

## Appendix A: What the Travel Literature Tells Us<sup>1</sup>

Some of today's most vexing problems—sprawl, congestion, oil dependence, climate change—are prompting states and localities to turn to land planning and urban design to reign in automobile use. Many have concluded that roads cannot be built fast enough to keep up with rising travel demands induced by road building itself and the sprawl it spawns.

The purpose of this meta-analysis is to summarize empirical results on associations between built environments and travel, especially non-work travel. A number of studies, including Crane (1996), Cervero and Kockelman (1997), Kockelman (1997), Boarnet and Crane (2001), Cervero (2002), Zhang (2004), and Cao et al. (2009b), provide economic and behavioral explanations on why built environments might be expected to influence travel choices. We accept these explanations and instead focus on measuring the magnitude of relationships.

Why another review of this literature on built environments and travel, one might ask? There are four reasons for this meta-analysis: the need to quantify effect sizes, the need to update earlier work, the need to expand to other outcome measures, and the need to address the methodological issue of self-selection.

### Quantifying Effect Sizes

Existing surveys seldom generalize across studies or make sense of differing results. Readers are left with glimpses of many trees rather than a panoramic view of this complex and rich forest of research. A meta-analysis, by its nature, reduces many studies to a single bottom line.

A literature review by Ewing and Cervero (2001) derived composite elasticities by “eye balling” rather than weighted averaging. It was an inherently imprecise process.

### Updating Earlier Work

The number of built environment-travel studies now exceeds 200, most having been completed since our 2001 review. Compared to earlier studies, these newer ones have estimated effects of more environmental variables simultaneously (including a 5<sup>th</sup> D, distance to transit), controlled for more confounding influences (including traveler attitudes and residential self-selection), and used more sophisticated statistical methods.

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<sup>1</sup> This appendix is taken from Ewing, R., & Cervero, R. (2010). Travel and the built environment—A meta-analysis. *Journal of the American Planning Association*, 76(3), 265-294.

In response to the U.S. obesity epidemic, the public health literature has begun to link walking to dimensions of the built environment. The first international studies have appeared using research designs similar to those of U.S. studies. This collective and enlarged body of research provides a substantial database for a meta-analysis.

### **Extending to Other Travel Outcomes**

The transportation outcomes we studied in 2001, vehicle miles traveled (VMT) and vehicle trips (VT), are critically linked to traffic safety, air quality, energy consumption, climate change, and other social costs of automobile use. However, they are not the only outcomes of interest. Walking and transit use have implications for mobility, livability, social justice, and public health. The health benefits of walking, in particular, are widely recognized (Badland and Schofield 2005; Cunningham and Michael 2004; Frank 2000; Frank and Engelke 2001; Humpel et al. 2002; Kahn et al. 2002; Krahnstoever-Davison et al. 2006; Lee and Moudon 2004; McCormack et al. 2004; Transportation Research Board 2005; Owen et al. 2004; Saelens and Handy 2008; Trost et al. 2002). Transit use is less obviously related to public health, but it still classified as active travel since it almost always requires a walk at one or both ends of the trip (Besser & Dannenberg, 2005; Edwards, 2008; Zheng, 2008). So to VMT, we add walking and transit use as outcomes of interest.

### **Addressing Self-Selection**

More than anything else, the possibility of self-selection bias has engendered doubt about the magnitude of travel benefits associated with compact urban development patterns. According to a National Research Council report (2005), “If researchers do not properly account for the choice of neighborhood, their empirical results will be biased in the sense that features of the built environment may appear to influence activity more than they in fact do. (Indeed, this single potential source of statistical bias casts doubt on the majority of studies on the topic to date.)”

At least 38 studies using nine different research approaches have attempted to control for residential self selection (Mokhtarian and Cao 2008; Cao et al. 2009a). Nearly all of them found “resounding” evidence of statistically significant associations between the built environment and travel behavior, independent of self-selection influences (Cao et al. 2009a, p. 389). However, nearly all of them also found that residential self selection attenuates the effects of the built environment.

Using travel diary data from the New York-New Jersey-Connecticut regional travel survey, Salon (2006) concluded that the effect of the built environment itself accounted for 1/2 to 2/3 of the total effect of a change in population density on walking level in most areas of New York City. Using travel diary data from the Austin travel survey, Zhou and Kockelman (2008) found that the built environment itself accounted for 58% to 90% of the “total” influence of residential location on VMT, depending on model specifications. Using travel diary data for four traditional and four suburban

neighborhoods in Northern California, Cao (2009) reported that that, on average, the causal influences of neighborhood type account for 61% of the total effect of the built environment on utilitarian walking frequency and 86% of the total effect on recreational walking frequency. Using data from a regional travel diary survey in Raleigh, NC, Cao et al. (2009c) estimated that anywhere from 48% to 98% of the difference in vehicle miles driven was due to direct environmental influences, the balance being due to self-selection; the percentage varied between pairs of locations (urban vs. suburban, urban vs. exurban).

So while the environment may play a more important role in travel behavior than do attitudes and residential preferences, both effects are present.

## **Five Ds of the Built Environment**

The potential to moderate travel demand through changes in the built environment is the most heavily researched subject in urban planning. In travel research, urban development patterns have come to be characterized by “D” variables. The original “three Ds,” coined by Cervero and Kockelman (1997), are density, diversity, and design. The Ds have multiplied since Cervero and Kockelman’s original article, with the addition of destination accessibility and distance to transit (Ewing and Cervero 2001; Ewing et al. 2009). Demand management, including parking supply and cost, is a sixth D, included in a few studies. While not part of the environment, demographics are the seventh D in travel studies, controlled as confounding influences.

Density is measured in terms of activity level per unit area. It can be measured on gross or net area basis, on a population or dwelling unit basis, and on an employment or building area basis. Population and employment density are two distinct dimensions. The two are sometimes summed to compute an overall “activity density.”

Diversity is related to the number of different land uses in an area and the degree to which they are represented in land area, floor area, or employment. Entropy measures of diversity, wherein low values indicate single-use environments and larger ones denote a variety of land uses, are widely used in travel studies. Job-to-housing or job-to-population ratios are less frequently used. What Handy (1993) refers to as local accessibility is part of diversity. It is measured by distance from home to the closest store or other local trip attraction.

Design includes street network characteristics within a neighborhood. Street networks vary from dense urban grids of highly interconnected, straight streets to sparse suburban networks of curving streets forming “loops and lollipops.” Street accessibility usually is measured in terms of average block size, proportion of four-way intersections, or number of intersections per square mile. In the occasional study, design also is measured in terms of sidewalk coverage, building setbacks, streets widths, pedestrian crossings, presence of

street trees, or other physical variables that differentiate pedestrian-oriented environments from auto-oriented ones.

Destination accessibility is synonymous with access to trip attractions. In some studies, destination accessibility is simply represented by distance to the central business district. In other studies, it is represented by the number of jobs or other attractions reachable within a given travel time, which tends to be highest at central locations and lowest at peripheral ones. The gravity model of trip attraction measures destination accessibility.

Distance to transit usually is measured from home or work to the nearest rail station or bus stop by the shortest street route. Distance to transit also may be represented by transit route density, stop spacing, or by the presence of stations within the zone or buffer area.

Note that the Ds are rough categories, divided by ambiguous and unsettled boundaries that may change in the future. Some dimensions overlap (e.g., density and destination accessibility). Regardless, it is useful to aggregate empirical results on the influences of each of the D variables on travel, if only to help organize the literature and provide order-of-magnitude insights.

## Literature

### Qualitative Reviews

There are at least 12 surveys of the literature on the built environment and travel (Badoe and Miller 2000; Cao et al. 2009a; Cervero 2003; Crane 2000; Ewing and Cervero 2001; Handy 2006; Heath et al. 2006; McMillan 2005; McMillan 2007; Pont et al. 2009; Saelens et al. 2003; Stead and Marshall 2001). There are another 13 surveys of the literature on the built environment and physical activity, including walking and bicycling (Badland and Schofield 2005; Cunningham and Michael 2004; Frank 2000; Frank and Engelke 2001; Humpel et al. 2002; Kahn et al. 2002; Krahnstoever-Davison et al. 2006; Lee and Moudon 2004; McCormack et al. 2004; National Research Council 2005; Owen et al. 2004; Saelens and Handy 2008; Trost et al. 2002). There is considerable overlap among these reviews, particularly where they share authorship as with the two reviews by McMillan and the National Research Council and Saelens and Handy reviews. The literature is now so vast it has produced two reviews of the many reviews (Bauman and Bull 2007; Gebel et al. 2007).

Weighing the evidence, what can be said, about measured associations between D variables of the built environment and key travel “outcome” variables: *trip frequency*, *trip length*, *mode choice*, and composite measure of travel demand, *vehicle miles traveled (VMT)*? These are the most common outcomes modeled, and hence their relationships can be described with more confidence than can, for example, the relationship of the built environment to trip chaining in multipurpose tours or internal capture of trips within mixed use developments.

We draw on the survey by Ewing and Cervero (2001) for this qualitative description. Trip frequencies are primarily a function of socioeconomic characteristics of travelers and secondarily a function of the built environment; trip lengths are primarily a function of the built environment and secondarily of socioeconomic characteristics; and mode choices depend on both (though probably more on socioeconomics). VMT and VHT also depend on both.

Trip lengths are generally shorter at locations that are more accessible, have higher densities, or feature mixed uses. This holds true for both the home end (that is, residential neighborhoods) and destination end (activity centers) of trips. The dominant environmental effect on trip lengths is destination accessibility.

Transit use varies primarily with local densities and secondarily with the degree of land-use mixing. Some of the density effect is, no doubt, due to better walking conditions, shorter distances to transit service, and less free parking. Walking varies as much with the degree of land use mixing as with local densities.

The third D—design—has a more ambiguous relationship to travel behavior than do the first two. Any effect is likely to be a collective one involving multiple design features. It also may be an interactive effect with other D variables. This is the idea behind composite measures such as Portland, Oregon’s “urban design factor.” The urban design factor is a function of intersection density, residential density, and employment density.

Readers are referred to the other reviews cited above for a more complete picture of built environmental relationships. The physical activity literature, in particular, is quite distinct from the travel literature summarized by Ewing and Cervero (2010). There is little doubt that utilitarian travel and leisure-time physical activity are subject to different influences.

## **Earlier Quantitative Synthesis**

Using 14 travel studies that included sociodemographic controls, Ewing and Cervero (2001) synthesized the literature by extracting elasticities of VMT and vehicle trips (VT) with respect to the first four Ds—density, diversity, design, and destination accessibility. These summary measures were incorporated into the EPA’s Smart Growth Index (SGI) model, a widely used sketch planning tool for travel and air quality analysis. In the SGI model, density is measured in terms of residents plus jobs per square mile; diversity in terms of the ratio of jobs to residents relative to the regional average; and design in terms of street network density, sidewalk coverage, and route directness (two of three measures relating to street network design).

Table A-1 presents the average elasticities computed in our 2001 study. These elasticities, for example, suggest a doubling of neighborhood density results in approximately a 5 percent reduction in both VT and VMT per capita, all else being equal. Note that the elasticity of VMT with respect to destination accessibility is much larger

than the other three, suggesting that areas of high accessibility—such as center cities—may produce substantially lower VMT than dense mixed-use developments in the exurbs.

In addition to simply eyeballing elasticities, and relying on only 14 studies, the 2001 review aggregated results for often dissimilar environmental variables (e.g., entropy and jobs-housing balance as measures of local diversity). This update involves the weighted averaging of results from more studies for more uniformly defined built environmental variables.

Table A-1. Typical Elasticities of Travel with Respect to Four D Variables (Ewing and Cervero 2001)

	Vehicle Trips (VT)	Vehicle Miles Traveled (VMT)
Local density	– .05	– .05
Local diversity (mix)	– .03	– .05
Local design	– .05	– .03
Regional accessibility	.00	– .20

## Meta-Analyses in Planning

Unlike traditional research methods, meta-analysis uses summary statistics from individual primary studies as the data points in a new analysis. From the standpoints of validity and reliability, this practice has both strengths and weaknesses. Every standard textbook on meta-analysis lists both (Lipsey and Wilson 2001; Hunter and Schmidt 2004; Schulze 2004; Littell et al. 2008; Borenstein et al. 2009).

The appeal of meta-analysis is that it aggregates all available research on a topic, allowing common threads to emerge. Pooling of samples provides the basis for greater generalizability. Meta-analysis is particularly appropriate where research outcomes are to be compared.

Meta-analysis has its drawbacks too. The combining of “strong” and “weak” studies has the potential to contaminate results. Further, meta-analysis inevitably mixes “apples and oranges” due to the variation among studies in modeling techniques, independent and dependent variables, and sampling units. As studies are increasingly segmented in an effort to achieve consistency within categories, sample sizes can become small. With small sample sizes, statistical reliability becomes questionable, which we admit

characterizes some of the breakdowns presented in this paper. In this sense, we hope that stratifying the results provide a baseline from which future studies can augment the small-sample results presented in this article. Lastly, the studies for a meta-analysis are usually chosen through a literature review. An inherent selection bias (called publication bias) may arise, since studies may tend to be published more readily if they show statistical significance (Rothstein et al. 2005). Publication bias may inflate effect size estimates in absolute terms.

Publication bias is minimized in this meta-analysis by searching the “gray literature” for unpublished reports, pre-prints, and white papers. Google Scholar and TRIS were particularly helpful in this search. The apples-oranges problem is minimized by focusing on a subset of studies that employed disaggregate data and comparably defined variables. This meta-analysis reflects tradeoffs. In an effort to avoid publication bias, we may have exacerbated the strong-weak study problem. In an effort to achieve greater construct validity by segmenting studies by variable type, this meta-analysis ends up with small sample sizes for dependent-independent variable pairs.

More than a dozen studies have applied meta-analytical methods to the urban planning field (Babisch, 2008; Bartholomew & Ewing, 2008; Bunn et al. 2003; Button & Kerr, 1996; Button & Nijkamp, 1997; Cervero, 2002; Debrezion et al., 2003; Duncan et al., 2005; Graham & Glaister, 2002; Hamer and Chida, 2008; Leck, 2006; Lauria & Wagner, 2006; Nijkamp & Pepping, 1998; Smith & Kaoru, 1995; Stamps, 1990; Stamps, 1999; Zhang 2009). Bartholomew and Ewing (2008) combined results from 23 recent scenario planning studies to calculate the impacts of land-use changes on transportation greenhouse gas emissions. Button and Kerr (1996) explored the implications of urban traffic restraint schemes on congestion levels. Cervero (2002) synthesized the results of induced travel demand studies. Debrezion et al. (2003) measured the impact of railway stations on residential and commercial property values. Nijkamp and Pepping (1998) analyzed critical success factors in sustainable city initiatives. Smith and Kaoru (1995) calculated the public’s willingness to pay for cleaner air. Stamps (1990 & 1999) applied meta-analysis to the visual preference literature.

Most relevant to the present study, Leck (2006) identified 40 published studies of the built environment and travel, and selected 17 that met minimum methodological and statistical criteria. While this meta-analysis stopped short of estimating average effect sizes, it did evaluate the statistical significance of relationships between the built environment and travel. Residential density, employment density, and land-use mix were found to be inversely related to VMT at the  $p < 0.001$  significance level.

## **Approach**

### **Sample of Studies**

Studies linking the built environment to travel were identified as follows. Academic Search Premier, Google, Google Scholar, MEDLINE, PAIS International, PUBMED,

Scopus, TRIS Online (National Transportation Library), TRANweb, Web of Science, and ISI Web of Knowledge databases were searched using the key words “built environment,” “urban form,” and “development,” coupled with keywords “travel,” “transit,” and “walking.” CDs of the Transportation Research Board’s annual programs were reviewed for relevant papers. All leading researchers in this subject area were contacted for copies of their latest research. A call was put out for built environment-travel studies on the academic planners’ listserv, PLANET. The bibliographies of the previous literature reviews were examined to identify other pertinent studies.

As a resource for readers, the bibliography of this article lists more than 200 studies that relate, quantitatively, characteristics of the built environment to measures of travel. From the universe of built environment-travel studies, effect sizes were computed for more than 50 studies (see Table A-2). These studies have several things in common. As they analyze effects of the built environment on travel choices, all selected studies control statistically for confounding influences on travel behavior, in particular, sociodemographic influences. They use different statistical methods because the outcome variables differ from study to study.<sup>1</sup> All apply statistical tests to determine the significance of the various effects. Almost all are based on good size samples (see Appendix). Most capture the effects of more than one D variable simultaneously. And most importantly, what distinguishes these studies from the others is the *availability of data* with which to compute effect sizes.

Many quantitative studies were not selected for one reason or another:

- Many studies failed to publish average values of dependent and independent variables from which point elasticities could be calculated. Follow-up contacts were made with authors in an effort to obtain these descriptive statistics. In many cases, the research was several years old, and authors had moved on to other subjects. In a few cases, it proved impossible to even track down authors, or get them to respond to repeated data requests.
- Many studies have used highly aggregated data, at the city, county, or metropolitan level (e.g., Newman and Kenworthy 2006; van de Coevering and Schwanen 2006). Such studies have limited variance of both dependent and independent variables to explain relationships. Their causal and associative inferences are threatened by the so-called ecological fallacy.
- Several studies used statistical methods from which summary effect size measures could not be calculated. Included are studies using structural equation models to capture complex interactions among built environment and travel variables (e.g., Bagley and Mokhtarian 2002; Cao et al. 2007; Cervero and Murakami, 2010). In SEM, there are multiple influences of the same independent variable via different equations, which have to be aggregated into a single elasticity. Doing that with coefficients and mean values is not sufficient because of the nonlinearity of the interactions between the equations.<sup>2</sup>



- Many studies were excluded because they deal with limited populations or trip purposes (e.g., Chen and McKnight 2007; Li et al. 2005; Waygood et al. 2009). Notably, several recent studies of student travel to school cannot be generalized to other populations and trip purposes. The literature suggests that students' (or their parents') choice of mode for the journey to school is based on very different considerations than other trip making (Ewing et al. 2004; Yarlagadda & Srinivasan 2008).
- Some studies were excluded because they characterize the built environment subjectively rather than objectively, that is, in terms of qualities perceived and reported by travelers rather than measured by researchers (e.g., Craig et al. 2002; Handy et al. 2005). This is common among public health studies. While perceptions are important, they differ from objective measures of the built environment and arguably are less readily influenced by planners or public policy makers (McCormack et al. 2004; McGinn et al. 2007; Livi-Smith 2009). For studies that include both types of measures, relationships were analyzed only for objective measures.
- Finally, several otherwise worthy studies were excluded because they created and then applied built environmental indices without true zero values (for example, indices derived through factor analysis). There is no defensible way to compute elasticities, the common currency of this article, for such studies (e.g., Estupinan and Rodriguez 2008; Frank et al. 2007; Livi-Smith 2009). For the same reason, several excellent studies were excluded because their independent variables, though initially continuous, were reduced to categorical variables to simplify the interpretation of results (Lee and Moudon 2006b; Oakes et al. 2007; McGinn et al. 2007).

Studies using nominal variables to characterize the built environment were analyzed separately from those using continuous variables. Such studies distinguish between traditional urban and conventional suburban development, or between transit-oriented and auto-oriented development. To be included, studies had to analyze disaggregate data and control for individual socioeconomic differences across their samples, thereby capturing the marginal effects of neighborhood type.<sup>3</sup>

Table A-2. Sample of Studies

	study sites	Data	methods	controls	self-selection*
Bento et al. 2003	Nationwide Personal Transportation Survey (114 MSAs)	D	LNR/LGR	SE/LS/OT	no

Bahtia 2004	20 communities in Washington DC	A	LNR	SE	no
Boarnet et al. 2004	Portland	D	LNR/PRR	SE/OT	no
Boarnet et al. 2008	Portland	D	TOR	SE	yes
Boarnet et al. 2009	8 neighborhoods in Southern California	D	NBR	SE	no
Cao et al. 2006	6 neighborhoods in Austin	D	NBR	SE/AT	yes
Cao et al. 2009b	8 neighborhoods in Northern California	D	SUR	SE/AT	yes
Cao et al. 2009c	Raleigh, NC	D	PSM	SE/AT	yes
Cervero 2002	Montgomery County, MD	D	LGR	SE/LS	no
Cervero 2006	225 LRT stations in 11 metropolitan areas	A	LNR	ST/LS	no
Cervero 2007	26 TODs in five California regions	D	LGR	SE/LS/WP/AT	yes
Cervero and Duncan 2003	San Francisco Bay	D	LGR	SE/OT	no
Cervero and Duncan 2006	San Francisco Bay	D	LNR	SE/WP	no
Cervero and Kockelman 1997	50 neighborhood in San Francisco Bay	D	LNR/LGR	SE/LS	no
Chapman and Frank 2004	Atlanta	D	LNR	SE	no
Chatman 2003	Nationwide Personal Transportation Survey	D	TOR	SE/WP	no
Chatman 2008	San Francisco/San Diego	D	LNR/NBR	SE/LS/OT	no

Chatman 2009	San Francisco/San Diego	D	NBR	SE/LS/OT/AT	yes
Ewing et al. 1996	Palm Beach County/Dade County	D	LNR	SE	no
Ewing et al. 2009	52 MXDs in Portland	D	HLM	SE	no
Fan 2007	Raleigh-Durham	D	LNR	SE/LS/OT/AT	yes
Frank et al. 2005	Seattle	D	LNR	SE/LS	no
Frank et al. 2007	Seattle	D	LGR	SE/LS	no
Frank et al. 2009	Seattle	D	LNR	SE	no
Greenwald 2009	Sacramento	D	LNR/TOR/NBR	SE	no
Greenwald and Boarnet 2001	Portland	D	OPR	SE/LS	no
Handy and Clifton 2001	6 neighborhoods in Austin	D	LNR	SE	no
Handy et al. 2006	8 neighborhoods in Northern California	D	NBR	SE/AT	yes
Hedel and Vance 2007	German Mobility Panel Survey	D	LNR/PRR	SE/OT	no
Hess et al. 1999	12 neighborhood commercial centers in Seattle	A	LNR	SE	no
Holtzclaw et al. 2002	Chicago/Los Angeles/San Francisco	A	NLR	SE	no
Joh et al. 2009a	8 neighborhoods in Southern California	D	LNR	SE/CR/AT	yes
Khattak and Rodriguez 2005	2 neighborhoods in Chapel Hill	D	NBR	SE/AT	yes
Kitamura et al.	5 communities in San	D	LNR	SE/AT	yes

1997	Francisco region				
Kockelman 1997	San Francisco Bay	D	LNR/LGR	SE	no
Kuby et al. 2004	268 LRT stations in nine metropolitan areas	A	LNR	ST/OT	no
Kuzmyak et al. 2006	Baltimore	D	LNR	SE	no
Kuzmyak 2009a	Los Angeles	D	LNR	SE	no
Kuzmyak 2009b	Phoenix	D	LNR	SE	no
Lee and Moudon 2006a	Seattle	D	LGR	SE/LS	yes
Lund 2003	8 neighborhoods in Portland	D	LNR	SE/AT	yes
Lund et al. 2004	40 TODs in four California regions	D	LGR	SE/LS/WP/AT	yes
Naess 2005	29 neighborhoods in Copenhagen	D	LNR	SE/WP/AT	yes
Pickrell and Schimek 1999	Nationwide Personal Transportation Survey	D	LNR	SE	no
Plaut 2005	American Housing Survey	D	LGR	SE/OT	no
Pushkar et al. 2000	795 zones in Toronto	A	SLE	SE/LS	no
Rajamani et al. 2003	Portland	D	LGR	SE/LS	no
Reilly 2002	San Francisco	D	LGR	SE/OT	no
Rodriguez and Joo 2004	Chapel Hill, NC	D	LGR	SE/LS/OT	no
Rose 2004	3 neighborhoods in Portland	D	LNR/POR	SE	no

Schimek 1996	Nationwide Personal Transportation Survey	D	SLE	SE	no
Shay et al. 2006	one neighborhood in Chapel Hill	D	NBR	SE/AT	yes
Shay and Khattak 2005	2 neighborhoods in Chapel Hill	D	LNR/NBR	SE	no
Shen 2000	Boston	A	LNR	SE	no
Sun et al. 1998	Portland	D	LNR	SE	no
Targa and Clifton 2005	Baltimore	D	POR	SE/AT	yes
Zegras 2006	Santiago	D	LNR/LGR	SE	no
Zhang 2004	Boston/Hong Kong	D	LGR	SE/LS/OT	no
Zhou and Kockelman 2008	Austin	D	LNR/PRR	SE	yes

Abbreviations:

A=aggregate

D=disaggregate

GEE=generalized estimating equations

HLM=hierarchical linear modeling

LGR=logistic regression

LNR=linear regression

NBR=negative binomial regression

NLR=nonlinear regression

OPR = ordered probit regression

POR=Poisson regression

PRR=probit regression

PSM=propensity score matching

PSS=propensity score stratification

SLR = simultaneous linear equations

SUR=seemingly unrelated regression

TOR=Tobit regression

AT=attitudinal variables

CR=crime variables

LS=level of service variables

OT=other variables

SE=socioeconomic variables

ST=station variables

WP=workplace variables

\* Per Cao et al. (2009a), nine different approaches have been used to control for residential self-selection. From least to most rigorous, they range from direct incorporation of attitudinal measures in multivariate regression models to jointly estimated models of residential choice and travel behavior, where residential choice is treated as an endogenous variable.

## Common Metrics

To combine results from different studies, a meta-analysis requires a common measure of effect size, a “common denominator” if you will. Our common metric is the elasticity of some travel outcome with respect to one of the D variables. An elasticity is a percentage change in one variable with respect to a one percent change in another variable (actually, the ratio of infinitely small changes). It is a dimensionless (unit-free) metric that measures the strength of association between two variables. Elasticities are the most widely used measures of effect size in economic and planning research.

For continuous outcomes such as number of walk trips, elasticities are the percent change in the outcome variable with respect to a one percent increase in the independent variables. For discrete outcomes such as the choice of walking over other modes, elasticities are the percent change in the probability of choosing a particular alternative when an independent variable is increased by one percent. Although they are not identical, these elasticities can be compared to demand elasticities because they also can be interpreted as the percent change in the market share (similar to demand) of the particular alternative when an independent variable is increased by one percent.

## Individual Elasticities

For individual studies, elasticity estimates were derived in one of four ways (as in Ewing and Cervero, 2001): (1) from published studies, taken at face value; (2) from regression coefficients and mean values of dependent and independent variables (called “midpoint elasticities”), either as reported in original studies or obtained directly from researchers; (3) from data sets already available to the authors, or made available by other researchers; or (4) by the original researchers at the authors’ behest.

