DECISION MAKING IN THE CONTEXT OF SUSTAINABLE TRANSPORTATION

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ABSTRACT

This paper provides a description of how decisions regarding transportation programs and project can be made in the context of sustainable transportation. It is shown how to identify appropriate performance measures for sustainable transportation. The identified performance measures were then quantified with a traffic simulation model (CORSIM) as well as transportation environmental models. These quantified measures could then be used as input into the newly developed index for sustainable transportation. The index was developed at the individual level and at the aggregate level and provides an indication of the relative sustainability. It was shown that the index could be used for a base case as well as a future year scenario. It was also shown that the methodology could be used to make decisions regarding transportation projects and that these decisions are different to ones that only consider the net present worth in monetary terms. The test beds used for this study comprised of transportation corridors in South Africa and the United States. It was shown how the methodology can be developed and applied for transportation corridors across functional classifications, modes, overall goals, and even nations.

KEY WORDS

DECISION MAKING / SUSTAINABLE TRANSPORTATION / PERFORMANCE MEASURES.

INTRODUCTION

Sustainable transportation addresses the dimensions of economic development, social equity and environmental stewardship in the transportation sector (Zietsman, 2002). The most important challenge with regard to sustainable transportation is to ensure that its concepts are implemented. This can be achieved if the concepts are clearly defined, quantified, and applied in the decision making process.

In this paper it is shown how to identify appropriate performance measures for sustainable transportation. These identified performance measures were then quantified with a traffic simulation model (CORSIM) as well as transportation environmental models. The quantified measures could then be used as input into the newly developed index for sustainable transportation. The index was developed at the individual level and at the aggregate level and provides an indication of the relative sustainability It was also shown that the methodology could be used to make decisions regarding transportation projects and that these decisions are different to ones that only consider the net present worth in monetary terms. It was shown that the methodology could be applied for transportation corridors across functional classifications, modes, analysis years, overall goals, and even countries. Four transportation corridors were used for the analysis, two in a developing nation (Tshwane, South Africa) and the other two in a developed nation (Houston, Texas).

The paper is broken down into seven sections. The first section contains the introduction to the paper. The second section provides a description of the test beds. The third section describes how the performance measures were selected. The fourth section discusses how the index was developed and applied. The fifth contains the results from the application of the indices. The penultimate section discusses the application of the decision making process. Lastly, the seventh section contains the concluding remarks.

DESCRIPTION OF THE TEST BEDS

South African corridor

The Mabopane Centurion Development Corridor (MCDC) consists of a freeway corridor (PWV-9) and a parallel commuter railway line. It runs from north to south on the western border of Tshwane (previously Pretoria). The PWV-9 freeway is approximately 40 km in length and is a divided 4-lane facility with full grade separation. A 20.3 km section of the PWV-9 freeway was selected for analysis. This section stretches from Mabopane in the north to Tshwane in the south. Figure 1 shows the greater Tshwane area and the location of PWV-9 corridor as well as the commuter railway line.

The commuter railway section that was analyzed runs parallel to PWV-9 from Mabopane to Klerksoord. At Klerksoord, the railway line crosses the freeway and then rejoins it at Herculus station, which is close to the central business district of Tshwane. This line operates at five to six minute headways and serves approximately 14,000 passengers per day.

