SUSTAINABLE TRANSPORTATION: FAD OR FABULOUS

Josias Zietsman (Texas Transportation Institute)
and
Laurence R. Rilett (Texas A&M University)

ABSTRACT

Sustainable transportation attempts to address economic development, environmental stewardship, and social equity of current and future generations. While numerous qualitative studies have been performed on this topic there has been little quantitative research and/or implementation of sustainable transportation concepts. The main reasons for this are related to a lack of understanding of sustainable transportation and a lack of quantified performance measures. It was found that the implementation of such concepts, can to a large extent, be improved if they are clearly defined, quantified and used in the decision-making process.

A framework is provided on how performance measures for sustainable transportation can be identified and quantified as part of the transportation planning process and how the quantified measures can lead to implementation. This framework was applied to a real test case in Houston, Texas. It was shown that by using quantified performance measures it is possible to produce sustainable transportation index values. This type of approach makes it possible to determine the sustainability index for different user groups commuting along the corridor as a result of projects, programs and policies.

It was concluded that sustainable transportation can potentially be a very useful concept for addressing economic development, environmental stewardship, and social equity of current and future generations. This can, however, only come to fruition if sustainable transportation is clearly defined, quantified and used in the decision-making process

INTRODUCTION

Transportation is an essential social and economic activity that also results in a number of negative externalities. These negative externalities are associated with all facets of the transportation lifecycle including the production of a vehicle, its use and, ultimately its disposal. Planners and environmentalists have predicted that current trends related to motorization will result in economic, social and environmental needs of both current and future generations not being met. This challenge led to the creation of the concept of sustainable development.

The principles associated with sustainable transportation are well documented and are supported by many decision makers. These principles are related to the economic, social and environmental dimensions of sustainable transportation and include the improvement and protection of the following: i) employment; ii) efficiency; iii) livability; iv) equity; v) safety and security; vi) accessibility; vii) mobility; and viii) the environment. Although these are all laudable goals, the challenge remains to insure that they are implemented.

The purpose of this paper is i) to highlight the negative effects associated with transportation; ii) to provide a description of the concept of sustainable transportation; iii) to highlight the difficulties that are typically encountered in implementing sustainable transportation; iv) to provide a framework on how to identify, quantify, and use performance measures for sustainable transportation in the decision making process; and v) to illustrate the concepts through an application of a real test case.

NEGATIVE EXTERNALITIES

The economic system takes renewable and non renewable resources from the environment, processes them to derive some benefits and then discards what is left as different forms of waste into the environment. The only continuous external input into the global system is solar energy and the only output leaving the system is low level heat. The dumping of waste streams may lead to substantial and sometimes irreversible damage to the environment. The interests of future generations are also damaged if we are using non renewable resources without enabling the production of full substitutes, if we are using renewable resources faster than they can reproduce, or if we are dumping more waste into the environment than the ecological systems can safely absorb (*1*).

Figure 1 shows how the world economy interacts with the global ecological subsystem. It may be seen in this figure that the economic subsystem is represented as the inner circle in the diagram and the global ecological system as the outer circle. In an unsustainable situation the size of the economic subsystem continues to increase up to a point that the ecological system is not able to accommodate it anymore (*1*). Transportation plays a key role in the economic system and, therefore, has a major impact on the ecological system. It was for example found that transportation is responsible for twenty-two percent of the global energy consumption and twenty-five percent of fossil fuel burning across the world (*2*). Typical negative externalities associated with transportation are i) air pollution, ii) noise pollution, iii) accidents, iv) global climate change, v) energy use, congestion, vi) social disruption, vii) resource use, viii) water pollution, ix) consumption of land, x) urban sprawl, xi) loss of habitat, xii) hazardous materials, xiii) vibration, xiv) visual intrusion, and xv) waste disposal problems.

Sustainable transportation has evolved as a strategy to address the compromise between the benefits associated with transportation and all its negative externalities over the short to long term (*3*).