Different formulas were used to compute elasticities for the different studies, in keeping with the different statistical methods used to estimate coefficient values (see Table 1 for statistical methods). The formulas employed are presented in Table A-3 (where  $\beta$  represents the regression coefficient value,  $y_o$  the mean value of the travel variable of interest, and  $x_o$  the mean value of the built environmental variable of interest).

Table A-3. Elasticity Estimation Formulas

Regression Specification	Elasticity
Linear	$\beta x_o / y_o$

log-log	B
log-linear	$\beta x_o$
linear-log	$\beta / y_o$
Logistic	$\beta x_o (1 - y_o/n)^*$
Poisson	$\beta x_o$
negative binomial	$\beta x_o$
Tobit	$\beta x_o / y_o$ (for $y_o > 0$ )**

\*  $y_o/n$  is the mean estimated probability of occurrence.

\*\* Applied only to positive values of the Tobit distribution.

When regression coefficients were statistically significant, elasticities were computed from reported coefficients using the formulas above. When regression coefficients were not significant, we had a choice: drop the observations, substitute zero values for the elasticities since the coefficients were not statistically different from zero, or use the reported coefficients to compute elasticities using the formulas above. Dropping the observations would have biased average elasticity values away from the null hypothesis of zero elasticity, and thus was rejected. Substituting zero values for computed elasticities would have had the opposite effect, biasing average values toward the null hypothesis, and was therefore also rejected. Instead we used the best available estimates of central tendency in all cases, the regression coefficients themselves, to compute elasticities. This is the common approach in meta-analysis (see, for example, Melo et al. 2009). Borenstein et al. (2009) argue against the use of significance levels as proxies for effect size since they depend not only on effect size but on sample size. “Because we work with the effect sizes directly we avoid the problem of interpreting nonsignificant p-values to indicate the absence of an effect (or of interpreting significant p-values to indicate a large effect)” (Borenstein et al. 2009, p. 300).

Ideally, elasticities would have been computed for each observation (trip/traveler/household) individually, and then averaged over the sample. Indeed, a few of the researchers who reported elasticities have done exactly that (e.g., Bento et al. 2003 and Rodriguez and Joo 2004). To do so consistently would have required all other researchers to go back and compute elasticities for each observation, assuming a 1% change in each independent variable, estimate the % change in the dependent variable, and then average over the sample. Obviously, this would have been too much to ask of busy people, and we have instead estimated elasticities at the overall sample means of the dependent and/or independent variables.



While commonplace, this procedure could introduce a fair amount of error in the elasticity estimates. Elasticities calculated at mean values of dependent and independent variables may differ significantly from the average values of individual elasticities due to the nonlinear nature of many of the functions involved (logistic functions, for example). “In general, the probability evaluated at the average utility underestimates the average probability when the individuals’ choice probabilities are low and overestimates when they are high” (Train 1986: 42). Talvitie (1976, as cited by Train) found, in a mode choice analysis, that elasticities at the average representative utility can be as much as two to three times greater or less than the average of individual elasticities. This is a concern, we note, with discrete-choice models versus linear regression-based analyses that, as revealed in Table A-2, are more common in the study of built environments and travel.

### **Weighted Average Elasticities**

Given individual elasticities from primary studies, we were able to compute weighted average elasticities for many dependent-independent variable pairs. Weighted average elasticities are presented in Tables A-4 through A-6. Averages are presented where three conditions are met: (1) a sample of at least three studies was available; (2) for these particular studies, dependent and independent variables were comparably defined; and (3) for these particular studies, disaggregate travel data were used to estimate models. Study sample sizes are as indicated in Table A-4 through A-6.

These results should be used only as ballpark estimates for two reasons. The first is our choice of minimum sample size required to conduct a meta-analysis. The second is our choice of weighting factor to compute weighted average elasticities.

Regarding the first reason, sample size, we settled on a minimum number of three studies due to data limitations (as in Tompa et al. 2008). While the built environment and travel is the most heavily researched subject in urban planning, when studies are segmented by variable type, we are left with samples that never reach what some would consider a reasonable minimum sample size (Lau et al. 2006). Also, to maximize our sample sizes, we mixed the relatively few studies that control for self-selection with the many that do not. Readers are advised to exercise caution in the use of elasticities when based on small samples of primary studies. Because we have sought to seed the meta-study of “built environments and travel” with the expectation that others will augment and expand our database over time, we opted to present elasticity estimates as long as they were drawn from three or more studies. We quote one study from another field that settled on seven studies as a minimum for a meta-analysis (Rodenburg et al., 2009):

“Some limitations of this meta-analytic study should be mentioned. Although the minimum number of studies to permit a meta-analysis is only three studies (Treadwell, Tregear, Reston & Turkelson, 2006) and many published meta-analyses contain nine or fewer studies (Lau, Ioannidis, Terrin, Schmid & Olkin, 2006), the small number of seven studies included in this meta-analytic review

limits the generalizability of our findings and the possibilities of examining and adjusting for publication bias by means of more complex analytic methods (Macaskill, Walter & Irwig, 2001).”

Regarding the second reason, weighting, we used sample size as a weighting factor, again, due to data limitations. The optimal way to estimate average effect size is to weight each effect size value by a term that represents its precision. Hedges and Olkin (1985) demonstrated that optimal weights are related to the standard errors of the effect size estimates, and this has become the gold standard in meta-analysis. Specifically, because larger standard errors correspond to less precise effect size values, the actual weights are computed as the inverse of the squared standard error values—called *inverse variance weights* in a meta-analysis (Lipsey and Wilson 2001; Hunter and Schmidt 2004; Schulze 2004; Littell et al. 2008; Borenstein et al. 2009). From a statistical standpoint, such weights are optimal since they minimize the variance of the average effect size estimates. Intuitively, such weights also make sense since they give the greatest weight to the most precise estimates from individual studies.

In this meta-analysis, optimal pooling procedures weren’t feasible. Lacking consistent standard error estimates from individual studies, we were forced to use sample size as the weighting factor. Weighting by sample size is by far the most common approach in meta-analyses since sample sizes are nearly always known (Shadish and Haddock 1994, p. 264). Inasmuch as variances of estimated effects decrease with increasing sample size, weighting by sample size may produce weighted averages that are not too different from those that would have been obtained using an optimal weighting scheme. However, when any weighting factor other than standard error is used, it is not possible to judge whether the resulting weighted averages are statistically different from zero. Since we combine significant and insignificant individual effect sizes, and because of data limitations, do not test for significance, statistical confidence is not reported for any of the results. It is thus possible that any given meta-elasticity is not significantly different from zero.

Table A-4. Weighted Average Elasticities of VMT with Respect to Built Environment Variables

	n total (n with controls for self selection)	<i>e</i>
DENSITY		
household/population density	9 (1)	-0.04
job density	5 (1)	0.0

<b>DIVERSITY</b>		
land use mix (entropy index)	10 (0)	-0.09
job-housing balance	4 (0)	-0.02
<b>DESIGN</b>		
intersection/street density	6 (0)	-0.12
% 4-way intersections	3 (1)	-0.12
<b>DESTINATION ACCESSIBILITY</b>		
job accessibility by auto	5 (0)	-0.20
job accessibility by transit	3 (0)	-0.05
distance to downtown	3 (1)	-0.22
<b>DISTANCE TO TRANSIT</b>		
distance to nearest transit stop	6 (1)	-0.05

Table A-5. Weighted Average Elasticities of Walking with Respect to Built Environment Variables

	n total (n with controls for self selection)	<i>e</i>
<b>DENSITY</b>		
household/population density	10 (0)	0.07
job density	6 (0)	0.04
commercial FAR	3 (0)	0.07

DIVERSITY		
land use mix (entropy index)	8 (1)	0.15
job-housing balance	4 (0)	0.19
distance to store	5 (3)	0.25
DESIGN		
intersection/street density	7 (2)	0.39
% 4-way intersections	5 (1)	-0.06
DESTINATION ACCESSIBILITY		
jobs within one mile	3 (0)	0.15
DISTANCE TO TRANSIT		
distance to nearest transit stop	3 (2)	0.14

Table A-6. Weighted Average Elasticities of Transit Use with Respect to Built Environment Variables

	n total (n with controls for self selection)	<i>e</i>
DENSITY		
household/population density	10 (0)	0.07
job density	6 (0)	0.01
DIVERSITY		
land use mix (entropy index)	6 (0)	0.12

DESIGN		
intersection/street density	4 (0)	0.23
% 4-way intersections	5 (2)	0.29
DISTANCE		
distance to nearest transit stop	3 (1)	0.29

## Discussion

As in our 2001 meta study, the D variable that is most strongly associated with VMT is destination accessibility. The elasticity from the earlier meta study, -0.20, is confirmed by this meta-analysis (based on “job accessibility by auto”). In fact, the -0.19 VMT elasticity is nearly as large as the highest elasticities of the first three D variables—density, diversity, and design—combined. This too is consistent with the earlier meta study.

The variable with the next strongest relationship to VMT is proximity distance to downtown (the inverse of distance to downtown). This variable is a proxy for many of the other Ds: living in the core city typically means higher densities in mixed-use settings with good regional accessibility. Next most strongly associated with VMT are design metrics expressed in terms of intersection density or street connectivity. This is surprising, given the emphasis in the qualitative literature on density and diversity, and the relatively limited attention paid to design. The elasticities of these two street network variables are fairly similar. Both short blocks and many interconnections shorten travel distances, apparently to about the same extent.

Equally surprising is the positive, albeit small, elasticity of VMT with respect to job density. Conventional literature holds that density at the work end of trips is as important as density at the home end as a VMT moderator (Ewing and Cervero, 2001). Since Table A-4 captures travel by residents, not employees, high job densities could reflect imbalanced environments that prompt some residents to travel farther by car.

As walking and transit use were not addressed by Ewing and Cervero (2001), the results in Tables A-5 and A-6 have no benchmarks against which to compare them. The mode share and likelihood of walk trips is most strongly associated with the design and diversity dimensions of built environments. Several variables that often go hand-in-hand with population density have elasticities that are well above that of density. Intersection density and jobs-housing balance appear to be most strongly associated with walking. A doubling of intersection density is accompanied by a 44 percent increase in walking, all

else being equal. Interestingly, intersection density is a more significant variable than street connectivity. You can have great connectivity, but if the blocks are long superblocks, walkability may be limited. Also of interest is the fact that jobs-housing balance has a stronger relationship to walking than the more commonly used land use mix (entropy) variable. Table A-5 also suggests that having transit stops nearby may stimulate walking (Cervero, 2001; Ryan and Frank, 2009). On the other hand, high job accessibility by car may discourage walking. Finally, Table 5 shows that as with VMT, job density is less strongly related to walking than is population density.

The mode share and likelihood of transit trips are most strongly associated with transit access. Living near a bus stop appears to be an inducement to transit riding, supporting the transit industry's standard of running buses within a quarter mile of most residents. Next in importance are design (intersection density) and diversity (jobs-housing balance). High intersection density shortens access distances, and provides more routing options for transit users. Jobs-housing balance makes it possible to efficiently link transit trips with errands on the way to and from transit stops. It is sometimes said that "mass transit needs 'mass'", however this is not supported by the low elasticity of population density in Table 6. In fact, the elasticity of transit riding with respect to retail density is three times greater than that of population density. High retail FAR increases the number of trip attractions near transit and may improve the walking environment.

No clear pattern emerges from scanning across the Tables A-4 to A-6. Perhaps what can be said with the most degree of confidence is that destination accessibility is most strongly related to both motorized (i.e., VMT) and non-motorized (i.e., walking) travel and that among the remaining Ds, density has the weakest association. The primacy of destination accessibility may be due to lower levels of auto ownership and auto dependence at central locations. Almost any development in a central location is likely to generate less automobile travel than the best-designed, compact, mixed-use development in a remote location.

The relatively weak relationships between density and travel likely reflect density's role as an intermediate variable that ultimately gets expressed by the other Ds – i.e., dense settings usually have mixed uses with small blocks and plentiful intersections that shorten trips and encourage walking. Among design variables, intersection density more strongly sways the decision to walk or take transit than street connectivity. This suggests that block size matters more than gridded designs if significant numbers of Americans are to be lured out of their cars. And among diversity variables, jobs-housing balance is a stronger predictor of non-auto mode choice than land-use mix measures. Linking where people live and work allows more to commute by foot and by transit which appears to shape mode choice more than sprinkling a multiplicity of land uses within a neighborhood.

Controls for residential self-selection appear to increase the absolute magnitude of elasticities (if they have any effect at all). There may be good explanations for this unexpected result. In a region with few pedestrian- and transit-friendly neighborhoods,

residential self-selection may lead to better matching of individual preferences with place characteristics, actually increasing the effect of the D variables. This possibility is posited by Lund et al. (2006, p. 256).

“ . . . if people are simply moving from one transit-accessible location to another (and they use transit regularly at both locations), then there is theoretically no overall increase in ridership levels. If, however, the resident was unable to take advantage of transit service at their prior residence, then moves to a TOD (transit-oriented development) and begins to use the transit service, the TOD is fulfilling a latent demand for transit accessibility and the net effect on ridership is positive.”

Similarly, Chatman (2009) hypothesizes that “Residential self-selection may actually cause underestimates of built environment influences, because households prioritizing travel access—particularly, transit accessibility—may be more set in their ways, and because households may not find accessible neighborhoods even if they prioritize accessibility.” He carries out regressions that explicitly test for this, and finds that self-selection is more likely to enhance than diminish built environmental influences.

The elasticities derived in this meta-analysis are based on arguably the most complete data available to date. However, sample sizes are small, and the number of studies controlling for residential preferences and attitudes is still miniscule. Also, data limitations prevent us from reporting confidence intervals for meta-analysis results. These shortcomings need to be weighed when applying results to any particular context or local setting. As more built environment-travel studies appear in the planning literature, it will be necessary to update and refine these meta-analytic results.

## Appendix B: What the Visual Preference Literature Tells Us<sup>2</sup>

Visual preference surveys have become a popular tool among planning and urban design practitioners. By tapping visual media, such surveys help to illustrate physical design alternatives in ways that words, plans, and other media cannot. They have found applications in visioning projects, design charrettes, and other physical planning activities with heavy public involvement.

Such surveys have become a mainstay of the new urbanist and smart growth movements. Their surveys suggest that the public prefers traditional small town and village scenes to contemporary suburban scenes (Constantine 1992; Nelessen 1994; Malizia and Exline 2000). This fact has been used both to argue for and to effect changes in development practices. Smaller cities such as LaCrosse, Wisconsin and Metuchen, New Jersey have written design codes based on expressed preferences (Nelessen and Constantine 1993). The City of Iowa City (2004) considered the results of a citywide visual preference survey when revising its comprehensive plan and zoning ordinance. The City of Orlando (2003) used a visual preference survey to identify pleasing design concepts for almost every element of the built environment including apartments, houses, offices, street layouts, signs, and even transmission towers.

A national visual preference survey conducted by A. Nelessen Associates for the National Association of Realtors showed that the public supports smart growth principles such as rural and open space preservation and compact and clustered development (National Association of Realtors, 2001). Statewide planning exercises like the Livable Delaware Summit (2001) and What Michigan Wants (2004) have assessed the public's reaction to different development patterns using visual preference surveys. Envision Utah (2000) decided on future development patterns for the Greater Wasatch Area based in part on visual preference surveys.

Yet, visual preference surveys have their limitations. Without further analysis, it is never clear whether expressed preferences are significant in a statistical sense nor whether other variables confound results. Nor is it obvious which physical features of scenes are responsible for high or low ratings. Is it the narrow streets, small building setbacks, mature trees, vernacular architecture, or some combination of these and incidental

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2 This appendix is taken from Ewing, R. (2000). Asking transit users about transit-oriented design. *Transportation Research Record*, 1735, pp. 19-24; Ewing, R., King, M., Raudenbush, S., & Clemente, O. (2005). Turning highways into main streets: Two innovations in planning methodology. *Journal of the American Planning Association*, 71, pp. 269-282; and Ewing, R., Handy, S., Brownson, R., Clemente, O., & Winston, E. (2006). Identifying and measuring urban design qualities related to walkability. *Journal of Physical Activity and Health*, 3, pp. s223-240.



features that contribute to overall preference for traditional urban scenes? More than one observer of this process has commented that when you show citizens stark images of new suburban subdivisions or strip centers versus beautified images from America's finest small towns, the outcome is predictable and largely meaningless (as in Figures B-1ab).

Figures B-1ab. Bias through Scene Selection ("What Michigan Wants Visual Preference Survey")



average score = 6



average score = -4

## Visual Assessment Studies

Fields allied with planning use the term visual assessment study to describe activities related to but distinct from visual preference surveys. Visual assessment methods have long been used as a research tool by forest managers, environmental psychologists, and architects and landscape architects.

The term visual assessment study implies more than a simple preference rating...it implies:

- critical analysis of scenes

- use of statistics to test the significance and strength of relationships
- control of confounding influences

The field of visual assessment took off in late 1970's. Researchers showed photographs of urban and rural scenes to groups of observers, who were asked to rate them according to personal preference, scenic value, or overall beauty. Some studies went a step further to explain what it was about scenes that caused them to be preferred (Carls 1974; Herzog, Kaplan, and Kaplan, 1976; Wohlwill 1980; Schroeder 1982; Anderson & Schroeder 1983; Buyhoff, Gauthier, & Wellman 1984; Schroeder 1988; Herzog 1992; Schroeder & Orland 1994).

In some studies, scenes were not rated for preference at all, but instead evaluated for mediating qualities that contribute to preference such as complexity, enclosure, naturalness, and safety. For example, several studies explored how the design of parking lots, urban parks, or landscapes could affect the perception of personal safety. Well maintained vegetation, visible buildings, and high tree density all contributed to the perception of safety (Appleton 1975; Herzog 1982; Nasar 1982; Shaffer & Anderson 1983; Schroeder & Anderson 1984; Kuo, Bacaicoa, & Sullivan 1998; Stamps 2005).

## Places

There is general agreement that the complexity of a scene plays a part in determining preference (Nasar 1983; Stamps 1999; Heath et. al 2000). When provided with images of city blocks, people generally prefer those that have a high level of detail. At the same time, one study found people prefer homogenous blocks (Stamps 1994). Together, these findings indicate that people enjoy looking at streetscapes where there is a balance between a high level of visual interest and the viewer's ability to make sense of the scene, in other words, people like complexity with coherence and order.

Herzog et al. (1982) studied peoples' preference for unfamiliar urban scenes. Scenes were divided into five categories: contemporary life, alley/factory, urban nature, unusual architecture, and older buildings. Scenes were rated with respect to four perceptual qualities: complexity, coherence, identifiably, and mystery. The study found that the most preferred scene type was urban nature while the least preferred was alley/factory. Urban nature rated high on the quality of mystery, while the alley/factory scene had an undesirable combination of high complexity and low coherence.

Nasar (1984) studied major arterial roads through city centers. Preferred scenes were well-maintained, had natural elements, and weren't crowded with traffic. Visual preference was therefore determined to be a function of two factors: order (order, naturalness, and upkeep) and diversity (high contrast, diversity, and few vehicles).

Cervero and Bosselmann (1998) tested whether Americans would accept higher densities in transit villages if coupled with amenities such as open space and retail plazas. They created photo slide images to simulate walks through neighborhoods with different densities and amenity mixes. The conclusion: Americans will accept higher densities in

transit villages in exchange for easy access to rail and the availability of amenities, in particular open space. The addition of more retail services such as bakeries and cafés was also well received by the respondents.

## **Buildings**

Several visual assessment studies have focused on peoples' preferences for architectural design features. In one study, Stamps (1999a) examined the degree to which qualities of architectural facades (surface complexity, silhouette complexity, and façade articulation) affect preference when varied simultaneously. The study found that the most important factor for visual preference was surface complexity; this factor had a far greater preference effect than both silhouette complexity and façade articulation. In another study, Stamps (1999b) sought to relate preferences to the visual complexity of facades. Qualities of facades, specifically the percentage of a façade covered by design elements and the number of turns in the silhouette, proved to be better predictors of preference than did characteristics of the observers themselves.

## **Landscapes**

Kaplan (1985) found that the most important factor influencing neighborhood satisfaction was not the amount of open space available but rather the type and arrangement of the space. Residents most valued the presence of trees, well-landscaped grounds, and places for taking walks. Similarly, Talbot et al. (1987) found that areas conducive to walking, including forests and ponds, were preferred by residents in multifamily neighborhoods.

Manicured and well maintained landscapes are preferred over wild, unmanaged nature (Schroeder 1982; Anderson and Schroeder 1983; Shaffer and Anderson 1983; Kaplan 1985; Talbot and Kaplan 1986; Kuo et al. 1998). Landscapes with trees are preferred over those without (Kaplan 1983). Lien and Buhyoff (1986) looked at the diameter of trees and found that peoples' preference for natural scenes increases with the average tree diameter. People also prefer landscapes with fewer, large trees that are set against smooth ground covers (such as manicured grass) rather than in dense forests with shrubs (Buhyoff et al. 1984; Kaplan 1985; Ulrich 1986; Talbot and Kaplan 1986; Schroeder 1988). A video-imaging study looked at clusters of trees and found that the highest preference ratings were assigned to landscapes with the most trees and largest cluster diameters (Schroeder & Orland 1994).

Along with trees, the presence of bodies of water is natural feature valued by residents of urban settings (Carls 1974; Schroeder 1982; Schroeder & Anderson 1984; Talbot et al. 1987).

## **Signage**

Nasar (1987) examined peoples' preferences for signage along commercial strips. Shoppers and merchants viewed photographs of street scenes, which varied in complexity and coherence. The respondents then ranked the scenes separately on three different

scales. Ratings were highest for moderate complexity and high coherence. In a later study, Nasar and Hong (1999) investigated the role of sign obtrusiveness (defined as low coherence) and complexity on peoples' preferences for urban signscapes. The study found that preference for signscapes is linked to reductions in sign obtrusiveness; people found less-obtrusive signscapes more legible and interesting.

We now go into some detail in describing three visual assessment studies that have followed best analytic practices. Their results are directly relevant to pedestrian- and transit-friendly design guidelines.

## **Main Street Design**

The guidebook, *Flexible Design of New Jersey's Main Streets*, recommends that state highways designated as "main streets" conform to special design standards and policies (Ewing & King 2002; Ewing 2002). The New Jersey Department of Transportation (NJDOT) response to the guidebook has been positive. But there is continued uncertainty at NJDOT as to exactly which state highways should be accorded this special status. To help answer this question, main street stakeholders were asked to rate different urban highways in a visual assessment survey. This section describes the process and resulting scoring formula (for more details, see Ewing et al. 2005).

## **Viewers**

The survey was conducted at the quarterly meeting of Main Street New Jersey/Downtown Revitalization Institute. At the meeting were representatives of urban, suburban, and rural communities throughout the state. Among them were directors of Main Street Programs and Special Improvement Districts, downtown advocates, downtown business owners, representatives of local governments, architects, engineers, and consultants. This group provided a broad cross section of people interested in promoting main streets in New Jersey.

This convenience sample of respondents was selected for their familiarity with main streets rather than their representation of the larger population. The purpose of the survey was to operationally define a good main street, not to assess public preferences for street characteristics. Given this purpose, main street stakeholders appeared well-suited as respondents.

The survey was administered as a PowerPoint presentation. It began with a short instructional session, including a sample of photographs of main streets from an earlier visual assessment survey of national experts. The idea was to show the range of possible streetscapes, so that participants would have a common basis for subsequent ratings.

## **Scenes**

NJDOT assisted in scene selection by nominating 83 "main streets" for inclusion in the study. These were of four types:

- Classic main streets such as Nassau Street in Princeton and Washington Street in Hoboken.
- Urban streets recently reconstructed to be more main street-like, such as Springfield Avenue in Maplewood and Maple Avenue in Red Bank.
- State highways that local authorities would like to make more main street-like, such as Route 202 in Bernardsville and Ocean Boulevard in Long Branch.
- Controversial roadways that have pitted NJDOT against local interests, such as Brunswick Avenue in Lawrenceville and Broadway in Salem.

Of these, 50 were chosen for the visual preference survey. Two streets were chosen from each of New Jersey's 21 counties, with the balance coming from the more urbanized counties. Most lie on state or county routes. Selection was driven by the desire for diverse roadway cross sections and diverse roadway edge conditions. Streets currently undergoing construction, and those that offered no safe place along the centerline from which to take photographs, were excluded from the sample.

In the survey, each street was depicted by both a panoramic photograph of the streetscape and a video clip giving an impression of traffic volumes and pedestrian activity. Film was shot outside the rush hour, generally between 10 a.m. and 4 p.m., on clear days. This was done to keep traffic volumes low enough so edge conditions were visible from the centerline, and to control for weather as an extraneous influence on main street scores.

## **Variables**

The photographs and video clips used in the survey were subsequently analyzed for content. Features of main streets and their immediate environments were measured for use as explanatory variables. Analysts worked together in an informal Delphi-like process to assign values to each variable, and discussed and debated until a consensus was reached. Twenty-three variables were measured from the panoramic photographs, and an additional two variables came from the video clips. The choice of variables was guided by an earlier survey of national experts and by the literatures on street and urban design.

From panoramic photographs, researchers determined:

- Average building height, in feet (10 ft per story)
- Average median width, in feet
- Average setback from curb to visible buildings, in feet
- Average shoulder width, in feet
- Average sidewalk width, in feet

- Average travel lane width, in feet
- Curb extensions visible, 1=yes, 0=no
- How well street pavement is maintained, subjective 1-5 scale
- Marked crosswalk visible, 1=yes 0=no
- Number of travel lanes
- Pedestrian-scaled streetlights, 1=yes, 0=no
- Posted speed limit, mph
- Proportion of street frontage with parking lots, vacant lots, and other dead spaces
- Proportion of street frontage with parked cars
- Proportion of street frontage with tree canopy
- Proportion of visible buildings that are commercial
- Proportion of visible buildings that are historic
- Ratio of building height to street width plus building setbacks
- Textured pavement visible, 1=yes, 0=no
- Total back-of-sidewalk to back-of-sidewalk width, in feet
- Total curb-to-curb width, in feet
- Underground utilities, 1=yes, 0=no
- Uniform building heights, subjective 1=yes, 0=no

From video clips, researchers determined:

- Number of moving vehicles visible
- Number of pedestrians visible

## **Results**

Figures B-2 through B-4 show a high rated scene, an average scene, and a low rated scene. Scenes were rated on a scale of 1 to 7.

