IDENTIFICATION AND QUANTIFICATION OF SUSTAINABILITY PERFORMANCE MEASURES

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ABSTRACT

Economic, social and environmental challenges across the world have given rise to the concepts of sustainable development. For sustainable transportation to be successfully implemented it is essential that the concepts are adequately understood, quantified and applied. The focus of this paper was to show how performance measures for sustainability could be quantified in both a developed and a developing nation using new and innovative technologies. It was shown that the concepts of sustainable transportation are universal across nations although the specific needs, available technologies, and funding sources differ between developed and developing nations.

For this research, a corridor in a city of a developed nation and one in a developing nation were selected as test beds. The corridor in the developed nation is the US-290 corridor in Houston, Texas whereas the corridor in the developing nation is the PWV-9 freeway in Tshwane, South Africa. A wide variety of innovative data collection techniques were investigated. It was found that the data collection methods vary greatly in terms of sophistication, accuracy, and cost. Automatic vehicle identification (AVI) systems and cellular phone tracking have been identified to have the most potential, both for developed and developing nations. It was further shown that basic data such as speed, travel time, and travel time variability could be used to quantify a wide range of sustainable transportation performance measures.

1. INTRODUCTION

Economic, social and environmental problems across the world have given rise to the concept of sustainable development. The objective of sustainable development is to address the economic, social and environmental needs of current and future generations. Sustainable transportation can be viewed as an expression of sustainable development in the transportation sector. For sustainable transportation to be successfully implemented it is essential that the concepts are adequately understood, quantified and applied (*1*).

The focus of this paper is to show how performance measures for sustainability can be quantified in both a developed and a developing nation using new and innovative technologies. It was shown that the concepts of sustainable transportation are universal across nations although the available technologies differ between developed and developing nations.

The paper is broken down into three sections. The first section provides a broad framework on how to identify performance measures for sustainable transportation as well as a description of typical performance measures that may be used. The second section provides an overview of possible technologies that may be used to quantify travel time, travel time variability, and speed as important building blocks for quantifying sustainable transportation performance measures. The final section shows some examples from the test corridors in Houston, Texas and the one in Tshwane (Greater Pretoria), South Africa.

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2. FRAMEWORK FOR IDENTIFYING PERFORMANCE MEASURES

The identification of appropriate performance measures is a very important task because inappropriate performance measures generally 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 for each target group. Engineers, for example, prefer a more quantitative approach and tend to strive for optimum results, whereas most decision makers are generally more comfortable with a qualitative approach. In addition, the increased demand for public participation requires performance measures that are understandable by the public at large. Apart from the different interest groups, the vastly different needs and available technologies of developed versus developing nations also result in different types of objectives and, therefore, performance measures in each instance.

A strategic planning approach is able to incorporate the needs and technical abilities of the various interest groups. It is comprised of a number of steps. These steps are to develop a vision, mission, goals, objectives, strategies, policies, and actions. The process does not flow smoothly from one step to the next. It is at best a highly iterative process that requires consistent checks to ascertain whether the outcomes of the existing step of the process are consistent with what have been proposed in previous steps.

Figure 1 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 (*1*). The strategic planning process forms part of Phase 1 as shown in Figure 1.

