Assessment of Sustainable Infrastructure: The Case of Exurban Dallas

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With increasing emphasis on sustainable infrastructure as a setting for sustainable development, two broad types of questions arise: when is a particular infrastructure project sustainable and how is its impact assessed? This paper presents a methodology, tested on two exurban town centers, for assessing the impact of sustainable infrastructure, using various assessment indicators found in existing literature and that fall within the triple bottom line approach (economic, environmental, social). Findings suggest that the method does yield useful information for gauging the impacts of sustainable infrastructure investment, and that the impacts are mostly consistent with the expected and desired outcomes of denser exurban development, increasingly diverse land-use mix, and compact circulation.

INTRODUCTION

An emerging consensus among planners, developers, civil engineers, architects, and other city builders emphasizes the importance of urban development that is "sustainable." Guided by the Brundtland Commission's widely cited definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," this consensus seeks to tackle such "wicked problems" (to borrow Rittel and Webber's (1973) term describing social problems that are difficult to define and whose policy solutions are political) as low-density sprawl and dependency on private automobiles (United Nations General Assembly 1987). Policy responses to these problems include reshaping urban form and travel behavior, involving such efforts as compact, mixed-use, infill, and transit-oriented development[1] (Caves 2005, Wheeler 2004). Yet planning, at least in the United States where public ethos tends to frown upon direct governmental intervention in the market, has little direct control over private investment and development, and little direct power to enact these schemes. Given this "planning paradox," planners tend instead to focus on providing the infrastructure and profitable conditions under which private investment and development can occur (Gottdiener and Hutchison 2011, Dear and Scott 1981). The provision of infrastructure — defined as a non-excludable good and includes roads, railways, urban transport, water supply, sanitation and sewerage, solid waste collection and disposal — thus facilitates and provides the contextual environment in which private decisions and activities of households and businesses take place (The World Bank 1994). The provision of urban infrastructure is therefore a key component in public-sector efforts to provide the setting for private-sector development, and sustainable infrastructure is key in sustainable development efforts.

With the increasing emphasis on sustainable urban infrastructure as a setting for sustainable development, two broad types of questions arise: when is a particular infrastructure project sustainable and how is its impact assessed (Feiden and Hamin 2011)? These questions have led to a substantial and growing literature that propose and test a host of indicators and assessment methods. Yet there is no generally accepted single method or set of indicators, due both to the broadness of the UN General Assembly definition and the wide-ranging use of the term "sustainable development," as well as to the diversity of infrastructure types. Debates and literature on this topic are still evolving. This study contributes to these debates and literature by proposing an assessment method that has been developed and tested in two exurban cities in the Dallas, Texas, metropolitan area.[2] This paper first briefly outlines some of the definitions and assessment methods in the existing literature, next describes the background and approach for this study, and then presents the analysis and findings, concluding with a summary and remarks about strengths and weaknesses and directions for further research.

SELECTED LITERATURE

One increasingly common approach to defining and assessing impacts of sustainable infrastructure is known as the triple bottom line approach. This approach, which started in the private sector but has been quickly adopted in the public sector, focuses not only on economic efficiency but equally on the environmental and social aspects of a project in recognition that development must consider more than simply financial returns if it is to be sustainable in the long term (The World Bank 2002, Caldwell 2011, Institute for Sustainable Infrastructure 2011). There have been few attempts to operationalize the triple bottom line approach in defining and assessing sustainable infrastructure. Shen et al. (2011) operationalize the triple bottom line approach in assessing a large-scale transit infrastructure project by developing what they call Key Assessment Indicators (KAIs) based on surveys of experts and fuzzy set data analysis. They draw from Zadeh's (1965) original work on fuzzy sets as a method for dealing with classes of phenomenon that display no clear set boundaries (as opposed to an ordinary set with clearly defined criteria for set membership), such as experts' opinions of assessment indicators for infrastructure project sustainability. They identify eight key economic indicators, five key social indicators, and seven key environmental indicators, and test these on a case study. They conclude that while the case study produces helpful results, the reliance on expert opinion to identify the indicators may preclude the identification of other important indicators.

Koo et al. (2009) operationalize the triple bottom line approach in assessing underground infrastructure projects by developing what they call the Sustainability Assessment Model (SAM). However, they find that many indicators are difficult to quantify, especially environmental and social ones, and those that they do eventually measure present the problem of incommensurability with other indicators (i.e., the various measures cannot be reduced to a common measure that allows for assessment), suggesting that the model cannot be easily integrated into a final assessment of sustainability.