Figure B-2. Washington Street, Hoboken (average score = 5.6)



Figure B-3. East Avenue (Route 40), Woodstown (average score = 4.2)



Figure B-4. Morris Avenue, Union Township (average score = 3.4)



Michael King

Many combinations of viewer and scene variables were tested to explain viewer ratings. The only available variables characterizing viewers—gender and affiliation (DOT or other)—proved to have no explanatory power. Apparently women and men, DOT employees and others, react similarly to street scenes. This is consistent with earlier

visual assessment literature revealing common environmental preferences across demographic groups (Stamps 1999).

By contrast, many of the variables characterizing scenes proved significant individually and in combination with each other. This again is consistent with the visual assessment literature. Altogether, 90 percent of the variation across scenes, and 39 percent of the overall variation in slide scores (including variation across viewers and measurement errors), were explained by the significant scene variables.

The variables in the best-fit equation related to land use context, facility design, and aesthetics. Land use context variables most clearly distinguished main streets from other roadways; facility design variables were nearly as important and can be manipulated by DOTs at the margin to make highways more main street-like; and aesthetic variables were included in the analysis to control for purely aesthetic influences on main street scores.

The statistically significant variables were:

- proportion of street frontage with parked cars at curbside – Curbside parked cars serve as a buffer between the sidewalk and street, and they slow traffic by narrowing the traveled way and creating "side friction" as cars pull in and out. This variable has the strongest influence on main street scores of those tested. The higher the proportion of parked cars, the higher the main street score.
- proportion of street frontage covered by tree canopy – Street trees add color, a sense of enclosure, a degree of complexity, and other valued urban design features to streetscapes. Given the emphasis on canopy in the variable definition, mature shade trees will add more value than younger shade trees or mature trees of other types. The higher the proportion of street frontage with tree canopy, the higher the main street score.
- curb extensions visible – Curb extensions provide space for plantings and street furniture, shorten crossing distances for pedestrians, make pedestrians more visible as they wait to cross, and may calm traffic. Only two of the scenes in the visual assessment study featured curb extensions, perhaps because curb extensions anywhere other than at intersections reduce the amount of curbside parking, another valued main street characteristic. Controlling for other variables, the presence of curb extensions increases the main street score.
- proportion of buildings that house commercial uses – In many viewers' minds, only shopping streets qualify as main streets. These viewers gave streets serving residential uses relatively low scores. However, other viewers scored residential streets as highly as commercial streets. So, while the scoring formula gives priority to commercial streets, the proportion of commercial buildings is only one factor among many in the formula.



- average sidewalk width – A few of the roadways in the sample lacked sidewalks altogether, and many had sidewalks of minimum width. Wider sidewalks are associated with a more extensive public realm and heightened pedestrian activity, essential qualities of great streets. The wider the sidewalks, the higher the main street score.
- number of travel lanes – Addition of travel lanes beyond the basic two is associated with higher speeds, more traffic, longer crossing distances for pedestrians, and more asphalt (an unaesthetic element). The association between number of travel lanes and main street scores is negative but relatively weak.
- proportion of street frontage made up of dead spaces – Dead spaces detract from the liveliness, walkability, and aesthetics of main streets. Counted as dead spaces in the content analysis were vacant lots, public parking lots, private parking lots separating commercial buildings from the street, driveways interrupting the continuity of street frontage, and blank walls. The higher the proportion of dead space in our sample of street scenes, the lower the main street score.

The other significant variables, underground utilities and quality of pavement maintenance, were included to control for purely aesthetic effects.

### **Omitted Variables**

After controlling for the preceding variables, the remaining variables proved insignificant. Many had the expected signs but fell below the conventional 0.05 significance level. These included (with partial correlation signs in parentheses):

- average median width (+),
- marked crosswalk visible (+),
- pedestrian-scaled street lights (+),
- proportion of visible buildings that are historic (+),
- textured pavement visible (+),
- total curb-to-curb width (-),
- uniform building heights (+),
- average shoulder width (-),
- average travel lane width (-),
- number of moving vehicles visible (-), and

- posted speed limit (-).

Certain context variables emphasized in the urban design literature did not perform as expected. For example, average building setback and ratio of building height to street width plus building setbacks are believed to affect the perception of streets as enclosed, positive spaces. The greater the building setback and the lower the height of buildings relative to the distance between them, the less well-defined street space becomes. Yet, average building setback and ratio of building height to street width plus building setbacks proved insignificant and actually had the "wrong" signs in various model runs, positive and negative signs, respectively. It is some consolation that one significant variable, the proportion of street frontage made up of dead spaces, accounts for parking in front of buildings and hence, to a degree, accounts for building setbacks.

## **Bus Stop Design**

The precursor to this manual, a transit-oriented design (TOD) manual prepared for the Florida Department of Transportation (FDOT), is based in part on a visual assessment survey of transit users, nonusers, and (for the sake of comparison) transit professionals. This may have been the first-ever application of visual preference survey methodology to transit facilities (for more details, see Ewing 2000).

Viewers were shown a series of paired slides of bus stops (50 pairs in all); slides were paired randomly to avoid the possibility of survey bias. Viewers were asked to choose the stop from each pair at which they would prefer to wait; asked to rate each stop chosen as a place to wait; and for the first 25 pairs, asked to explain why they chose the stops they did.

## **Viewers**

Survey participants were recruited by the Sarasota County (FL) Transportation Authority, Sarasota's local bus operator. Free transit passes were offered as an inducement to participate, and refreshments were provided as well. Two separate sessions were held to better accommodate participants' schedules.

## **Scenes**

Slides of downtown transit centers, transfer facilities, and bus shelters from around the state were shown at the midpoint of each session, and ratings and comments were solicited. However, for purposes of quantitative analysis, the "core" visual assessment survey was limited to one type of facility (bus stops) from one part of the state (South Florida). The stops selected for the survey represent the widest range possible from those available in South Florida. They were selected from many hundreds of bus stops photographed for the TOD manual. Sample selection was designed to maximize variance in attributes across bus stops.

All stops were photographed from the same angle and distance, near the curb and about 40 feet in front of the stop. This vantage point takes in the stop itself plus: (a) one side of the street up close and the entire streetscape in the distance; (b) the sidewalk and any cross streets on the bus stop's side; (c) the land use immediately to the rear of the stop; and (d) the background land uses for some distance. All slides were taken on sunny days to minimize any effect of weather conditions.

## **Variables**

Slides used in the survey were subsequently analyzed for content; features of the bus stops and their surroundings were measured/quantified for later use as explanatory variables. Three analysts worked together in an informal Delphi-like process. Each independently assigned a value to a feature. They then discussed values and rationales until a consensus was reached on assigned values. Nineteen variables were measured/quantified in this manner for each slide. The choice of variables was guided by the literatures on transit-oriented design, urban design, defensible space, and environmental preference. The variables tested were:

### Bus Stop Variables

- ADS = 1 if advertisement is present on bench and/or shelter; 0 otherwise
- BENCH = 1 if the bus stop has a bench but no shelter; 0 otherwise
- CARS = 1 if cars are parked in front of the bus stop; 0 otherwise
- CURB = 1 if the street has a vertical curb at the stop; 0 otherwise
- FURNITURE = number of different types of street furniture (newspaper boxes, telephones, etc.)
- INTERSECTION = 1 if the bus stop is located at an intersection; 0 otherwise
- RIDERS = number of users waiting at the stop
- SETBACK = distance from the bus stop to the street edge (in feet)
- SHADE = percentage of the bus stop area which is shaded
- SHELTER = 1 if the bus stop has a shelter; 0 otherwise
- TURNOUT = 1 if the bus stop has a turnout; 0 otherwise
- WINDOWS = 1 if windows overlook the bus stop; 0 otherwise

### Background Variables

- CROSSWALKS = total number of crosswalks visible in the background
- LANES = total number of traffic lanes of abutting street
- LIGHT = 3 if the background lighting is bright; 2 if it is average; 1 if it is dim
- PASSERSBY = number of people visible in the background
- SIDEWALK = 3 if the sidewalk leading to the bus stop is continuous; 2 if the sidewalk is intermittent; and 1 if there is no sidewalk
- TRAFFIC = number of cars clearly visible on the abutting street
- TREELINE = percentage of street frontage lined by trees
- MIXED = 1 if the background has mixed uses; 0 otherwise
- NEIGHBORHOOD = 1 if the background has houses fronting on the street; 0 otherwise
- OFFIND = 1 if the background has offices and/or industry; 0 otherwise
- PARKLIKE = 1 if the background is a park or park-like; 0 otherwise
- STOREFRONT = 1 if the background has stores fronting on the street; 0 otherwise
- STRIP = 1 if the background has stores fronting on a parking lot; 0 otherwise
- SUBDIVISION = 1 if the background has subdivisions backing up to the street; 0 otherwise

#### Viewer Variables

- PLACE = 1 if the viewer's place of residence is in the suburbs; 0 if it is in the city
- SEX = 1 if the viewer is a male; 0 if female

## Results

Examples of stops chosen by most viewers, and given high ratings when chosen, are shown in Figures B-5ab. Stops selected by few viewers, and given low ratings by those few, are shown in Figures B-6ab. Scenes were rated on a scale of 1 to 5.

Figures B-5. Most Preferred Scene



Times Selected = 89%  
Average Rating = 3.9

Figures B-6. Low Rated Scene



Times Selected = 27%  
Average Rating = 1.6

For all viewers combined, the variables that most increase the likelihood of a bus stop being chosen are (in order of declining significance based on "asymptotic" t-statistics):

- a bus shelter
- a bus bench (without a shelter)
- trees or an overhang shading the stop
- a vertical curb at the stop
- trees along the street leading to the stop

All of these variables are significant and positive for each of the three viewer groups. One additional variable—the presence of advertising on the shelter or bench—is significant and negative for each of the groups.

A slightly different set of variables affect the ratings of chosen bus stops. In this case, the most significant variables are (again, in order of declining significance):

- a bus shelter
- trees along the street leading to the stop
- the setback of the stop from the street edge
- location of the stop at an intersection
- a vertical curb at the stop

As a final measure of significance, five variables significantly affect (at the 0.001 level) both the choices and ratings of all viewers combined.

- a bus shelter
- trees along the street leading to the stop
- a vertical curb at the stop
- the setback of the stop from the street edge
- a continuous sidewalk leading to the stop

## Urban Design Qualities

The two preceding studies sought to explain viewer preferences in terms of physical features of scenes. A third study instead sought to explain viewer ratings on perceptual scales thought to affect walkability (see Chapter 2).

The methodology is described in detail elsewhere (Ewing et al. 2005b; Ewing et al. 2006; Ewing & Handy 2008). It is the basis for an illustrated field survey manual posted on the Active Living Research website (Clemente et al. 2005).

## Viewers

An expert panel was recruited for this study. It consisted of 10 urban design and planning experts from professional practice and academia. The 10 panel members were recruited from different disciplines and have different orientations (for example, some new urbanist, others not). They are leaders in their respective fields, and have intimate knowledge of urban design concepts from their research, teaching, and/or practice.

The 10 were *Victor Dover*, urban designer, Dover, Kohl & Partners Town Planning; *Geoffrey Ferrell*, urban designer/code expert, Geoffrey Ferrell Associates; *Mark Francis*,

landscape architect, University of California, Davis, CA; *Michael Kwartler*, architect/simulations expert, Environmental Simulation Center; *Rob Lane*, urban designer, Regional Plan Association; *Anne Vernez Moudon*, urban designer/planner, University of Washington; *Tony Nelessen*, urban designer, A. Nelessen Associates, Inc.; *John Peponis*, architect/space syntax expert, Georgia Institute of Technology, Atlanta, GA; *Michael Southworth*, urban designer, University of California, Berkeley, CA; and *Dan Stokols*, social ecologist, University of California, Irvine, CA

## **Scenes**

To ensure that reactions to street scenes were not biased by different filming techniques, a consistent filming protocol was developed. A great deal of experimentation and dialogue among the investigators went into the development of a protocol that would mimic the experience of pedestrians. Pedestrians are usually in motion, sway a bit as they walk, have peripheral vision, and tend to scan their environments. The protocol specified the starting point on a street block, walking speed, and panning motions; the distance covered and time length of the clips varied somewhat depending on actual walking and panning speeds but averaged between 1 and 1 ¼ minutes.

Working off a shoot list, more than 200 clips were filmed in dozens of cities across the United States. Diversity of street scenes was ensured by the different regional locations of the investigators and the travels of the investigators on other business during the course of the study. The focus was on commercial streets in urban or “main street” settings – all places with sidewalks and other pedestrian amenities such as landscaping, pedestrian lighting, street furniture, and businesses or public spaces within view.

From the larger set, 48 clips were selected that best matched the combinations of high/low values in a fractional factorial design. Following the design as closely as possible resulted in the selection of clips that were distinctly different.

## **Variables**

To measure physical features of streetscapes, all 48 video clips were analyzed for content. All told, more than 130 features were measured in this manner for each scene. The process typically required more than an hour for each video clip, and much more for the more complex scenes. Detailed operational rules for measuring each physical feature were developed to ensure consistency.

For most features, there was almost perfect agreement or substantial agreement among the team members. It is relatively easy to count objects and measure widths. Several features had low or even negative inter-rater reliability values. Of these, features such as the number of landscape elements could probably be rated more consistently with better operational definitions. Other features, such as landscape condition, involve a high degree of judgment and might require training and/or photographic examples to achieve reasonable inter-rater reliability.



## Results

Figures B-7 through B-10 are static images from four of the video clips, illustrating variation in urban design qualities. Clips were rated by our expert panel on a scale that represented low to high levels of each quality (1 to 5).

Figure B-7. Scene Rated High on All Urban Design Qualities (Annapolis, MD)



Figure B-8. Scene Rated High on Imageability, Linkage, and Coherence (Washington, D.C.)



Figure B-9. Scene Rated High on Enclosure, Transparency, and Complexity (San Francisco, CA)



Figure B-10. Scene Rated Low on All Urban Design Qualities (Rockville, MD)



Expert panel ratings were used as dependent variables in the estimation of statistical models. The physical characteristics of the street environment were the independent variables. The models provided several important bits of information: which physical characteristics are statistically associated with each perceptual quality; the direction of the association, whether positive or negative; the share of variation in ratings of each perceptual quality across the scenes explained by the physical characteristics in the model; and the share of total variation in ratings (including variation across video clips, expert panelists, and measurement error) explained by the model.

The following discussion covers eight urban design qualities. Five of the eight urban design qualities were operationalized with a degree of validity and reliability deemed adequate for future research. The five are: imageability, enclosure, human scale, transparency, and complexity. Our operational definitions do not always comport with the qualitative definitions, and provide new insights into the nature of these urban design qualities.

Of more than 130 physical features tested, 38 proved significant in one or more models (including models of legibility, linkage, and coherence). Seven features were significant in two models: long sight lines, number of buildings with identifiers, proportion first floor façade with windows, proportion street wall, common tree spacing and type, and number of pieces of public art. Two features were significant in three models: number of people in a scene and presence of outdoor dining.

### **Imageability**

*Previous Attempts to Operationalize.* Beyond Kevin Lynch's detailed qualitative characterizations, we could find no attempts to operationalize imageability either in visual assessment studies or design guidelines.

*Operational Definition.* An imageability model was derived from expert panel ratings and a content analysis of scenes. The final model differs slightly from that reported previously (Ewing et al. 2005b). Based on field experience, the number of people visible in a scene, including those standing and sitting, was substituted for the number of moving

pedestrians. Features contributing significantly to the perception of imageability are (in order of significance):

- number of people (+)
- proportion of historic buildings (+)
- number of courtyards, plazas, and parks (+)
- presence of outdoor dining (+)
- number of buildings with non-rectangular silhouettes (+)
- noise level (-)
- number of major landscape features (+)
- number of buildings with identifiers (+)

The significance of the number of people and outdoor dining points to the importance of human activity in creating imageable places. The lack of significance of landmarks, memorable architecture, and public art forces us to rethink just what makes a place memorable. This model is strong with respect to validity and reliability (see Ewing et al. 2005b; Ewing et al. 2006).

## **Enclosure**

*Previous Attempts to Operationalize.* The visual assessment literature suggests that enclosure is an important factor in human responses to environments, and that solid surfaces are the important variable in impressions of enclosure. Using photographs of Paris, Stamps and Smith (2002) found that the perception of enclosure is positively related to the proportion of a scene covered by walls, and negatively related to the proportion of a scene consisting of ground, the depth of view, and the number of sides open at the front. These results were confirmed in later visual simulations (Stamps 2005).

Enclosure is defined both qualitatively and quantitatively in many urban design guidelines and several land development codes. The qualitative definitions sometimes capture the multi-faceted nature of the concept, for example, Denver, CO's: "Building facades should closely align and create a continuous facade, punctuated by store entrances and windows. This produces a comfortable sense of enclosure for the pedestrian and a continuous storefront that attracts and encourages the pedestrian to continue along the street" (City of Denver 1993).

However, when it comes to operationalizing the concept of enclosure, urban design guidelines tend to limit themselves to one aspect of enclosure, the relationship between

street width and abutting building heights. Guidelines from the Raleigh, NC, illustrate this limited approach:

The condition of enclosure generated by the height-width ratio of the space is related to the physiology of the human eye. If the width of a public space is such that the cone of vision encompasses less street walls than the opening to the sky, then the degree of spatial enclosure is slight. A 1:6 height-to-width ratio is the minimum for appropriate urban spatial definition. An appropriate average ratio is 1:3. As a general rule, the tighter the ratio, the stronger the sense of place (City of Raleigh 2002).

Maximum setback limitations in certain zoning districts of progressive jurisdictions (for example, New York, Seattle, and San Francisco) seem aimed in part at creating a sense of street enclosure. Likewise, required building lines (build-to requirements) in the new form-based codes may have this purpose (Arlington, VA; Woodford County, VA; Pleasant Hill BART Station Property Code).

*Operational Definition.* Based on expert panel ratings and a content analysis of scenes, features contributing significantly to the perception of enclosure are (in order of significance):

- proportion street wall—same side of street (+)
- proportion street wall—opposite side of street (+)
- proportion sky—across street (-)
- number of long sight lines
- proportion sky—straight ahead (-)

The signs of the coefficients in the model are as expected, with long sight lines, proportion of the view ahead that is sky, and proportion of the view across the street that is sky detracting from the perception of enclosure. A more continuous “street wall” of building facades, on each side of the street, adds to the perception of enclosure. This model suggests that enclosure is influenced not just by the near side of the street but also by views ahead and across the street. Surprisingly, the average street width, average building setback, average building height, and relationship between the width of the street and building height were not significant. This model is strong with respect to validity and reliability (see Ewing et al. 2005b; Ewing et al. 2006).

## **Human Scale**

*Previous Attempts to Operationalize.* Land development ordinances and urban design guidelines occasionally make reference to human scale as a desirable quality. Davis CA’s define human scale in qualitative terms: “The size or proportion of a building element or space relative to the structural or functional dimensions of the human body.

Used generally to refer to building elements that are smaller in scale, more proportional to the human body, rather than monumental (or larger scale)” (City of Davis undated).

A few ordinances get more specific, for example, Placer County, CA’s:

The relationship of a building, or portions of a building, to a human being is called its relationship to “human scale”. The spectrum of relationships to human scale ranges from intimate to monumental. Intimate usually refers to small spaces or detail which is very much in keeping with the human scale, usually areas around eight to ten feet in size. These spaces feel intimate because of the relationship of a human being to the space... The components of a building with an intimate scale are often small and include details which break those components into smaller units. At the other end of the spectrum, monumental scale is used to present a feeling of grandeur, security, timelessness, or spiritual well being. Building types which commonly use the monumental scale to express these feelings are banks, churches, and civic buildings. The components of this scale also reflect this grandness, with oversized double door entries, 18-foot glass storefronts, or two-story columns (Placer County 2003).

There has been only one previous attempt to operationalize human scale via a visual assessment survey, and this strictly with respect of architectural massing (Stamps 1998). The most important determinant was the cross sectional area of buildings, second was the amount of fenestration, and third was the amount of façade articulation and partitioning.

*Operational Definition.* The best-fit human scale model differs slightly from that reported previously (Ewing et al. 2005b). Based on our field experience, the number of pieces of street furniture and other miscellaneous items was substituted for a more limited set of street items. Features contributing significantly to human scale are (in order of significance):

- number of long sight lines (-)
- number of pieces of street furniture and other miscellaneous items (+)
- proportion first floor with windows (+)
- building height (-)
- number of small planters (+)

The signs of the coefficients are in the expected direction. Human scale is the only quality for which characteristics of viewers proved significant in our expert panel ratings: urban designers tended to rate scenes higher than did other panel members. This model is strong with respect to validity and reliability (see Ewing et al. 2005b; Ewing et al. 2006).

## Transparency

*Previous Attempts to Operationalize.* Transparency is the urban design quality most frequently defined in urban design guidelines and land development codes. Some definitions of transparency are strictly qualitative. Others get quantitative. The concept is operationalized almost always in limited terms of windows as a percentage of ground floor façade. San Jose's operational definition is typical:

Transparency: A street level development standard that defines a requirement for clear or lightly tinted glass in terms of a percentage of the façade area between an area falling within 2 feet and 20 feet above the adjacent sidewalk or walkway (City of San Jose 2004).

*Operational Definition.* The three contributors to perceptions of transparency (in order of significance) are:

- proportion first floor with windows (+)
- proportion street wall-same side of the street (+)
- proportion active uses (+)

The signs of the coefficients are in the expected direction. The model confirms but expands the standard approach to operationalizing transparency. It suggests that both being able to see into buildings and having human activity along the street contribute to the perception of transparency. Note that windows above ground-level do not increase the perception of transparency (after controlling for other variables). This model is strong with respect to validity and reliability (see Ewing et al. 2005b; Ewing et al. 2006).

## Complexity

*Previous Attempts to Operationalize.* Complexity is one perceptual quality that has been measured extensively in visual assessment studies. It has been related to changes in texture, width, height, and setback of buildings (Elshestaway 1997). It has been related to building shapes, articulation, and ornamentation (Stamps 1999; Heath et al. 2000).

*Operational Definition.* In order of significance, contributors to complexity are:

- number of people (+)
- number of dominant building colors (+)
- number of buildings (+)
- presence of outdoor dining (+)
- number of accent colors (+)

- number of pieces of public art (+)

The signs of the coefficients are in the expected direction. The significance of pedestrians and outdoor dining suggests that human activity may contribute as much to the perception of complexity as do physical elements. The lack of significance of several other variables is notable: number of building materials, number of building projections, textured sidewalk surfaces, number of street lights and other kinds of street furniture, among others. This model is strong with respect to validity and reliability (see Ewing et al. 2005b; Ewing et al. 2006).

### **Coherence**

*Previous Attempts to Operationalize.* Achieving coherence (often termed compatibility) may be the overriding purpose of urban design guidelines and standards. As the City of Glendale, California, puts it: “The purpose of the design review process is to ensure compatibility and a level of design quality acceptable to the community.”

In visual assessment studies, the coherence of scenes is frequently assessed by individual raters. The judgments tend to be very consistent/reliable across raters. Two studies have gone on to relate coherence to physical characteristics of scenes. Nasar and Stamps (2009) found that streets were rated as more coherent if infill houses had a style considered compatible with the surrounding styles (based on previous ratings of style compatibility). Streets were also rated as more coherent if the infill house was not more than roughly twice as large as other houses on the street. Previously, Nasar (1987) had found that viewers prefer street scenes with signage that is moderately complex and highly coherent. Coherent signage has a consistent vocabulary of heights, sizes, shapes, materials, colors, and lettering. If signs have enough characteristics in common, the street scene will appear orderly, logical, and predictable to pedestrians strolling by. If not, it will appear messy.

*Operational Definition.* In order of significance, contributors to coherence are:

- common window proportions (+)
- number of people (+)
- common tree spacing and type (+)
- number of pedestrian-scale street lights (+)

Two of the variables have strong conceptual connections to coherence: common window proportions and common tree spacing and type. Connections to the other two variables are less obvious. Pedestrian scale street lights are always of uniform style and size and unify scenes visually to a surprising degree. Pedestrians become a dominant and relatively uniform element as their numbers increase. Other conceptually important variables are missing from the model, including common architectural styles and common building masses.

## **Legibility**

*Previous Attempts to Operationalize.* Only one visual assessment study has attempted to measure legibility, this in connection with natural rather than urban landscapes (Herzog and Leverich 2003). Legibility was highly correlated with another perceptual quality, coherence. The hypothesized relationship to landmarks proved to be weak.

*Operational Definition.* In order of significance, contributors to legibility are:

- terminated vista (+)
- number of buildings with identifiers (+)
- common tree spacing and type (+)
- memorable architecture (+)
- number of place/building/business signs (+)
- number of pieces of public art (+)

The number of buildings with identifiers and the number of signs have obvious conceptual connections to legibility; the significance of common tree spacing and memorable architecture is less easily explained but may be related to the ability to place the street in a larger spatial context. The set of variables in the model also has conceptual connections to imageability, suggesting that panelists may have had difficulty distinguishing between these two concepts.

## **Linkage**

*Previous Attempts to Operationalize.* We could find no attempts to operationalize linkage in visual assessment studies or design guidelines (except those relating to sidewalk connections).

*Operational Definition.* In order of significance, contributors to linkage are:

- common building heights (+)
- number of visible doors (+)
- number of street connections (+)
- presence of outdoor dining (+)
- proportion recessed doors (+)



The significance of recessed doors, outdoor dining, and common building heights suggests the importance of psychological as well as physical connections between buildings, sidewalks, and streets.

## Appendix C: What the Hedonic Price Literature Tells Us<sup>3</sup>

Theoretically, if the market values pedestrian- and transit-oriented design, as suggested by the survey literature outlined in Chapter 1, that valuation should be reflected in the price people are willing to pay to live in well-designed places. In the words of the economist, pedestrian- and transit-friendly design features should be capitalized in the purchase or rental price (Landis, Guhathakurta & Zhang, n.d.). Characteristics such as land use mix (Cao and Cory 1981; Song and Knaap 2004), street pattern (Guttery 2002), municipal amenities (Shultz and King 2001; Benson et al 1998), proximity to transit stations and commercial centers (Bowes and Ihlanfeldt 2001; Song and Knaap 2004), etc. have been shown to affect the value of residential properties located nearby.

### Hedonic Price Analysis

The most commonly used method for assessing the impacts of urban conditions on the price of real estate is the “hedonic” model developed by Rosen (1974). Hedonic models are based on the intuitive understanding that the value of a piece of real estate is not monolithic nor completely intrinsic to the property itself, but is the result of a multitude of characteristics, many of which come from the context in which the property is situated (Kestens, Theriault & des Rosiers 2004). Each of those characteristics adds or detracts from the property’s overall total price according to how buyers in the market value that characteristic. To understand the relative influence of these characteristics, a typical hedonic price study will use sales data for a large number of real estate transactions across a wide range of development conditions to tease out the amount that buyers are willing to pay for the individual features that make up the total price for a piece of real estate (Can 1990, 1992; Dubin 1998).