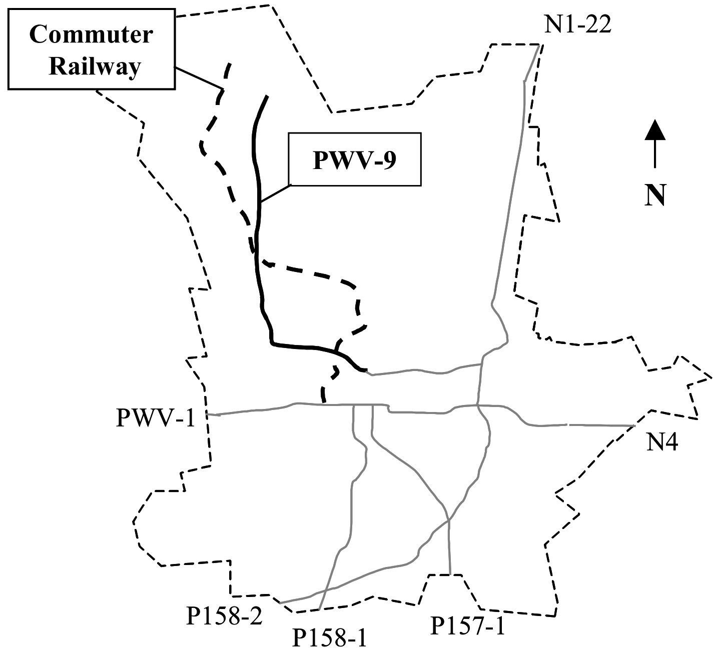

Figure 1 - Location of the PWV-9 Corridor and Commuter Railway Line

United States corridor

The US-290 corridor consists of a freeway facility (US-290) and a parallel arterial (Hempstead). The US-290 freeway is a divided facility with full grade separation, three to four lanes per direction, and a High Occupancy Vehicle (HOV) lane in the median. A 23.0 km section of this freeway was chosen for this study. The test section begins just east of the FM 1960 and extends to just west of I-610 beltway.

The Hempstead arterial runs parallel to US-290 and is located on its southern side. A 12 km section of this arterial was selected for analysis. This section stretches from just east of the Sam Houston Tollway to just west of the I-610 beltway. It is comprised of 15 signalized intersections located at the north-south cross streets. Figure 2 shows the location of the Hempstead arterial and US 290 freeway in the Houston area.

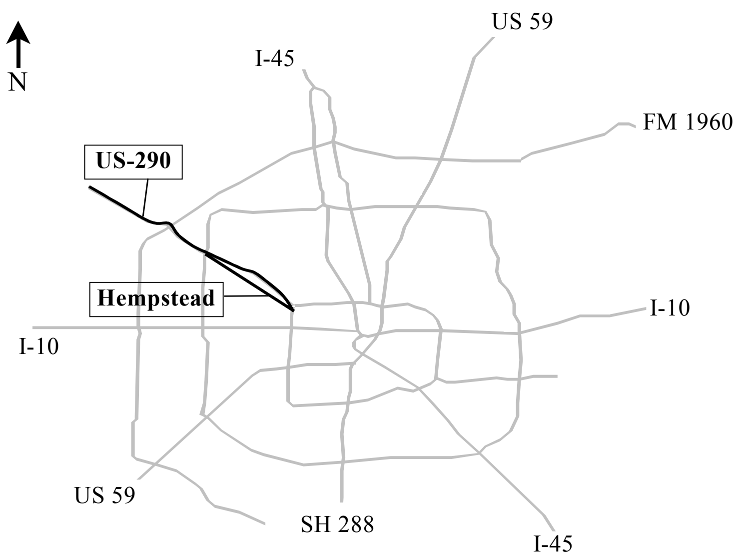

Figure 2 - Location of the US 290 Freeway and Hempstead Arterial

SELECTED PERFORMANCE MEASURES

The concept of sustainable transportation can be quantified by using performance measures. These measures are geared to address the dimensions of sustainable transportation and could differ form the conventional focus of congestion and mobility. The following sections describe how the performance measures for sustainable transportation are identified. It should be noted that this process is based on the strategic planning approach, which is documented elsewhere (Zietsman, 2002).

The following section describe the goals and objectives of the test corridors from which the performance measures were derived.

Tshwane corridor
The transportation-related goals and objectives that would influence the MCDC can be summarized as follows (Strategy, 2001 and Transportation, 2001):

- 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.
- Minimize the negative environmental effects of transportation.

Houston corridor
The transportation-related goals and objectives that would influence the US-290 corridor can be summarized as follows (Vision, 1997 and Metropolitan, 2000):

- 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.
- Improve safety and security for the transportation system.