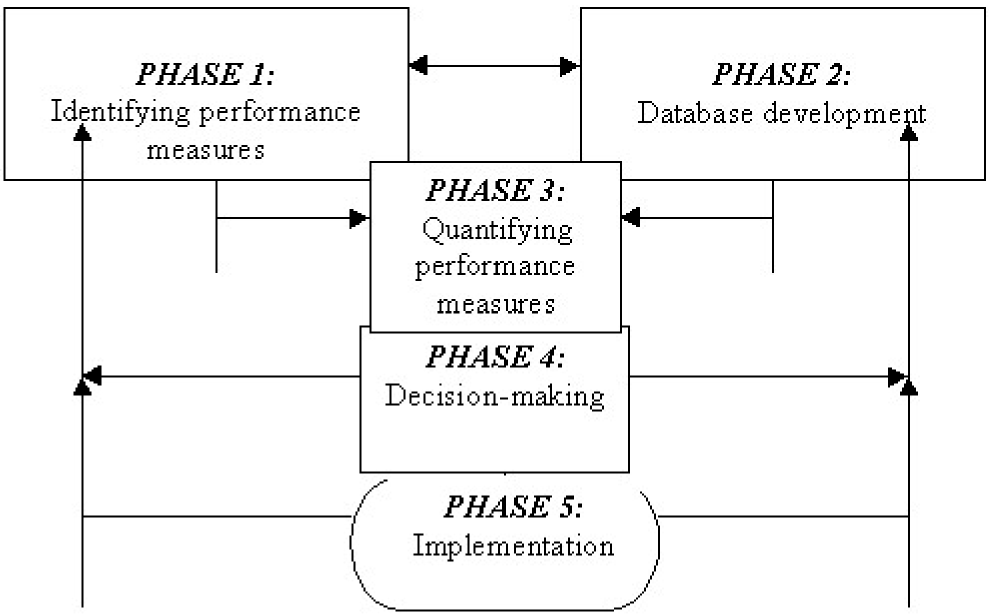

Figure 1. A Framework for Identifying and Applying Performance Measures.

3. TYPICAL SUSTAINABILITY PERFORMANCE MEASURES

Table 1 shows the most common objectives related to sustainable transportation as well as examples of performance measure that may be used to measure each of the objectives. It should be noted, however, that the selected objectives for developed versus developing nations might be vastly different.

Table 1. Objectives and Performance Measures for Sustainable Transportation.

Objective:	Performance measures:
1. Maximize accessibility	Number of travel objectives that can be reached within an acceptable travel time
2. Maximize comfort and convenience	Frequency of service
3. Maximize economic benefit	Jobs added
4. Maximize equity	Percentage of population within walking distance to transit services
5. Maximize livability	Number of major services within walking distance of residents
6. Maximize mobility	Travel rate
7. Maximize pedestrian and bicycle usage	Quality of pedestrian and bicycle environment.
8. Maximize productivity	Operating cost per passenger trip
9. Maximize reliability	Variance of point-to-point travel time
10. Maximize safety	Accident rate
11. Maximize security	Incidents of crime
12. Maximize transit usage	Mode split
13. Minimize air pollution	Concentration of HC, NO_x, and CO emissions
14. Minimize private vehicle (auto) usage	Vehicle-miles of private vehicle (auto) travel
15. Minimize capital costs	Capital cost
16. Minimize congestion	Total delay
17. Minimize displacement	Acres of land acquired
18. Minimize ecosystem impacts	Area of wetlands taken
19. Minimize energy consumption	Per capita fuel consumption
20. Minimize noise impacts	Noise levels
21. Minimize operating costs	Operating cost
22. Minimize travel cost	Point-to-point out of pocket travel cost
23. Minimize travel time	Point-to-point travel time

4. TRAVEL TIME DATA COLLECTION TECHNIQUES

Travel time, travel time variability, and speed have been identified as important building blocks for quantifying a number of sustainable transportation performance measures.

Specifically, these measures can be used as input for quantifying the following sustainable transportation objectives (2,3,4*):*

- maximize accessibility;
- maximize equity;
- maximize mobility;
- maximize reliability;
- minimize air pollution;
- minimize congestion;
- minimize energy consumption;

- minimize noise impacts;
- minimize travel cost; and
- minimize travel time.

Two techniques have traditionally been used to measure travel time, namely the license plate technique and the floating car technique. The advent of Intelligent Transportation Systems (ITS), however, has made it possible to obtain travel time information much easier and often much more accurately. The following are examples of ITS techniques that may be used for quantifying travel time, travel time variability, and speed data in urban areas:

4.1 Automatic Vehicle Identification (AVI)

An AVI system consists of an in-vehicle transponder (tag), a roadside reading unit, and a central computer system. When a vehicle, which is equipped with a transponder, passes a roadside reader unit, information such as the vehicle's identification number, time and date of the tag read as well as the number of the reader unit is recorded. This information is then sent, via a modem, from the reader unit to a central computer. The central computer is used to store the tag reads and to establish tag matches. Travel times and speeds are then computed from the matched information and the distances between the AVI readers. Such systems are used extensively in Houston, Texas and Toronto, Canada.

4.2 Automatic Vehicle Location (AVL)

Research among most major car manufacturers is currently moving in a direction where every car in future might double as a moving sensor. Vehicles might send information about location, travel time, speed, weather condition, congestion, and road surface conditions to a central computer. Some vehicles are currently equipped with satellite navigation systems, which can provide information on the vehicle's location, which can be translated into travel times. In addition to the car manufacturers, some major companies such as 3M are also making great strides in their AVL research.