Other scholars have raised similar criticisms of the triple bottom line approach, arguing that its inherent incommensurability renders the TBL approach mere jargon at best (Robins 2006, Norman and McDonald 2004). The triple bottom line approach has also been criticized for implicitly portraying the three bottom lines as necessarily in competition with one another forcing "trade-offs" in practice, where "weak" sustainability tolerates trade-offs and "strong" sustainability discourages trade-offs (Coffman and Umemoto 2010, Hecht 2007). At the same time, the TBL approach is commended for broadening awareness of more than simply the economic bottom line, and some critics argue that, for "strong" sustainable development, not only must all three bottom lines be at play but also a "holistic mindset" as well as democratic public participation (to secure buy-in from community and stakeholders) (Robins 2006, Coffman and Umemoto 2010, Hecht 2007).

Regarding "trade-offs," skeptics often raise concerns about the potential negative economic impacts of sustainable infrastructure even when it is seen as socially or environmentally beneficial (Deakin 2011). Thus economic impacts, particularly impacts on property values, are frequently a key focal point of impact assessment, especially for cash-strapped local governments that need to consider opportunity costs of expenditures on infrastructure. Rising property values are seen as desirable not only for the local tax base but also as a catalyst for changing land uses and increased density (Alperovich 1983, Gatzlaff and Smith 1993). Many studies use hedonic pricing methods for assessing impacts of infrastructure on property values. For example, Hess and Almeida (2007), who also provide a useful summary of the extensive literature on this topic, assess the impact of transit development on nearby property values, and find that in a declining central city (Buffalo, NY), transit development has weak positive effects on property values, contrary to what studies have shown for growing cities, such as San Francisco. Nicholls and Crompton (2005) assess the impact of a different kind of sustainable infrastructure, namely urban greenbelt development, on nearby property values in a growing city (Austin, TX), and find that greenbelts have a clear positive effect on property values.

Yet, hedonic pricing methods have been criticized for possible multicollinearity as well as lack of depth and breadth of data considered (Nicholls and Crompton 2005). Rather than hedonic pricing methods, Clower et al. (2007) use a mixed measures approach to assess the impact of transit-oriented developments in central Dallas on nearby property values. They combine quantitative and qualitative data, including windshield surveys, interview data, and archival research, in an attempt to capture data that can be overlooked when using more conventional sources. They find that TOD has significant positive impact on property values, although they caution that some impacts may develop slowly given time lags in market responses to infrastructure development.

Many of these existing studies of sustainable infrastructure assessment focus on urban areas and central cities, whether declining or growing. This focal point may not be surprising given that compact development requires the higher densities found in urban areas. Yet, smaller edge cities and exurban neighborhoods that are not on transit lines, can and do utilize sustainable infrastructure, for example, street-design measures such as traffic calming, complete streets, context-sensitive design, etc., to foster compact development (Deakin 2011). This study describes and presents the results of a method for assessing the impact of sustainable infrastructure (in this case, street improvements for compact development) in two exurban town centers nearby each other within the Dallas metropolitan area, drawing on the triple bottom line approach. The results show strong positive impact on property values as well as on many of the other, albeit not all, indicators. As with the transit-oriented developments in central Dallas studied by Clower et al. (2007), impacts measured by some indicators in this study here may experience time lags due perhaps to the exurban location or perhaps to other constraints such as the Great Recession.

BACKGROUND AND STUDY APPROACH

With nearly 6.5 million people, the Dallas metropolitan region (also referred to as the Dallas-Fort Worth, or DFW, Metroplex) became, in the mid-2000s, the fourth largest metro region in the United States (behind New York, Los Angeles, and Chicago)—and its regional population is greater than the state-level populations of over 30 states (Mackun and Wilson 2011). Yet, it is far from the fourth densest region: sprawling over not quite 10,000 square miles, its population density is just one-quarter that of New York, Los Angeles, or Chicago, and more typical of recently developing, low-density urban areas in the U.S. sunbelt. Sustainable infrastructure planning takes on particular challenges in low-density sprawling regions. Thus to counteract low-density sprawl, the sustainable infrastructure programs of the North Central Texas Council of Governments (NCTCOG), the regional planning agency for the DFW metropolitan region, do not focus simply on rail and transit but rather "provide for a diverse range of mobility options, such as rail, automobiles, bicycling, transit, and walking" (North Central Texas Council of Governments n.d.).