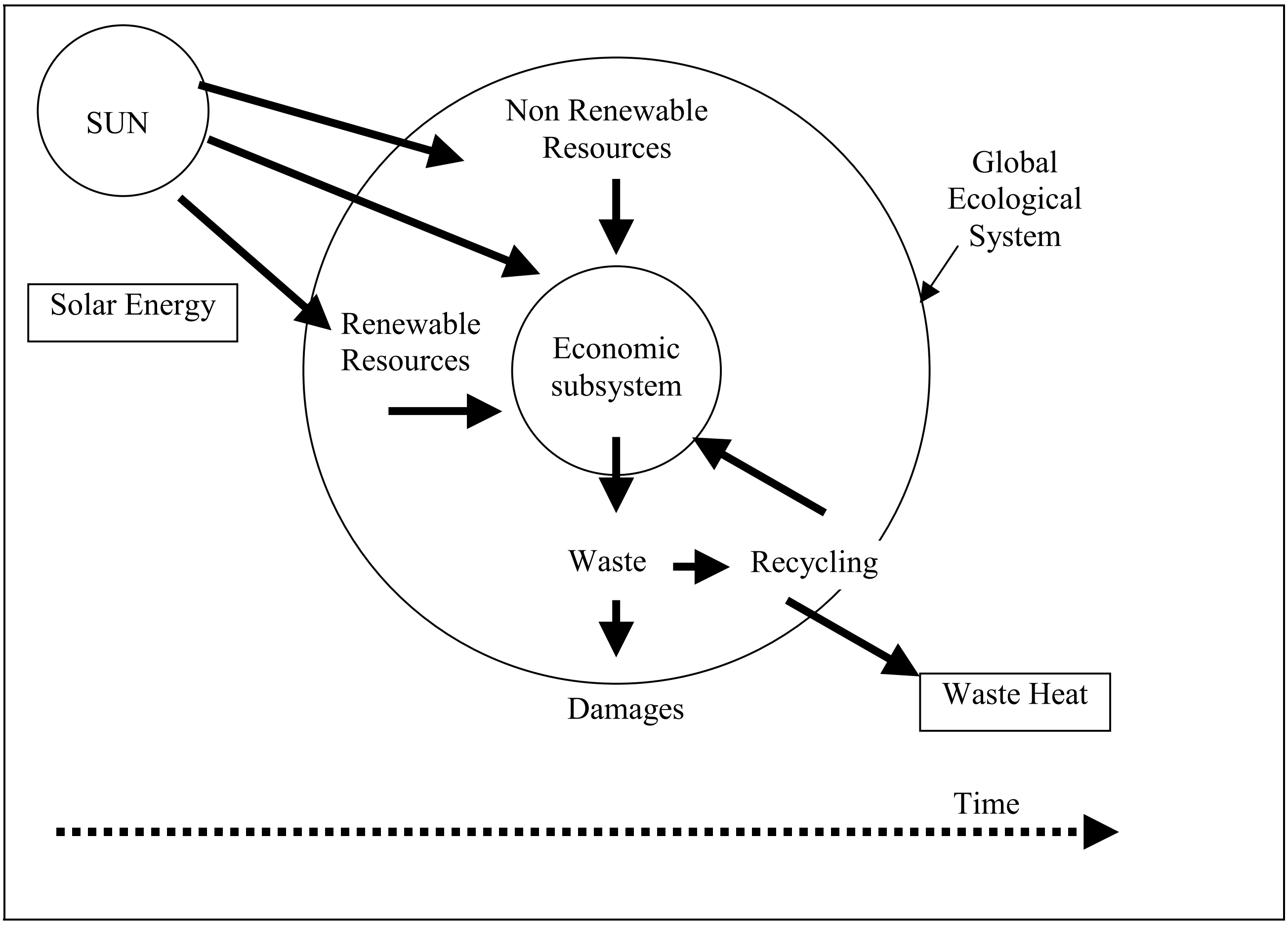

FIGURE 1: Interaction of the World Economy with the Global Ecological System (*1*)

EVOLUTION OF SUSTAINABLE DEVELOPMENT

In order to obtain a thorough understanding of the concept of sustainable transportation it is instructive to explore its evolution. While the term sustainable development is fairly recent, some principles associated with it date back to the eighteenth century economist and philosopher Thomas Malthus. He theorized that temporary improvements in human living standards would trigger population surges, which would outpace technological growth and resource availability (*4*). These theories were rekindled during the early 1960's when there was a growing concern over the human impact on the environment. In the 1970's some specific concerns were identified such as global warming, acid rain, depletion of the ozone layer, excessive population growth, loss of tropical forests, and biological diversity. The term sustainable development was first used by the World Conservation Strategy (WCS) in 1980. They stressed the interdependence of conservation and development and emphasized that humanity is part of nature and has no future unless nature and natural resources are conserved (*2*).

