Comparison of Urban Developments Using a Transportation Sustainability Index

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***Abstract* - A Transportation Sustainability Index has been developed for assessing the extent of transportation sustainability in an urban development. The index, constructed based on pedestrian and bicycle infrastructure, transit infrastructure, mixed-use and transit-oriented developments,traffic calming infrastructure, and sustainable operations, has been applied to three urban developments in north Texas and the two cities of Austin, TX and Portland, OR. The results are used to make recommendations on how the developments could improve in certain transportation sustainability index categories. It is also shown that the index can be used as a sustainability audit tool to assist communities in assessing where they stand in terms of sustainability of their transportation systems and what additional steps they can take to become more transportation sustainable.**

***Key Words*- Transportation sustainability, Sustainability index, Sustainability audit, Sustainability indicators**

I. Introduction

A. Project Goal and Objectives

There are a handful of cities throughout the U.S. that are known for their sustainable transportation systems. Austin, TX is often cited for its bicycle and pedestrian-friendly streets. Likewise, Portland, OR is also often cited as having one of the most sustainable transportation systems in the country because of its free mass transit andits extensive network of bicycle lanes, routes, and paths.

It is possible to use certain measures to characterize transportation sustainability in a city or at a district or neighborhood level.

How do cities, districts, or neighborhoods, which are known anecdotally to promote sustainable transportation, score against those measures? And how do other developments measure against those standards? Are there locations that could in fact be used as industry standardsfor transportation sustainability?

The goal of this project is to use the Transportation Sustainability Index previously created (Ardekani &Bakhtiari, 2012) to assess the extent of transportation sustainability in the "gold standard" cities of Austin, TX and Portland, OR as well as three other developments in north Texas, namely, the Plano Transit Village in Plano, Texas, the Bishop Arts District in Dallas, Texas and Sundance Square in Fort Worth, Texas.

B. General Definitions of Sustainability

There is no universal definition for sustainability, sustainable development, or sustainable transportation (Beatley, 1995). Sustainability was first defined by the Brundtland Commission of the United Nations in 1987 as a kind of development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987). A merely environmental definition of sustainability is not sufficient. Economic and social equity are also generally incorporated into the definition of sustainability (Greene & Wegener, 1997).

Consistent with the above definitions, the North Central Texas Council of Governments (NCTCOG) defines Sustainable Development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. This multidisciplinary focus integrates environmental, economic, and social development policies" (NCTCOG, 2011, p. 5-24).

The following are some of the other definitions or concepts of sustainability found in the literature:"Sustainable development is the achievement of continued economic development without detriment to the environmental and natural resources" (Litman & Burwell, 2006).
"The goal of sustainable transportation is to ensure that environment; social and economic considerations are factored into decisions affecting transportation activity" (Transport Canada, 1999)."Sustainability is not about threat analysis; sustainability is about systems analysis. Specifically, it is about how environmental, economic, and social systems interact to their mutual advantage or disadvantage at various space-based scales of operation" (Transportation Research Board , 1997).

Sustainability may also be defined as a framework describing a desirable, healthy, and dynamic balance between human and natural systems or a vision which describes a future that anyone would want to live in (CH2MHILL and Good Company, 2009).

According to these definitions and concepts, sustainability is about three elements of life: economic considerations, environmental protection, and social quality. These are considered as "triple bottom line of sustainability" (see Figure 1). Although Figure 1 may imply that each issue fits in one category or another, in practice most of the time there are overlaps among them. Considering these overlaps, the statement below may be one of the most applicable definitions for sustainability and sustainable development:

"Sustainable development tries to improve the economics of the society and social quality of life while limiting impacts on the environment to the carrying capacity of nature" (CH2MHILL and Good Company, 2009).Recognition of the need to support a growing economy and to reduce the social and economic costs of economic growth at the same time is common to both the public policy and business perspectives. Sustainable development is not only a trade-off between social, economic, and environmental aspects but the synergy between them (U.S. EPA, 2011).

