calculated by accounting for non-single occupant vehicles (SOVs) in the general purpose lanes, high-occupancy vehicle (HOV) lanes, buses, and parallel rail facilities.

Air Quality Index

The Air Quality Index is a measure structured to take into account the mobile source emissions that affect human health, as well as the non-attainment status of the area under consideration per the National Ambient Air Quality Standards (NAAQS). The components considered in terms of the NAAQS are Ozone, Particulate Matter (PM) and Carbon Monoxide (CO). Then, the emissions for Ozone precursors, PM and CO are individually quantified, rated and combined to obtain a final Air Quality Index value expressed on a 0-1 scale.

Daily CO_2 Emissions

Carbon Dioxide (CO_2) is a gas emitted from burning fossil fuels, which is associated with global warming. Vehicular emissions are a significant anthropogenic source of CO_2 and these must be considered while assessing the sustainability of transportation systems. Emissions rates are obtained from an emissions model, as in the previous measure, and are expressed as the daily emissions of CO_2 in grams per km of roadway.

Application of the MAUT

As discussed previously, the MAUT was selected as the multi-criteria decision making method to be applied for this project. The basic steps of applying the MAUT to the selected performance measures can be summarized as follows:

1. Quantify the performance measures based on predefined processes/equations
2. Scale the performance measures to express their value on a 0-1 scale, where 0 corresponds to the worst possible value for the measure, and 1 corresponds to the best value
3. Combine the scaled measures into a final evaluation index value as the weighted sum of individual scaled performance measures. This index will also be expressed on a scale of 0-1.

The quantification of measures is carried out based on data elements assembled for the particular study corridor. The scaling is based on “best case scenario” and “worst case scenario” values defined for each of the performance measures. A quantified performance measure equaling the best case is assigned a scaled value of 1, while one equaling the worst case is assigned a value of 0. Intermediate performance measure values are assigned a scaled value based on linear interpolation between the extremes. The default weights to be assigned for individual measures

were identified through a Delphi process conducted with members of the Transportation Planning and Programming division at TxDOT. A more detailed discussion of how the MAUT is applied in this research, including the process of weighting and scaling the performance measures is presented by Ramani et al. (2009).
In this research, the performance measures and index values are calculated for individual segments of the study corridor (termed as "links") as well as aggregated for the entire corridor (termed as the "study section"). This enables identification of problem areas within a highway corridor, and shows which links perform better or worse than average.

Development of a User-friendly Analysis Tool

A user-friendly analysis tool was developed in the form of a Microsoft Excel®-based calculator to implement the performance measurement framework and methodology. The calculator can quantify the selected performance measures and calculate the index values. It is developed so that the users can select the default weights or enter their own weights for the measures, based on the specific project. The user is prompted to enter certain basic data into the data entry sheet. After the data has been entered, the calculator performs the calculations and determines the performance measure values and index values for individual links as well as for the entire study section. The calculator is designed to compare results for a base case scenario, along with a future case scenario to identify trends over time. It can also provide outputs in terms of performance with respect to individual goals and measures.

PILOT APPLICATION

The analysis tool was used to conduct pilot applications for three case study corridors located in Texas. This section discusses the case study and the analysis results for the pilot corridor located on US Highway 281 in San Antonio, Texas.

Description of the Test Bed

The pilot corridor is comprised of a 24 km section of US-281 in the San Antonio, TX area. The pilot section stretches from I-410 in downtown San Antonio in the south to the Comal/Bexar county line in the north. The section from I-410 to Loop 1604 (approximately half the total section) is comprised of three lanes per direction with a concrete barrier in the median. The remaining section from Loop 1604 to the Comal/Bexar county line is a divided facility with three lanes per direction for about 3 km, and two lanes per direction beyond this point. The corridor begins next to the San Antonio International Airport with mostly dense commercial development. Approximately 12 km north of I-410, past Loop 1604, the development becomes less dense, with pockets of commercial development (mostly retail). Approximately 5.5 km north of Loop 1604 the development becomes even sparser with occasional lower density residential developments and small retail outlets. Figure 1 shows a map of greater San Antonio area and the location of the pilot facility. Figure 2 shows photographs of the urban and rural portions of the facility.

Both a base case and a future scenario were developed for analysis and comparison. The base case comprised of the existing corridor and using data that are as close as possible to 2005 values. The future scenario is based on projections 20 years into the future (2025). The future scenario has the 2-lane sections upgraded to 3-lanes in each direction, as planned by TxDOT.