In 1987 the report by the World Commission on Environment and Development (the so-called Brundtland Commission) re-emphasized the importance of sustainable development and provided a widely used definition, 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*" (*5*). The United Nations Conference on Environment and Development (UNCED) that was held in Rio de Janeiro in 1992, gave the concept of sustainable development the status of a global mission through the adoption of the so-called Agenda 21 (*6*).

The momentum for achieving sustainable development accelerated during the 1990's and there are currently numerous initiatives of sustainable development across the world, particularly in Europe, Canada and the United States. Important initiatives in the United States include the President Council on Sustainable Development, various smart growth initiatives and the so-called Livability Agenda (*7*).

DEFINING SUSTAINABLE TRANSPORTATION

Numerous authors have provided definitions for sustainable development and sustainable transportation. These definitions are mostly based on the one mentioned above by the Brundlandt Commission. Sustainable transportation can be seen as an expression of sustainable development in the transportation sector. A more comprehensive definition for sustainable development is as follows (*8*): *It is development that ensures intergenerational equity by simultaneously addressing the multi-dimensional components of economic development, environmental stewardship, and social equity. It is a dynamic process, which considers the changing needs of society over space and time. Sustainable development can be viewed as a continuum, representing various degrees of sustainability. It must, however, be achieved within resource, environmental, and ecological constraints."*

The dimensions, principles, and constraints associated with sustainable transportation can be described as follows (*8*):

Dimensions

- *Social equity:* People must be able to interact with one another and with nature. A safe and secure environment must be provided. There must be equity between societies, groups and generations. It includes issues such as equity, safety, security, human health, education, and quality of life.
- *Economic development:* Resources need to be adequately maintained. Financial and economic needs of current and future generations must be met. It includes issues such as business activity, employment, productivity, tax issues, and trade.
- *Environmental stewardship:* Use renewable resources at below their rates of regeneration and non-renewable resources at below the rates of development of renewable substitutes. Provide a clean environment for current and future generations.

Principles

- *Intergenerational equity:* There should be an equitable distribution of resources between communities and generations. Both current and future generations should, therefore, be able to enjoy an acceptable quality of life.
- *Multi-dimensional:* The three dimensions of sustainable development are economic development, environmental stewardship, and social equity. These dimensions are interrelated and must be simultaneously addressed in order to meet the needs of current and future generations.
- *Dynamic:* In considering intergenerational equity it is necessary to take cognizance of the fact that the needs of societies change over space and time.
- *Continuum:* Sustainability is not represented by discrete indications of sustainability or unsustainability, but rather as a continuum, which represents various degrees of sustainability.

Constraints

- *Resource:* Non-renewable resources should not be used without enabling the production of substitutes, and renewable resources should not be used at a faster rate than they can be reproduced.
- *Ecological:* The ecological boundaries are exceeded if more waste is dumped into the ecological system than the system can safely absorb, or if the system is damaged by taking excessive amounts of good arable land to provide transportation infrastructure.
- *Environmental:* The environment is damaged by excessive pollution that can result in ill health for humans and animals and damage to plant species. Pollution can also result in climate changes, which can cause floods, droughts and increased diseases.
- *Technological:* Technology can have a positive effect on sustainable development. With regard to transportation for example, technology can change travel behavior, the efficiency of travel modes and introduce more equitable systems in paying for transportation.

CHALLENGES FOR IMPLEMENTING SUSTAINABLE TRANSPORTATION

Sustainable transportation can be considered as one of the most debated but least applied concepts in urban and transportation planning (*9*). In this regard, many authors have investigated possible deficiencies with regard to current transportation planning practice and identified the following as key areas for improvement: i) the lack of understanding and recognition of the increasing important social, economic, environmental and public policy issues; ii) the lack of practical guidelines on how to address these challenges; iii) the lack of quantified measures so that progress can be monitored and decisions made; and iv) the lack of co-ordination between decision makers and other stakeholders.