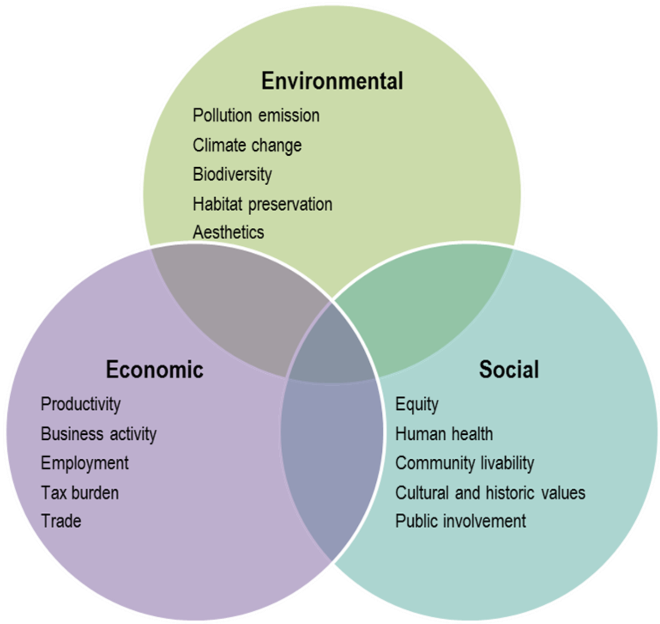

Figure 1: Triple Bottom Line of Sustainability

C. Transportation Sustainability

Transportation is a major consumer of two critical "exhaustible" resources: oil and land (Greene & Wegener, 1997). Environmental, social, and economic impacts of transportation make it an important factor in sustainability. Some of those impacts are listed in Table I.

Table I. Transportation Impact on Sustainability

Economic	Social	Environmental
Traffic congestion	Inequity of impacts	Air and water pollution
Mobility barriers	Mobility disadvantaged	Habitat loss
Accident damages	Human health impacts	Hydrologic
Facility costs	Community interaction	DNRR*
Consumer costs	Community livability	
DNRR*	Aesthetics	

*DNRR: Depletion of non-renewable resources.

The University of Plymouth Centre for Sustainable Transport provides a widely accepted definition of a sustainable transportation system that states:
“A sustainable transportation system is one that: allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations; is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; limits emissions and waste within the planet’s ability to absorb them, minimizes consumption of non-renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise” (CH2MHILL and Good Company, 2009).

Until recently, there was an assumption among economists (Boarnet, 1997) that if social and environmental costs lead to increase in mobility then there would be economic benefits in the project. However, recent research shows that due to decline in marginal productivity of increased travel, any increase in motor vehicle beyond an optimum level can have negative economic impacts. Moreover, vehicle use could have external costs that can offset direct economic gains (Boarnet, 1997).This indicates that sustainability planning does not always require trade-offs between economic, social, and environmental objectives. It is rather a matter of finding strategies that help achieve all of these objectives over the long term by increasing transportation system efficiency (Litman & Burwell, 2006).

The conventional transportation planning assumes that older modes of transportation are less important than the newer ones. This series model of transport progress is shown below:

Walk → Bicycle → Train → Bus → Automobile → Improved automobiles

Accordingly, there would be no harm if increasing automobile traffic causes congestion delay to public transit or creates a barrier to pedestrian or bicycle travel. From this perspective, it would be unnecessary to give bicycle or public transit priority over automobiles. On the other hand, sustainable transportation suggests a parallel model that assumes each mode of transportation is equally important and useful. The ideal system would be a balanced transport system that uses each mode for what it does best(Litman & Burwell, 2006).The next section describes identification of a set of indicators used in the Transportation Sustainability Index. As discussed earlier, such an index may be used for assessment of where cities or urban districts stand in the transportation sustainability spectrum.