The method incorporates several underlying assumptions that have been the basis for some criticism (e.g., Wilhelmsson 2000). First, construing the marginal price of a particular characteristic as the willingness of buyers to pay for that characteristic assumes that the real estate market is in equilibrium—that for each seller of real estate in a particular market there is a buyer. This is never the case. In any market, demand and supply change rapidly, with sometimes more buyers than sellers and at other times the reverse condition. Second, hedonic methods implicitly assume possession of complete information on the nature of the characteristics important to the value of real estate by all sellers and all buyers. This, too, is almost never the case: buyers are nearly always at an information disadvantage. The midnight braying of a neighbor’s beagle, with which the seller is all too familiar, will very likely not be known by potential sellers. Nevertheless, despite these problems, hedonic analysis’s reliance on empirical data provide it with a

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<sup>3</sup> This appendix is taken from Bartholomew, K. and Ewing, R. (2011). Hedonic price effects of pedestrian- and transit-oriented development, *Journal of Planning Literature*, 26(1), 18-34.

strength missing from alternative methods that largely rely on stated preference survey data (Federal Transit Administration 2000; Tajima 2003; Whitehead, et al. 2008).

The characteristics included as explanatory variables in hedonic models are of two basic types—those related to structures built on the land and those related to the land itself (Bowes & Ihlaneldt 2001; Fujita 1989; Debrezion, Pels & Rietveld 2007). In the case of residential hedonic studies, which are the most common type, structural attributes often include features such square footage of living, number of bedrooms and bathrooms, presence of a garage, the age of the house, the presence of a pool, and other features known to influence sales transactions. Characteristics related to the land, apart from the structure, are frequently further separated into attributes related to the land's location and those related to the environment surrounding the land. Locational attributes will often include distance from a regional central business district or other commercial hub, distance to parks, transit stations, and other amenities, distance to airports, landfills, heavy manufacturing and other disamenities, and location in particular neighborhoods. Environmental attributes will sometimes include measurements of noise and air pollution, crime rates, and density of development. Another way to categorize non-structural attributes that is more aligned with the purpose of this chapter is to group them into access-related characteristics and amenity-related characteristics.

## **Access-Related Price Effects**

The old adage about real estate being about location, location, location, is really a statement about the role that accessibility plays in the development potential of property and, hence, its value. Any discussion about the urban economic influence of accessibility invariably starts with the work of Johann von Thünen, who in 1863 theorized about the value of farm land as a function of the land's relative proximity and, thus, its accessibility to the market place. The closer (and more accessible) the land, the higher the value. Assuming equal levels of soil productivity, as values rise, farmers are induced to plant crops that yield higher returns per unit of land. Thus, accessibility to the market place not only influences the relative price of land, but also the intensity to which the land is used. Later work translated von Thünen's work beyond the farmland context to other types of land use categories, showing similar relationships between accessibility, property value, and development intensity (Alonso 1964; Mills 1967; Muth 1969). The function laying behind these relationships is the relative market attractiveness of a given piece of land. As land becomes more accessible, its perceived usefulness as a location for business or residential activity increases, leading to increased demand for the land, which raises its value and induces the ultimate land developer/user to use the land more efficiently by increasing the development intensity (Landis & Huang 1995).

## **Proximity to the CBD**

Traditionally, these relationships between accessibility, property value, and land use intensity have been explained by physical proximity to a city's or region's central business district (CBD). Because CBDs have, at least historically, been the areas with the greatest accessibility to the largest number and variety of activities, land values were

observed to be inversely proportional to distance to the CBD—the shorter the distance to the CBD the higher the land values, and vice versa. The reason for this effect is sourced in transportation and convenience costs associated with accessing various locations. Because central locations are highly accessible, the transportation and convenience costs of getting to and from those locations are lower compared to other locations in a region. This increases demand for central locations, thereby driving up the price. On the other hand, more distant locations are generally less accessible, meaning that their transportation and convenience costs are higher, which reduces the demand for those locations and, hence, the price (Fujita 1989).

Although these effects have been reduced somewhat by the replacement of the pre-1950s single-centered metropolitan pattern with a modern multi-centered form (Anjomani & Chimene 1982), they are still observable, particularly in older metro regions that retain some of their mono-centric past. A 1997 analysis of the price effects of agricultural open space in the Washington, DC region, for example, shows a 1.7% decrease in the sales prices of single-family homes for every 10% increase in the distance from DC, all other things being equal (Geoghegan, Wainger & Bockstael 1997). Similar relationships have recently been observed in London (Gibbons & Machin, 2008), Quebec (Kestens, Theriault, des Rosiers 2004), Dallas (Peiser 1989), Bangkok (Chalermpong 2007), Atlanta (Bowes & Ihlanfeldt 2001). As might be expected, the higher land costs associated with central locations usually translates into greater development density in such locations (Hansen 1959; Peiser 1989; Wassmer & Baass 2006). Hence, central locations not only benefit from the destination accessibility effects on travel behavior outlined in Chapter 3, but also from higher density and, not infrequently, other “D” variables that tend to co-locate.

Figure C-1. Proximity to the CBD (Charlotte, NC)



Dan Burden

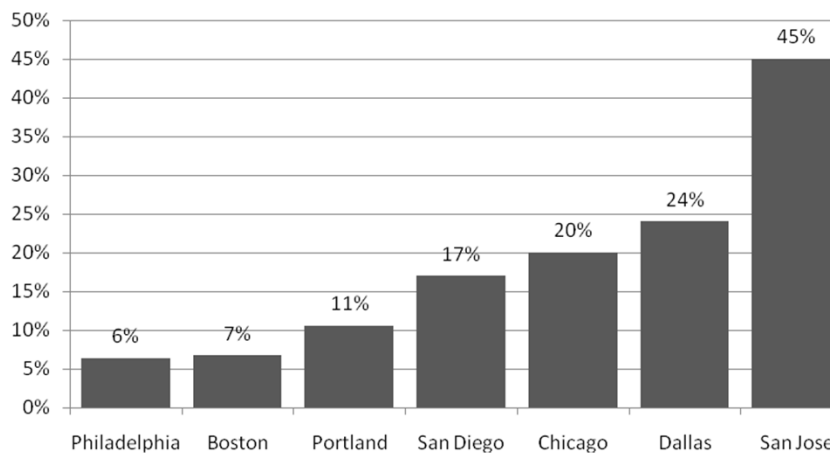
### **The Transit Effect**

The introduction of transit service to an area increases travel options for residents and employees of the area and can reduce travel times to the CBD and other activity centers,

particularly if the service operates in its own right of way (Fejarang 1994). This has the net effect of increasing the relative accessibility of that area compared to other areas at the same distance from the CBD/activity centers but without transit (Baum-Snow & Snow 2000). In theory, the increase in relative accessibility translates into increased development potential and land values (Hess & Almeida 2007; Nelson 1992, 1999; Nelson & McClesky 1990).

Results from empirical studies of these relationships are varied and at times contradictory. The majority of the evidence, however, points to the introduction of transit facilities leading to enhanced land values, as the theory predicts (Bowes & Ihlanfeldt 2001). Most of the studies use some continuous measure of distance to the transit platform, either as the crow flies or actual walking distance, as the primary explanatory variable, while controlling for structural and other locational variables (Landis, Guhathakurta & Zhang, n.d.). Some studies make simpler assessments by comparing prices of real estate located within a certain cordon around a transit station (e.g., ½ mile) with real estate outside that cordon. The extensiveness of the literature is now so vast that even the literature reviews are becoming numerous (Anas 1982, 1983; Cambridge Systematics 1998; Cervero, Ferrell & Murphy 2002; Cervero et al. 2004; Huang 1994; Knaap 1998; Landis & Huang 1995; Parsons Brinckerhoff 2001; Ryan 1999; Smith & Gihring 2004; Vessali 1996). Cervero's 2004 review synthesizes studies completed since 1993, showing price premiums for housing located within a ¼ to ½ mile radius of rail transit stations of between 6.4% and 45%, compared to comparable housing outside of the station areas (see Figure C-2). The same review shows premiums for commercial property values ranged from 8% to 12% along Denver's 16<sup>th</sup> Street Mall to 40% for the area surrounding Dallas' Mockingbird light rail station.

Figure C-2. Percent price premium for housing in transit station area vs. non-station areas.



Source: Cervero et al. (2004)

Figure C-3. Premium for Commercial Property on the 16<sup>th</sup> Street Transit Mall (Denver, CO)



Dan Burden

Not all of the studies show such strong value/transit relationships, and in a small number of cases the data indicate a negative relationship (i.e., proximity to the transit station results in a price penalty). In an effort to rationalize the wide ranging results, Debrezion, Pels, and Rietveld (2007) conducted a meta-analysis that used data drawn from multiple studies, giving them 57 transit/property value observations. The conclusion from their regression analysis is that transit proximity still matters, with residential property values increasing 2.4% for every 250 meters closer to a station and commercial properties increasing 0.1% for every 250 meters. The effects are greater for stations served by commuter rail than for those served by heavy rail. In the case of bus rapid transit stations, the data show a price discount for nearby properties. These results are, in all likelihood, conservative estimates, given the number of potentially confounding factors that could not be controlled for, including housing types, local real estate market conditions, possible negative disamenities (e.g., crime and noise), and whether other complementary TOD planning strategies were being used (e.g., pedestrian-oriented street design, mixed-use zoning).

Some of these factors are being teased out in some of the more recent studies. Consistent with Debrezion et al., Cervero and Duncan (2002) show that price premiums for commercial property vary with the degree of regional access provided by different transit technologies. Using the San Jose, California area, which is served by both commuter and light rail, they show that downtown properties within a ¼ mile of a station in the regional commuter rail system commanded a \$25 per square foot premium, while downtown properties within a ¼ mile of a station for the city-wide light rail system showed only a \$4/sq. ft. advantage. The effects of differing levels of transit service and regional access are further demonstrated in Debrezion, Pels, and Rietveld's 2011 analysis of Amsterdam, Rotterdam, and Enschede. Duncan (2008), in his analysis of the San Diego light rail system, shows that the "rail proximity premium" for multi-family housing is three times (16.6%) than that for single family housing (5.7%), supporting the notion that buyers in

the condominium market have a stronger demand for transit access than buyers of single-family homes.

In his assessment of the light rail system in Buffalo, New York, where both population and transit ridership are declining, Hess (2007) shows that the price advantages of transit-served properties appear to withstand adverse market conditions. Bowes and Ihlanfeldt (2001) demonstrate that, at least with heavy rail systems, there can be a “disamenity zone” close to the station where noise and potential crime effects offset the transit accessibility benefits. Their findings show that properties within the first ¼ mile of a MARTA station in Atlanta had a 19% discount compared to properties more than three miles away, while properties within 1 to 3 miles of the station had a significant price bonus. Similarly, Landis et al. (n.d.) show that residential properties outside of downtown San Jose and within 300 feet of the same commuter rail line observed in Cervero and Duncan had a discount of as much as \$51,011. Goetz, et al. (2010) show that proximity to light rail tracks can have a similar disamenity effect on residential prices, but at a much lower level, perhaps reflecting light rail’s lower noise and vibration levels. Moreover, the disamenity effect—starting at \$-16 for every meter closer to the tracks—is, in most cases, outweighed by positive accessibility benefits—which start at \$30 for every meter closer to a light rail station.

In a study of the new Phoenix light rail system, Atkinson-Palombo (2010) show distinct impacts of TOD zoning, apart from the accessibility effects of the transit system. In single-use residential neighborhoods, the imposition of TOD zoning had a negative effect on real estate prices, whereas the TOD zoning brought an addition 37% premium to condos located in mixed-use areas.

As outlined above, theory would predict that the increased property values in transit station areas would translate into higher intensity/higher value development projects. Evidence from the land use and transit development history of the London region supports the theory, showing that as the network of surface and underground transit facilities were constructed over a 150-year period, the residential densities of the station areas outside the central core increased, while the commercial densities proximate to core area stations also increased (Levinson 2008). Another leading example of this effect is the Pearl District, near downtown Portland, Oregon where the city constructed a new streetcar line in 1997 (City of Portland 2008). Before the streetcar was built, development in the area was constructed at less than half the density (as measured by floor-area-ratio (FAR)) that was allowed by zoning. Projects built since 1997, however, have been constructed at 60% to 90% of the allowable density (see Figure C-5). To date, more than \$3.5 billion in private capital has been invested within the two blocks of the streetcar alignment, including more than 10,000 units of new housing and 5 million square feet of commercial space.

Figure C-4ab. Investment in the Pearl District (Portland, OR)

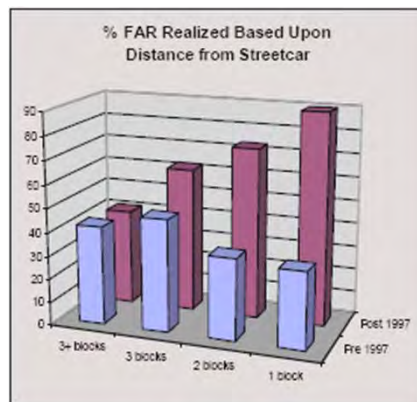


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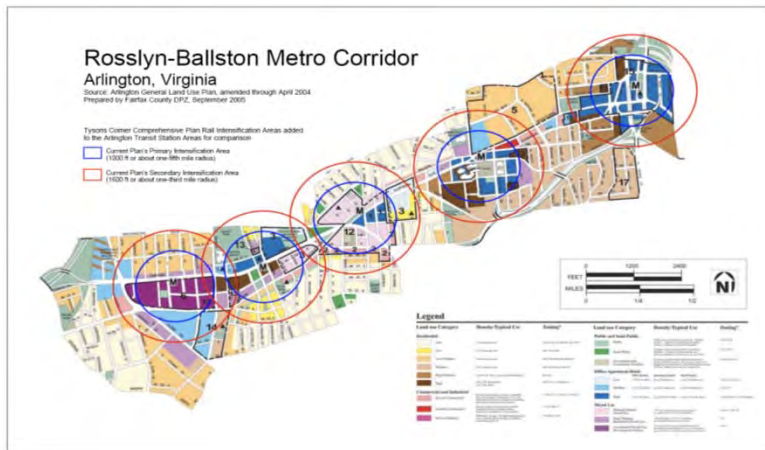
**Figure C-5. Percent of allowable density constructed within 3+ blocks of the Portland, Oregon streetcar line—pre-streetcar (pre-1997) vs. post-streetcar (post-1997) (City of Portland, 2008).**





Another example is the Rosslyn-Ballston corridor of Arlington County, Virginia, which includes five stations along the Washington Metrorail system's Orange Line. In the 1960s, this corridor was characterized by failing low-density strip-malls, but by 2004, the corridor had become host to more than 58 million square feet of new commercial and residential development (Fairfax County 2005). Planning for the corridor's station areas, which began well before the Orange Line's opening in 1979, focuses high-intensity development in Primary Intensification Areas that include lands within 1000 feet of each station. Secondary Intensification Areas, running from 1000 to 1600 feet of the station, step down density levels in stages, both to facilitate blending with surrounding neighborhoods and to help focus the market for high-density development in the primary areas (see Figure C-6).

**Figure C-6. Plan for the Rosslyn-Ballston Metrorail Corridor, Arlington, Virginia.**



By 2004, development in these planning areas had resulted in the construction of more than 21 million square feet of office space (plus another 2 million approved), 2.8 million square feet of retail space, and 26,000 units of housing (see Table C-1). As with Portland's Pearl District, the Rosslyn-Ballston Corridor shows how the accessibility advantages provided by a transit investment can, when supported by appropriate planning and zoning, result in higher intensity/higher value developments.

Source: Fairfax County (2004).

Another phenomenon suggested by the Arlington example is the tapering off of the accessibility-related property value impacts as the transit station distance from the CBD increases. Zoning around the Rosslyn station—the closest station in the corridor to the Washington, D.C. CBD—generally allows for floor-area ratios (FARs) of 3.8 to 4.8. In recent years, however, the county board has allowed denser projects to be built, some of which are as high as 9.9 FAR. This has effectively bumped up the average FAR of development constructed or permitted in the station area to 1.78, which is 23% higher than the built FAR in the next station area in the corridor (Courthouse) and 36% higher than the corridor average. Studies of other Metrorail station areas show a similar effects: the further a station is from the CBD, the lower the property value, other things being equal (Federal Transit Administration 2000). These findings comport to theory-based expectations, which posit that the capitalization of accessibility benefits in transit station area property values is not only a function of a property’s proximity to a station, but also the station’s proximity to the center of the region. Similar studies in other metropolitan areas confirm these expectations (Bowes & Ihlanfeldt 2001; Cervero & Duncan 2002; Chalermpong 2007; Debrezion, Pels & Rietveld 2007; Pan & Zhang 2008).

## **Amenity-Related Price Effects**

Most of the hedonic price studies cited in the previous section focused on the accessibility benefits of transit-oriented development (TOD), not on the pedestrian design and mixed-use attributes that are commonly understood to be central to the TOD concept.<sup>4</sup> In fact, very few studies have sought to separate out the effect of TOD design/mixed-use amenities on real estate prices, apart from the transit accessibility benefits. Mindful of the distinction now recognized between transit-*oriented* development and transit-*adjacent* development,<sup>5</sup> the differences in real estate price effects between accessibility- and amenity-based benefits are important. As has been noted, the failure to make those distinctions in past studies may have confounded, in part, assessments of presumed TODs.

## **Pedestrian Design in Transit Station Areas**

Probably the first hint that the design components in TOD are important comes from studies suggesting that the construction of transit—even high-capacity heavy rail—into auto-oriented suburban environments without supportive transit-oriented design, planning, and zoning provisions has a negligible effect on station area land use

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<sup>4</sup> The Maryland Transit Administration defines *transit-oriented development* as “a relatively high-density place with a mixture of residential, employment, shopping, and civic uses located within an easy walk of a bus or rail transit center. The development design gives preference to the pedestrian and bicyclist” (Cervero, et al., 2004, p. 6).

<sup>5</sup> *Transit-adjacent development* (TAD) is variously defined as “conventional single-use development patterns, with conventional parking requirements” (Cervero, et al., 2004) and “development that is in close proximity to transit, but with a design that has not been significantly influenced by it” (CalTrans, 2000).

development. Landis and Zhang's (1995) evaluation of suburban station areas in the San Francisco Bay Area BART system showed that sites closer to the stations were *less* likely to be developed than sites further away. This finding was true for both the period of time when BART was under construction (1965-75), as well as the system's first 15 years of operation (1975-1990). In the same study, Landis and Zhang analyzed station areas along the San Diego Trolley, finding that although sites closer to those stations were more likely to have been developed than sites further away, the effect was weak, leading the authors to conclude: "neither BART nor the San Diego Trolley has had a significant effect on land-use patterns in their immediate station areas" (p. 79). One of the compelling reasons the authors cite for the outcome is the presence of significant institutional barriers to change, including a lack of supportive local government planning and zoning provisions. Bollinger and Ihlanfeldt (1996) and Gatzlaff and Smith (1993) make similar findings with respect to Atlanta's MARTA rail system and Miami's Metrorail, respectively. These findings are further bolstered by Atkinson-Palombo's analysis (2010), outlined above, of the independent impacts that TOD zoning has on real estate prices.

#### Figure C-7. One Station Area that Has Developed (Pleasant Hill, CA)

Another strand suggesting an independent effect of the non-transit dimensions of TOD is the variation in real estate price effects between "park and ride" and "walk and ride" transit stations. The former are, at least in American practice, almost uniformly auto-oriented in their designs, while the latter are more likely to be pedestrian-oriented. In his extensive study of gentrification trends in transit station areas across 14 metropolitan areas, Kahn (2007) shows that, over a 10-year period, the prices of homes in park and ride station areas suffer a 1.9% price decrease, while those in walk and ride station areas enjoy a 5.4% increase. Over 20 years, the walk and ride premium increases to 10.8%. Bowes and Ihlanfeldt (2001) show a similar effect in their study of Atlanta's MARTA system. The price of homes located between ½ and one mile of a park and ride MARTA station demonstrate a 1.4% discount, while homes more than three miles from a park and ride station show a 4.7% price premium. These results suggest that for close-in residents the disamenity of being near a parking lot (that they probably do not need to use to access the transit system) outweighs the accessibility benefits of the transit service itself. On the other hand, the more distant residents are able to enjoy the benefit of using the parking lot to access the transit system, while being located far enough away to not feel the downside of living proximate to a large parking facility. Atkinson-Palombo's study (2010) of Phoenix shows comparable results on this issue as well.

These findings are bolstered by Goetz, et al.'s (2010) study of the Hiawatha light rail line in Minneapolis, which shows substantial differences in residential prices between properties on the west side of the rail line—which have direct access to station platforms—and those on the east side—which are separated from the stations by an arterial and industrial buildings. In the west side station areas, condos and single-family houses receive price premiums of \$350 and \$45 per meter of proximity to station platforms, respectively. On the east side, however, the disamenity effects of the arterial and industrial uses overwhelm the transit accessibility benefits. Interestingly, because the

researchers make calculations both before and after the construction of the rail line, they are able to identify a moderating of the negative impacts from the arterial and industrial uses as a result of transit accessibility. In other words, having transit nearby, while not overcoming the negative attributes on the east side neighborhoods, makes them less onerous.

## **Mixed-Uses**

As outlined above, the presence of a relatively high degree of mixed land uses within a walkable area is central to most definitions of TOD, as well as to other related development concepts such as Smart Growth and New Urbanism (Congress for the New Urbanism 1996; Smart Growth Network 2009). From a planning perspective, the principle reason for mixing uses is to provide the residents and workers in a neighborhood with easy access to at least some of the destinations that comprise a typical daily itinerary, such as employment, housing, schools, shopping, local services, and cultural and recreation facilities. This increase in proximity and convenience has been linked to smaller daily activity spaces, shorter daily travel distances, lower average vehicle trip rates, and fewer total vehicle miles of travel (Ewing & Cervero 2001; Fan & Khattak 2008). Logically, the increased convenience should also find favor in real estate markets. Anecdotally, we observe this logic when we read real estate ads that list things like “close to shopping” and “easy walk to elementary school” as positive features. We should then expect to see these advantages capitalized in the prices of properties within or close to a mixed-use environment. There is evidence that this is the case, although the literature on the question is sparse.

One of the early studies in this area is Grether and Mieszkowski’s (1980) analysis of the impacts of non-residential land uses on the prices of nearby housing. Their objective was not to assess the effects of mixed-use development, per se, but to test one of a central assumption for modern, single-use zoning—that allowing non-single-family residential uses within single-family neighborhoods suppresses the value of the homes in those neighborhoods. To test the assumption, the authors conducted 16 “experiments” using hedonic methods to assess price impacts on single-family homes located in homogeneous neighborhoods within ¼ mile of a variety of non-single-family residential uses, including an elevated highway, garden apartments, public housing projects, light industrial areas, strip commercial areas, and neighborhood commercial districts. Of the 16 areas tested, proximity to the non-residential uses was statistically significant at the 0.01% level in only 3 areas, suggesting that proximity to non-residential uses has little effect on home prices. Of the 3 significant tests, two showed proximity (to an industrial district and a public housing project) had a discount effect. The other test, however, showed proximity to neighborhood commercial to have a positive price effect. Cao and Cory (1981) make similar findings in their analysis of Tucson, Arizona.

**Figure C-8. Neighborhood Commercial (Tucson, AZ)**

Similar to Grether and Mieszkowski, another early analysis by Li and Brown (1980) focuses on the “micro-scale” externalities of noise and visual pollution, as well as proximity to non-residential uses. While acknowledging the accessibility benefits of proximity to daily destinations such as shopping, Li and Brown recognize that such destinations frequently have noise and congestion elements associated with them that may have a negative impact on the prices of surrounding housing. In a manner consistent with the discussion above about proximity to transit, Li and Brown postulate that the impacts of the negative externalities decrease more rapidly with distance than the positive effects of accessibility (see Figure C-9). In other words, the disamenities of the commercial uses tend to be “next door” phenomena, experienced primarily by those immediately adjacent to the shops, while the benefits of having easy access to shopping are enjoyed by residents in a wider geographic area.

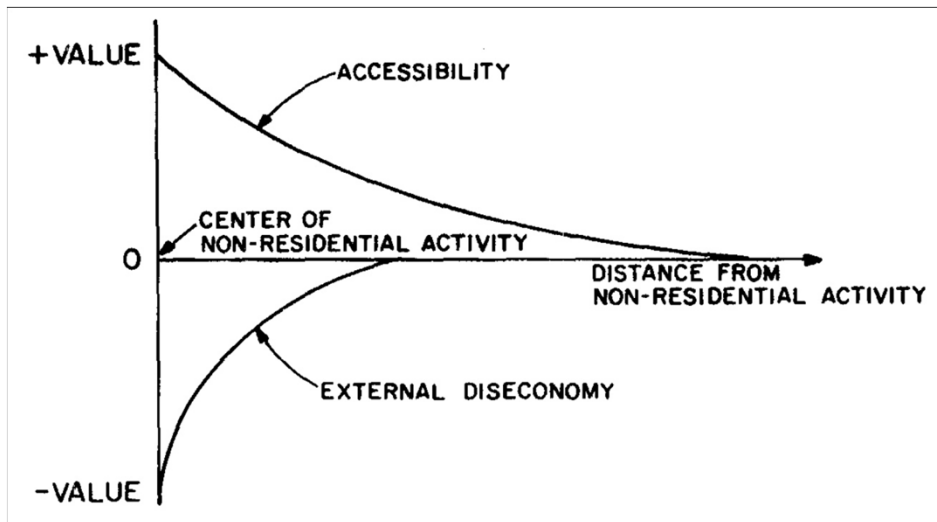


Figure C-9. Positive and negative influences on residential land prices of proximity to non-residential land uses (source: Li and Brown 1980).

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Although their analysis of single-family home sales in suburban Boston is inconclusive on the effects of disamenities, the results do show a relationship on the accessibility benefits that is significant and negative. In other words, as distance to the commercial use decreases, the home price increases. The authors estimate the magnitude of this effect at \$1,486 for every 10 meters.