Selected performance measures
It may be noticed from the previous discussion that the sustainability goals for the Tshwane corridor (although differently phrased) are similar to the sustainability goals for the Houston corridor. Regardless, the proposed procedure of this paper can applied to totally different goals resulting in totally different performance measures. Table 1 shows these goals in relation to the three dimensions of sustainable transportation as well as the specific performance measures that would address the various goals.

Table 1 - Selected Sustainability Goals and Performance Measures

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

DEVELOPING AND APPLYING AN INDEX

Formulation of the index
Quantified performance measures can be aggregated and weighted to produce composite measures known as indices (Better, 1997). Indices are often used to measure trends and to track progress towards a goal. In this context it is used to compare a number of corridors with different attributes.

There are several approaches that can be followed to develop an index. The proposed index for this research is based on the multi-criteria decision-making approach. This approach was selected because it allows for a wide range of objectives to be considered at varying degrees of relative importance. There are many multi-criteria decision-making techniques available but for this analysis it was decided to use the multi-attribute utility theory (MAUT) approach because it is a fairly simple and intuitive approach to decision-making. Additionally, it allows the decision-maker to allocate relative weights to the various criteria (Mickelson, 1998).

The formulation of the sustainable transportation index and the normalized criteria values are shown in Equations 1 and 2, respectively. It may be seen in Equation 1 that the index value is determined as the weighted sum of normalized criteria values. The normalized criteria values are determined by using a single-attribute utility function on a normalized scale.

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

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

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
$f_j(s_j)$	=	Single-attribute utility function on a normalized scale
s_j	=	Value of criterion *j*

Determination of weights

The use of weights is a controversial issue because it opens the analysis up to a certain amount of subjectivity. It could, however, serve as an important tool to allocate the relative importance of the various factors as perceived by the decision makers. For this research a dual approach was followed, one that includes weights and one without weights.

Typically, the weights are derived through an interactive process with the decision makers. A paired comparison or a simple ranking approach is used to derive the weights. For this research, researchers assigned the final weights for the performance measures based on discussions with representatives from the city of Tshwane and the Greater Houston-Galveston Area Council as well as with a group of researchers. These researchers individually determined the weights, then, as a group, discussed the weights and developed an average of the revised weights.

It was found, however, that the analyses with and without the weights produced fairly similar results. For simplicity sake, the results shown in this paper are the ones without the weights (all attributes considered equally important).

Determination of criteria values

The values of the quantified performance measures (criteria values) are normalized for comparison purposes because they have different units of measurement. The normalized criteria values are determined by using a single-attribute utility function on a normalized scale. The normalized scale ranges from zero (worst performance) to one (the best performance).

Normalization is used because the different performance measures have different units of measurement. Three different shapes – linear, concave, and convex were used to reflect the driver's and/or planning organization's perception with regard to the different performance measures. The equation for the single-attribute utility functions is shown in Equation 3. The shapes of the utility functions for the various performance measures are shown in Figure 3.

$$
\begin{aligned}
U(x) &= a + bx && \textit{when } c = 0,\ \textit{straightline} \\
&= a + be^{(-cx)} && c \neq 0,\ \textit{parabola}
\end{aligned}
\qquad (3)
$$

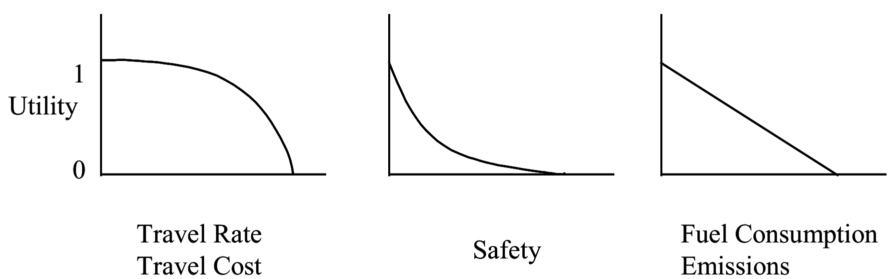

Figure 3 - Shapes of Utility Functions

RESULTS OF THE APPLICATION

Quantifying performance measures

The CORSIM simulation model was used to determine the traffic flow characteristics such as volume, speed, and travel time for the AM peak hour. Researchers used a per-kilometer basis to quantify performance measures for each of the links of the three test corridors. The various performance measures were calculated as follows:

- Travel rate is the rate of motion in minutes per kilometer, for a specified roadway segment and is calculated by dividing the segment travel time by the segment length. Travel rate was determined from the individual travel time information.
- Accident rate is defined as the number of accidents per vehicle miles of travel. It was determined from accident data and volume information.
- Fuel consumption was determined with a widely used energy-based instantaneous model (IM) developed by Akcelic (Biggs, 1986).
- Emissions were determined for three pollutants, volatile organic compounds (VOC) carbon monoxide (CO) and oxides of nitrogen (NOx). The MOBILE5a emissions model was used to determine the necessary emission rates.
- Travel cost was based on the total cost associated with travel time, fuel consumption, emissions, maintenance and tires, and safety.

Calculating index values

The index values were based on the above-mentioned performance measures except in the case of the commuter railway line for which only travel rate and travel cost were used. The index values were then calculated using Equation 1.

Two approaches were used for comparing sustainability on a corridor basis. In the first approach, researchers determined the indices based on the total traffic conditions on the corridor. For this approach, the performance measures were calculated for the entire corridors. In the second approach, the performance measures were calculated at the individual driver level. The assumption was that the corridors perform differently based on the experiences of the individual drivers than the group as a whole. Note that in both cases the same micro-simulation output was used.

Figure 4 shows the final performance indices for the test corridors. It is shown in this figure that it is possible to compare the various corridors based on the index values. It is also clear that there is a considerable difference in index values between the individual and aggregate approaches. Based on the aggregate approach, the PWV-9 and Hempstead arterial have the highest index value. On the individual level, however, the commuter railway line has the highest index value.

These are different because, in the aggregate case, the performance of the system is considered, whereas in the individual case the performance per individual is considered. For example, the fuel consumption per kilometer along the Hempstead arterial is fairly low as compared to that of the high volume US-290. However, per individual, the Hempstead arterial has a much higher fuel consumption rate per kilometer than US-290. The performance measures such as travel rate, fuel consumption, emissions, and travel cost have the same tendency, resulting in Hempstead fairing better than US-290 on the system level and worse on the individual level.

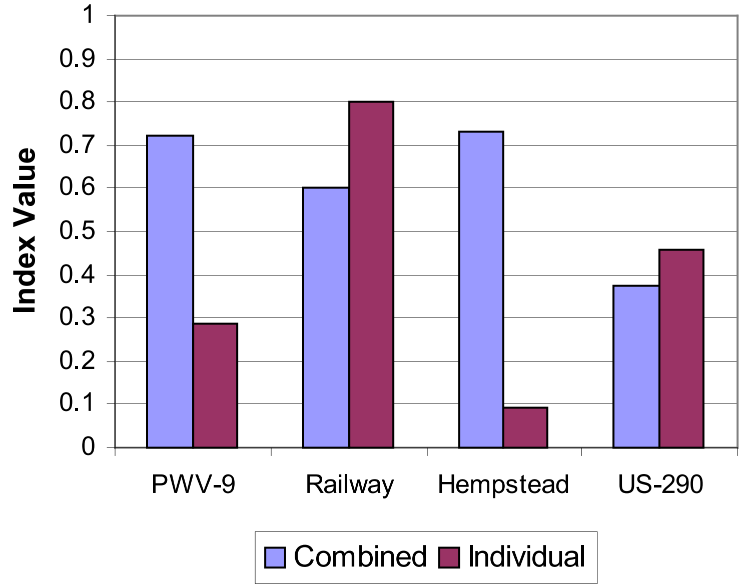

Figure 4 Index Values for Corridors.

Future year scenario
One of the most important elements of sustainable transportation is "intergenerational equity" through which the needs of current and future generations are addressed. It is, therefore, important to not only assess sustainable transportation for the current situation and generation but also for the future. To illustrate this concept, sustainable transportation index values were determined for a scenario that was ten years into the future (2010).