II. Transportation Sustainability Indicators

Typically, quantifiable indicators are used to define goals, identify trends, and compare and evaluate solutions. Roadway levels of service, average traffic speeds, parking convenience and price, and crash rates are some examples of conventional indicators for transportation policies. “Development of a Transportation Sustainability Index for Urban Communities” (Ardekani &Bakhtiari, 2012) broke down the indicators into six sustainability categories as follows:

1. Pedestrian infrastructure
2. Bicycle infrastructure
3. Transit infrastructure
4. Mixed-use and transit-oriented developments
5. Traffic calming measures
6. Sustainable operations

Each category contains several indicators. The number of indicators in each category range from four for transit infrastructure to 18 indicators for pedestrian infrastructure. The following table summarizes each category with its corresponding indicators.

Table II. Summary of Indicators

1. Pedestrian infrastructure Availability of sidewalks Availability of crosswalks Availability of pedestrian signals Availability of its pedestrian treatments Disability infrastructure Availability of trails Other pedestrian friendly features and amenities **2. Bicycle infrastructure** Availability of on-street bicycle facilities Availability of off-street bicycle facilities Availability of designated bike crossings Bike detectors Other bicycle amenities Availability of bike sharing services	**4. Mixed-use and transit-oriented developments** Location within ¼ to ½ mile of light or commuter rail stations, respectively Mixed-use buildings Density of use Favorable jobs/population balance Zoning/form based code Building form/setback Median household income Housing and transportation costs Mixed housing types Public financing for infrastructure to facilitate TOD Vehicle ownership per household Parks/open and green spaces/playgrounds Bicycle and pedestrian accessibility
3. Transit infrastructure Mode variety Efficient/ Effective service Dedicated bus lanes	**5. Traffic calming measures** Speed control measures - vertical treatments Speed control measures – horizontal treatments Volume control measures **6. Sustainable operations** Low power systems Alternative power systems Infrastructure for alt-fuel vehicles Xeriscaping

A. Favorable Values

There are several alternative options to find the favorable values for each indicator. One option is to assemble a panel of experts who could collectively agree on what the favorable value for each indicator should be. The agreement can be reached through discussion or through a quantitative survey. For example, each panel member could be asked to complete a survey form on what the desirable value for each indicator should be; and the mean of the values could be considered as the favorable value. Under this approach, the panel size and the diversity of the panel members should be carefully considered so as to ensure reasonable and unbiased values.

An alternative is to identify a sustainable development that is generally viewed as the "gold standard" in transportation sustainability. Then the values from those sites could be used to define favorable values. In doing so, it is important to consider historical regional engineering and planning cultures so that cities in North Texas, for example, are not measured against Amsterdam or Portland, Oregon but rather against peer cities in their region or State with good sustainability practices.

To avoid the latter pitfall, a third alternative may be to use the average values of the indicators for the sites being studied as favorable values. In this case, the larger the number of sites the more reasonable the favorable values will be. As will be discussed later, this was the procedure undertaken in the current study. Each indicator was accordingly quantified using the defined measurement units and compared to its respective "favorable value" as a key step in determining transportation sustainability indices for each study site. This process will also be further described in a later section.

B. Transportation Sustainability Index Computations

Using the indicators inTable II, the Transportation Sustainability Index is computed. To do so, each indicator in each of the six categories is scored as zero or one depending on how the value compares to the favorable value. The scores are then combined to compute an index value.

Depending on how the index computation is conducted, one of three types of indices can be determined. These include 1) a raw Transportation Sustainability Index, 2) a normalized Transportation Sustainability Index, and 3) an area-weighted Transportation Sustainability Index.

C. The Raw Transportation Sustainability Index

In determining a raw index, each indicator in each of the six categories is scored as a zero or one. The scores are then summed across all possible indicators. The sum is divided by the maximum possible sum to obtain a fractional value, which is presented as the raw index. For example, if a development scores 32 out of 68, its raw index will be 0.47 (32/68).