Among the more recent analyses of the impacts of mixed uses, Din, Hoesli, and Bender’s (2001) analysis of a variety of environmental variables, including proximity to shopping, produced inconclusive results. De Graaff, et al. (2007) assessed the value that employees of an “edge city” outside Amsterdam place on having shopping, day care, and other facilities near their places of work. The analysis, while showing that many employees

find the availability of such services important, used a “willingness to pay” methodology which is generally considered less reliable than hedonic model approaches (Federal Transit Administration, 2000; Tajima, 2003). Mathur’s (2008) analysis of King County, Washington shows accessibility to retail jobs increasing the price of “low-quality” housing while decreasing the price of “high-quality” housing. As the study measures accessibility only to retail jobs, and does so on the basis of auto driving time, its value to assessing the impacts of TOD-style mixed use is limited. Matthews and Turnbull (2007) find that the price effect of mixed uses depends on the development pattern of the neighborhood. In automobile-oriented neighborhoods with curvilinear and cul-de-sac street patterns, the presence of retail uses within walking distance has no significant effect. In pedestrian-oriented neighborhoods with interconnected streets, however, retail proximity has both positive and negative effects relating, respectively, to the accessibility and disamenity influences postulated by Li and Brown (1980): the negative externalities associated with retail uses (noise, light, traffic, trash, etc.) depress the price of immediately adjacent houses by as much as \$14,453, while the accessibility benefits result in a \$9,675 premium. The negative effects fall off quickly with distance, though, and at approximately 235 feet from the retail use they are overwhelmed by the accessibility effects.

Song and Knapp (2004) make similar findings in their analysis of Washington County, Oregon:

Our fundamental conclusion is that mixing certain types of land uses with single family residential housing has the effect of increasing residential property values. This is especially true for houses that are closer to public parks or are located in neighborhoods with a relatively large amount of land devoted to public parks. Housing prices also increase when they are close to neighborhood-scale commercial uses, or are part of a community with a relatively large amount of neighborhood-scale commercial uses. In other words, a house tends to be sold at a higher price if it is closer to a public park or a neighborhood store. Additional premium exists when the neighborhood store is situated within pedestrian walkable distance. It is important to note that the research indicates that the size and scale of the commercial development is important to consumers. The larger or more intense the commercial development, the more it can have a negative effect on housing prices (pp. 675-676).

In a 2011 study of the San Diego Trolley light rail system, Duncan makes comparisons between station areas containing various levels of “population serving employment” (i.e., entertainment, food-related, retail, and service businesses). The results show that proximity to a light rail station has no significant effect in condo sales prices in neighborhoods with average levels of population serving employment. With higher levels of these types of uses (above the 68th percentile of the variable’s range), station proximity significantly increases sales prices, suggesting that the capitalization of accessibility benefits of transit is conditioned, in part, on the presence of mixed uses.

## Open and Public Spaces

While the effects of mixed uses on home prices has not been studied extensively, the literature on the hedonic price effects of urban parks and open space is extensive (Benson, et al. 1998; Bolitzera & Netusilb 2000; Irwin 2002; Shultz & King 2001). Studies in Washington County, Oregon; Austin, Texas; Minneapolis–St. Paul; and other areas have used residential sales data, census data, and Geographic Information Systems (GIS) to examine the marginal values of different types of open space (Anderson & West 2006; Nicholls & Crompton 2005; Song & Knaap 2004). These studies find that urban parks, natural areas, and preserved open spaces have positive effects on property values

A recent review of more than 60 published articles concluded that while studies generally show that there is value to most types of open space land uses, the magnitude of effect depends on the size of the area, the proximity of the open space to residences, the type of open space, and the method of analysis. The review found the marginal implicit price of being located 200 meters closer to a given open space area ranges from negative to 2.8 percent of the average house price (McConnell & Walls 2005). The economic boost in property value exists up to 500–600 feet away from the park. In the case of community-sized parks over 30 acres, the effect may be measurable out to 1,500 feet, but 75 percent of the premium value generally occurs within the 500–600-foot zone (Crompton 2004). Walsh (2007) calculated that the average household living one-half mile from open space would be willing to pay a one-time amount of \$4,104 (in 1992 dollars) to reduce its distance from open space by one-quarter mile.

The size of the park itself may have a bearing on the magnitude and proximity of the economic effect. Using data from Portland, Oregon, Lutzenhiser and Netusil (2001) found house prices increase with the size of the natural area nearby and estimate the optimal size of parks and natural areas to be similar to that of a golf course. Increasing the percentage of open space land surrounding a property tends to increase average house prices between 0 and 1 percent of the total property value (Acharya & Bennett 2001; Geoghegan, et al. 2003; Irwin 2002).

Figure C-10. Trail System Along the River (Portland, OR)



Dan Burden

The type of open space providing the highest economic value to the surrounding property may depend on location (Anderson & West 2006). In rural and suburban areas, preserved farmland has greater value on surrounding real estate values than potentially developable land. There is mixed evidence about how much households are willing to pay to preserve the farmland, but studies do find that there is a price premium when farmland perceived to be under the threat of development is preserved (Geoghegan 2002; Geoghegan, et al. 2003; Irwin 2002; Irwin & Bockstael 2003).

The value of all kinds of open space may be higher in urban areas than in suburban locations, with parks, greenways, forests, and other natural areas providing increased economic benefits as density increases (Acharya & Bennett 2001; Anderson & West 2006). Greenbelts, urban growth boundaries, and open spaces in clustered subdivisions also appear to have value, but the relationship is difficult to distinguish from the effect of supply of buildable land (Knaap 1985; Nelson 1985 1986).

Although most of the literature in this area is focused on medium to large scale open and green spaces, the market also seems to value smaller amounts of greenery. In an analysis recently completed by the Forest Service's Pacific Northwest Research Station, researchers estimate the impact of street trees on neighborhood real estate prices (Donovan & Butry 2010). Analyzing more than 3000 residential properties in the Portland metropolitan area, the researchers determine that two tree-related variables—the number of trees fronting a property and the crown area within 100 feet of a house—are statistically significant. Together, these two variables can add more than \$8000 to the price of a house, the equivalent of adding 129 finished square feet to the floor plan.

## **Street Design**

A final feature common to TOD, Smart Growth, and New Urbanism is the design of streets that provide a pedestrian- bicycle-friendly environment while still facilitating auto travel. One element of that type of street design is the adoption of connected street system, rather than one dominated by dead ends and cul-de-sacs. Although this does not necessarily mean a gridiron-like street pattern, many people equate connectivity with grids. In their study of Seattle neighborhoods, Mathews and Turnball (2007) find that the effect of gridded street patterns depends on the nature of other design features. In neighborhoods containing other pedestrian-oriented features—narrow street cross-sections, neighborhood retail—a more grid-like pattern increases house prices, while the opposite is true in more auto-oriented neighborhoods. Focusing more broadly on street connections and block size, Song and Knaap (2003) find that home buyers in Portland, Oregon are willing to pay a premium for houses in neighborhoods containing interconnected streets and smaller blocks. They also show a preference for pedestrian accessibility to commercial uses. Duncan's (2011) study of San Diego light rail, outlined above, similarly shows that condo buyers will pay more for proximity to light rail stations if the neighborhood contains higher levels of street intersections per hectare.



Figure C-11. Housing on Gridded Streets (Seattle, WA)



Reid Ewing

On the other hand, Guttery (2002) examined the sale prices of 1672 houses located in the Greater Dallas-Fort Worth-Denton metroplex and found negative impacts from having rear-entry alleyways, a feature characteristic of traditional development. Likewise, Asabere (1990), using data from Halifax, Nova Scotia, showed that location on a cul-de-sac yields a 29 percent price premium over houses located on a grid street pattern, the grid again being characteristic of traditional development.

The impact of bicycle facilities on house prices is mixed and appears to depend on the neighborhood location within a region and on the type of facility. Krizek's (2006) analysis of on-road and off-road bicycle lanes and paths in the Twin-Cities region shows that city residents will pay more for a house close to an off-road path, but less for a house near a road-side path, even after controlling for the disamenity of being proximate to the busy streets where these facilities tend to be located. On-road bike lanes, meanwhile, have no significant effect on city house prices. In the suburbs, all three facility types have a significant and negative impact on house prices, with a discount of between \$364 to \$1058 for locating 400 meters closer to these facilities.

Traffic calming, one type of street design treatment, uses changes in street alignments, the installation of barriers, and other physical measures "to reduce traffic speeds and/or cut-through volumes, in the interest of street safety, livability, and other public purposes" (Fehr & Peers 2008). There are two theories relating traffic calming to property values. One theory is that traffic calming eliminates or lessens negative externalities of motor vehicle use. Property values rise in response. The other theory is that traffic calming stigmatizes a street, announcing to all prospective property owners that traffic is a problem. Property values fall in reaction. Absent much empirical evidence one way or the other, property values might be expected to depend on the aesthetics and functionality of measures and the severity of preexisting traffic problems. A series of over-marked and over-signed speed humps on a low-volume residential street may detract from the appearance of the street and advertise a problem. Nicely landscaped devices that eliminate some or all through-traffic from a street previously overrun is bound to enhance residential amenity. The subject of aesthetics is covered in Chapter 4.

The two rigorous studies of the property value impacts from traffic calming in the literature point empirically in different directions. This is doubtless for the reason just cited -- different measures were employed under different conditions. In one study (Bagby 1980), one neighborhood was traffic calmed with diagonal diverters in the aftermath of a fatal traffic accident, while another with a nearly identical street network and land-use pattern was not calmed. In the period following treatment, residential property appreciated at a much faster rate in the neighborhood with the traffic calming than in the non-calmed neighborhood. In the other study (Edwards & Bretherton 1998), neighborhoods treated with speed tables were paired with similar neighborhoods left untreated. The rate of price appreciation was compared for arms-length home sales. For six pairs, the neighborhoods with tables showed more appreciation. For three, they showed less. For one pair, the rate of appreciation was the same. In most cases, the differences were slight.

Beyond these two studies, only anecdotal evidence is available. In the Old Northwood neighborhood of West Palm Beach, streets were closed and traffic circles, neckdowns, and humps installed for speed control. Home sale prices, which averaged \$65,000 in 1994, now average \$106,000. For the first time in years, real estate agents have lists of potential home buyers just waiting for the right resale unit to come on the market (Lockwood 1998).

Figure C-12. Traffic Calming in the Old Northwood Neighborhood (West Palm Beach, FL)



Reid Ewing

If the evidence of the price effects from pedestrian-friendly street design are ambiguous, the price-effects from the presumed opposite treatment—auto-oriented street design—are a bit less equivocal. It is intuitive that houses located on busy, noisy, high-trafficked streets would sell at lower prices than houses on quieter—calmer—streets, and the literature says as much (Hughes 1992; Kawamura & Mahajan 2005; Nelson 1982). Wilhelmsson (2000) reports a 0.6% discount in house price for each increase in decibel (dB) from traffic noise, resulting in a 30% price differential between a house on a noisy street and one on a quiet street. Bateman, et al. (2001) estimate the per decibel discount at 0.2%, while Kim, Park, and Kweon (2007) find the rate to be -1.3% for every 1% increase in volume. Thebe (2004) asserts that the noise discount does not rise linearly with the sound

level, finding that sound levels below 55 dB do not result in a price discount, but levels above 65 dB “appear to be capitalized into prices, with a maximum discount of approximately 12 percent” (p. 227).

Perhaps the final word on this topic belongs to the two studies analyzing the real estate price effects of replacing major highways with boulevards and parks. Tajima (2003) estimates the price impacts on real estate surrounding Boston’s “Big Dig”—the replacement of the elevated Central Artery freeway with an underground facility and the transformation of the surface to a linear parkway and boulevard. Though written while the project was still under construction, Tajima uses coefficients of the price impacts from the proximity to parks in Boston neighborhoods to conclude that “the demolition of the highway should result in \$732 million increase in property values, and the new parks should increase property values by at least \$252 million” (p. 649). More convincing is Cervero, Kang, and Shively’s (2009) analysis of the price effects resulting from the demolition of the Embarcadero and Central freeways in San Francisco after the Loma Prieta earthquake made them structurally unstable. Both freeways were replaced with a surface boulevard that while having important pedestrian amenities, still carry large volumes of traffic. In the case of the Embarcadero Freeway, real estate prices tended to decrease with distance from the freeway before the earthquake because of the amenity value of the waterfront just on the other side of the freeway. After the replacement of the freeway with the new boulevard, that effect was amplified, suggesting the freeway had had a disamenity effect mitigating the benefit of being proximate to the waterfront. The authors find that this effect was about \$118,000 (in inflation adjusted dollars) for a typical residential unit. In the case of the Central Freeway, real estate prices tend to climb with distance from both the freeway and the boulevard that replaced it. However, the steepness of the curve is significantly less with the boulevard. The authors estimate that the price of the typical residential unit in the corridor increased by \$116,000 the year that the boulevard opened.

### **Synergistic Effects**

While the studies reported so far attempt to address individual features of pedestrian-oriented design independently, there is a body of literature that addresses the subject holistically. Understanding that design is probably perceived in an integrated way by most consumers, this literature makes some intuitive sense.

Consumers seem willing to pay a premium to locate in New Urbanist developments that feature higher-than-average densities, a mix of housing types, commercial centers, interconnected streets, and prominent public spaces (Eppli and Tu 1999, 2002, 2007; Plaut & Boarnet 2003). Compact developments can command a price premium of as much as 40 to 100 percent compared to houses in nearby single-use subdivisions, according to Chris Leinberger of the Brookings Institution (2008). The homes at Kentlands, Maryland sell at a 25 percent premium over comparable large-lot developments in the same zip code (Tu & Eppli 1999). Song and Knaap (2003) show a \$24,255 premium for Portland-area homes in New Urbanist areas compared to those in conventional suburban neighborhoods. Ryan and Weber (2007), on the other hand, find a 21% to 27% discount for housing located in traditional neighborhood developments

(TND) compared to infill projects. Critics of this latter analysis, however, suggest a series of possible confounding variables that may have influenced the analysis, including variations in design quality, the inclusion of public housing in the TND projects, and the use of assessed values instead of sales prices (New Urban News 2007).

Of course, key to the TOD concept is integrating these design features with high-quality transit. Returning to Duncan's analysis of the San Diego Trolley (2011), the author shows that a good pedestrian environment—which he defines as people serving jobs, connected streets, and flat (i.e., walkable) terrain—located in a transit station area can result in a condo price premium as high as \$20,000, or 15%. More importantly, he demonstrates a degree of mutual dependence between pedestrian design and of transit proximity. As already outlined, the author shows that transit station proximity provides no statistically significant price premium in the absence of a good pedestrian environment. He also shows that the reverse appears to be true—that a good pedestrian environment provides no price premium in the absence of station proximity. For example, at 0.1 km distance to a transit station, the presence of people serving jobs provides a significant and strong price premium; the premium declines with distance from the station and at 0.9 km becomes insignificant. This reciprocity between design and transit leads Duncan to conclude that “TOD does seem to have a synergistic value greater than the sum of its parts, at least in the San Diego condo market” (p. 121). Atkinson-Palombo (2010) shows similar effects in Phoenix, with single-family houses in mixed-use neighborhoods enjoying a 6% premium because of proximity to light rail, while the effect of station proximity is insignificant for houses in residential-only neighborhoods. Condos in mixed-use neighborhoods enjoy a 16% premium if they are walking distance to transit plus an additional 37% if the area is zoned for TOD. In the residential-only neighborhoods, however, condos within walking distance achieve a only a 3% premium, and that small advantage is overwhelmed if the area is zoned for TOD, which depresses prices by 11%.

## Conclusion

In summary, the hedonic price literature confirms that the market shifts in favor of pedestrian- and transit-designed development indicated by survey data and demographic analyses are, indeed, being capitalized into real estate prices. As such, this literature provides a third, independent method of confirming and observing those market shifts. The literature also demonstrates that the amenity-based elements of transit-designed development play an important positive role in urban land markets, in addition to the accessibility benefits provided by transit. In fact, the newest literature suggests that the benefits of transit accessibility and TOD-based design are linked synergistically and may be, to a degree, mutually dependent. This tends to validate the distinctions others have made between transit-oriented and transit-adjacent development and suggests that planners, elected officials, transit agencies, and developers pay closer attention to the non-transit, amenity-based elements of land developments proximate to transit facilities.

Paradoxically, the literature of transit-related effects on real estate prices is both mature and yet still in its infancy. With more than 50 empirical studies in the last 35 years, there

is a great deal of published research on the connections between transit and real estate. However, because much of that literature ignores the roles that urban form and development design play in real estate values (and transit ridership), its explanatory power is severely limited. Given that much of this literature was written during a period of burgeoning interest in land use-transportation interactions, in general, and in TOD, in particular, it is curious that hedonic research did not better reflect land use-transportation interactions. Only now are we beginning to see research that is beginning to unpack the market impacts of these interactions.

Perhaps the lag in the literature is the natural result of a limitation inherent to all revealed-preference methods, including hedonic price analysis: the need for transactional data. One cannot test market acceptance of pedestrian- /transit-oriented development using hedonic methods until there is enough of it actually constructed and on the market to provide statistically reliable samples. Now that these product types are becoming more available, one would hope that hedonic research would take advantage of the data to further explore what pedestrian- and transit-based design features mean for real estate markets. Some of the later studies outlined in this appendix are a good start in this direction.

When pedestrian- and transit-oriented development was first discussed as a response to contemporary transportation and urban development challenges, skeptics asked “Will anyone buy it?” The hedonic literature presented here shows that many people will, indeed, buy these types of development.

## Appendix D: What the Traffic Safety Literature Tells Us<sup>6</sup>

In 2007, a front page story in *USA Today* proclaimed: “16 states see road deaths slashed” (January 30, 2007). State officials attributed the drop to traffic enforcement, education, and unspecified improvements in highway design. However, the article ended on a less congratulatory note. One expert called it “unfair” to give too much credit to these factors, without looking at “*vehicle miles traveled*, the cost of gas, whether people were driving as much” (emphasis added). And the final paragraph noted: “In states where fatalities rose substantially, agencies cited increases in *pedestrian deaths*, aggressive driving, drunken driving, and *speeding* as factors” (emphasis added). Readers who turned to page 3 learned that 10 states saw very significant increases in traffic fatalities.

Before we declare victory in the war against highway deaths and injuries, we should take a closer look at the factors highlighted in the previous paragraph. This chapter summarizes the literature on the relationship between the built environment and traffic safety. We begin by examining broad impacts on traffic safety at the macro levels of the region and community, and then examine impacts at the micro levels of the street and site.

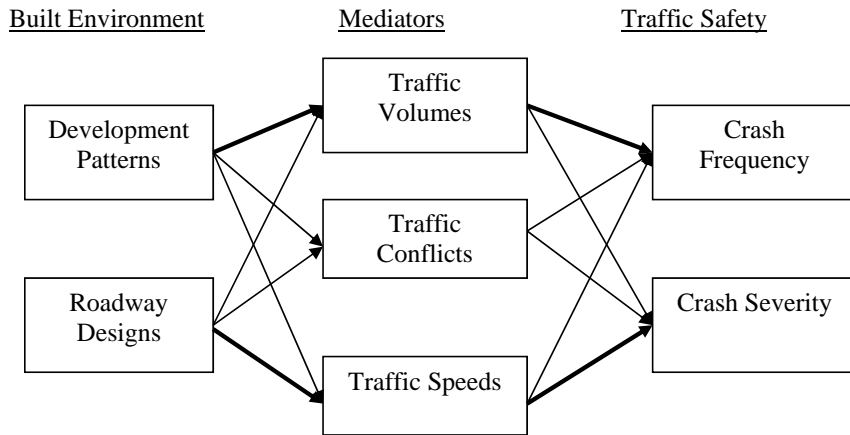
### Conceptual Framework

A conceptual framework for this literature review is presented in Figure D-1. The published literature is generally supportive of this framework. In this framework, the built environment affects crash frequency and severity through the mediators of traffic volume and traffic speed. Development patterns impact safety primarily through the traffic volumes they generate, and secondarily through the speeds they encourage. Roadway designs impact safety primarily through the traffic speeds they allow, and secondarily through the traffic volumes they generate. Traffic volumes in turn are the primary determinants of crash frequency, while traffic speeds are the primary determinants of crash severity.

Figure D-1. Conceptual Framework Linking the Built Environment to Traffic Safety

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<sup>6</sup> This appendix is taken from Ewing, R. and Dumbaugh, E. (2009). The Built Environment and Traffic Safety: A Review of Empirical Evidence, *Journal of Planning Literature*, 23(4), 347-367.



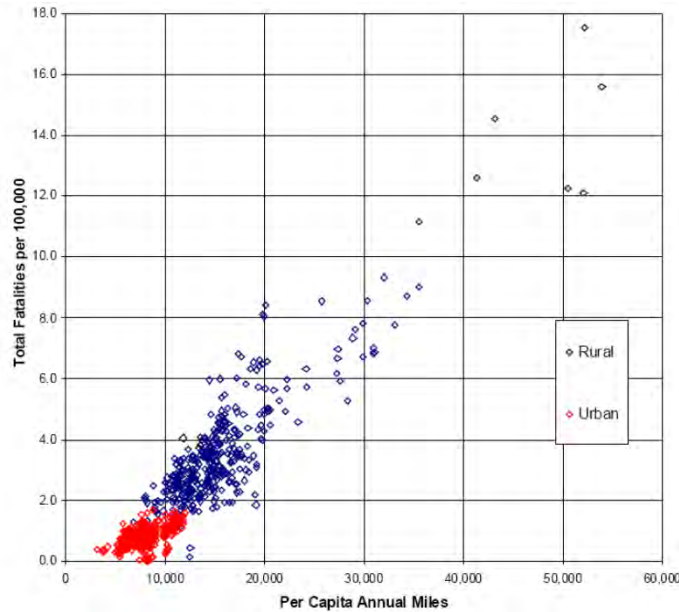
## Mediating Factors

### *Traffic Volume*

A key tenet in traffic safety is that humans are prone to error. Failure to notice a potential hazard, delayed response to a perceived hazard, or unexpected behaviors by other road users can all produce traffic crashes. Thus, each and every trip—whether as a motorist, pedestrian, or bicyclist—involves an element of risk.

*Ceteris paribus*, the more vehicular travel, the more risk of crashes. Litman and Fitzroy (2005) examined the relationship between per capita traffic fatalities and vehicle miles traveled (VMT) for urban and rural areas in the United States. As shown in Figure D-2, the relationship is roughly linear: as VMT increases, so do traffic fatalities. For urban areas, each 1% increase in travel is associated with a 1% increase in traffic fatalities. For rural areas, each 1% increase in VMT is associated with a 1.5% increase in traffic fatalities (Litman and Fitzroy 2005).

Figure D-2: Traffic Fatalities and VMT for Urban and Rural Areas



Source: Litman and Fitzroy (2005)

Balkin and Ord (2001) found that fatalities along individual highway facilities vary seasonally, with crashes increasing during periods that experience seasonal increases in VMT. A study of young drivers found that “the consistently significant factor influencing risk of motor vehicle crash involvement was *quantity* of kilometres driven” (Bath 1993). Similarly, the lower crash rate observed for female drivers is approximately equal to their lower average driving mileage (Butler 1996).

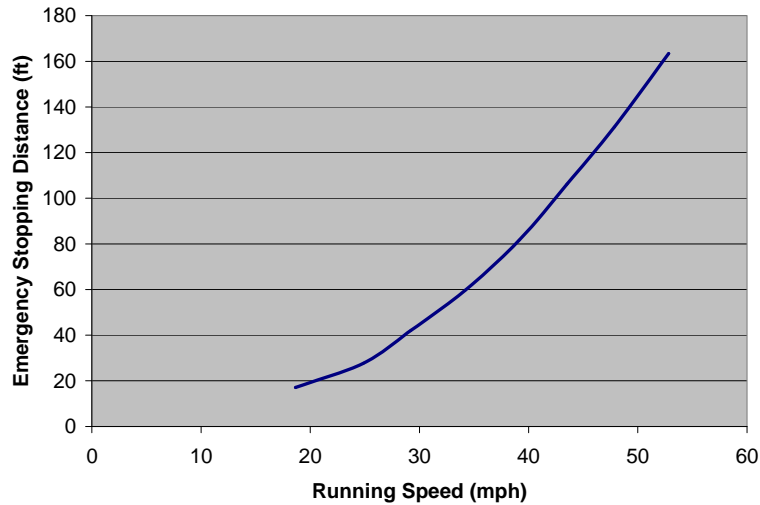
Other studies finding significant relationships between average daily traffic or VMT and crash frequency include Levine et al. (1995a, 1995b), Roberts et al. (1995), Hadayeghi et al. (2003), Lovegrove et al. (2006), and Hess et al. (2004).

### Traffic Speed

The other main mediating factor is traffic speed. Simple physics tells us that higher operating speeds give drivers less time to react to unforeseen hazards and result in increased force of impact when crashes occur. At a running speed of 40 mph, a typical driver needs more than 80 feet to stop on wet pavement; at 30 mph, emergency stopping distance drops to just over 40 feet and at 20 mph, it is about 20 feet (see Figure D-3).

Figure D-3. Typical Emergency Stopping Distance on Wet Pavement for Various Running Speeds ()

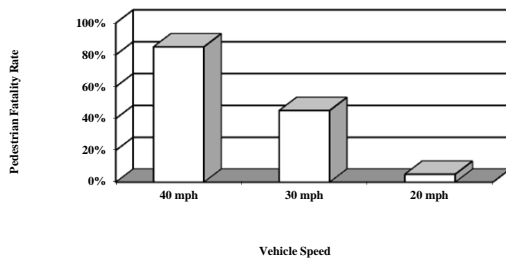




Source: Transportation Research Institute (1997).

Beyond the generalized safety benefits associated with lower vehicle operating speeds, lower speeds have a profound effect on pedestrian safety. Struck by a vehicle traveling 40 mph, a pedestrian has an 85 percent chance of being killed. The fatality rate drops to 45 percent at 30 mph and to 5 percent at 20 mph or less (U.K. Department for Transport 1997; Zegeer et al. 2002a). This relationship is non-linear as well, with crash severity increasing exponentially with vehicle speed (see Figure D-4).

Figure D-4. Pedestrian Fatality Rates for Collisions at Different Speeds.



Source: Zegeer et al. (2002a, p. 13)

Yet perhaps more importantly, the very likelihood that a pedestrian-related crash will occur appears to increase with vehicle operating speeds. In general, low speed, “main street” type designs experience the lowest rates of vehicle-pedestrian crashes, while downtown areas with wide travel lanes and higher operating speeds experience the highest rates (Garder 2004).

It is for these reasons that European roadway engineers design for lower vehicle operating speeds, at least in developed areas (Federal Highway Administration 2001; Lamm et al. 1999; Organisation for Economic Co-Operation and Development [OECD] 1998; U.K. Department for Transport 2007).