Through its sustainable infrastructure programs, the NCTCOG provides seed and matching grant monies to cities and towns to foster sustainable development. For exurban town centers[3], the types of sustainable infrastructure that are funded through these grants include, among other things, investment in street construction and improvements to promote denser development, more diverse land use mix, and compact circulation within the center (Mandapaka 2010). This study assesses the impacts, using a number of indicators described below, of sustainable infrastructure investment in street construction and improvements, in two exurban town centers located toward the northern edge of the Dallas metro region (Figure 1). The two town centers, referred to in this study as AR and FS, are both new master-planned, mixed-use communities, including mixes of residential, commercial, office, and recreational uses. AR bills itself as "an up-scale, master planned community" while FR bills itself as "a multi-generational, master planned development… similar to a European village," and both communities describe themselves as, without citing Leinberger's oft-alluded-to description of edge cities from the 1980s, providing "the opportunity to live, work, shop, and play in the same geographic area" (The Colony Convention and Visitors Bureau n.d., Frisco Square Development n.d., Leinberger and Lockwood 1986). Both the AR and FS infrastructure projects involve street construction and improvements, including wider than normal sidewalks on

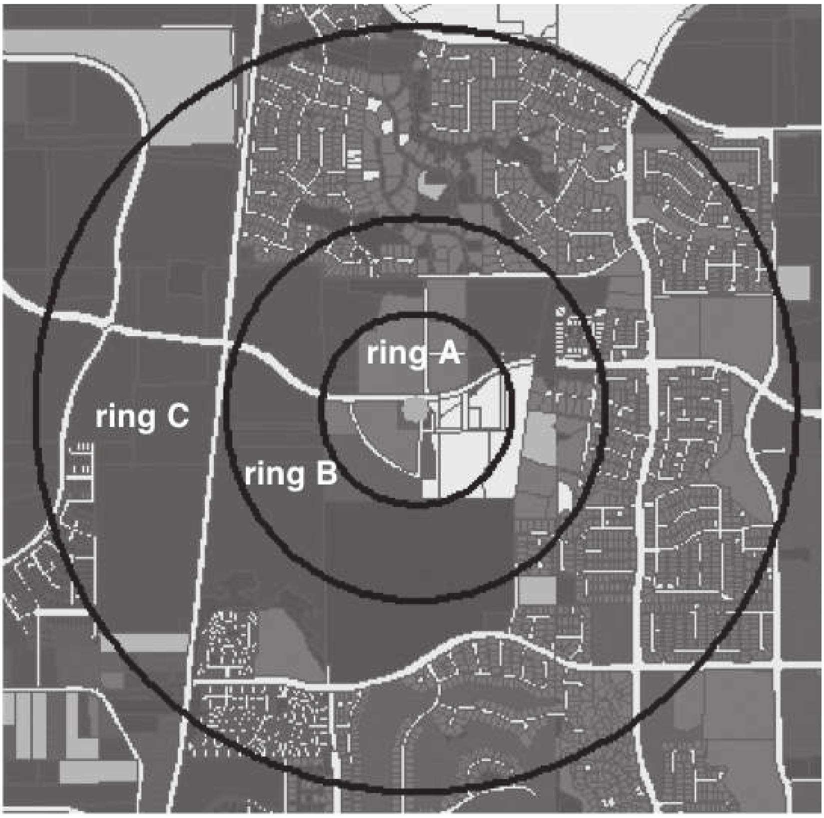
Figure 1: Location of the Study Area Within the Dallas Metropolitan Region

both sides of the street to promote walkability, and wider than normal outside lanes to promote bicycling. Both projects were initiated in 2003 with the aim of promoting compact development within their respective town centers.

Both AR and FS are home to predominantly non-Hispanic white families with incomes above the region's median. A control site located nearby is also assessed as a reference point to help isolate the possible causes of observed changes at the study sites. The control site has similar historical, demographic, and growth characteristics as the study sites but does not have mixed land uses or publicly funded sustainable infrastructure and instead represents traditional exurban development.

To assess spatial variations in impacts as the distance from the sustainable infrastructure site changes, each of the three study areas (the two sustainable infrastructure sites and the control site) is divided into three concentric rings, A, B, and C, emanating from the center of each site (Figure 2). The cordons are set at one-quarter mile for ring A, one-half mile for ring B, and one mile for ring C, from the center of each study site. A quarter mile is considered the typical walking distance for bus transit, and half a mile is considered the typical walking distance for rail transit (Dittmar and Ohland 2003). The third cordon of one mile is placed to determine if the infrastructure's impact spreads beyond half a mile. Since data for this study are collected from several different geographic units, including census tracts, parcels, and traffic analysis zones (TAZ), and since the boundaries of these geographic units may not lie neatly within a concentric ring, data from these units are considered to belong within a ring if at least half their area falls within that ring (the actual boundary of each cordon is thus not so neat as portrayed in Figure 2). Depending on availability, data are collected from roughly one year before initiation of the sustainable infrastructure project to roughly five years after completion of the project.