4.3 Cellular Phone Tracking

Cellular telephone systems are radio-based mobile communication systems. They use many base stations to transmit or receive the signals from the mobile telephones. These base stations are distributed over a service area, normally in a hexagonal pattern. There are three ways that positioning can be derived in a cellular positioning system: i) The signal profiling technique involves measuring the characteristics of the received signal and comparing it with a database of previous measurements; ii) The angle of arrival technique uses a large antenna in order to estimate the angle of arrival of the received signal; iii) The timing measurement technique requires a receiver to make an accurate determination of the time-of-arrival of received signals. The arrival time of the signal is a function of distance traveled, which makes it possible to combine measurements from different base stations to determine positions.

It is anticipated that cellular phones will be the dominant communication medium for ITS applications in the foreseeable future. This notion is based on cellular's declining price, its growing consumer base, and the fact that regulations in certain countries, such as the United States, dictate that cellular phones should be traceable to assist with emergency services. There are today more than sixty million cellular subscribers in the United States. Currently almost one third of these phones are digital and this proportion is consistently growing, making its applicability as an ITS technique even more realistic.

4.4 Distance Measuring Instruments (DMI)

A sensor of the electronic DMI is attached to a test vehicle's transmission where it receives consecutive pulses while the vehicle is moving. A DMI typically can provide distances and instantaneous speeds up to every 0,5 seconds. This detailed travel time information can be downloaded automatically to a portable computer in an easy-to-use data format. The integration of an electronic DMI with the floating car technique provides an easier, safer, and more accurate way of collecting detailed travel information as compared with traditional methods.

4.5 Electronic License Plate Matching

Early methods of license plate matching relied on observers to manually note the license plates of passing vehicles as well as the corresponding time stamps onto paper or a tape recorder. Recent advances have substantially improved the ease and accuracy of this technique. A popular method is to use video images of the license plates as well as the time stamps when the image is taken. Current research deals with ways to provide automatic matching of the video images. This is done through image recognition, which is well advanced in certain countries such as Germany.

4.6 Global Positioning System (GPS)

A GPS system comprises a satellite-based radio navigation system that provides continuous coverage to an unlimited number of users who are equipped with receivers capable of processing the signals being broadcast by the satellites. The receivers used for determining speeds and travel times are in-vehicle GPS data loggers. Information that is transmitted from the orbiting satellites to the GPS data logger includes a time stamp, satellite position, and an indication of the satellite motion. This information can then be converted to latitude and longitude information, while keeping track of the timestamp. By matching GPS information to an existing road network map it is possible to calculate travel time and speed information.

4.7 Inductive Loop Detectors

Inductive loop detectors are imbedded into the pavements of roadways and are designed to detect the presence of vehicles passing over it. Such detectors can be placed in either a single or a double configuration. A single loop detector is able to collect vehicle counts and lane occupancy (percent of the time that vehicles occupy the loop detector). A double loop configuration, where two loops are spaced at about ten meters apart, makes it possible to determine the difference in arrival times at consecutive loop detectors. This information provides spot speeds (time mean speeds) but is not useful in determining travel times. Only under uncongested conditions can spot speeds be used to provide an indication of travel times. In addition, variation in speeds at loop detectors has very little correlation with travel time variability (*5*).

4.8 Video Imaging

Several video-based systems are being developed to measure travel times and speeds. The basic notion is that the video system captures vehicle images and attempts to match these images from different camera locations. The technologies for video-based systems, however, are not as well developed as some other techniques. Particularly, the electronic matching of vehicle images is still in the development phase.

The abovementioned techniques vary greatly in terms of sophistication, accuracy, and cost. In the case of developing nations, methodologies are sought that have fairly low costs and are not overly complex. Of the above-mentioned techniques, AVI systems and cellular phone tracking have the most potential, both for developed and developing nations. The reasons being that AVI systems can be funded through toll proceeds and cellular phone systems are generally in place and only the tracking component needs to be added. The best quality information can also be obtained through these approaches.

5. MODELING TECHNIQUES

If the relevant ITS technologies are not available, traffic simulation models need to be used in conjunction with basic traffic count data to obtain travel time, travel time variability, and speed data. Transportation models are also used to obtain forecast traffic patterns to predict future sustainability. Models for quantifying sustainable transportation include transportation models, transportation environmental impact models, and economic models.