### **Traffic Conflicts**

It is not traffic speed alone that causes crashes. Rather it is speed differentials among vehicles in the traffic stream. Likewise, it is not traffic volume alone that causes crashes, but rather conflicting movements when traffic volumes are high. The independent role of conflicts comes up in discussions of on-street parking, access management, traffic calming, intersection control, and pedestrian countermeasures. To make this point explicit, an extra box, representing the mediating effect of traffic conflicts, has been added to Figure D-1.

## **Development Patterns and Traffic Safety**

### **Accepted Theory**

The literature is replete with studies showing that areas with more residents, more employment, and more arterial lane miles experience more crashes (Levine et al. 1995a, 1995b; Hadayeghi et al. 2003; Kmet, Brasher and Macarthur 2003; Ladron de Guevara et al. 2004; Hadayeghi et al. 2006; and Lovegrove et al. 2006). Such studies may be useful for crash prediction. However, they do not explain the relative risk of crashes or the rate of crashes per capita, only overall crash frequency. Where there are more people and jobs, there tends to be more of everything, from traffic to crime to coffee shops. Most of these crash prediction studies do not control for the confounding influence of VMT.

Some small-area studies have reported more crashes at higher population densities. Any attempt to infer a causal relationship is fraught with difficulty (Hadayeghi et al. 2003). Areas with high population densities tend to be located in or near employment centers, thus experiencing not only local traffic but also regional traffic entering from other areas. Also, high density areas are more likely to be traversed by multi-lane arterials, roadways with high crash rates. These too are confounding influences.

### **Alternative Theory**

Given the direct relationship between VMT and crash exposure, development patterns with lower VMT should also have lower traffic crash rates.

Starting in about 1990, researchers began to rigorously study the relationships between the built environment and travel, with the term “3Ds” being coined to describe the factors most likely to influence travel behavior—density, diversity, and design (see Chapter 3). Other Ds were added subsequently. The D’s are consistently found to have a significant effect on the distance people travel and the mode they choose. Trip lengths are generally shorter at locations that are more accessible, have higher densities, or feature mixed uses. This holds true for both the home end (i.e., residential neighborhoods) and non-home end (i.e., activity centers) of trips. Walk and transit modes claim a larger share to all trips at higher densities and in mixed-use areas, meaning that the number of vehicle trips (VT) drops as well.

### Urban Sprawl

If the relationship between VMT and traffic fatalities is near-linear, then “sprawling” environments, which are known to generate higher per capita VMT, should also report higher rates of traffic crashes and fatalities (Ewing et al. 2002). The *Mean Streets* series, put out by the Surface Transportation Policy Project, shows pedestrian fatality rates, adjusted for exposure, to be higher in metropolitan areas generally viewed as more sprawling (2000, 2002, 2004). STPP created a pedestrian danger index by adjusting annual pedestrian fatality rates for a measure of exposure, the share of commuters walking to work from the U.S. Census. The 10 most dangerous places in terms of this index are all sprawling sunbelt metros (see Table D-1).

Limiting the value of these studies is the fact that they (1) do not measure sprawl explicitly, (2) do not control for potentially confounding variables such as income and age distribution, (3) use an imprecise measure of pedestrian exposure, and (4) fail to test for statistical significance. As with all studies at this level of geographic aggregation, the possibility of aggregation bias may preclude extension of results to smaller areas.

Table D-1. Most Dangerous Metropolitan Areas for Pedestrians\*

	<b>Metro Area</b>	<b>Pedestrian Danger Index</b>
1	Orlando, FL	243.6
2	Tampa-St Petersburg-Clearwater, FL	215.3
3	West Palm Beach-Boca Raton, FL	209.9
4	Miami-Fort Lauderdale, FL	166.3
5	Memphis, TN-AR-MS	159.1
6	Atlanta, GA	144.4
7	Greensboro--Winston-Salem--High Point, NC	122.5
8	Houston-Galveston-Brazoria, TX	121.9
9	Jacksonville, FL	120.7
10	Phoenix-Mesa, AZ	117.2

\* The Pedestrian Danger Index is calculated by dividing the average annual fatality rate per 100,000 population for a metropolitan area by the percentage of commuters walking to work in that metropolitan area, using “journey to work” data from the decennial Census.

Source: Surface Transportation Policy Project (2004)

A study for the U.S. Environmental Protection Agency (EPA) matched metropolitan areas in terms of size and density, but consciously chose metros with contrasting transportation systems (EPA 2004). Differences were evident in block size, street network density, intersection density, percent of four-way intersections, and transit service density. Metros with smaller blocks, dense streets and intersections, more four-way intersections, and more transit service were said to epitomize “smart growth.” The others were more representative of sprawl. The matched comparison showed that metros with smart growth transportation systems (the first one in each set in Table D-2) sometimes had lower annual traffic fatality rates per million population. This was the case for Philadelphia, New Orleans, and Omaha. Other times the reverse was true. Results were also mixed for annual fatalities per billion VMT traveled.

Applicability of these results is, once more, limited by the geographic scale of the places compared, by lack of control variables, and lack of statistical testing. Compared to the results of studies using more complete measures of the built environment, they suggest that transportation system characteristics by themselves (absent more compact land use patterns) do not guarantee a safer traffic environment.

Table D-2. Traffic Safety Measures for 13 Study Regions

	Fatalities per million population per year	Fatalities per billion VMT per year
Philadelphia	66	9.6
Atlanta	119	9.8
Houston	137	14.2
Pittsburgh	99	10.9
Tampa/St. Petersburg	179	20.2
St. Louis	89	8.1
New Orleans	112	19.2
Charlotte	145	11.8
Nashville	175	15.5
Omaha	81	10.1
Little Rock	190	16.3
Erie	135	22.9
Binghamton	107	8.9

Source: EPA (2004)

In an attempt to overcome such limitations, Ewing et al. (2002, 2003a) developed metropolitan sprawl indices and related them to various transportation outcomes. Sprawl was defined by: (1) a population widely dispersed in low density residential development; (2) a rigid separation of homes, shops, and workplaces; (3) a lack of distinct, thriving activity centers, such as strong downtowns or suburban town centers; and (4) a network of roads marked by very large block size and poor access from one place to another. Principal component analysis was used to reduce 22 land use and street network variables to four factors representing these four dimensions of sprawl, each factor being a linear combination of the underlying operational variables. The four were combined into an overall metropolitan sprawl index. All indices were standardized on a scale with a mean value of 100, and a standard deviation of 25. The way the indices were constructed, the higher the value of the index, the more compact the metropolitan area. The lower the value, the more sprawling the metropolitan area.

Controlling for sociodemographic differences across metropolitan areas, three of the factors—density, mix, and centering—were significantly related to annual traffic fatalities per 100,000 residents (see Table D-3). The higher the density, the finer the mix, and the more centered the development pattern, the fewer highway fatalities occur on a per capita basis. This is in part due to the mediating influence of VMT per capita, which is lower in compact metropolitan areas. But it may also be due to another mediating

influence, lower average speeds. The traffic fatality rate actually declines at a faster rate than VMT as density, mix, and centering increase.

Table D-3. Best-fit regression equation for annual traffic fatalities per 100,000 residents (t-statistics in parentheses).

constant	20.16
metropolitan density factor	-0.105 (-2.5)*
metropolitan mix factor	-0.041 (-2.5)*
metropolitan centeredness factor	-0.037 (-2.3)*
metropolitan streets factor	0.0149 (0.8)
metropolitan population	-9.4E-08 (-0.3)
average household size	0.667 (0.3)
percentage working age population	0.226 (1.1)
per capita income	-0.00032 (-2.6)*
adjusted R <sup>2</sup>	0.44

\* .05 probability level

\*\* .01 probability level

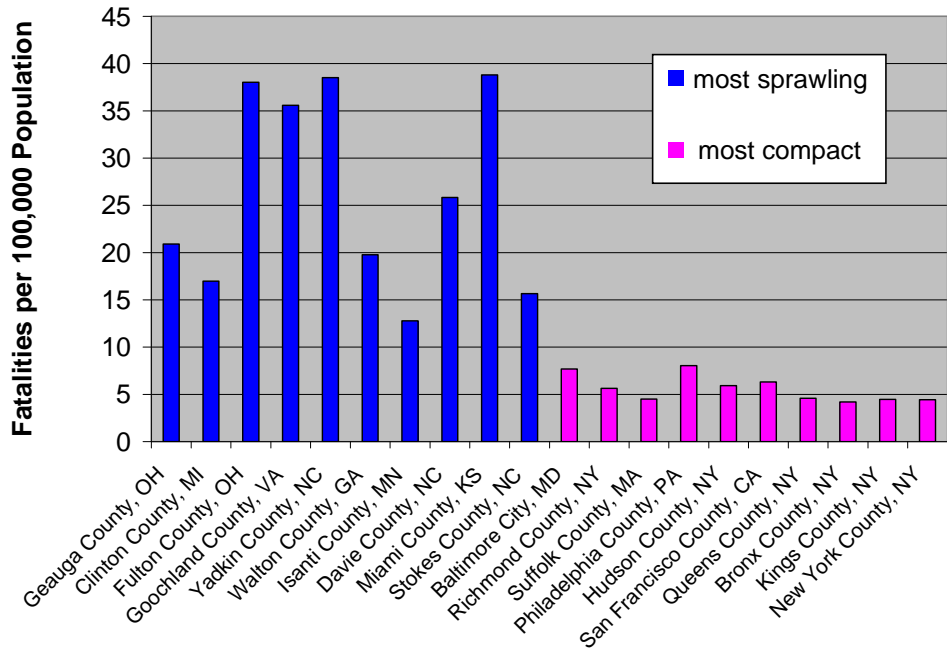
\*\*\* .001 probability level

Source: Ewing (2002)

Ewing et al. (2003b) also developed a simpler county sprawl index to measure the built environment at a finer geographic scale, the individual county. It is a linear combination of six variables from the larger set, these six being available for counties, whereas many of the larger set are available only for metropolitan areas. Four of the variables relate to residential density and two relate to street accessibility from one place to another. Principal component analysis was used to extract the single factor that best represents the degree of sprawl. The factor was then transformed into a scale with a mean of 100 and standard deviation of 25.

County-level sprawl proved significantly related to each of three accident-related variables, the overall county-level traffic fatality rate per 100,000 residents and two county-level traffic fatality rates specific to pedestrians. Controlling for socioeconomic differences across counties, the more sprawling the area, the higher the all-mode traffic fatality rate and the higher the rate of pedestrian fatalities, adjusted for exposure (see Figure D-5). The relationship between county-level sprawl and miles driven has recently been confirmed for teenage drivers as well (Trowbridge and McDonald 2008).

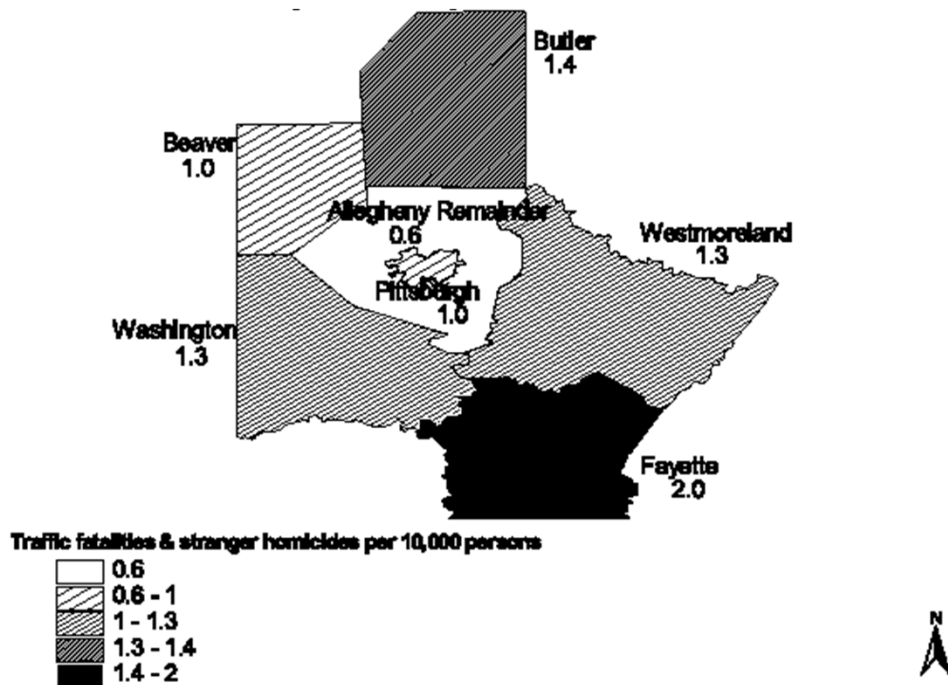
Figure D-5. All-Mode Traffic Fatality Rate for Most Sprawling and Most Compact Counties



Source: Ewing et al. (2003b)

Finally, a novel study by Lucy and colleagues (Lucy and Rabalais 2002; Lucy 2003; Lucy and Phillips 2006) compared the relative risk of living in cities and suburbs, taking into account both traffic fatalities and homicides. Leaving home proved more dangerous for residents of outer suburban areas than for many central city residents and for nearly all inner suburban residents. They reached this conclusion by analyzing the locations and rates of traffic fatalities and homicides by strangers. The metropolitan areas examined were Baltimore, Chicago, Dallas, Houston, Milwaukee, Minneapolis-St. Paul, Philadelphia, and Pittsburgh for the years 1997 through 2000. Homicides committed by family and friends, usually in the home, were excluded as irrelevant to the study of safety and the built environment. The overall fatality rate by county for one metropolitan area is plotted in Figure D-6. Note the greater danger associated with outlying areas.

Figure D-6. Average Rate of Traffic Fatalities + Stranger Homicides for the Pittsburgh Metropolitan Area



Source: Lucy and Rabalais (2002)

### Street Network Design

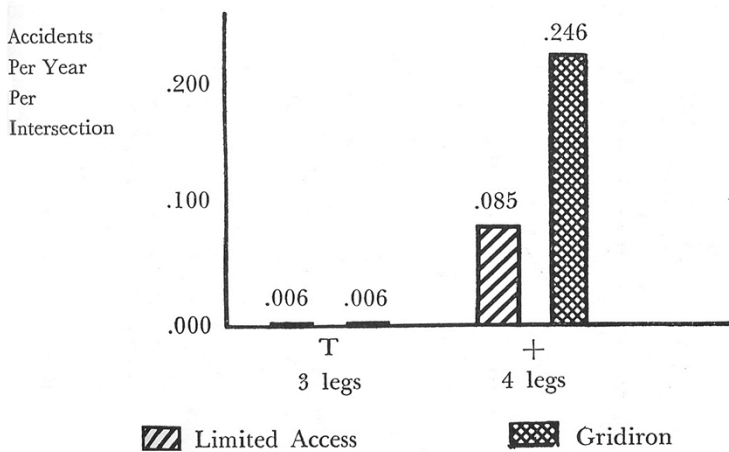
The traditional urban grid has short blocks, straight streets, and a crosshatched pattern. The typical contemporary suburban street network has large blocks, curving streets, and a branching pattern. The two prototypical networks differ in three respects: (1) block size, (2) degree of curvature, and (3) degree of interconnectivity.

One early study compared crash rates in subdivisions with the two types of networks, referred to as gridiron and limited-access (Marks 1957). These roughly correspond to the traditional and contemporary networks described above. The distribution of crashes was fairly uniform across the gridirons; crashes were concentrated wherever two continuous streets met at a four-way intersection. Where there were interruptions in the grid, creating three-way intersections, crashes were infrequent. The limited-access networks also had crashes concentrated at four-way intersections, but there were relatively few of these intersections in the network. The large number of T-intersections in the limited-access network had practically no crash history. Overall, the crash frequency for the five-year period studied was 77.7 crashes per year for the gridiron subdivisions and 10.2 crashes per year for the limited access subdivisions. The difference was in the proportion of four-way vs. three-way intersections for the two types of networks. Crash frequencies



were dramatically higher for four-way than three-way intersections, regardless of the network type (see Figure D-7). As discussed in the traffic calming section below, roundabouts and other techniques can mitigate dangers at four-way intersections, thus addressing the safety concerns of a gridiron network.

Figure D-7. Crash History of 3-Way and 4-Way Intersections



Source: Marks (1957)

The Marks study has been criticized for failing to consider the severity of crashes in the two networks, and the rate of crashes for the networks as a whole (not just the portion within subdivisions). Still, the main conclusions are supported by more recent studies.

Lovegrove et al. (2006) found that areas with more 4-way intersections had higher crash rates than those with 3-way intersections. They also found that areas with more lane miles of arterials had significantly higher crash rates relative to those with more local street mileage. Ladron de Guevara et al. (2004) similarly found a positive relationship between percentage of roadways classified as arterials or collectors and rates of total and injurious crashes, if not fatal ones. Higher intersection densities were associated with fewer total, injurious, and fatal crashes, a result attributed to lower speeds.

Generalizing, it appears that the shorter the uninterrupted length of roadway, the slower the traffic will travel and the less severe any crashes will be. Short stretches ending in T-intersections are particularly effective in reducing speed, crash frequency, and crash severity.

## Roadway Design and Traffic Safety

### Accepted Theory

The conventional theory of roadway design is that wider, straighter, flatter, and more open is better from the standpoint of traffic safety. High speed designs are presumed to be more forgiving of driver error, and thus to lead to reduced incidence of crashes and injuries. As stated in the AASHTO *Green Book*: “every effort should be made to use as high a design speed as practical to attain a desired degree of safety” (AASHTO 2004a, p. 67).

Two facts and two concurrent trends support this view. One fact is that high speed design features such as wide shoulders and gentle curves improve highway safety in rural areas, particularly on two-lane rural roads (Zegeer and Council 1995). The other fact is that the Interstate highway system, which is designed for high speeds, generally experiences lower crash rates than other roadway classes.

The concurrent trends are (1) the sharp decline in crash rates over the past 40 years at the same time (2) lanes and shoulders have been widened, curves straightened, and design speeds generally raised. Concurrent timing has led to the assumption of causality, specifically, that the use of higher design speeds enhances roadway safety (Dumbaugh 2005a).

The conventional engineering wisdom fails to account for an array of confounding factors that influence the safety performance of highways. Land use context and vehicle operating conditions are entirely different in urban than rural areas. The much greater degree of conflict among road users in urban areas renders findings from rural safety studies of limited value in urban areas. The lower crash rates on the Interstate highway system are at least in part attributable to controlled access, which eliminates the turning maneuvers and speed differentials that produce the majority of urban crashes (Dumbaugh 2005a; 2006b). In addition, pedestrians and bicyclists, vulnerable road users, are banned from the Interstate highway system.

As for the concurrent trends, after accounting for changes in the demographic mix of the driver population, increased seat belt use, and improvements in emergency services, one national study of crash performance found that:

Changes in highway infrastructure that have occurred between 1984 and 1997 have not reduced traffic fatalities and injuries, and have even had the effect of increasing total fatalities and injuries... other factors, primarily changes in the demographic age mix of the population, increased seat belt usage and improvements in medical technology are responsible for the downward trend in fatal accidents (Noland 2001).

This study was replicated using more focused data for the state of Illinois, and again it was found that “changes in infrastructure have actually led to increased accidents and fatalities” (Noland and Oh 2004).

## Alternative Theory

Beginning with Jane Jacobs' *The Life and Death of Great American Cities* (Jacobs 1961) and extending to the New Urbanism (Duany and Talen 2002), walkable communities (Bicycle Federation of America 1998), and smart growth (Smart Growth Network) movements, urban planners have argued for narrower, shorter, more enclosed, and more interconnected streets. The viewpoint of planners is almost 180 degrees counter to conventional engineering practice.

Planner/engineer Peter Swift studied approximately 20,000 police accident reports in Longmont, Colorado to determine which of 13 physical characteristics at each accident location (e.g., width, curvature, sidewalk type, etc.) accounts for the crash. The results are not entirely surprising: the highest correlation was between collisions and the width of the street. A typical 36-foot wide residential street has 1.21 collisions/mile/year as opposed to 0.32 for a 24 foot wide street. The safest streets were narrow, slow, 24-foot wide streets (Swift 2006).

Who is right? How to reconcile these different points of view? Based on a review of urban safety studies, this section concludes that what is good for rural roads and urban freeways is not necessarily best for urban roadways generally. Due to their different operating conditions and different contexts, urban roadways appear to follow a different set of safety rules more in line with the views of the urbanists. Still, when it comes to on-street parking, access management, and pedestrian countermeasures, the engineers may have gotten it right.

## Road Width

There is constant pressure to add lanes and widen roads in order to relieve congestion. Whatever the operational benefits, research has shown the road widenings occur at the expense of safety, even after controlling for traffic volumes (Dumbaugh 2005b; Harwood 1986; Milton and Mannering 1998; Noland and Oh 2004; Sawalha and Sayed 2001; Vitaliano and Held 1991; Hummer and Lewis 2000--see Table D-4). Conversely, eliminating lanes appears to improve traffic safety. Studies of "road diet" projects, which are projects that convert four-lane roadways into roadways with two-through lanes and a center turn lane, find that traffic crashes decrease as lanes are eliminated (Huang et al. 2002; Knaap and Giese 2001).

Table D-4. Collision Rates by Cross Section, Development Type, and Development Density

Development Density: Development Type: Cross Section	Collisions per 100 Million Vehicle Miles			
	Medium		High	
	Residential	Commercial	Residential	Commercial
Two-lane	110	270	230	<sup>a</sup> .
Three-lane	180	210	190	230 <sup>b</sup> .

Undivided four-lane	230	260	370	1500 <sup>b</sup>
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<sup>a</sup>. No data

<sup>b</sup>. Very small sample sizes

Source: Hummer and Lewis (2000)

Wide lanes may also adversely affect traffic safety, at least in urban areas. Noland and Oh (2004) found that wider lanes were associated with statistically-significant increases in total and fatal crashes in the state of Illinois. Lee and Mannering (1999) discovered that while wide lanes reduced the probability of run-off-roadway crashes in rural settings, they were associated with *increases* in the same crash types in urban areas. Hauer (1999) re-examined the historical literature on lane widths and traffic safety, and found that research from 1940 forward has consistently shown crashes increasing as lanes exceed 11 feet in width.

The root cause may be speed. Vehicle operating speeds decline somewhat as individual lanes and street sections are narrowed (Harwood 1990; Farouki and Nixon, 1976; Heimbach et al. 1983; Clark 1985; Gattis and Watts 1999; Gattis 2000; Fitzpatrick et al. 2001). Drivers seem to behave less aggressively on narrow streets, running fewer traffic signals, for example (Untermann 1990). Also, drivers may feel less safe and drive more cautiously on narrow streets (Mahalel and Szternfeld 1986). On two-lane roads, prudent drivers set the pace and others must follow. On multi-lane roads, where passing is possible, high-speed drivers set the prevailing speed (Burden and Lagerwey 1999).

Yet, one should be careful not to give too much credit to narrow cross sections alone. Dumbaugh (2005b) concluded that it is not narrow lanes by themselves that reduce speeds, but narrow lanes combined with other design elements, such as roadside streetscape elements, that re-enforce the message to slow down.

#### *On-Street Parking*

Good shopping streets nearly always have on-street parking. So do most residential streets. Parked cars act as a buffer between traffic and pedestrians (Schmitz & Scully 2009; Livingston 2005). They are a convenience to shoppers and residents.

However, these benefits may be realized at the expense of traffic safety. The limited literature on the subject suggests that on-street parking accounts for a significant proportion of urban crashes (Seburn 1967; Humphreys et al. 1978; Texas Transportation Institute 1982; McCoy et al. 1990; McCoy et al. 1991; Box 2000; ITE 2001; Box 2002; Box 2004). This is especially true for children, as a large number of child injuries and fatalities from motor vehicle crashes occur when children dart out from between parked cars. If parking is permitted, conflicts with parked cars produce about 40 percent of total crashes on two-way major streets, 70 percent on local streets, and a higher percentage on one-way streets (Box 2000). The number of crashes increases with the parking turnover rate, meaning that land uses which generate high turnover will also generate more traffic

crashes (Humphreys et al. 1978). Crash rates are particularly high with angle parking, as compared to parallel parking (McCoy et al. 2001; ITE 2001; Box 2002).

Interestingly, we could find no study of crash rates on comparable roadway sections with and without curbside parking, the ultimate test of on-street parking's safety impact. One study that did measure residential street typology and the rate of crashes with pedestrians found that the existence of parking had no affect on crash rates (Swift 2006). It is possible that where parking is provided, parked cars account for a large proportion of crashes, and yet overall crash rates are about the same as on sections without parking.

Another consideration with on-street parking is its effect on bicycle safety. One of the main causes of vehicle-bicycle incidents is “dooring” – a vehicle occupant suddenly opening a door into the path of a cyclist. Designers go to great lengths to create facilities that place cyclists out of the door zone. Norwegian research suggests that prohibiting on-street parking leads to a 20-25 percent reduction in vehicle-bicycle collisions. So while parking acts as a buffer for pedestrians and provides “friction” which slows vehicles, it presents challenges for cyclists and can “hide” children from drivers

## **Traffic Calming Measures**

Speed humps, traffic circles, and other traffic calming measures are perceived by some traffic engineers, residents, and members of the media as obstacles in the roadway. Were they truly obstacles, such measures might increase crash rates. They do just the opposite by slowing traffic.

The Insurance Corporation of British Columbia summarized 43 international traffic calming case studies (Geddes 1996). Collision frequencies declined by anywhere from eight to 100 percent with traffic calming. Ewing (2001) compared collision frequencies before and after traffic calming measures were installed. For the sample as a whole, collisions declined to a very significant degree after traffic calming (the difference being statistically significant at the .001 probability level). Adjusting for changes in traffic volumes, and dropping cases for which volume data were not available, collisions still declined significantly at the conventional 0.05 probability level. As for individual traffic calming measures, all reduced the average number of collisions on treated streets, and 22-foot tables and traffic circles produced differences that were statistically significant (see Table D-5).