Figure 2: Quarter Mile (Ring A), Half Mile (Ring B), and One Mile (Ring C) Cordons from the Center of the Study Site



Drawing on the triple bottom line approach, this study considers economic, environmental and social indicators in assessing the sustainable infrastructure impact. Jeon and Amekudzi (2005) review over a dozen studies on sustainable infrastructure assessment, providing a comprehensive list of measures and indicators used in the studies they review. The indicators selected for use in this study are typical of those used in other studies, albeit they are a small subset of Jeon and Amekudzi's comprehensive list. The specific indicators selected for this study are based on existing literature, along with the research team's knowledge and experience of their relevance for the DFW region, and are constrained by data availability at the geographically disaggregated level of the exurban town center, which is analyzed here. Table 1 lists the indicators used in this study, along with their measurement units normalized per acre (normalizing the data per acre helps address the critique of the TBL approach about incommensurability of data). Table 1 also lists the data source(s) for each indicator, as well as the expected direction of change for each indicator resulting from the impact of the sustainable infrastructure investment.

Table 1: List of Indicators for Impact Analysis and Expected Direction of Change

Indicator	Units	Data Source(s)	Expected Value/Direction of Change for Sustainable Infrastructure Sites Ring A Compared with all Control Site Rings
Economic			
business density	sq. ft/ac	Council of Govts' parcel data (supplemented by google maps and windshield surveys)	higher/increase
employment density*	jobs/ac	Council of Govts' traffic analysis zones (TAZ)	higher/increase
income	median income/ac	U.S. census data	higher/increase
property value*	total value/ac	Council of Govts' appraisal data	higher/increase
sales tax revenue	revenue/ac	State Comptroller of Public Accounts	higher/increase
vacancy rate	sq. ft/ac	real estate companies' absorption studies	lower/decrease
Environment (Built And Physical)			
housing stock*	number of single-family houses/ac	Council of Govts' parcel data (denoted as a binary of single-family vs. other types)	lower/decrease
land use mix (dissimilarity index)*	sq. ft. residential/ ac, sq. ft. commercial/ ac, etc.	Council of Govts' parcel data and symbology function of GIS layer feature (see discussion for details)	higher/increase
sidewalk density*	sq. ft./ac	estimated from GIS maps (see discussion for details)	higher/increase
street density*	lane-mile/ac	roadway data from Council of Govts' GIS database	higher/increase
Social			
average daily traffic	number of trips/day/ac	city traffic studies, Council of Govts	lower/decrease
household density*	number of households/ac	TAZ data from Council of Govts	higher/increase
population density*	number of people/ac	TAZ data from Council of Govts	higher/increase
residential ethnicity	% white/ac, % black/ac, etc…	U.S. census data	same/no change
walking/bicycling trips	number of trips/day/ac	surveys, traffic studies, GPS aps (e.g., iTunes' Cycletracks)	higher/increase

*indicators for which data are readily available and that are considered in this study

Before presenting the results of the analysis, Table 1 is briefly discussed.

Economic Indicators

Business density. Business density is the total number of businesses per acre, and can be obtained from NCTCOG parcel data for each ring, supplemented by Google Maps and windshield surveys. Compared with all rings of the control site, business density is expected to increase the most in ring A of the sustainable infrastructure sites.

Employment density. Employment density is the number of jobs per acre and is calculated using data from the NCTCOG Traffic Analysis Zones (TAZ). Compared with all rings of the control site, employment density is expected to increase the most in ring A of the sustainable infrastructure sites.

Income. Income is average household income and can be obtained from census data. Higher incomes are expected in ring A of the sustainable infrastructure sites compared with rings B and C and with all rings of the control site because the infrastructure and subsequent development improves quality of life, attracting residents who can afford to live there.

Property value. Property value data are obtained from NCTCOG appraisal data. Average property value is expected to increase the most in ring A of the sustainable infrastructure sites compared with rings B and C and also compared with all rings of the control site. If the results of the analysis show that property values increase after the projects are completed, compared with the control site, this is an indication that sustainable infrastructure projects can increase the tax base as well as be a catalyst for compact development (see discussion above and also Alperovich 1983, Gatzlaff and Smith 1993).

Sales tax revenue. Sales tax revenue per acre can be calculated using gross sales data collected in the area, and obtained from The Texas State Comptroller of Public Accounts. Sales tax revenue is expected to increase the most in ring A of the sustainable infrastructure site due to expected increase in business density.