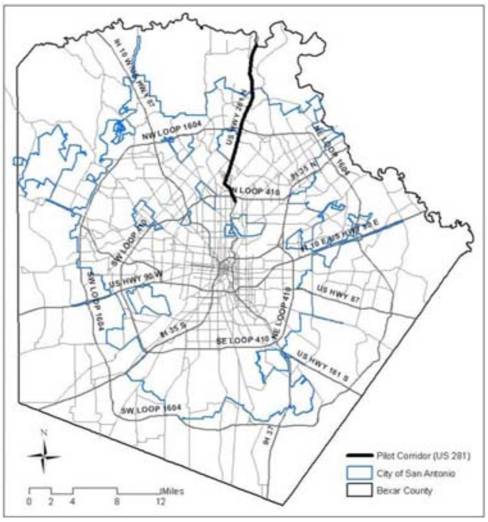

FIGURE 1 Location of Pilot Corridor, San Antonio, Texas

FIGURE 2 Photographs from the Pilot Corridor

Results

The analysis tool results are shown in Figures 3 and 4. Figure 3 shows the results of the composite index value for each link and for the total section, while Figure 4 shows the relative performance of the entire section with respect to the individual goals in TxDOT's strategic plan. These results can help identify problem links on the corridor that require future attention, as well as goals that need extra attention in order to improve overall sustainability.

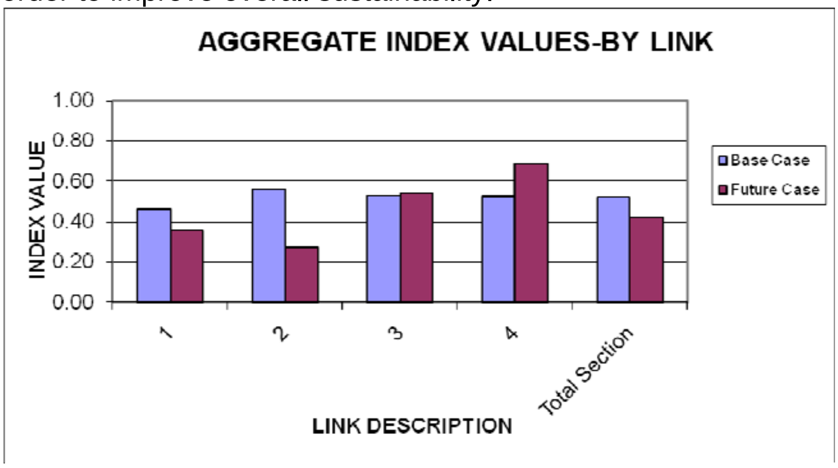

FIGURE 3 Link-Wise Results for Pilot Corridor

From the results in Figure 3, it can be seen that the links closer to the downtown area perform significantly worse in the future, which can be explained by the higher traffic levels in the area. Overall, the study section shows a worse performance in the future, indicating that there are sustainability-related concerns that need to be addressed, especially on Links 1 and 2.

In terms of the goal-wise performance shown in Figure 4, it can be seen that the goal of reducing congestion is the most negatively affected in the future and needs to be addressed to improve sustainability. The air quality, safety and transportation asset goals are improved in the future, while the economic opportunity goal remains unchanged. Overall, the performance declines slightly. These findings from the analysis tool results can aid transportation planners in taking measures toward improving sustainability.