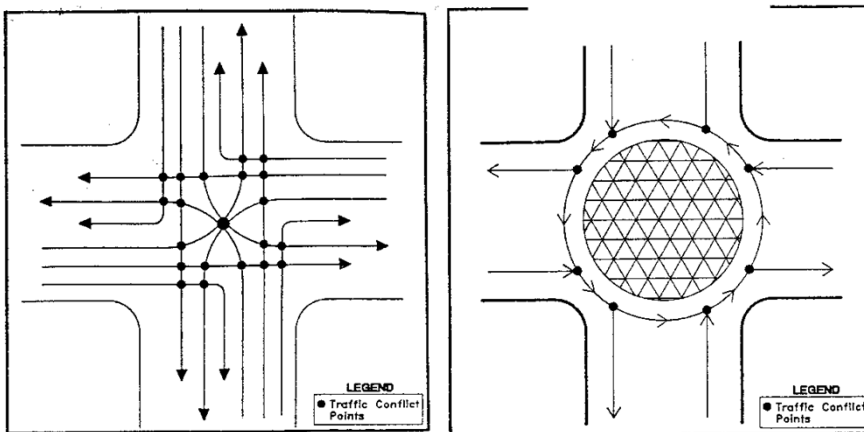
The mitigating role of traffic conflicts is implicit in these statistics. Speed tables are believed to have a better safety record than speed humps because their higher design speeds require less deceleration on the approach, and less acceleration on the exit (Ewing 1999). This reduces the likelihood of rear-end collisions. Seattle traffic circles particularly improve safety by reducing the number of conflicting movements at uncontrolled four-way intersections. Seattle circles thus overcome the primary disadvantage of the traditional urban grid (see Figure D-8 and “Street Network Design”).

Table D-5. Safety Impacts of Traffic Calming Measures

	Number of Observations	Average Number of Collisions Before/After Treatment	% Change in Collisions Before->After Treatment	t-statistic (significance level—two-tailed test)
Humps	54	2.8/2.4	-14%	-1.2 (.22)
22' Tables	51	1.5/.8	-47%	-3.0 (.005)
Circles				
without Seattle	17	5.9/4.2	-29%	-2.2 (.05)
with Seattle	130	2.2/.6	-73%	-10.8 (.001)
All Measures				
without adjustments	235	2.2/1.1	-50%	-8.6 (.001)
with adjustments	47	1.8/1.2	-33%	-2.5 (.05)

Source: Ewing (2001)

Figure D-8. Conflict Points for Uncontrolled Intersection without and with a Traffic Circle



It is curious that safety impacts of traffic calming in the U.S., while favorable, would be less pronounced than outside the U.S. One possible explanation is that European and British traffic calming treatments are more intensive and more integrated with their surroundings than U.S. treatments. Reported speeds drop on average by almost 11 mph or 30 percent in a British sample (County Surveyors Society 1994) compared to under 7 mph or 20 percent for U.S. treatments (Ewing 2001).

All of the traffic calming literature referenced thus far relates to traffic collisions generally. One recent study showed that the presence of speed humps on a street was associated with lower odds of child pedestrians being injured within their neighborhoods or being struck in front of their homes (Tester et al. 2004).

## Access Management

Speed is not the only culprit in urban traffic crashes. The presence of driveways and side streets along arterials create conflicts between through-moving vehicles and those attempting to turn into and out of adjacent driveways. Rear-end crashes are common as drivers decelerate to negotiate turns or enter the traffic stream from driveways or side streets at lower-than-prevailing speeds. Angle crashes are commonplace as drivers attempt to turn left into driveways or side streets, but have insufficient time to clear opposing traffic lanes.

Two strategies exist for moderating access-related crashes. The first is to reduce the speeds of through-moving vehicles, thereby minimizing speed differentials with turning vehicles (Dumbaugh 2006a). The second is to control turning movements, while maintaining higher speeds for through-moving vehicles, through access management. Access management is the control of the location, spacing, and operation of driveways, median openings, and street connections to a main roadway.

The traffic safety benefits associated with access management techniques are summarized by S&K Transportation Consultants (2000). They range from a 20 percent reduction in crashes associated with the addition of right turn bays, to a 67 percent reduction associated with the addition of left-turn dividers. Crash rates appear to vary with the square root of access density, up to about 40 access points per mile (Committee on Access Management 2003). Crash rates are higher on roads with unlimited left turns (Gluck et al. 1999). The dual effects of two variables—access point density and non-traversable medians—are reflected in Table D-6.

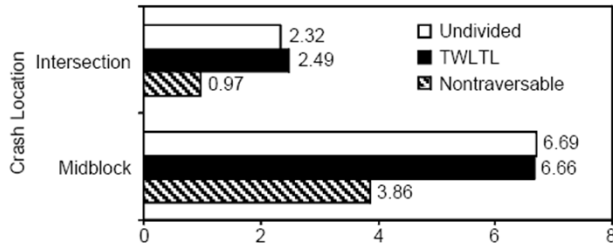
Table D-6. Crash Rates on Urban and Suburban Roads with Different Levels of Access Control (per million vehicle miles)

Access Points per Mile	Median Type		
	Undivided	Two-Way Left-Turn Lane	Non-Traversable Median
≤ 20	3.8	3.4	2.9
20-40	7.3	5.9	5.1
40-60	9.4	7.9	6.8
>60	10.6	9.2	8.2

Source: Committee on Access Management (2003)

Raised medians, embraced by highway agencies for operational reasons, are favored by pedestrian advocates as well. They provide refuge areas for pedestrians, who can cross in stages. A study of pedestrian-vehicle crash experience on arterial roadways in Atlanta, Phoenix, and Los Angeles found that crash rates were about half as high on arterials with raised medians compared to undivided roadways or roadways with center two-way left-turn lanes (see Figure D-9).

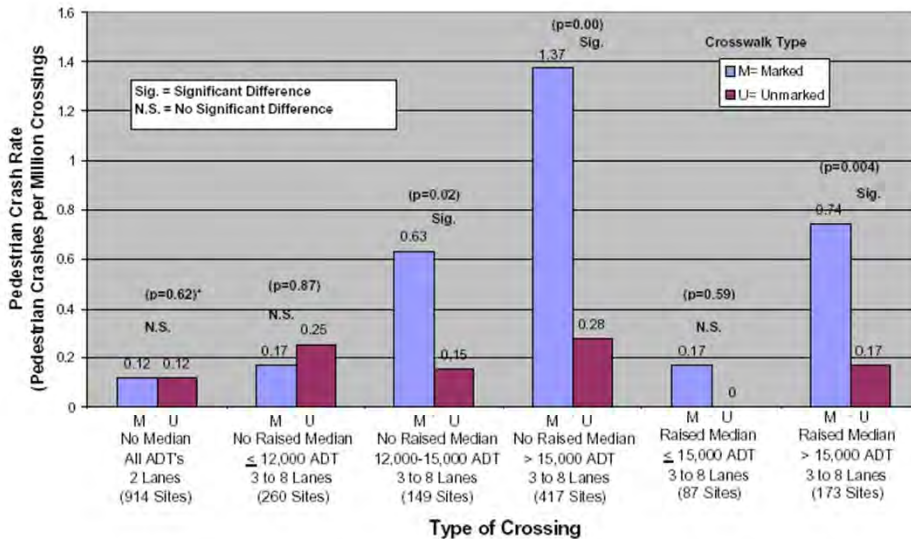
Figure D-9. Pedestrian Crash Rates for Suburban Arterials with Different Access Control



Source: Bowman and Vecellio (1994)

Safety benefits of medians appear to vary by type and width. In one study, pedestrian collisions fell by 23 percent when a 6-foot painted median was replaced with a wide raised median (Claessen and Jones 1994). In another study, the narrowest medians (four feet) had four times the pedestrian crash rate of the widest medians (10 feet) (Scriven 1986). Very narrow medians may reduce vehicle-to-vehicle crashes but have no effect on pedestrian crashes (Johnston 1962; Leong 1970). Raised medians and raised crossing islands may reduce vehicle-pedestrian crashes on multi-lane roads, while painted medians and two-way left turn lanes do not (see Figure D-10).

Figure D-10. Pedestrian Crash Rates by Type of Crossing



Source: Zegeer et al. (2002b, p. 8)



Access management can also benefit cyclists for the same reason it affects overall traffic flow. Without the distraction of constant driveways and cross-traffic, cycling is safer and more comfortable.

Before one declares access management a win-win for motorists and pedestrians, two caveats should be noted. First, while medians may enhance pedestrian safety, it is not clear that access management strategies, considered as a whole, also do so. Central to the concept of access management is wide spacing of signalized intersections, preferably with distances of one-quarter mile or greater (Florida Department of Transportation 2006; Minnesota Department of Transportation 2002; Nevada Department of Transportation 1999). Such spacing limits the number of opportunities for pedestrians to cross with signals, thus encouraging hazardous midblock crossings. Also, access management may involve the provision of service roads adjacent to the main line or parallel reliever roads for local traffic. A portion of the reported safety benefits currently attributed to access management may be lost when access-related crashes are transferred from a main arterial to parallel roads.

## **Intersection Control**

Crashes are concentrated at intersections because vehicle-vehicle and vehicle-pedestrian conflicts are concentrated there. Some forms of intersection control are more effective at reducing conflicts than others.

All-way stops have never been a favorite with U.S. traffic engineers. Yet, all-way stops produce lower vehicle speeds near intersections than do traffic signals or two-way stops. From a safety standpoint, they appear to outperform signals at moderate traffic volumes, say, up to 10,000 vehicles per day on the major street (Bissell and Neudorff 1980; Ebbecke and Schuster 1977; and Syrek 1955). One study found that pedestrian collisions declined by 25 percent when traffic signals at low-volume urban intersections were converted to all-way stops (Persaud et al. 1997).

Historically, U.S. traffic engineers have not favored roundabouts either, as modern roundabouts were mistaken for old-fashioned traffic circles. With modern roundabouts, yield to circulating vehicles, deflection at entry, and the curvature of the travel path through the intersection, all reduce travel speeds. Counter-clockwise circulation around the center island reduces the number of conflict points, largely eliminating certain types of collisions such as right angle and left turn head-on crashes.

Several studies have shown that roundabouts outperform other intersection control devices with respect to safety (Persaud et al. 2002; Jacquemart 1998; Maycock and Hall 1984; Robinson 2000; Schoon and Minnen 1993; Schoon and Minnen 1994). Even where crash frequencies are comparable to other intersections, crash severity is lessened (Brown 1995). Persaud et al. (2002) evaluated the change in crash rates following the conversion of 24 intersections to modern roundabouts in the United States. There was a significant overall reduction of 39 percent in crash rates. For crashes involving injuries, the reduction was 76 percent. Crashes involving deaths or incapacitating injuries fell by about 90 percent.

Small and medium capacity roundabouts are safer than large or multilane roundabouts (Maycock and Hall 1984; Alphand et al. 1991). Single-lane roundabouts, in particular, have been reported to produce substantially lower pedestrian crash rates than comparable intersections with traffic signals (Brude and Larsson 2000). Crash reductions are most pronounced for motor vehicles, less pronounced for pedestrians, and uncertain for bicyclists, depending on the study and bicycle design treatments (Robinson 2000; Schoon and Minnen 1993; Schoon and Minnen 1994; Brown 1995). Comparative crash statistics from one study are presented in Table D-7.

Table D-7. British Crash Rates for Pedestrians at Roundabouts and Signalized Intersections

Intersection Type	Pedestrian Crashes per Million Trips
Mini-roundabout	0.31
Conventional roundabout	0.45
Flared roundabout	0.33
Signals	0.67

Source: Robinson (2000).

While the European experience with roundabouts suggests that they are relatively safe for pedestrians and bicyclists, there remains in the United States a preference for traffic signals at locations with high pedestrian and bicycle traffic. Signals provide a periodic gap in traffic for crossing pedestrians, while the continuous flow of roundabouts does not. Signals require no deflection of motor vehicles crossing an intersection, while roundabouts may cause motorists to cross paths with bicyclists. There are particularly serious issues of access for pedestrians with disabilities. Some of this may be attributed to low levels of cycling and walking in the United States as compared to Europe, which creates a more hostile relationship between drivers and other roadway users.

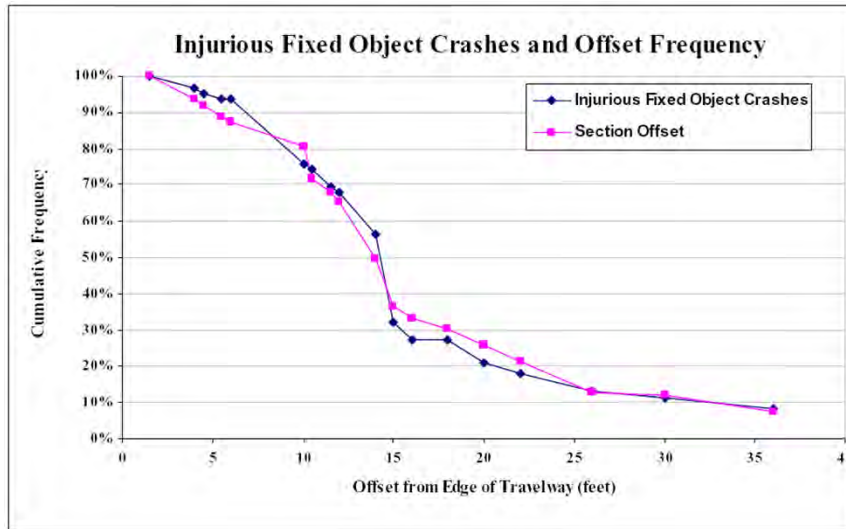
## Roadside Design

The roadside is the location for most pedestrian amenities, including sidewalks, street trees and street lighting. Conventional engineering design practice encourages placement of such features as far away from the roadway as possible, to create a wide “clear zone” in case motorists lose control and leave the roadway. “...the wider the clear zone, the safer it will be” (Transportation Research Board 2003, p. V-43).

This recommendation is based on the physical locations of roadside crashes. Hall et al. (1976) observed that most utility pole crashes occur along curves and within 11.5 feet of the travelway, Zeigler (1986) that 85 percent of tree-related crashes occurred within 30 ft of the travelway, and Turner and Mansfield (1990) that 60 percent of trees involved in crashes were located along horizontal curves, and that 80 percent were within 20 feet of the travelway.

Such descriptive statistics only tell us where roadside crashes occur, not whether roadside crashes are more likely or more severe when fixed objects are near the roadway. Also, any conclusions related to clear zones on high-speed rural roads will not necessarily apply to low-speed urban streets. Lee and Mannering (1999) found that urban roadways with trees located in the nominal “clear zone” actually have fewer roadside crashes than locations where trees were not present. Naderi (2003) examined the safety effects of urban streetscape improvements along five arterial roadways in downtown Toronto, and concluded that the addition of roadside features such as trees and concrete planters reduced crashes by 5 to 20 percent. Plotting the frequency of injurious roadside crashes against the actual percentage of road segments that had clear zones of each offset width, Dumbaugh (2005b) found that the probability of a roadside-object related crash was largely independent of the roadway’s fixed-object offset (see Figure D-11).

Figure D-11. Injurious Roadside Crashes and Roadside Offset



Source: Dumbaugh (2005b)

### Pedestrian Countermeasures

Pedestrian countermeasures are engineering actions taken to improve the safety of roadways for pedestrians. One study classified countermeasures into three broad categories: separation of pedestrians from vehicles by time and space; measures that increase the visibility and conspicuity of pedestrians; and reductions in vehicle speed (the last of these already covered under the heading of traffic calming) (Retting et al. 2003). The *Pedestrian Facilities Users Guide* lists 47 such measures (Zegeer et al. 2002a).

Most of the studies of pedestrian countermeasures have used proxies for traffic safety to document impacts. Travel speeds have been measured in some cases, conflict counts and yielding behavior in others. Actual crash rates are seldom measured in such studies.

This may not constitute as big a shortcoming as would at first appear, however, since conflict counts have been shown to provide an accurate estimate of multi-year crash rates (Hauer and Garder 1986).

Sidewalks are an absolute necessity along all through-streets serving developed areas. Vehicle-pedestrian collisions are more likely on street sections without sidewalks than those with them, two and one-half times more likely according to one study (Knoblauch et al. 1988). Sidewalk clearances, vertical curbs, street trees between street and sidewalk, and parked cars all add to the sense of security.

At signal- and stopped-controlled intersections, traffic is forced to stop for pedestrians with or without marked crosswalks. The issue is whether to mark crosswalks at uncontrolled intersections and midblock locations. In one study of uncontrolled locations, drivers were found to approach pedestrians in a crosswalk somewhat slower, and crosswalk usage was found to increase, after markings were installed (Knoblauch et al. 2001). However, this study found no changes in driver yielding behavior or pedestrian assertiveness. Overall, the study concluded that marking pedestrian crosswalks at relatively low-speed, low volume, unsignalized intersections is a desirable practice.

Another study evaluated driver speeds before and after installation of crosswalk markings at uncontrolled intersections (Knoblauch and Raymond 2000). Speed data were collected under three conditions: no pedestrian present, pedestrian looking, and pedestrian not looking. Overall, there was a significant reduction in speed under both the no pedestrian and the pedestrian not looking conditions. It appeared that crosswalk markings made drivers on relatively low-speed arterials more cautious and more aware of pedestrians.

The most ambitious study of crosswalks at uncontrolled locations involved a comparison of five years of pedestrian crashes at 1,000 marked crosswalks and 1,000 matched unmarked comparison sites. All sites in this study lacked traffic signals or stop signs on the approaches (Zegeer et al. 2002b). The study results revealed that on two-lane roads, the presence of a marked crosswalk alone at an uncontrolled location was associated with no difference in pedestrian crash rate, compared to an unmarked crossing. Further, on multi-lane roads with traffic volumes above about 12,000 vehicles per day, having a marked crosswalk alone (without other substantial improvements) was associated with higher pedestrian crash rates (after controlling for other site factors). Hazards were mitigated by raised medians.

A comparative evaluation of different engineering treatments found that the particular crossing treatment employed has a dramatic effect on motorists' propensity to yield to crossing pedestrians. Treatments that show a red signal indication to motorists have a statistically significant advantage over devices that do not show a red indication. Specifically, midblock signals, half signals, and high-intensity activated crosswalk (HAWK) signal beacons have compliance rates greater than 95 percent even on busy, high-speed arterial streets. Pedestrian crossing flags and in-street crossing signs also were effective in prompting motorist yielding, achieving 65 and 87 percent compliance, respectively. However, most of these crossing treatments were installed on lower-speed and lower-volume, two-lane roadways. High visibility signs and markings, and overhead

flashing beacons, had much lower compliance rates. On this basis, the study recommended changes in the *Manual on Uniform Traffic Control Devices* (MUTCD) pedestrian traffic signal warrant.

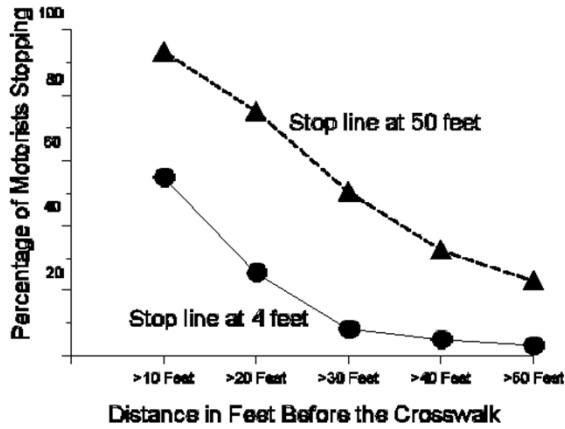
Studies from other countries speak to the safety benefits of pedestrian activated signals at uncontrolled crossing points. Installing so-called Pelican signals was highly effective in reducing crashes in Australia, the quarterly crash rate falling by 90 percent (Geoplan 1994). The Pelican signal is similar to a standard mid-block pedestrian signal, except that during the pedestrian clearance phase, the display facing motorists changes to a flashing yellow, indicating that vehicles may proceed cautiously through the crossing but are required to yield to pedestrians. In this way these signals produce less delay for motorists than standard pedestrian-activated signals. Installing standard pedestrian activated signals at midblock locations also gave rise to statistically significant reductions in crashes. In this case the adjusted reduction was 49 percent.

Canadian research in the area of pedestrian safety has focused on six countermeasures:

- Interventions to prompt pedestrians to look for turning vehicles when crossing at signalized crosswalks, including modification of the pedestrian signal head.
- Modification of pedestrian signals to increase the clarity of the indication for the clearance interval.
- The use of pedestrian activated flashing beacons at midblock crosswalks and at crosswalks on major roads at intersections not controlled by traffic signals.
- The use of advance stop lines to get motorists to stop upstream of crosswalks.
- Interventions to increase the conspicuity of crosswalks.
- The use of multifaceted programs that focus on engineering, enforcement, and education (the three E's) to increase yielding to pedestrians in crosswalks.

Studies of these countermeasures have demonstrated changes in behavior of motorists and/or pedestrians (Van Houten and Malenfant 1999). For example, advance stop lines, placed 50 feet upstream of a crosswalk rather than the standard four feet, cause a higher percentage of drivers to stop well in advance of the crosswalk rather than encroaching on it (Figure D-12). At signalized intersections, exclusive pedestrian intervals—which stop all vehicle traffic for all or part of the pedestrian crossing signal—have been shown to significantly reduce conflicts between pedestrians and motor vehicles (Van Houten et al. 2000). Two studies of in-pavement flashing warning lights automatically activated by the presence of pedestrians have shown reductions in both vehicle speeds and conflicts at uncontrolled crossings (Hakkert et al. 2001; Prevedourous 2001).

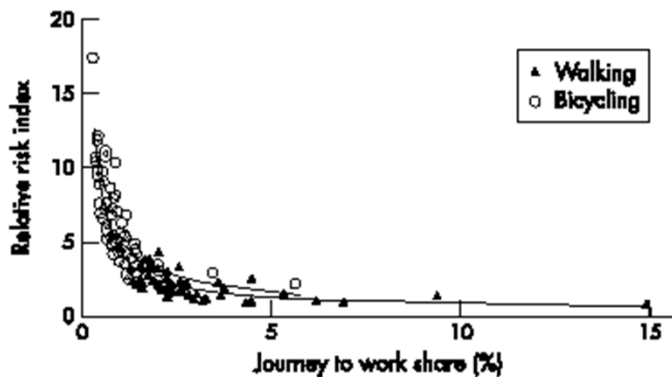
Figure D-12. Percentage of vehicles stopping more than 10 ft, 20 ft, 30 ft, 40 ft, and 50 ft from the crosswalk for each placement of the stop line



Source: Van Houten and Malenfant (1992)

Finally, the most compelling countermeasure for pedestrian and bicyclist safety is simply more people out walking and bicycling, which can be viewed as another positive effect of compact development patterns. There appears to be safety in numbers. Jacobsen (2003) demonstrated a direct relationship between number of cyclists and pedestrians and their safety (see Figure D-13). For a 100 percent increase in walking, the attendant increase in injuries is only 32 percent. So while there might be more injuries, there are fewer per capita. Australian research has confirmed these findings. “If cycling doubles, the risk per kilometre falls by about 34 percent; conversely, if cycling halves, the risk per kilometre will be about 52 percent higher” (Robinson 2005).

Figure D-13. Relative risk of pedestrian and bicyclist crashes as a function of journey to work mode shares in 68 California cities



Source: Jacobsen (2003).

## **Context-Sensitive Design**

In urban areas, the literature generally shows enhanced safety with lower-speed, less “forgiving” design treatments—such as narrow lanes, traffic calming measures, and street trees close to the roadway. The reason for this apparent anomaly may be that less forgiving designs provide drivers with clear information on safe and appropriate operating speeds, thereby preparing drivers to respond to the many vehicle and pedestrian “conflicts” present in highly-urbanized areas. As detailed by Dumbaugh (2005b), the basis is both biological and psychological. There is a well-documented communicative process that exists between the road environment and the roadway user. Where a roadway consistently informs the driver that caution is warranted, the result is that drivers are more vigilant in their search for oncoming hazards, as well as better prepared to respond to these hazards when they occur.

European designers have long recognized that the use of high design speeds leads to higher operating speeds, and have sought to remedy this problem by designing roadways for their intended operating speeds (Study Tour Team 2001). Unlike in the United States, where roadways are classified mainly in terms of their access and mobility functions, European design practice begins by examining the developmental context of a roadway, identifying the hazards that are expected to exist in these environments, and then specifying a target design speed to ensure that the driver travels at speeds that are appropriate given these hazards (Lamm et al. 1999). The result is that a roadway’s operating speed is consistent with its target speed, contributing to per capita traffic fatalities that are 50 to 75 percent lower than those in the United States (World Health Organization 2004).

Many individual engineers have recognized the need for lower-speed designs in urban contexts, a recognition that has led to the emergence of “context-sensitive design” as a new paradigm. The context-sensitive redesign of Bridgeport Way, the main street of University Place, Washington, led to a 69 percent crash reduction. Several local, state, and national organizations now encourage engineers to practice context-sensitive design on a project-by-project basis, and many exemplary projects have been built in recent years (Committee on Geometric Design 2004; Congress for the New Urbanism 2002; AASHTO 2004b). Yet, national and state highway design manuals continue to point engineers in the wrong direction, toward less safe designs, in urban settings (Ewing 2002). This may be changing, thanks to efforts such as the Institute of Transportation Engineers’ proposed recommended practice for major urban thoroughfares, prepared through an unprecedented collaboration with the Congress for the New Urbanism (Daisa et al. 2006).

## **Discussion**

Contemporary transportation engineering practice is oriented towards mobility, with safety identified as a complementary goal. This is readily evidenced in the goal statements of metropolitan planning organizations and state departments of

transportation, where the provision of a “safe and efficient” transportation system is listed as a single agency goal. Because safety and efficiency are treated as mutually-supportive goals, most conventional transportation planning applications begin by identifying levels of congestion for a given horizon year, and then proposing mobility-oriented solutions, such as road widenings. Once a mobility need is identified, safety is addressed by designing these improvements for higher design speeds under the presumption that higher design speeds equate to enhanced safety performance. To the extent that the built environment is considered at all, it is solely for forecasting future levels of traffic demand to identify needed mobility improvements.

Yet, the empirical evidence on traffic safety strongly suggests that safety and mobility may be conflicting goals, at least in urban areas. Contrary to accepted theory, the stop-and-go, high-volume traffic environments of dense urban areas appear to be safer than the lower-volume environments of the suburbs. The reason is that many fewer miles are driven on a per capita basis, and the driving that is done is at lower speeds that are less likely to produce fatal crashes. Also contrary to accepted theory, at least in dense urban areas, less “forgiving” design treatments—such as narrow lanes, traffic calming measures, and street trees close to the roadway—appear to enhance a roadway’s safety performance when compared to more conventional roadway designs. The reason for this apparent anomaly may be that less forgiving designs provide drivers with clear information on safe and appropriate operating speeds.

Considered broadly, the fundamental shortcoming of conventional traffic safety theory is that it fails to account for the moderating role of human behavior on crash incidence. Decisions to reduce development densities and segregate land uses, or to widen specific roadways to make them more forgiving, are based on the assumption that in so doing, human behavior will remain unchanged. And it is precisely this assumption – that human behavior can be treated as a constant, regardless of design – that accounts for the failure of conventional safety practice (Dumbaugh 2005b; 2006). If safety is to be meaningfully addressed, we must begin to develop our understanding of how the built environment influences the both the incidence traffic-related crashes, injuries, and deaths, as well as the specific behaviors that cause them.