Vacancy rate. Vacancy rate is the percentage of all housing units that are unoccupied or all apartment units that are not rented, and can be obtained from absorption studies by local real estate companies. It is expected that vacancy rates are lower in ring A of the sustainable sites compared with all rings of the control site because sustainable infrastructure development improves quality of life, which attracts prospective residents.

Environmental Indicators (Built Environment and Physical Environment)

Housing stock. Housing stock for each cordon is obtained from NCTCOG parcel data, and is denoted as a binary variable of single-family vs. other types (such as mobile homes, condominiums, townhomes, multi-family, duplex, farm and ranch). It is expected that all rings of the control site would include more single-family homes than the corresponding rings of the sustainable development sites, and that growth in single-family homes would be greater at the control site.

Land Use Mix (Dissimilarity Index). To construct the dissimilarity index, NCTCOG parcel data are used in conjunction with the symbology function of the GIS layer feature, where different colors are assigned to represent each land use category. A grid, with 300 x 300 ft cells, is set on top of the land use layer and is positioned so that the center of the development coincides with the center of the grid. An index is created for each cell by considering the eight adjacent cells. If land use in an adjacent cell is akin to the land use of the cell under investigation, a 0 is assigned; otherwise, a 1 is assigned. These values are then summed and divided by the number of cells. A weighted index is then created by multiplying the index obtained in the previous step by the area of the cell captured within each ring and divided by the cell's overall area (900 ft^2). For each ring, an average index is obtained by summing all the indices for the cells contained within that ring. The interpretation of the index is simply a rule of thumb estimation: if a cell has ≥ 30% heterogeneous use, it is considered a mixed-use cell. Compared with all rings of the control site and rings B and C of the sustainable infrastructure sites, it is expected that land uses will be more mixed in ring A of the sustainable infrastructure sites.

Sidewalk density. Sidewalk density is estimated from GIS maps by dividing the square footage of sidewalk within each ring by each ring's acreage. Square footage of sidewalk is estimated by multiplying the total length of sidewalk by the width. In this study, it is assumed that all sidewalks are four feet wide as called for by city design codes, with the following assumptions as the basis for computing sidewalk length, and then multiplying by the segment length:

- "Primary Highway" (each direction) has one sidewalk along each segment
- "Major Arterial" (each direction) has one sidewalk along each segment
- "Minor Arterial" (both directions) has two sidewalks along each segment
- "Connecting Road" has two sidewalks along each segment
- "Service Road" has one sidewalk along each segment
- "Access Ramp" has one sidewalk along each segment
- "Other" roads have one sidewalk along each segment

Sidewalk density is expected to increase in ring A of the sustainable infrastructure sites as walkability and compact development increases, especially compared with rings B and C of the sustainable infrastructure sites and all rings of the control site.

Street density. Street density is measured by lane-miles, for example, a two-lane street that is one mile long has two lane-miles. Lane-mile data are obtained from roadway data in the NCTCOG's GIS database. Street density is calculated by dividing the total lane-miles within a ring by the ring area. It is expected that street densities will increase in ring A of the sustainable infrastructure sites as a result of the street construction and improvements, compared with rings B and C of the sustainable infrastructure sites and with all control site rings.

Social Indicators

Average daily traffic. Average daily traffic (ADT) can be measured using daily traffic counts in each ring. However, NCTCOG does not have historical data on ADT. Were these data available, we would expect a reduction in the number of trips in ring A of the sustainable infrastructure sites compared with rings B and C and also with all control site rings.

Household density. Household density is the number of households per acre, and is calculated using TAZ household data available from NCTCOG. Household densities are expected to increase in ring A of the sustainable infrastructure sites compared with rings B and C and with all rings of the control site.

Population density. Population density is calculated using TAZ data from NCTCOG. Population density is expected to increase in ring A of the sustainable infrastructure sites compared with rings B and C and with all rings of the control site.

Residential ethnicity. Residential ethnicity is the percentage of residents in different ethnic groups within each ring and can be obtained from census data. In exurban centers such as those analyzed in this study, residential ethnic diversity is expected to remain the same in all rings of the sustainable development sites. While the opposite trend (namely, sustainable development leading to increased ethnic diversity) would be desirable and in fact would be expected in central city sustainable infrastructure projects due to gentrification, it is not expected in homogenous exurbs (Gottdiener and Hutchison 2011).

Walking/bicycling trips. Walking/bicycle trip data can be obtained through surveys, manual or automated counts (taken by field data collectors or specialized equipment), or GPS applications (such as iTunes' CycleTracks). It is expected that non-motorized modes of transportation will increase in ring A of the sustainable infrastructure sites compared with rings B and C of the sustainable infrastructure sites and with all rings of the control site.