5.1 Transportation Models

The most important transportation model in this context is the traffic micro simulation model. Examples of traffic simulation models are the Transportation Analysis and Simulation System (TRANSIMS), which was developed by the Los Alamos National Laboratory. This model uses the cellular automata or particle hopping logic to simulate traffic dynamics on an individual level. Other commonly used micro simulation models are CORSIM, VISSIM, and SATURN, which are mostly based on car following logic.

5.2 Environmental models

Environmental models used for sustainable transportation include emission models, noise models, and fuel consumption models. The most commonly used emission model in the USA is the MOBILE 6 model. With regard to noise models, the Federal Highway Administration has developed a new noise prediction model called TNM. There are many fuel consumption models available. These models are either macroscopic in nature or based on instantaneous acceleration and speed characteristics.

6. EXAMPLE APPLICATIONS

6.1 Description of the Test Beds

For this research, a corridor in a city of a developed nation and one in a developing nation were selected as test beds. The corridor in the developed nation is a twenty-kilometre section of the US-290 corridor, which is located seven kilometres from the central business district of Houston, Texas. The corridor in the developing nation is an eleven-kilometer section of the PWV-9 freeway on the north western side of Tshwane (the new name for Greater Pretoria), South Africa. This section of freeway is part of the so-called Mabopane-Centurion development corridor (*6*). Table 2 shows a general comparison between the US-290 and PWV-9 corridors.

Table 2. General Comparison Between US-290 and PWV-9 Corridors.

Consideration	**Houston, US-290**	**Tshwane, PWV-9**
Household income	High, >$30,000 per annum	Low, <$5,000 per annum (40% below breadline)
Unemployment	Low, <4%	High, >35%
Mode split	95% automobiles	50% automobiles, 40% minibus taxis, 10% buses
Age of vehicle fleet	New, typically < 5 years	Old, typically > 5 years
Data availability	Traffic counts and AVI data	Only traffic counts

It may be seen in Table 2 that the circumstances of the US-290 and PWV-9 corridors are vastly different. However, even though there are many differences the basic objectives and therefore the underlying performance measures are fairly similar.

Table 3 shows the goals in relation to the three dimensions of sustainable transportation as well as the goals that would typically be pursued and the associated performance measures. The technologies available for quantifying these measures are, however, different for the two corridors.

6.2 Strategic plans

6.2.1 Tshwane corridor

The transportation-related goals and objectives for the Tshwane corridor can be found in the Strategy for the Transportation Division of the Tshwane Metropolitan Authority (*7*) and a document entitled Transportation Planning, Operations, and Services in the City of Tshwane (*8*). The latter document was the result of extensive workshops that involved officials and decision-makers of Tshwane.

The transportation-related goals and objectives identified by these two documents can be summarized as follows:

- Use the provision of transportation to support economic growth;
- Integrate land use and transportation planning;
- Effectively regulate and control public transportation;
- Provide a safe and secure transportation system;
- Provide affordable mobility for all; and
- Minimize the negative environmental effects of transportation.

The first three goals relate to broader planning approaches that cannot readily be measured. It may be noticed that as the last three goals address the three dimensions of sustainable transportation – economic development, environmental stewardship, and social equity. Each of these goals can in turn be quantified through one or more performance measures.

6.2.2 Houston corridor

The transportation-related goals and objectives for the Houston corridor can be found in the Vision 2020 Metropolitan Transportation Plan (*9*) and the 2022 Metropolitan Transportation Plan (*10*), both prepared by the Houston-Galveston Area Council.

The combined goals and objectives identified by these two documents are as follows:

- Provide a multi-modal transportation system;
- Enhance and maintain existing infrastructure;
- Coordinate land use and transportation development;
- Increase accessibility and mobility options;
- Protect the environment;
- Promote energy conservation;
- Promote a cost effective and affordable transportation system; and
- Improve safety and security for the transportation system.

The first three goals relate to broader planning approaches that cannot be readily measured, whereas the last five goals address the three dimensions of sustainable transportation.

6.3 Selected performance measures

It may be noticed from the above-mentioned discussion that the sustainability goals for the Tshwane corridor (although differently phrased) are the same as the sustainability goals for the Houston corridor. Table 3 shows these goals in relation to the three dimensions of sustainable transportation. The table also contains specific performance measures that would address the various goals.