D. The Normalized Transportation Sustainability Index

The raw index computed in the above manner is naturally weighted heavily towards those categories with a greater number of indicators, such as the Pedestrian Infrastructure, while underrepresenting other categories such as the Transit Infrastructure. In order to weigh each category equally, a normalized Transportation Sustainability Index is defined whereby raw indices are separately computed for each category, resulting in six raw indices. The raw indices are then averaged to determine a normalized index value. For example, in the development cited in the previous section, the scores were 10 of 18 in pedestrian category, 3 of 8 in the bicycle category, 3 of 4 in the transit category, 6 of 15 in the mixed-use category, 7 of 16 in the traffic calming category, and 3 of 7 in the sustainable operations category, then the normalized index is calculated to be 0.49, namely,

$$\frac{(10/18)+(3/8)+(3/4)+(6/15)+(7/16)+(3/7)}{6} = 0.49$$

This compares to a raw index value of 0.47 as per calculations in the previous section.

E. The Area-Weighted Transportation Sustainability Index

The normalized index computed as described above does not, however, convey any information about the size of the development for which this index score was obtained. For instance, a normalized index of 0.49 over a large city development or a large district is considerably more significant than having the same index score over a one or two-square block development. The area-weighted index is introduced to account for this disparity. The index is computed by multiplying the normalized index value by the size of the development in acres to represent the amount of effort and resources expended to achieve the index value. This is somewhat analogous to the amount of energy required to lift an object to a certain height. Naturally, the heavier the object is the more energy it would take.

III. Applications of the Transportation Sustainability Index

The Transportation Sustainability Index was computed for the Central Business Districts (CBDs) of Austin, TX and Portland, OR. This section describes each of the sites and discusses the application of the index to each site. The score of each indicator for the corresponding study area is presented, followed by the computation of the raw and normalized index values for the respective site. The normalized index values are then weighted according to the area size.

A. Austin Central Business District, Austin, TX

1) Site Description

This area is bounded by Guadalupe Street on the west, Red River Street on the east, Cesar Chavez Street on the south, and Martin Luther King Jr Boulevard on the north. The total area of the site is 450 acres (0.70 mi^2). It is situated in the center of the Downtown Austin, just south of the University of Texas at Austin.

2) The Austin CBD Data Collection

Various sources were used to collect data for the Austin CBD. Data from online maps such as Google maps and Google Earth were fairly easy to obtain but labor intensive at times. Field inspection was not an option because of distance, and therefore, the online maps were heavily depended on. A few sources, such as housing and transportation costs, were difficult to access and could not be accounted for in the index value. The main sources used to obtain the indicator values and compute the index values were as follows:

- Use of Google map or Google Earth
- Email correspondences with the City of Austin staff
- The United States Census Bureau website
- The Metro website and other miscellaneous websites

3) The Austin CBD Index Computations

Based on the number of indicators, the maximum possible index value for the Austin CBD was 65. Out of this theoretical maximum, Austin received a total of 33 points. The raw index, as shown in the table below, is 0.51. The corresponding normalized index was also 0.51. The weighted index, considering the size of the area, was 231. The weighted index is computed as the product of the normalized index and the area in acres.

Table III. Summary of Index Values for Austin CBD

Sustainability Indicator	Total Possible Index Value	Raw Index Value
Pedestrian Infrastructure	18	14
Bicycle Infrastructure	8	3
Transit Infrastructure	4	3
Mixed-Use And Transit-Oriented Developments	12	6
Traffic Calming Measures	16	4
Sustainable Operations	7	3
Total	**65**	**33**

Raw Index	Normalized Index	Area-Weighted Index (acres)
33/65 = **0.51**	(1/6)x{(14/18)+(3/8)+(3/4)+(6/12)+(4/16)+(3/7)}=**0.51**	0.51x450=**231**

B. Portland Central Business District, Portland, OR

1) Site Description

This area is bounded by IH-405 on the west, Naito Parkway on the east, Glisan Street on the north, and Market Street on the south. The total area of the site is 440acres (0.69 mi^2). It consists predominantly of downtown Portland, with some additional area to the north.

2) Portland CBD Data Collection

Like the Austin CBD, similar sources were used to collect the data for the Portland CBD. As before, data collection from online maps was heavily depended upon because field inspection was not feasible. The main sources used to obtain the indicator values were as follows:

- Use of Google map or Google Earth
- E-mail correspondence with City of Portland engineer
- The Tri-County Metropolitan Transportation District of Oregon website
- Other miscellaneous websites

3) The Portland CBD Index Computations

The total possible index value for Portland CBD was 65, from which the area under study scored 43 points. The raw index, as shown in the table below, was 0.66, and the normalized index was 0.70. The area-weighted index, computed as the product of the normalized index and the area in acres, was 307.