ANALYSIS AND FINDINGS

Using the measures and methods outlined above, this section discusses findings for those indicators for which data are readily available. Given the scope and time frame of this study, data are not readily available for all indicators, thus a subset is analyzed and compared among the sites and rings.

Economic Indicators

Employment density. Table 2 summarizes findings for employment density. Compared with the control site, employment density is expected to increase in ring A of the sustainable infrastructure sites. Yet contrary to expectations, the results show strong increase in employment density in the control site, as well as in ring B of one of the sustainable development sites (AR)—albeit these strong percentage changes reflect very minor absolute growth. On the other hand, the strong growth in employment density in AR's ring A appears to indicate, consistent with expectations, that a commercial center has been created subsequent to the sustainable infrastructure investment.

Table 2: Employment Density (Jobs/Acre)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2010	4.8	2.4	5.9	0.9	1.2	0.8	1	1.5	1.2
2005	2.7	1.4	4.9	0.7	1.2	0.8	0.4	1	0.9
2000	0	0.1	3.5	0.6	1.1	0.7	0.1	0.6	0.6
annual % change 2000–2010	16%*	230%	7%	5%	1%	1%	90%	15%	10%

*annual % change 2005-2010

Property value. Table 3 shows findings for average property values. Consistent with expectations, there was a strong increase in average property values in ring A of the sustainable development sites, AR and FS, particularly compared with the control site. This increase could be a clear indication that sustainable development infrastructure can be a catalyst for development and an increased tax base.

Table 3: Average Property Values (000s Dollars/Acre)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2007	277	199.1	389.6	678.4	320.7	167.5	454.8	475.1	357.4
2006	239.7	129.2	282.6	345.8	246.2	98.3	455.3	422.7	350.4
2005	209.9	105.6	273.6	341.4	260.6	111.5	384	356.8	318
2004	142.1	106.4	247.8	336.2	164.7	164.7	342.5	347	284.6
2002	38.9	120	265.9	88.8	147.6	67.3	235.1	164.8	212.3
annual % change 2002-2007	122%	13%	9%	133%	23%	30%	19%	38%	14%

Environmental Indicators

Housing stock. Table 4 presents findings for changes in single-family housing stock. For each ring, the single-family housing stock at the control site is greater than at the two sustainable development sites, except for 2002, which is before the sustainable infrastructure investment in 2003. This finding is consistent with expectations.

Table 4: Single-Family Housing Stock (Number Of Single-Family Houses/Acre)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2007	0	0.21	1.14	0.06	0.18	0.27	0.49	0.7	1.41
2004	0	0.16	1.06	0.02	0.14	0.27	0.43	0.64	1.06
2002	0	0.16	1.05	0.02	0.14	0.27	0.41	0.61	0.72
annual % change 2002-2007	-	6%	2%	40%	6%	0%	4%	3%	19%

Land use mix (dissimilarity index). Table 5 summarizes the land-use mix of the two sustainable development sites compared with the control site. Consistent with expectations, prior to the infrastructure investment in 2003, ring A of both sustainable development sites had little (AR) to some (FS) mixed land uses, yet after the investment both rings have significant mixed land use. The increasing diversity of land use in ring A of the sustainable development sites is all the more pronounced compared with lack of changes in land-use mix in rings B and C and in all rings at the control site, suggesting that the sustainable infrastructure investment has achieved one of its key goals.

Table 5: Land Use Mix/Dissimilarity Index (≥ 30% ≡ Mixed Use)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2007	0.316	0.01	0.086	0.7	0.481	0.298	0.161	0.064	0.104
2006	0.316	0.01	0.087	0.449	0.481	0.278	0.205	0.073	0.037
2005	0.316	0.01	0.085	0.449	0.482	0.294	0.161	0.073	0.038
2004	0	0	0.052	0.365	0.431	0.35	0.137	0.064	0.019
2002	-	0	0.067	0.415	0.413	0.33	0.156	0	0

Sidewalk density. Table 6 presents the findings for sidewalk density. Consistent with expectations, sidewalk density increased in ring A compared with rings B and C of the sustainable infrastructure sites and compared with all rings of the control site.