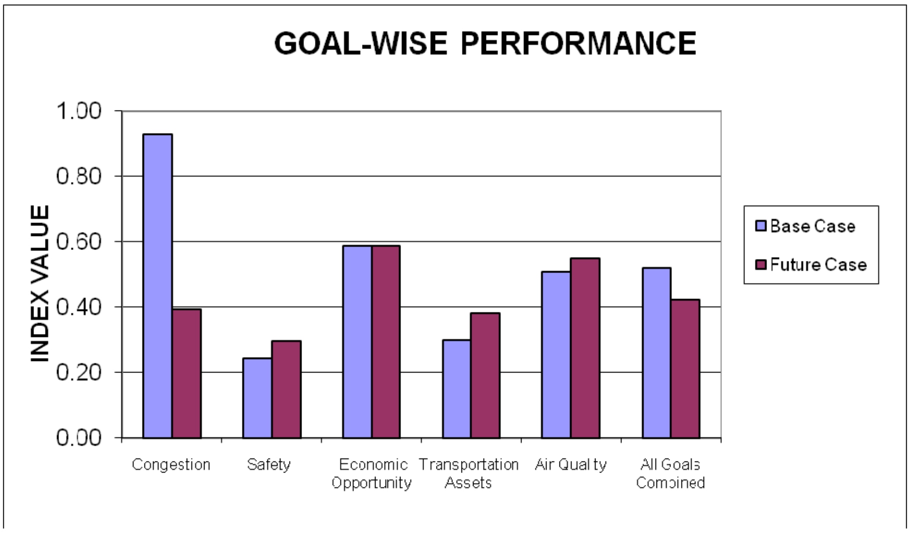

FIGURE 4 Goal-Wise Performance for Pilot Corridor

INTEGRATION INTO THE TRANSPORTATION PLANNING PROCESS

The sustainability evaluation methodology developed as a part of this research, and implemented in the form of a spreadsheet-based analysis tool can assist transportation planners in state DOTs to assess sustainability. The research team is currently in the process of developing workshops to provide TxDOT staff with hands-on experience in using the analysis tool. The workshops will cover lessons on the various aspects of the research project and findings, hands-on training on using the analysis tool, and allow an opportunity to participate in interactive exercises. These workshops are expected to be conducted in the coming year, and represent a step toward integrating sustainability into the transportation planning process at TxDOT.

CONCLUSIONS

Sustainable transportation from TxDOT's perspective was defined as: "*the provision of safe, effective, and efficient access and mobility into the future while considering the economic, social, and environmental needs of society."* This research identified a set of performance measures that could address TxDOT's five strategic goals, as well as improve sustainability. The MAUT approach was selected as the decision support framework for evaluating the performance measures.

The performance measures and decision support method were coded into a user-friendly Microsoft Excel®-based calculator that can quantify the selected performance measures and calculate the index values. The methodology was applied to a pilot corridor on US-281 in the San Antonio, TX area. The pilot section stretches from I-410 in downtown San Antonio in the south to the Comal/Bexar county line in the north. The methodology was applied to both a base case (2005) and a future scenario (2025).

The methodology made it possible to identify the specific performance measures that need improvement to enhance the overall sustainability. The analysis tool developed provides a powerful tool for state DOTs to assess the relative sustainability of their transportation corridors now and in the future. It allows for comparisons within a corridor and with other corridors and identifies the improvements needed to enhance the sustainability.

ACKNOWLEDGMENTS

This paper was based on research performed for TxDOT under the department's Research Program. The authors would like to thank the following individuals from TxDOT that contributed to this project – Janie Temple, Duncan Stewart, Mary Perez, Loretta Brown, Bob Appleton, and Eduardo Calvo. The authors would also like to thank the following researchers for their contributions – Duane Rosa, Bill Eisele, David Schrank, Bob Brydia, Jeremy Johnson, Steve Venglar, Dale Picha, Ming-Han Li and Phillip Reeder.

REFERENCES

Bruntdland Comission (1987) World Commission on Environment and Development (Brundtland Commission). *Our Common Future.* Oxford University Press, Oxford, England

Giuliano, G. A. (1985) Multicriteria Method for Transportation Investment Planning. *Transportation Research, Part A.* Vol. 19, No. 1, Elsevier Science Ltd, Exeter, England, 1985, pp. 29-41.

Jeon, C. and A. Amekudzi.(2005) Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics*. Journal of Infrastructure Systems*, ASCE, March 2005. Pp. 31-50.

Litman, T. (2005) *Well Measured: Developing Indicators for Comprehensive and Sustainable Transportation Planning*. Victoria Transportation Policy Institute, Victoria, British Columbia, Canada, June 2005.

Lomax, T., S. Turner, and G. Shunk (1997). *Quantifying Congestion: Final Report and User's Guide.* Report 398, National Cooperative Highway Research Program, Washington, D.C., 1997.

Olson, D. L. (1996) *Decision Aids for Selection Problems.* Springer, New York, 1996.

Texas Department of Transportation (2009)*TxDOT 2009-2013 Strategic Plan*. Texas Department of Transportation. http://www.dot.state.tx.us/about_us/, accessed April 2009.

Ramani, T.L., et al.(2009) *Improving the Performance-Measurement Based MCDM Approach for Transportation Planning Applications.* Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C.

World Bank (1996*) Sustainable Transportation: Priorities for Policy Reform*. The World Bank, Washington, D.C., May 1996.

Zietsman, J., and L.R. Rilett. (2002) *Sustainable Transportation: Conceptualization and Performance Measures.* Report SWUTC/02/167403-1, Southwest Region University Transportation Center, The Texas A&M University System, College Station, Texas, March 2002.

Zietsman, J., et al (2008). *Sustainability Enhancement Tool for State Departments of Transportation Using Performance Measurement.* Presented at the 87th Annual Meeting of the Transportation Research Board, Washington, D.C.