These deficiencies can to a large extent be addressed if the concepts associated with sustainable transportation are clearly defined and quantified. The reality, however, is that the sustainability implications of transportation have not been quantified and is even qualitatively unclear. The reasons why sustainable transportation has not been adequately quantified can be summarized as follows (*8*): i) sustainable transportation is a fairly new concept of which the objectives and scope of activities are unclear; ii) there is a lack of guidelines for identifying appropriate performance measures; iii) the current state of the practice in terms of modeling and planning techniques are too limited in its level of accuracy and detail to adequately quantify sustainable transportation performance measures; and iv) even if sustainable transportation performance measures can be adequately quantified, it is unclear how to make trade-offs and decisions in a consistent and unbiased manner. The following section contains a framework on how to identify, quantify, and use performance measures for sustainable transportation.

FRAMEWORK FOR IMPLEMENTING SUSTAINABLE TRANSPORTATION

Identifying and quantifying performance measures are important components of the transportation planning process because it provides the decision maker with information on which to base decisions regarding transportation projects, programs, and policies. Figure 2 shows a framework on how performance measures can be identified and quantified as part of the transportation planning process and how the quantified measures can lead to implementation.

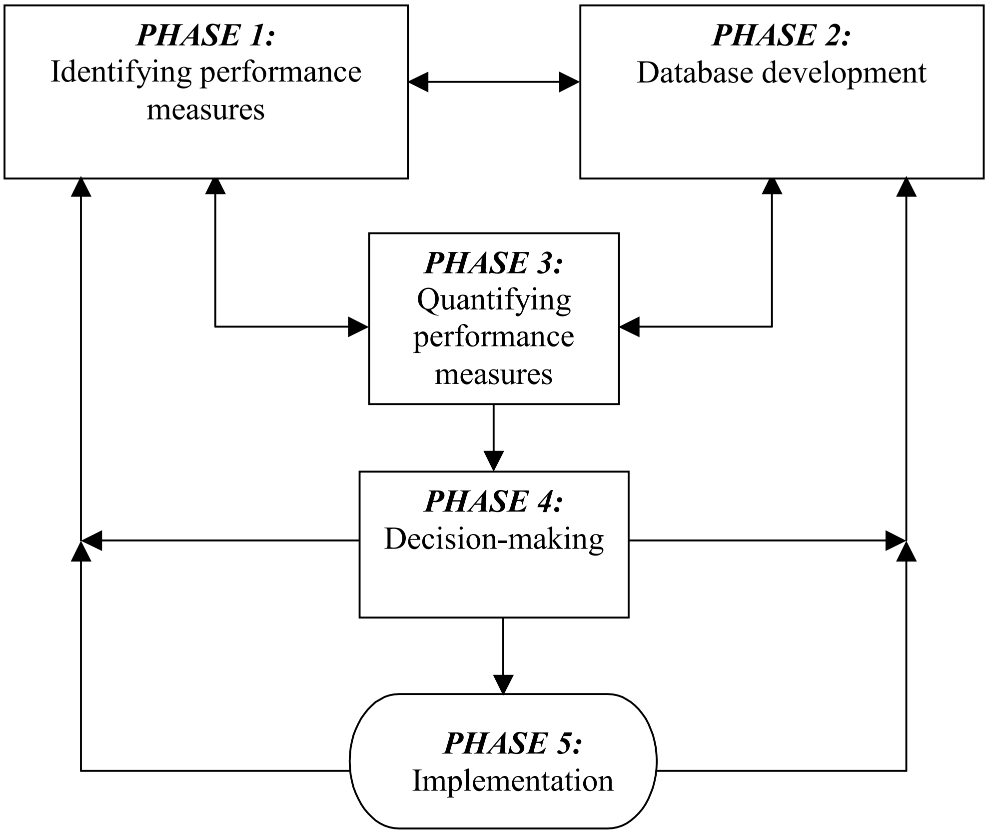

FIGURE 2: Framework for Identifying, Quantifying and Using Performance Measures

It may be seen in Figure 2 that the framework comprises of five phases that lead to implementation, namely i) identifying performance measures; ii) database development; iii) quantifying performance measures; iv) decision-making; and v) implementation. Phases 1 and 2 can occur simultaneously, while Phases 3 to 5 follow in sequence. The general flow of information is, therefore, from strategic planning and database development towards implementation. At the center of the activities is the quantification of performance measures, which is linked to Phases 1 to 4. Once the decision-making or implementation has occurred, feedback is required to the first two phases, to ensure that any necessary adjustments can be made. Each of the five phases of the framework will now be discussed in turn to illustrate how they can be developed and applied.