All the required performance measures (travel rate, fuel consumption, emissions, accidents, and travel cost) were quantified with the projected traffic volumes that were based on projected growth rates for Tshwane and Houston. The same procedures were followed as discussed above to quantify the performance measures. The quantified measures could then be used to calculate the forecasted index values and compare it with that of the base case.

The index values for the base case and future year (from the perspective of the individual commuter) are shown in Figure 5. It may be seen in this figure that there is not a dramatic difference between the base year and design year indices. PWV-9 shows a decrease because it is not currently fully congested and additional traffic affect the individual performance values negatively. US-290 on the other hand is already fully congested and additional traffic would simply not get onto the freeway before some of the existing traffic is cleared, which may actually result in some relief along the main lanes, but tremendous delays on the ramps.

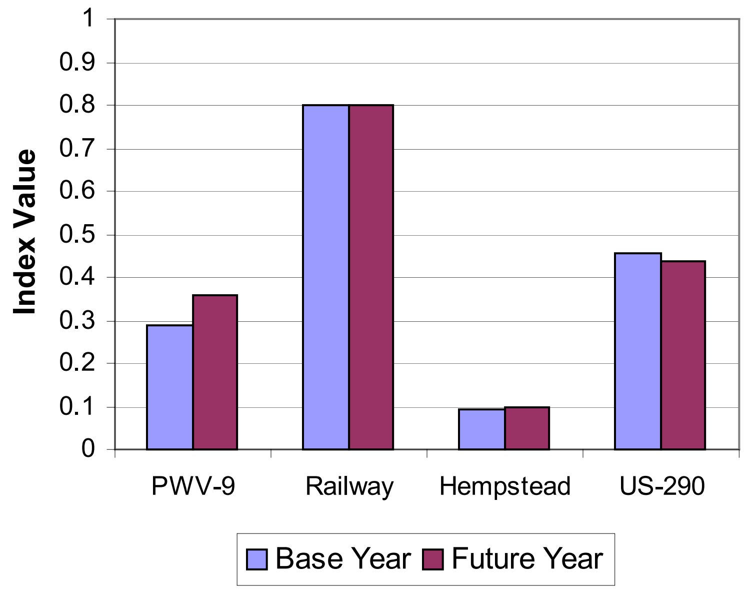

Figure 5 Index Values for Corridors

EXAMPLE OF DECISION MAKING

In this example the objective is to decide on an appropriate section of the PWV-9 corridor that should be widened by one lane so that the greatest benefit in terms of sustainable transportation can be achieved. For this analysis, the PWV-9 freeway was divided into four separate sections or links. Figure 6 shows a schematic layout of the various link combinations. The various alternatives (including the do-nothing alternative), as well as their estimated costs are shown in Table 2.

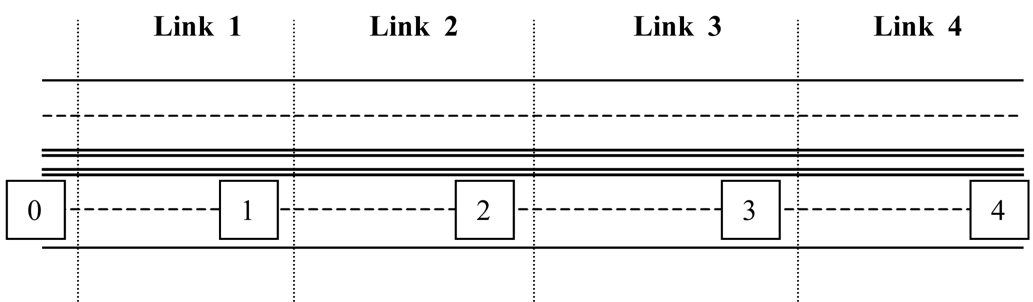

Figure 6 - Schematic Layout of the Link Combinations.