Table 3. Sustainability Dimensions, Goals and Performance Measures.

Sustainability dimension	Goals	Performance measures
Social	Maximize mobility Maximize safety	Travel rate Accidents per 100 million vehicle miles of travel
Economic	Maximize affordability	Point-to-point travel cost
Environmental	Minimize air pollution Minimize energy use	VOC, CO, and NOx emissions Fuel consumption

<u>6.4 Data Collection Techniques</u>

6.4.1 Developing Nation: PWV-9 Corridor

In the case of the PWV-9 corridor, there is only traffic count data available. For determining speed and travel time data for this corridor, some innovative approaches need to be selected. In deciding which technique to use, it is necessary to consider approaches that could ideally be effective, affordable, and labour intensive.

Labour is generally abundant in developing nations and job creation is a major consideration. Data collection techniques that are highly labour intensive should, therefore, be considered. Video imaging and DMI technology fall into this realm. Cellular phones are also very prevalent in most countries, including developing nations. There is, therefore, a real potential to use cellular phone tracking in the future. Another technology that may become a very important source of travel time related information is electronic tolling or AVI. Most developing nations are currently implementing toll roads. These toll facilities will eventually be equipped with AVI technology, providing a rich source of travel time-related information.

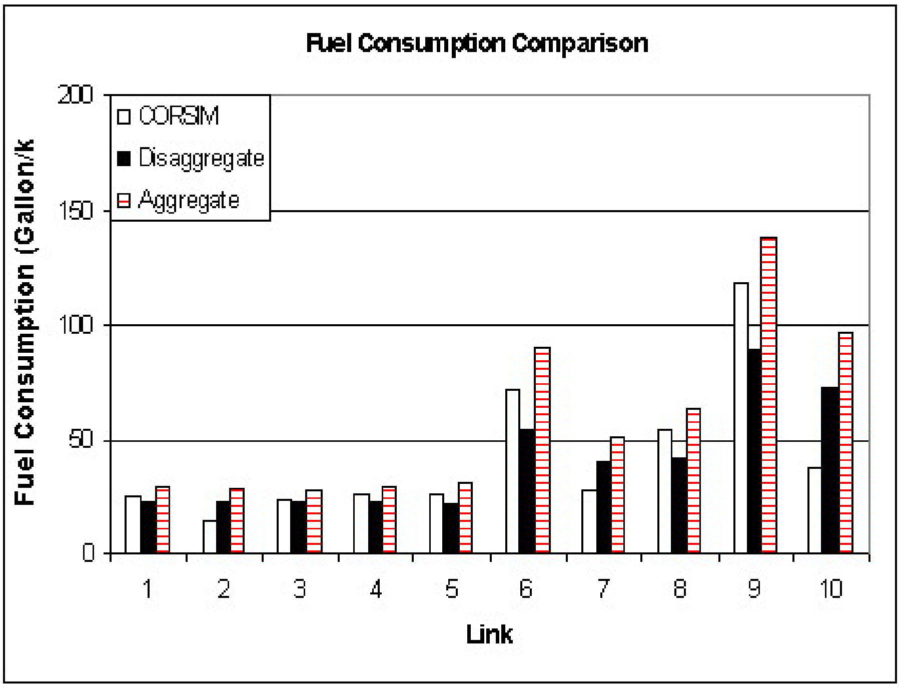

Figure 2. Estimated Fuel Consumption on PWV-9.

In the case of the PWV 9 corridor the CORSIM micro simulation model was used to simulate the traffic patterns and to produce the fundamental information used to quantify the sustainability performance measures. For illustration purposes the fuel consumption along PWV 9 is shown in Figure 2. Three different models were used to estimate the total fuel consumption on a link-by-link basis. The three models are the most disaggregate model, namely the instantaneous model, followed by the fuel consumption module of CORSIM, and finally the more aggregate FREFLO model. It may be seen in this figure that the three models result in quite different estimates of fuel consumption. The total average traffic volumes on this test corridor, is in the order of 35,000 vehicles per day.