Table 6: Sidewalk Density (Sq. Ft./Acre)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2007	1,989	394	1,066	1,369	2,664	1,766	910	1,029	1,333
2004	1,640	394	984	887	1,658	1,206	840	1,029	1,333
2002	0	372	984	528	1,546	1,176	840	869	1,261
annual % change 2002-2007	7%*	1%	2%	32%	14%	10%	2%	4%	1%

*annual % change 2004-2007

Street density. Table 7 presents findings for street density. Consistent with expectations, ring A of the sustainable infrastructure sites shows a significant increase in street density compared with rings B and C and with all rings of the control site. This increase in ring A suggests that the sustainable infrastructure investments may have contributed to denser development within the two town centers, which is one of the key goals of the sustainable infrastructure investment.

Table 7: Street Density (Lane Miles/Acre)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2007	0.122	0.019	0.066	0.172	0.252	0.167	0.043	0.049	0.068
2004	0.078	0.019	0.062	0.084	0.157	0.114	0.04	0.049	0.068
2002	0	0.018	0.062	0.05	0.146	0.111	0.04	0.041	0.064
annual % change 2002-2007	19%*	6%	6%	71%	42%	33%	8%	16%	5%

*annual % change 2004-2007

Social Indicators

Household density. Table 8 shows findings for household density. The greatest increases in household density are in ring A of all sites (i.e., the control site and both of the sustainable infrastructure sites), as well as ring B of one sustainable infrastructure site (AR). Yet these notable percentage increases reflect relatively small changes in absolute numbers in all rings except one of the sustainable infrastructure sites (AR), particularly in ring A of this site. Thus, these data, in terms of percent change, appear to somewhat support the expected finding that household densities will increase in ring A of the sustainable infrastructure sites compared with rings B and C and with all rings of the control site. Yet when considering the absolute numbers, the most dramatic increases in household density occur in all rings of AR but not so much in the rings of FS or the control site, suggesting that perhaps something else is going on in AR, in addition to the sustainable infrastructure investment (such as continued build-out of the master planned community), to cause this increase in household density.

Table 8: Household Density (Number of Households/Acre)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2010	10.8	5.3	4.2	0.3	1	1.1	1.9	1.4	1
2005	5	2.8	3.7	0.3	0.9	1	1.3	1.1	0.7
2000	0	0.4	2.2	0.005	0.2	0.5	0.2	0.5	0.4
annual % change 2000-2010	23%*	123%	9%	590%	40%	12%	85%	18%	15%

*annual % change 2005-2010

Population density. Table 9 presents findings for population density. Consistent with expectations, the sustainable infrastructure sites (particularly one of them — AR) have higher population densities, and greater percent increases in population densities, than the control site. However, contrary to expectations, the FS numbers are unexpected, and the higher densities, in terms of absolute numbers, are in the outer rings rather than ring A of FS. In addition, contrary to expectations, the control site had significant percentage increases in population density in ring A.

Table 9: Population Density (Number of People/Acre)

Year	AR Rings			FS Rings			Control Site Rings		
	A	B	C	A	B	C	A	B	C
2010	27.4	13.6	11.9	1	2.8	3.1	3.7	2.9	2.2
2005	12.7	7.3	10.8	1	2.6	2.8	2.5	2.1	1.6
2000	0	1.2	6.5	0.2	0.8	1.4	0.4	1.1	1
annual % change 2000-2010	23%*	103%	8%	40%	25%	12%	83%	16%	12%

*annual % change 2004-2007

Summary of Findings

Table 10 summarizes these findings, showing whether the findings for each indicator confirm, or compromise, the expected values and direction of change of the sustainable infrastructure sites' ring A compared with all control site rings. Several findings warrant highlighting. First, according to most of the *economic* and *environmental* indicators analyzed in this study (two of the three factors in the TBL approach), the sustainable infrastructure investments had the desired impacts. Specifically, the sustainable infrastructure sites show clear increases in property values, land use mixes, sidewalk and street densities, and relatively less growth in single-family housing stock, compared with the control site. These changes at the sustainable infrastructure sites compared with the control site suggest that the sustainable infrastructure investment (*viz*., investment in various types of street improvements) provided the hoped-for catalyst for denser development, increasingly diverse land-use mix and compact circulation within the town centers. Thus, sustainable infrastructure programs targeted at Sunbelt-style exurbs need not necessarily emphasize traditional strategies of rail and transit, more appropriate for older or central cities, to produce the desired outcome of fostering sustainable development.