Table 2 - Alternatives to be Evaluated

Alternatives	From link - To link	Total Length (km)	Construction Cost (Rand million)
0	0-0	0	0
1	0-1	5.92	11.8
2	0-2	10.96	21.9
3	0-3	16.93	33.9
4	0-4	20.30	40.6
5	1-2	5.04	10.1
6	1-3	11.01	22.0
7	1-4	14.38	28.8
8	2-3	5.98	12.0
9	2-4	9.34	18.7
10	3-4	3.36	6.7

Calculation of utility values

Two approaches were used to illustrate their effects on the final decision. The first application uses a pure Net Present Worth (NPW) analysis and only considers that cost and benefits of the project in monetary terms. In the second application the MAUT approach was used and the effects on sustainable transportation were considered.

New simulation runs were performed for each scenario, resulting in new values for all the performance measures. The NPW and MAUT values could be determined based on the new values of the performance measures.

Figure 7 shows the results of this analysis. It may be seen in this figure that according to both the NPW and MAUT approaches alternative eight seems to be the best and alternative one the second best. However, the remaining placings differ quite substantially between the two techniques.

The analyses, therefore, illustrate that the type of decision making methodology, and particularly whether the sustainability effects are included, have a direct effect on the final decision. The MAUT approach made it possible to include a broad range of sustainability issues and it is, therefore, recommended to use this approach. The decision maker, however, still needs to choose how to allocate the available funding once the priorities are determined.

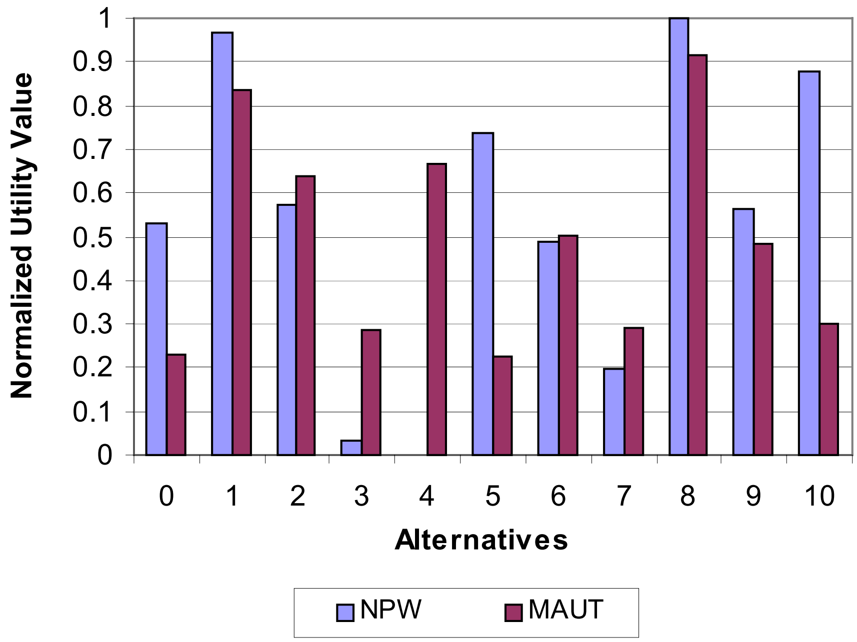

Figure 7 - Normalized Utility Values on PWV 9

CONCLUDING REMARKS

This paper illustrates how the concepts of sustainable transportation can be incorporated into the decision making process through the use of a newly developed index and decision making methodology. The following are some of the specific conclusions:

- Performance measures were identified that addressed the goals and objectives of the two cities as well as the three dimensions of sustainable transportation.
- An index for sustainable transportation was developed that is based on the multi-attribute utility theory technique.
- Different index values were obtained depending on whether it was viewed from the perspective of the individual driver or the system as a whole.
- It was shown that the index could also be used to predict the sustainability for future years.
- The methodology could also be used to make decisions regarding transportation projects and it was shown that these decisions are different to ones that only consider the conventional net present worth in monetary terms.
- The methodologies proposed in this paper allow for comparison between corridors, irrespective of functional classification, overall goals, mode, analysis year, or even nations.

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