6.4.2 Developed Nation: US-290 Corridor

In the case of the US-290 corridor there are traffic count and AVI data available. The AVI data can be used to determine travel time, travel time variability and speed data at both an individual level and at an aggregate (average) level. Additionally, the AVI data can be applied at the level of the AVI links or at any combination of AVI links, including the entire corridor. The US-290 corridor has six AVI stations, resulting in five AVI links. The proportion of vehicles that carry transponders was found to be in the order of five percent, while the total average traffic volumes on the test corridor was noticed to be in the order of 100,000 vehicles per day. Noticed or measured.

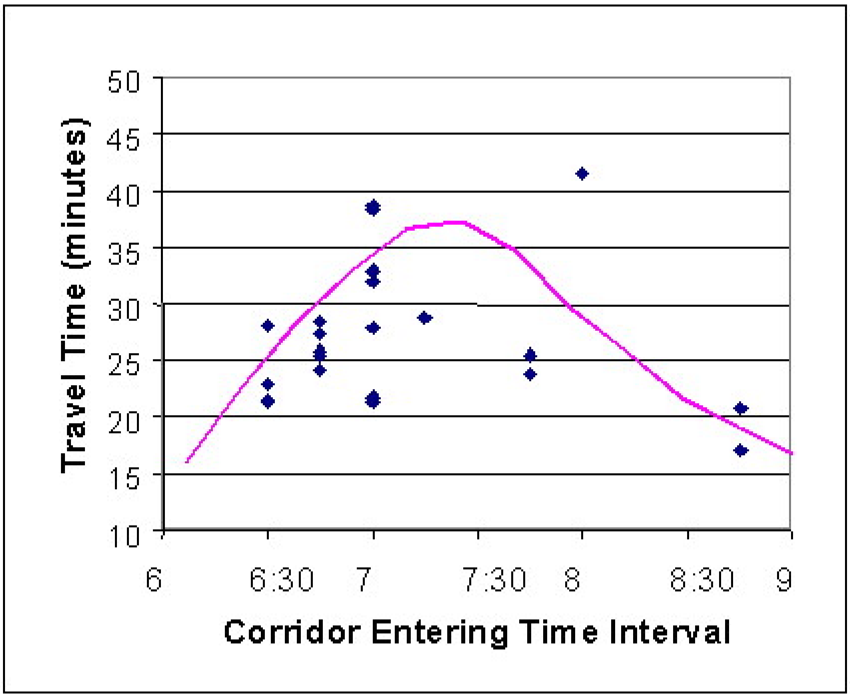

Figure 3. Travel Times of an Individual Commuter Versus Aggregate Estimates.

The transformed AVI data could be used to determine travel time, travel time variability, and speeds at both the individual and aggregate levels. Figure 3 shows an example of the corridor travel times versus start times of a specific individual vehicle. Also shown in this figure is the aggregate estimate for all vehicles combined. It may be seen in this figure that the travel times of this regular commuter are quite dispersed from the aggregate estimate. This shows the importance of being able to determine speeds at the individual level.

7. CONCLUDING REMARKS

To ensure that that the concepts of sustainable transportation are implemented, it is essential that they be quantified with appropriate performance measures. The identification of appropriate performance measures was shown to be a very important task.

The strategic planning process was proposed as a methodology to identify appropriate performance measures for sustainable transportation. This approach was found to be effective in dealing with different interest groups from either developed or developing nations that have vastly different needs.

Travel time, travel time variability, and speed have been identified as important building blocks for quantifying a number of sustainable transportation performance measures. The Advent of Intelligent Transportation Systems (ITS) has made it possible to obtain travel time information fairly easily and often at a relatively low cost. There are numerous ITS techniques available to obtain travel time, travel time variability, and speed data. In deciding which approach to use in developing nations, it is often necessary to consider approaches that could ideally be effective, affordable, and labor intensive. Video imaging and DMI technology were found to be possible techniques to be used for the PWV-9 corridor in Tshwane, South Africa. Cellular phone tracking and AVI technology can be considered as more long-term solutions for this corridor.

Automatic Vehicle Identification data was used in the case of the US-290 corridor in Houston, Texas. It was found that the AVI data could be used to determine travel time, travel time variability and speed data at both an individual level and at an aggregate (average) level. Additionally, the AVI data could be applied at the link level or over the full extent of the corridor.

The quantified performance measures can be used as follows:

- to indicate the overall degree of sustainability of the corridor;
- to highlight which aspects of sustainable transportation need to be improved to enhance the overall sustainability of the corridor; and
- to serve as information base to be used for decision making regarding the corridor.

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