Table 10: List of Indicators Comparing Expected With Actual Direction of Change

Indicator	Expected Value/Direction of Change for Sustainable Infrastructure Sites Ring A Compared With All Control Site Rings	Actual Direction of Change for Sustainable Infrastructure Sites Ring A Compared With All Control Site Rings
Economic		
employment density	higher/increase	ambiguous: higher for AR but not FS/increase greatest at Control Site and Ring B of AR
property value	higher/increase	strongly confirmed
Environment (Built And Physical)		
housing stock	lower/decrease	mostly confirmed
land use mix (dissimilarity index)	higher/increase	strongly confirmed
sidewalk density	higher/increase	confirmed
street density	higher/increase	strongly confirmed
Social		
household density	higher/increase	ambiguous: higher for AR but not FS/increases at all sites various rings
population density	higher/increase	ambiguous: higher for AR but not FS/increases at all sites various rings

Second, the positive effect on property values confirms findings of previous studies, reinforcing the notion that local governments need not worry about trade-offs between environmental vs. economic impacts. Rather, at least in this case, positive economic impacts have accompanied positive environmental impacts, leading to a virtuous cycle of development. Third, most of the hoped-for impacts occurred in rings A and B of the sustainable infrastructure sites, suggesting that the infrastructure's impact does not spread beyond half a mile from the center. Since half a mile is considered a comfortable walking distance to a destination, this finding reinforces the notion that the sustainable infrastructure is promoting walkability and compact development at the town center. Fourth, both of the *social* indicators analyzed in this study (the third leg of the TBL approach) show mixed results. Specifically, the data for household and population densities do not show the expected clear increase in density at the sustainable infrastructure sites, especially compared with the control site. Perhaps if additional social indicators were used, such as travel habits (i.e., average daily traffic counts, or walking/bicycle trips), then clearer impacts on social choices could be assessed. Fifth, the ambiguous social impacts might also be rendered more certain by directly involving citizens in the planning process. The TBL approach has been criticized for privileging the economic and environmental over the social, particularly democratic public participation. Increased citizen participation, through, for example, community meetings, focus groups, and participatory media, could increase public input and support for sustainable infrastructure and development, contributing to changed social choices and behavior that reinforce the economic and environmental impacts.

CONCLUSION AND RECOMMENDATIONS

This paper presents a methodology, tested on two exurban town centers, for assessing the impact of sustainable infrastructure, using various assessment indicators commonly found in existing literature and that fall within the triple bottom line categories (economic, environmental, social). To better assess spatial variation in impacts, the study areas are cordoned into concentric rings, a control site is selected as point of comparison, and the data are normalized per acre to address the problem raised in previous studies about incommensurability of economic, environmental, and social data. Findings suggest that the method used in this study does yield useful information for gauging the impacts of sustainable infrastructure investment, and that the impacts are mostly consistent with the expected and desired outcomes of denser development, increasingly diverse land-use mix and compact circulation, within the town centers. Limitations of this study include the limited number of indicators for which data are available at the geographically disaggregated level, and the limited observations (years) for this data. Future applications of the methodology presented here ideally would utilize a wider variety of indicators over more observations (spanning more years), particularly social indicators such as direct citizen input. Despite the limitations of the existing study, the methodology presented here can be a useful contribution to the literature on sustainable infrastructure assessment, in a field where there is no generally accepted single method or set of indicators to assess sustainable infrastructure. The test application of this methodology on two exurban town centers suggests that sustainable infrastructure programs in low-density exurbs, even if not focused on traditional strategies of rail and transit, can be effective in promoting mixed land use and compact development.

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Endnotes

1. These terms are often found in policies that address sprawl and dependency on private automobiles, and generally can be defined or described as follows. Compact development is typically described as contiguous high-density development that enables walking or public transportation (Caves 2005). Mixed-use development is contradistinguished from single-use,

separated, non-diverse land uses promoted by traditional zoning of the early-to-mid twentieth century (Wheeler 2004). Infill development can be described as the use or re-use of vacant or underused parcels or buildings within the central urban area (Caves 2005). Transit-oriented development is development in high-density, mixed-use areas where various forms of mass-transit (such as bus or rail) serve as focal point (Caves 2005). All these forms of development are seen as complementary ways of addressing unsustainable development.

2. Exurbia can be defined, following Caves (2005), as the low-density development beyond a metropolitan area's suburbs but within its commuting shed. Its development is facilitated by the shift to a service and information economy and the accompanying spatial decentralization of economic activity. This development is further facilitated by the extension of transportation systems on the urban fringe, pursuit of the "American Dream" lifestyle, and White flight (defined as spatial segregation resulting from the massive population shift to the suburbs and exurbs along racial and class lines [see Caves 2005, and Gottdiener and Hutchison 2011]).

3. According to Caves (2005), exurbia is predominantly residential but is serviced by small urban centers, often with locally owned small businesses, resulting in a diverse mix of land uses and a small-town feel.

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