Phase 1: Identifying Performance Measures

The identification of appropriate performance measures is a very important task because poor performance measures can lead to poor decisions and poor outcomes. It should be noted that because interest groups such as the general public, engineers, managers, and decision makers have different expectations, needs, and technical expertise, it is possible to identify different sets of performance measures. Engineers, for example, prefer a more quantitative approach and tend to strive for optimum results, whereas most decision makers are very comfortable with a more qualitative approach. The increased demand for public participation requires performance measures that are understandable by the public at large. Consideration of the needs and technical abilities of the target group, therefore, is of key importance. The strategic planning approach is able to incorporate the needs and technical abilities of the various interest groups.

Phase 2: Database Development
Data of the transportation system are obtained through the monitoring of performance as well as specific data collection exercises. The monitoring of performance is mostly a routine activity that is part of operational management. Data collection on the other hand is mostly done on an ad hoc basis. Various models can change the data into information for either the base year or the forecast year. All the manipulated data is included in a database. The information contained in the database is used for quantifying performance measures that were identified through the strategic planning exercise.

Phase 3: Quantifying Performance Measures
In this phase the identified performance measures as determined through Phase 1 and the database as compiled through Phase 2 are combined in order to quantify the appropriate performance measures. The identified performance measures are grouped into three categories, namely input, output and outcome measures. The flow of information is from input measures, to output measures and then to outcome measures. The final result of an iterative process of formulating and quantifying performance measures is a number of quantified performance measures that can be used in the decision making process.

Phase 4: Decision-making
In assessing transportation projects, multiple and conflicting objectives need to be considered in the decision-making process. There are many multi-criteria decision-making techniques available. Multi Attribute Utility Theory (MAUT) is most often used as a technique for evaluating projects, programs, and policies in terms of sustainable transportation. This technique is popular because it is a relatively intuitive process and decision makers can see how their weightings for the various criteria influence the final outcome. With this technique the quantified performance measures are rated and weighed to produce the utility values. The decision makers can base their decisions on the utility values, although other factors such as available funding and political influences may also play a crucial role in the decision-making process.

Phase 5: Implementation
The implementation stems from the decision, which can be in the form of a project, program, policy or a combination the three. Project management is then used to turn the project, policy or program into a final product.

EXAMPLE APPLICATION

The proposed methodology is perhaps best illustrated in the form of a simple example. In this example an index for sustainable transportation is developed and used to illustrate how decisions can be based on quantified performance measures. Specifically, it is shown how the sustainability of existing and proposed projects can be assessed with an index for sustainable transportation.

Very few authors have looked into indices for sustainable transportation. The proposed index for this example considers a number of sustainability factors in a linear additive equation. It should be noted that this proposed index is only used for illustration purposes and further research is required to develop a comprehensive sustainable transportation index. The formulation of the proposed index is shown as Equation 1 and the determination of the normalized criteria values as Equation 2.

$$I_s = N_m W_m + N_p W_p + N_f W_f \qquad (1)$$

$$N_j = f_j(s_j) \qquad (2)$$

Where I_s = Sustainable transportation index value
N_m, N_p, N_f = Normalized criteria values for mobility, emissions and fuel consumption, respectively
W_m, W_p, W_f = Weights for mobility, emissions and fuel consumption, respectively
$f_j(x)$ = Single-attribute utility function on a normalized scale
s_j = Value of criterion j

The test bed for this analysis is a twenty-two kilometer section of the Interstate 10 (I-10) corridor in Houston, Texas. It is a divided freeway with full grade separation, three to four lanes per direction, and a High Occupancy Vehicle (HOV) facility in the median. Five automatic vehicle identification (AVI) stations, and therefore four links, are located on this section of freeway. For this analysis, only the eastbound direction (towards the central business district of Houston) and only the a.m. peak hour (from 7 to 8 a.m.) were considered. Figure 3 shows a diagrammatic layout of the I-10 corridor as well as the locations of the AVI stations.