Table IV. Summary of Index Values for Portland CBD

Sustainability Indicator	Total Possible Index Value	Raw Index Value
Pedestrian Infrastructure	18	14
Bicycle Infrastructure	8	6
Transit Infrastructure	4	4
Mixed-Use And Transit-Oriented Developments	12	11
Traffic Calming Measures	16	5
Sustainable Operations	7	3
Total	**65**	**43**

Raw Index	Normalized Index	Weighted Index (acres)
43/65 = **0.66**	(1/6)x{(14/18)+(6/8)+(4/4)+(11/12)+(5/16)+(3/7)} = **0.70**	0.70x440=**307**

IV. IndexAssessments for Three North Texas Developments

Similar measurements were done (Ardekani&Bakhtiari, 2012) for three north Texas developments, namely the Plano Transit Village, the Dallas Bishop Arts District, and the Fort Worth Sundance Square. The resulting index values for these three sites are summarized in Table V below.

Table V. Summary of Index Value for North Texas Sites

	Plano Transit Village (65.5 ac)		Bishop Arts District (398.0 acres)		Sundance Square (39.3 acres)	
Sustainability Indicator	Total Possible	Raw Index	Total Possible	Raw Index	Total Possible	Raw Index
Pedestrian Infrastructure	18	10	18	8	18	11
Bicycle Infrastructure	8	4	8	0	8	2
Transit Infrastructure	4	3	4	3	4	4
Mixed-Use And Transit-Oriented Developments	12	5	11	3	10	4
Traffic Calming Measures	16	6	16	1	16	1
Sustainable Operations	7	3	7	6	7	1
Total	**65**	**31**	**64**	**21**	**63**	**23**

Study Area	Raw Index	Normalized Index	Weighted Index (acres)
Portland CBD	0.66	0.70	306
Austin CBD	0.51	0.51	231
Plano Transit Village	0.48	0.50	33
Bishop Arts District	0.33	0.40	158
Sundance Square	0.37	0.41	16

After tallying the scores for each index, the areas could be compared to each other as well as to Austin and Portland. As expected, the Portland CBD and Austin CBD both score high in the sustainability indices. Portland had the greatest values in all three index categories, proving that it is the most sustainable city among the ones surveyed. Austin had the second best scores for all three indices.

The Portland CBD performed very well overall with a raw index of 0.66 and a normalized index of 0.70. It had high scores in all of the categories except traffic calming measures and sustainable operations. In looking at the other four cities, none of them performed well in the traffic calming category, with the Plano Transit Village scoring the highest at 6 out of 16. This could indicate that there are either too many indicators in this category, or the index is placing too much emphasis on the quantity in the category and not the quality. For example, both Portland and Austin have a large amount of on-street parking, which may be considered a greater traffic calming measure overall than another indicator like diagonal diverters. In addition, some of these indicators may be overlapping in the sense that if there is a lot of on-street parking then a city wouldnot typically have a high number of neckdowns.

The Austin CBD also performed well overall with both a raw index and normalized index of 0.51, but had scores over 50% only in the categories of pedestrian infrastructure and transit infrastructure. Austin actually scored at least 75% in both of these categories, so this kept the raw index rather high. The weighted index for Austin was quite high as well at 231. Austin has potential in the future to improve its index, especially in the lower scoring categories. A few LED signals have been installed, but not enough to receive a favorable value in this category. However, the City of Austin plans on implementing more in the future. Another indicator value that will change in the near future is public financing for infrastructure to facilitate TOD. Currently, Austin does not have public financing but has plans for infrastructure investments. Once both of these are implemented along with other future improvements, Austin's index value will be closer to Portland's.