A useful application of the sustainable transportation index would be to determine the sustainability experienced by various user groups that travel along the corridor. For illustration purposes, it was assumed that different user groups could be clustered according to the different origin-destination (O-D) pairs as defined by the AVI stations. Sustainable transportation indices were determined for all the O-D pairs for both the do-nothing alternative (Alternative 0) and for a scenario that involves the addition of a lane between AVI stations 1 and 4 (Alternative 1).

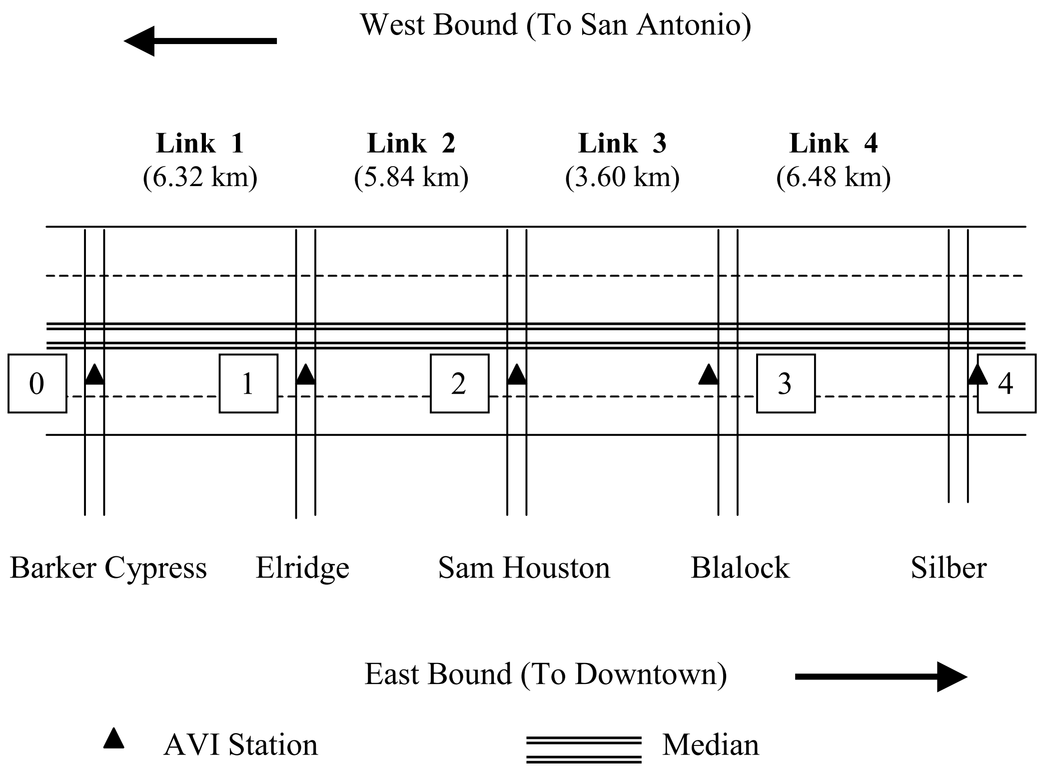

FIGURE 3: Layout of the I-10 Corridor and the Locations of the AVI Stations

Mobility is represented by the travel rate measure, emissions is represented by HC, CO, and NOx emissions, and fuel consumption is represented by the fuel consumption rate. The travel rate was directly quantified with output from the TRANSIMS simulation model. The emissions and fuel consumption were quantified with output from the TRANSIMS simulations and by making use of the MOBILE 5a and FREFLO models, respectively (*10,11,12*). The quantified criteria values for the two alternatives are shown in Table 1.

The criteria weights were determined by applying professional judgment. The following weights were allocated to the various criteria, namely 100% for mobility, 60% for emissions, and 40% for fuel consumption. There was also a distinction made with regard to the importance of the different pollutant types by allocating 100% for HC, 90% for NOx, and 80% for CO. Both the criteria values and criteria weights were subsequently normalized on a linear scale from zero to one. Equation 1 was then used to determine sustainable transportation index values for both scenarios and for all the O-D pairs. It should be noted that the above-mentioned weights may be appropriate for the Houston case, whereas different weights may be selected for a corridor in South Africa.

Table 1: Criteria Values for the Two Alternatives

Alternative 0							
From	**To**	**Distance (m)**	**Travel rate (min/km)**	**HC (g/m)**	**CO (g/m)**	**NOx (g/m)**	**Fuel (gal/hr)**
0	1	6356	0.769	4.753	68.833	13.533	0.214
0	2	12229	0.958	5.212	68.656	13.043	0.250
0	3	15850	1.166	5.408	68.528	12.188	0.247
0	4	22368	1.094	5.646	72.797	13.259	0.271
1	2	5873	1.163	5.708	68.465	12.513	0.288
1	3	9494	1.431	5.846	68.324	11.288	0.269
1	4	16012	1.222	6.001	74.371	13.150	0.293
2	3	3621	1.866	6.069	68.095	9.301	0.237
2	4	10139	1.257	6.171	77.792	13.519	0.296
3	4	6518	0.919	6.227	83.178	15.863	0.329
Alternative 1							
From	**To**	**Distance (m)**	**Travel rate (min/km)**	**HC (g/m)**	**CO (g/m)**	**NOx (g/m)**	**Fuel (gal/hr)**
0	1	6356	0.614	4.511	71.740	12.994	0.210
0	2	12229	0.656	4.625	70.141	12.716	0.214
0	3	15850	0.639	4.349	66.804	11.784	0.205
0	4	22368	0.592	4.512	71.029	11.873	0.210
1	2	5873	0.703	4.749	68.410	12.414	0.219
1	3	9494	0.655	4.241	63.499	10.974	0.202
1	4	16012	0.583	4.513	70.747	11.428	0.210
2	3	3621	0.579	3.417	55.534	8.639	0.175
2	4	10139	0.513	4.376	72.101	10.858	0.205
3	4	6518	0.477	4.909	81.305	12.090	0.222

The final result of the application is shown in Figure 4. It may be seen in this figure that the sustainability index for Alternative 0 (do-nothing) shows a decreasing trend as the O-D pairs approach the CBD of Houston. A minimum is reached for O-D pair two to three with a sustainability index value of less than 0.3. Alternative 1 results in much higher and more consistent index values, with all indices being more than 0.7. It may also be seen in Figure 4 that the worse O-D pair in Alternative 0, namely two to three, is the best O-D pair in Alternative 1. For this example, the sustainability as experienced by the user group that travels between AVI stations two to three is vastly improved if Alternative 1 is implemented. This type of approach makes it possible to monitor the extent to which the different user groups experience sustainable transportation as a result of projects, programs and policies.