The Plano Transit Village scored similar to the Austin CBD, with a raw index of 0.51 and a normalized index of 0.50. However, because it encompasses a relatively small area, its weighted index was much smaller at 33 compared to Austin's 231. Although this large gap is primarily caused by the size of the study area, it can be argued that if a similar area was taken for Plano as was taken for Austin, then it would most likely perform much worse for transportation sustainability. Conversely, if the Plano Transit Village was not intended to expand in the future, the higher scores for the other two indices are a better indicator of the area's sustainability.

As stated previously, Bishop Arts District and Sundance Square both scored poorly in the traffic calming category. In addition, both areas scored very poorly in the bicycle infrastructure category with Sundance Square only receiving two out of eight possible points, and Bishop Arts District scoring zero. If either place was looking to improve their transportation sustainability scores, these would be the first two areas to try and improve upon. Both could be done fairly easily with something like the addition of some bicycle racks or adding some mid-block street humps or a neckdown.Bishop Arts did quite well in the sustainable operations category with 86%, but Sundance Square only had 14%. This would be another category that Sundance Square might want toimprove.

V. Conclusions and Future Directions

A. Summary

The overall goal of this study was to propose a tool for assessing the transportation sustainability of urban developments, to apply the proposed tool to several such developments, and to show how those developments compare to each other. Austin and Portland have long both been considered ahead of the game when it comes to transportation sustainability and being "green." This study helped confirm this supposition by providing a tangible measurethat could be used to quantifiable the degree of transportation sustainability in a city or urban development and to compare such developments around the nation and the world.

A brief account of the different categories and sustainability indicators used for the indices was given in the beginning of the report. This was only meant to serve as a general overview of the process and indicators; however each indicator is more precisely defined in an earlier work (Ardekani&Bakhtiari, 2012).

The scores obtained were compiled across all indicators into a raw sustainability index. The raw indices were then normalized to the number of indicators in each category to ensure that each category received equal emphasis in the index, resulting in a "normalized index." The normalized index for each site was then multiplied by the size of the area in acres to obtain a third index, the "area-weighted index." The above procedure was applied to all five sites, namely the Austin CBD, Portland CBD, the Plano Transit Village, the Dallas Bishop Arts District, and the Fort Worth Sundance Square.

B. Recommendations and Future Directions

A discussion of three alternative methods for determining "favorable values" for each indicator was presented. The approach adopted in this study was to set the mean value of the indicators for all study sites as the respective favorable values. Each indicator value was compared to its favorable value to determine a sustainability score of zero or one. The above procedure was applied to five sites. For each site, the raw, normalized, and area-weighted index values were determined.

The presented tool is intended to assist communities in assessing where they stood in transportation sustainability and what additional steps they may take to become more transportation sustainable. Through the use of this tool, communities have the option to compare themselves to either "gold standard" cities or peer communities within their region. The tool could possibly be used as an input in funding decisions for sustainable development projects.

Like many other new tools, much can be done to enhance and improve this tool. First, adjustments can be made to index calculations based on available data, additional indicators, or indicator categories. The indictor categories and indicators identified in this study are by no means comprehensive and are subject to revision and expansion as additional relevant indictors are identified. Secondly, as more sites are studied and indexed in this manner, it would be possible to identify low, medium, and high threshold values for each index type. As more sites are studied, it may also be feasible to define index value ranges for various types of developments. It is in fact possible that different ranges and thresholds are defined for different types of developments such as TODs, downtowns, suburban neighborhoods, etc.

Further research is also needed to develop weights for indictors using techniques such as the concordance method. For example, the significance of each indicator can be assessed according to its potential to contribute to the three "E"s of sustainability, namely Environment, Equity, and Economics. This potential can be assessed by a panel of experts carefully assembled to have representatives from various community constituents and experts. Research is also needed to better define what "favorable" values should be for each indicator. In this study, the mean values of the indicators for the five sites studied were used as favorable values. However, a more reasonable approach may be to identify a sustainable development which is generally viewed as the "gold standard" in transportation sustainability and use the values from that site as favorable or target values. The gold standard community may be selected globally, nationally, statewide, or even regionally.

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