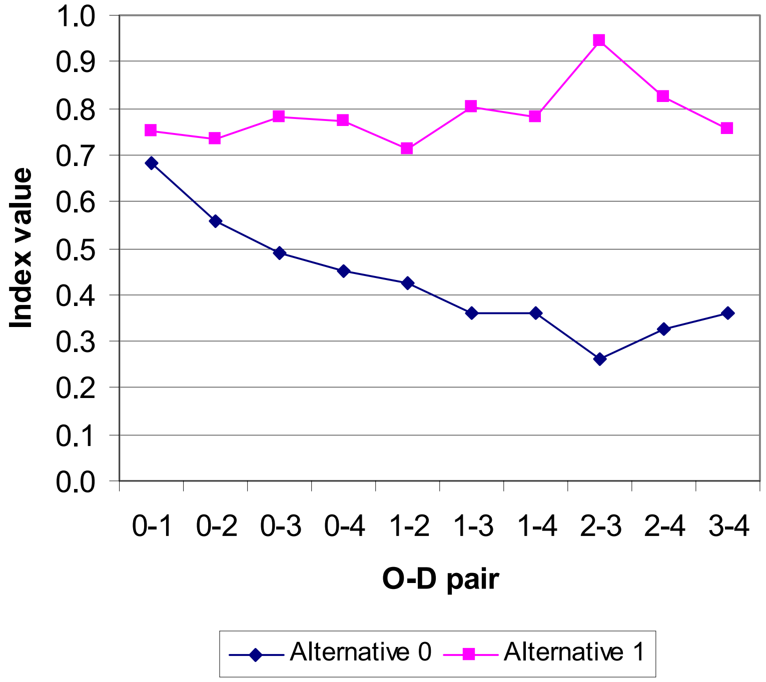

FIGURE 4: Sustainable Transportation Index Values for the Various O-D Pairs

CONCLUSIONS

Sustainable transportation can be defined in terms of a number of dimensions, principles, and constraints. The implementation of sustainable transportation concepts, however, has up to now been fairly disappointing. It was found that the implementation of such concepts can to a large extent be improved if they are clearly defined, quantified and used in the decision-making process.

A framework is provided on how performance measures can be identified and quantified as part of the transportation planning process and how the quantified measures can lead to implementation. This framework was applied to a real test case in Houston, Texas. A useful application of the sustainable transportation index would be to determine the sustainability experienced by various user groups that travel along the corridor.

It was shown that by using quantified performance measures it is possible to produce sustainable transportation index values. This type of approach makes it possible to determine the sustainability index for different user groups commuting along the corridor as a result of projects, programs and policies.

It was concluded that sustainable transportation can potentially be a very useful concept for addressing economic development, environmental stewardship, and social equity of current and future generations. This can, however, only come to fruition if sustainable transportation is clearly defined, quantified and used in the decision-making process

REFERENCES

1. Hohmeyer, O. *Social Costs of Climate Change Strong Sustainability and Social Costs.* Proceedings of a Conference Held in Ladenburg, Springer, Berlin, Germany, May 1995.

2. Haq, G. *Towards Sustainable Transportation Planning: A Comparison Between Britain and the Netherlands.* Avebury, Aldershot, England, 1997.

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

4. *Toward a Sustainable Future: Addressing the Long-Term Effects of Motor Vehicle Transportation on Climate and Ecology.* Special Report 251. Committee for a Study on Transportation and a Sustainable Environment, Transportation Research Board, National Research Council, Washington, D.C., 1997.

5. World Commission on Environment and Development (Brundland Commission). *Our Common Future.* Oxford University Press, Oxford, England, 1987.

6. *Towards Sustainable Transportation*. Proceedings of OECD Conference Held in Vancouver, Canada. OECD, Paris, France, 1997.

7. Livable Communities. http://www.house.gov/blumenauer/livable.htm. Accessed November 1999.

8. Zietsman, J. *Incorporating Sustainability Performance Measures Into the Transportation Planning Process.* Ph.D. Dissertation, Texas A&M University, College Station, Texas, December 2000.

9. Lindquist, E. Moving Toward Sustainability: Transforming a Comprehensive Land Use and Transportation Plan. In *Transportation Research Record* 1617, Transportation Research Board, National Research Council, Washington, D.C., 1998, pp. 1-9.

10. Nagel, K., P. Stretz, M. Pieck, S. Lecky, R. Donnelly, and C.L. Barrett. *TRANSIMS Traffic Flow Characteristics.* Report LA-UR-97-3530, Los Alamos Nation Laboratory, Los Alamos, New Mexico, July 1997.

11. United States Environmental Protection Agency (EPA). http://www.epa.gov/. Accessed January 1999.

12. Rao, K. S., and R. A. Krammes. Energy-Based Fuel Consumption Model for FREFLO. In *Transportation Research Record* 1444, Transportation Research Board, National Research Council, Washington, D. C., 1994, pp. 36-43.

SUSTAINABLE TRANSPORTATION: FAD OR FABULOUS

Josias Zietsman (Texas Transportation Institute)
and
Laurence R. Rilett (Texas A&M University)

VITA: Sias Zietsman

Sias Zietsman holds a bachelor's and master's degree in Civil Engineering from the University of Pretoria, and a Ph.D. from Texas A&M University.

The first 3 years of his career were spent in road construction. He then joined the East Rand Metro where he was responsible for public and private transportation planning.

In December 1997, he moved to the United States to commence with his Ph.D. in Civil Engineering at Texas A&M University. After completing his studies in September 2000, he joined the Texas Transportation Institute as an Associate Research Scientist.