## Appendix E: What TOD Manuals Tell Us

Planning agencies and transit operators have come to realize that transit ridership depends as much on the urban environment in which transit operates as on the level of transit service provided. With this in mind, transit-oriented development (TOD) guidelines have been prepared by many planning agencies and transit operators throughout North America. All told, more than 50 TOD manuals are currently available.

This review covers the following topics from these manuals: land use; roadway design; site planning; pedestrian and bicycle facilities; pedestrian amenities; and transit stops.

### TOD Manuals Reviewed

TOD manuals are more numerous than we imagined at the beginning of our review. Some can be characterized as land planning/urban design manuals with a transit orientation; others as transit facility design manuals that pay secondary attention to land planning and urban design. The former emphasize the needs of transit users accessing the system, the latter the needs of the transit operator running the system. A few of the manuals are essentially informative brochures while others are more comprehensive.

As a group, the manuals are largely duplicative of one another, even to the point of reproducing each other's graphics. Thus, we can review a subset of TOD manuals with some confidence that we will not miss too much. Our sample consists of the following manuals, listed in chronological order:

#### Land Planning/Urban Design Manuals

Alameda-Contra Costa (CA) Transit District, *Guide for Including Public Transit in Land Use Planning*, 1983a. (Oakland)

Municipality of Metropolitan Seattle, *Encouraging Public Transportation through Effective Land Use Actions*, 1987. (Seattle)

Orange County (CA) Transit District, *Consideration of Transit in Project Development*, 1987. (Orange County)

Calthorpe Associates, *Transit-Oriented Development Design Guidelines*, prepared for Sacramento County, 1990. (Sacramento)

Beimborn and Rabinowitz, *Guidelines for Transit-Sensitive Suburban Land Use Design*, Urban Mass Transportation Administration, 1991. (National)

Delcan Corporation, *Guide to Transit Considerations in the Subdivision Design and Approval Process*, prepared for the Transportation Association of Canada (TAC) Ottawa, 1991. (TAC Canada)

City of Winnipeg, *Planning and Building Transit Friendly Residential Subdivisions*, 1991. (Winnipeg)

Ontario Ministry of Transportation, *Transit-Supportive Land Use Planning Guidelines*, 1992. (Ontario)

Regional Transportation Commission of Washoe County (RTC), Nevada, *Planning for Transit - A Guide for Community & Site Planning*, 1992. (Reno)

Calthorpe Associates, *Transit-Oriented Development Design Guidelines*, prepared for the City of San Diego, CA, 1992. (San Diego)

Metropolitan Transit Development Board (MTDB), *Designing for Transit*, San Diego, 1993. (San Diego Metro)

Snohomish County (WA) Transportation Authority, *A Guide to Land Use and Public Transportation for Snohomish County*, 1989; Update, 1993. (Snohomish County)

Tri-County Metropolitan Transportation District of Oregon, *Planning and Design for Transit*, Portland, 1993. (Portland)

BC Transit, *Transit Friendly Subdivision & Development Guidelines*, prepared for the Victoria (British Columbia) Regional Transit System. (Victoria)

Glattig Jackson Kercher Anglin Lopez Rinehart, Inc., *Central Florida Mobility Design Manual*, LYNX, The Central Florida Regional Transit Authority, 1994. (Orlando)

Skidmore, Owings & Merrill, *Planning for Transit-Friendly Land Use: A Handbook for New Jersey Communities*, New Jersey Transit, 1994. (New Jersey)

Regional Transportation District (RTD), *Creating Livable Communities: A Transit Friendly Approach*, Denver, CO., 1995. (Denver)

Lohan Associates, *Guidelines for Transit-Supportive Development*, Chicago Transit Authority, 1996. (Chicago)

Monterey-Salinas Transit, *Designing for Transit: A Manual for Integrating Public Transportation and Land Use in Monterey County*, Monterey, CA, 1996. (Monterey)

Triangle Transit Authority, *Station Area Development Guidelines for the Regional Transit Stations*, Research Triangle Park, NC, 1997. (Raleigh-Durham)

Transit Services of Frederick County, *Transit-Oriented Design Guidelines*, Frederick County, MD, 2001. (Frederick County)

Mid-America Regional Council, *Smart Choices: Transit-Supportive Development Guidebook*, Kansas City, 2001. (Kansas City)

Calthorpe Associates, *Wasatch Front Transit Oriented Development Guidelines*, Envision Utah, Salt Lake City, 2002. (Salt Lake City)

San Francisco Bay Area Rapid Transit District, *BART Transit-Oriented Development Guidelines*, San Francisco, 2003. (San Francisco)

City of Calgary, *Transit Oriented Development: Best Practices Handbook*, 2004. (Calgary)

Neighborhood Planning and Zoning Department, *Transit-Oriented Development (TOD) Guidebook*, City of Austin, TX, 2006. (Austin, 2006)

City of Ottawa, *Transit-Oriented Development Guidelines*, Ottawa, 2007. (Ottawa)

Department of Planning, Building & Code Enforcement, *Transit-Oriented Development, San Jose*, CA, undated. (San Jose, undated)

### **Transit Facility Design Manuals**

Southeastern Michigan Transportation Authority (SEMTA), *Designing for Transit: A Transit Design Criteria and Standards Manual*, 1982. (SE Michigan)

Alameda-Contra Costa (CA) Transit District, *Transit Facilities Standards Manual*, 1983b. (AC Transit Facilities)

D.R. Jessup, G. Van Wormer, and H. Preston, *Guidelines for the Design of Transit Related Roadway Improvements*, Metropolitan Transit Commission, St. Paul, Minnesota, 1983. (Minneapolis-St. Paul)

Center for Transportation Research, The University of Texas at Austin, *Transit Facility Design Guide, Prepared for the Capital Metropolitan Transportation Authority*, Austin, 1988. (Austin, 1988)

Maryland Department of Transportation, *Access by Design: Transit's Role in Land Development*, 1988. (Maryland)

Pace Suburban Bus Service, *Pace Development Guidelines*, Illinois, 1989. (Suburban Chicago)

Texas Transportation Institute (Fitzpatrick et al.), *Guidelines for Planning, Designing and Operating Bus Related Street Improvements*, 1990. (Texas)

Municipality of Metropolitan Seattle, Metro Transportation Facility Design Guidelines, 1991. (Seattle Facilities)

Orange County (CA) Transportation Authority, *Design Guidelines for Bus Facilities*, 1992. (Orange County Facilities)

Canadian Urban Transit Association (CUTA), *Canadian Transit Handbook*, Toronto, 1993. (CUTA Canada)

Herbert-Halback, Inc., *Customer Amenities Manual*, LYNX Members, The Central Florida Regional Transportation Authority, Orlando, FL, 1994. (Orlando Amenities)

Hillsborough Area Regional Transit Authority, *Transit-Friendly Development*, Tampa, FL, 1994.

Niagara Frontier Transportation Authority, *Building for Tomorrow: A Guide to Transit Friendly Designs for New Residential, Commercial and Light Industrial Developments in the Niagara Frontier*, Buffalo, NY, 1997. (Buffalo)

City of Brunswick, *Transit-Oriented Design Guidelines*, Brunswick, MD, 2006. (Brunswick)

## Land Uses

“Transit-oriented development (TOD) is the functional integration of land use and transit via the creation of compact, walkable, mixed-use communities within walking distance of a transit stop or station” (Austin 2006, p. 5). The distance that a person is willing to walk to take transit defines the primary area within which TOD should occur (Calgary 2004).

The industry standard is 1/4 mile (see Table E-1). However, walking distances are known to depend on user characteristics, the pedestrian environment, climate and topography, and transit quality of service. High-quality rail service is believed to extend walking distances to 1/2 mile or more. The propensity to use transit drops off long before the "maximum walking distance" is reached and extends beyond "maximum walking distance" for those with no other means of transportation.

Table E-1. Maximum Walking Distances

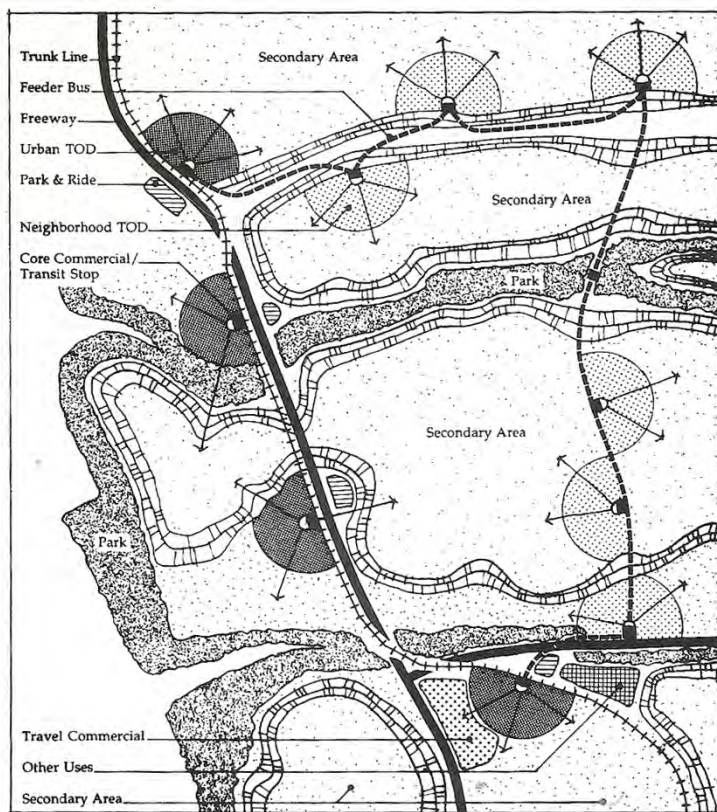
660 ft (1/8 mi)	for seniors, SE Michigan, 1982
750 ft	for seniors, Seattle, 1987; for mobility impaired, Snohomish County, 1989
1,000 ft	Seattle, 1987; Snohomish County, 1989
1,320 ft (1/4 mile)	SE Michigan, 1982; Suburban Chicago, 1989; Texas, 1990; National, 1991; Rabinowitz et al., 1991; Ontario, 1992; TAC Canada, 1991; Winnipeg, 1991; Buffalo, 1997
1,500 ft	Maryland, 1988; CUTA Canada, 1993;
2,000 ft	San Diego, 1992; Austin, 2006; Ottawa, 2007
2,640 ft (1/2 mile)	for rail, Raleigh-Durham, 1997

TOD manuals prescribe compact development within walking distance of transit stops (Seattle 1987; Snohomish County 1989; Sacramento 1990; TAC Canada 1991; San Diego 1992; Oakland 1992; Ontario 1992; CUTA Canada 1993; San Diego Metro 1993; New Jersey 1994; Kansas City 2001; Salt Lake City 2002). Compact development may take the form of high activity nodes (Sacramento 1990; San Diego 1992; Portland 1993),

high activity corridors (National 1991; Oakland 1992; Reno 1992; CUTA Canada 1993; San Diego Metro 1993), or both nodes and corridors (Ontario 1992).

Peter Calthorpe's node-based TODs consist of mixed-use neighborhoods built around commercial cores and transit stops, with average maximum walking distances to the stop of 1/4 mile prescribed for Sacramento and 2,000 feet or less for San Diego (Sacramento 1990; San Diego 1992). Each nodal development is designated an "Urban TOD" or "Neighborhood TOD" and is intended to create a pedestrian-oriented settlement that emphasizes transit while not eliminating or ignoring the role of the automobile (this is a common theme among TOD manuals). Depending on "location, purpose, and market demand" (San Diego 1992, p. 3), exact uses in the commercial core will vary. Surrounding the TOD is a "secondary" area extending up to a mile in distance (within bicycling range), containing medium-density housing, schools, parks, some retail uses, and park and ride lots.

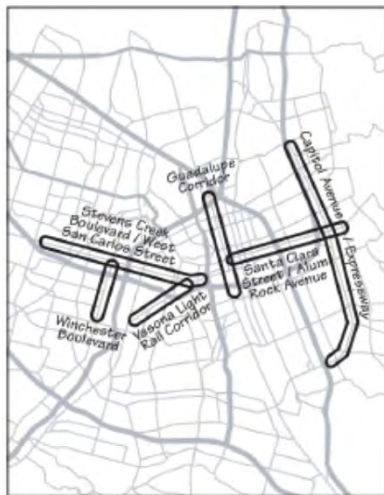
Figure E-1. San Diego TODs.



Source: San Diego (1992 p. 9)

Beimborn and Rabinowitz's transit corridor districts (TCDs) consist of linear developments 1/2 mile wide featuring transit-oriented land uses (National 1991). In TCDs, densities decline with distance from the transit line, and housing, office, retail, and light industrial uses are mixed. Auto-oriented uses are relegated to parallel corridors separated from the transit line by at least 1/4 mile.

Figure E-2. San Jose's Transit-Oriented Development Corridors



Source: San Jose (undated, p. 134)

Whether located in nodes or corridors, some land uses are more transit-supportive than others. The National manual (1991) rates land uses for their compatibility with public transit. Uses receiving the highest score (5) include commercial airports, colleges and universities, and shopping centers. Scoring next highest (4) are apartments, schools, hospitals, and office buildings. Snohomish County (1989), Portland (1993), New Jersey (1994), Denver (1995), and Raleigh-Durham (1997) also rate land uses for compatibility with transit, while the Reno manual (1992) offers a compatibility worksheet to be used on a case-by-case basis. Calgary (2004), Austin (2006), and Ottawa (2007) classify some land uses as transit supportive, and others as non-transit supportive.

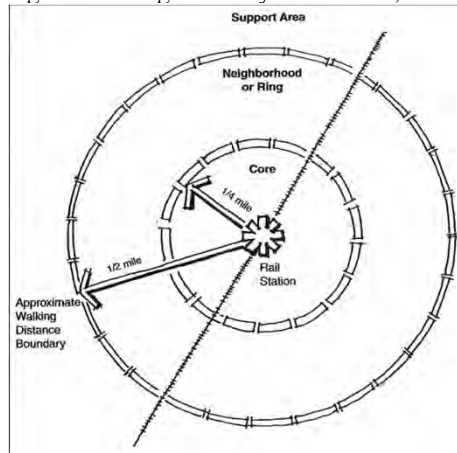
Figure E-3. Transit Supportive and Non-Transit Supportive Land Uses

transit supportive land uses	non-transit supportive land uses
<ul style="list-style-type: none"> <li>Multi-dwelling residential</li> <li>Affordable housing</li> <li>Small lot single-family</li> <li>Offices</li> <li>Hotels</li> <li>Health care facilities</li> <li>Medical clinics</li> <li>High schools and colleges</li> <li>Daycare facilities</li> <li>Cultural institutions</li> <li>Athletic/recreational facilities</li> <li>Health Clubs</li> <li>Personal services</li> <li>Retail shops</li> <li>Restaurants</li> <li>Grocery Stores</li> <li>Coffee shops</li> <li>Local pubs</li> <li>Outdoor cafes</li> <li>Financial institutions</li> <li>Dry cleaners</li> <li>Entertainment facilities</li> <li>Neighbourhood oriented businesses</li> </ul>	<ul style="list-style-type: none"> <li>Automotive sales &amp; display</li> <li>Automotive services &amp; repair</li> <li>Car washes</li> <li>Large format/warehouse retail</li> <li>Large format food stores</li> <li>Drive-in/drive-through services</li> <li>Warehouse distribution</li> <li>Outdoor storage</li> <li>Regional parks</li> <li>Funeral homes</li> <li>Large format faith facilities</li> <li>Parking lots</li> <li>Low density single-family housing</li> <li>Low intensity industrial uses</li> </ul>

Source: Calgary (2004, p. 8)

TOD manuals agree that, at a minimum, medium residential densities are required to support basic bus service. Lower densities may suffice at lower levels of service, and higher densities may be required for higher levels of service (see Table E-2). TOD manuals sometimes prescribe density gradients moving out from stops or stations. New Jersey (1994), Denver (1995), and Raleigh-Durham (1997) call for high densities within a quarter mile of stops and medium densities from a quarter to a half mile.

Figure E-4. High Density in the Core, Medium Density in the Secondary Area



Source: Raleigh-Durham (1997, unnumbered)

Table E-2. Minimum Residential Densities for Transit Service (dwellings/acre)

2	Oakland (45-minute service)*
3	Suburban Chicago*
	Texas
4	Ontario (60-minute service)
	County (60-minute service)
5	Oakland (30-minute service)*
	San Diego Metro (suburban areas)
6	Maryland
7	National (30-minute service)
	Ontario (30-minute service)
	Reno
	Seattle
	San Diego (suburban areas)
	Raleigh-Durham (rail station area in neighborhood)
	Denver
	New Jersey (local bus service)
8	Oakland (20-minute service)*
	Portland (suburban neighborhoods)
	Snohomish County (30-minute service)
	Salt Lake City (suburban areas)
12	Sacramento (Neighborhood TOD)
	San Diego (urban areas)
15	National (10-minute service)
	Portland (mixed-use centers/urban neighborhoods/urban corridors)



	Sacramento (Urban TOD)
	Raleigh-Durham (rail station area in core)
	Denver (net in community centers)
	New Jersey (rail service)
	Austin (Neighborhood Center TODs)
20	San Jose (Transit Corridor Residential)
30	San Diego (urban centers)
	Salt Lake City (urban areas)
20/40	San Francisco (gross density/net density)
40	Denver (net density in urban centers)

\*Density standards were converted from persons per square mile to dwelling units per acre, assuming approximately 2 persons per household.

It turns out that once the transit capture rate and cost recovery ratio are established, the density required to support transit service is a simple function of level of service (National 1991). The higher the level of service, the higher the density required to support it. This relationship is captured in Pushkarev and Zupan's density standards, which have been incorporated into several TOD manuals (Seattle, Sacramento, San Diego, Ontario, National) (see Table E-3).

Table E-3. Minimum Residential Densities for Different Service Frequencies

Service Frequency	Residential Density
1 hour service	4 units/acre
1/2 hour service	7 units/acre
10 minute service	15 units/acre

Many TOD manuals also establish commercial intensity standards for transit service (see Table E-4 and Figure E-5).

Table E-4. Minimum Commercial Intensities for Transit Service

FARs	
.25	Suburban employment centers (Portland, 1993)
.35	Office uses with surface parking (San Diego, 1992); suburban neighborhoods (Portland, 1993); office uses in urban and suburban areas within 1/4 mile of bus stops (San Diego Metro, 1993)
.50	Office uses with structured parking (San Diego, 1992); urban corridors without structured parking, urban neighborhoods, and mixed use centers (Portland, 1993); office uses in urban centers within 1/4 mile of bus stops (San Diego Metro, 1993); rail stations in core areas (Raleigh-Durham, 1997); commercial centers with surface parking (Denver, 1995)
1.0	Near transit stops (National); office uses in urban and suburban areas, and in urban

centers within 1/2 mile of transit (San Diego Metro, 1993); commercial centers with structured parking (Denver, 1995)

1.5 Activity nodes in small municipalities (Ontario)

2.0 Activity nodes in large municipalities (Ontario); urban corridors with structured parking (Portland, 1993)

#### Employees/Acre

10 San Francisco – per gross acre (2003)

20 Portland (1993)

30 Portland (for light rail) (1993)

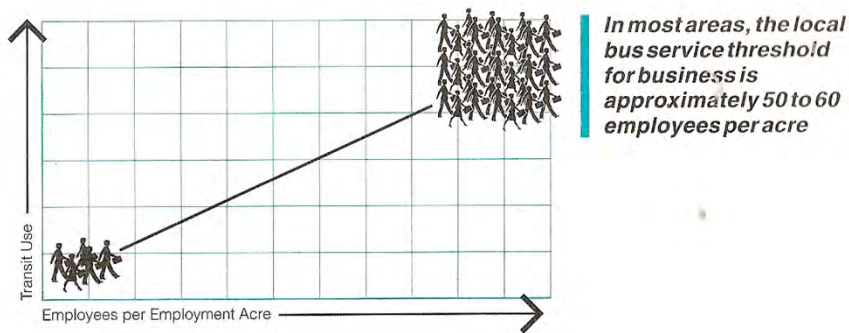
40 New Jersey (local bus service) (1994)

50 Seattle (1987); Snohomish County (1989); Denver (1995)

60 Ontario (1992)

150 New Jersey (for rail) (1994)

Figure E-5. Ridership vs. Employment Density



Source: Denver (1993, p. 12)

Most TOD manuals call for a mix of land uses in transit corridors or around transit stops (Seattle 1987; Snohomish County 1989; Suburban Chicago 1989; Sacramento 1990; National 1991; TAC Canada 1991; Orange County 1992; San Diego 1992; Ontario 1992; Reno 1992; Portland 1993; San Diego Metro 1993; CUTA Canada 1993; New Jersey 1994; Denver 1995; Raleigh-Durham 1997; Frederick County 2001; Kansas City 2001; Salt Lake City 2002; Calgary 2004; Austin 2006; Ottawa 2007; San Jose, undated). This is done to encourage pedestrian activity, allow errands on the way to or from transit

stops, establish the security of a 24/7 environment, and provide interesting points of interest on the walk to transit stops.

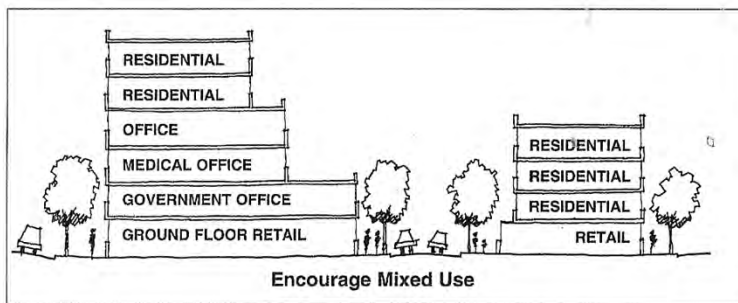
Only Sacramento (1990), San Diego (1992) and Portland (1993) offer detailed guidance regarding the appropriate mix of land uses in TODs. Minimum percentages of site area from the San Diego and Portland manuals are shown in Table E-5.

Table E-5. Minimums Percentages of Different Uses

Centers	Neighborhood TOD	Urban TOD	
Public	10%	10%	30%
Core Commercial	10%	30%	30%
Housing	40%	20%	40%

Snohomish County (1989), Sacramento (1990), San Diego (1992), Ontario (1992), Portland (1993), New Jersey (1994), Salt Lake City (2002), and Ottawa (2007) all encourage vertical mixing of uses—that is, the mixing of uses from floor to floor within individual buildings—as well as horizontal mixing from building to building. The mix may include residential, office and retail use in a single building or, in the case of parking structures, parking above and retail below. Retail uses are generally preferred at ground level, because they generate more pedestrian traffic (San Jose, undated). “Long expanses of street-level office space without multiple entries or visual interaction with the street create ‘dead zones’ along pedestrian paths and should be discouraged. Encourage, instead, pedestrian-oriented uses that activate the street with customer traffic, especially those uses that are open beyond normal 9 am to 5 pm business hours” (New Jersey 1994, p. 25).

Figure E-6. Vertical Mixing of Uses



Source: New Jersey (1994, p. 22)

Some TOD manuals go so far as to prescribe the percentage of the population living and/or working in transit-served areas. Ontario (1992) requires that at least 65 percent of

households and jobs be within 1/8 mile of stops, and 90 percent within 1/4 mile. Oakland (1983a) and Texas (1990) have coverage standards that vary with population densities in areas served. At densities of more than 4,000 persons per square mile, Austin (1988) recommends that 90 percent of households have service within 1/4 mile; at densities of 2,000 to 4,000 persons per square mile, the standard drops to 50 percent of households within 1/2 mile of transit lines.

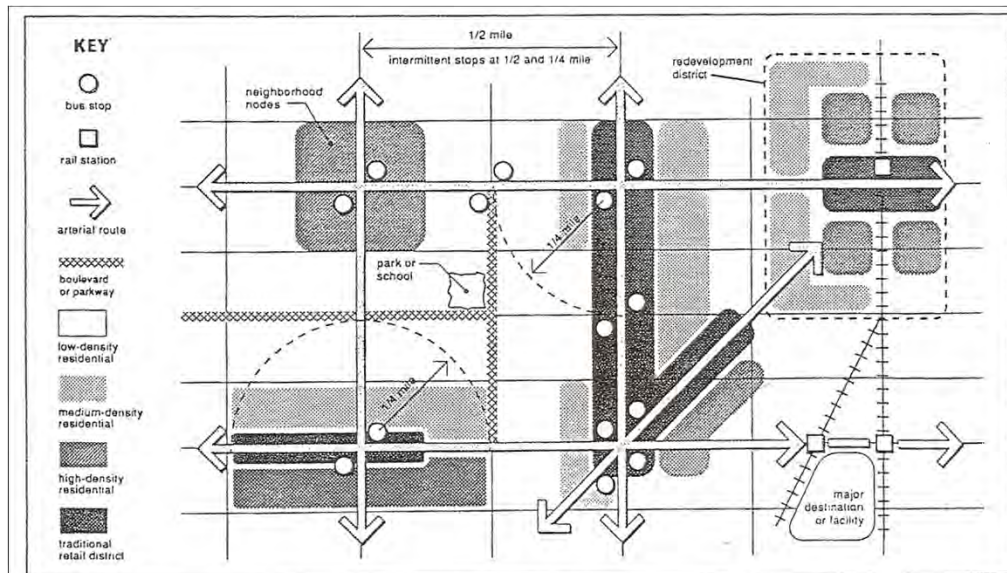
## Roadway Design

TOD manuals agree that, for transit operation, interconnected, grid-like road networks are superior to the discontinuous, curvilinear networks found in many suburbs (Seattle 1987; Suburban Chicago 1989; Orange County 1992; Ontario 1992; San Diego 1992; Reno 1992; Portland 1993; Denver 1995; Buffalo 1997; Raleigh-Durham 1997; Frederick County 2001; Kansas City 2001; Salt Lake City 2002; Austin 2006; Ottawa 2007).

"Typical suburban streets often follow a curvilinear pattern with little opportunity for through routing. In addition, adjoining subdivisions may well have non-aligned streets or complete boundary separations. In this situation transit vehicles are required to make frequent turns and may need to 'backtrack' in order to provide service within a reasonable distance of homes or places of work" (National 1991, p. 14).

Many manuals contend that grid-like networks are better not only for buses but for transit users accessing the system. Traveling at pedestrian speeds, users need direct routes to transit stops. The suburban road hierarchy, with its curves and cul-de-sacs, makes for very circuitous trips to transit stops.

Figure E-7. Grid Supportive of Compact Development and Transit

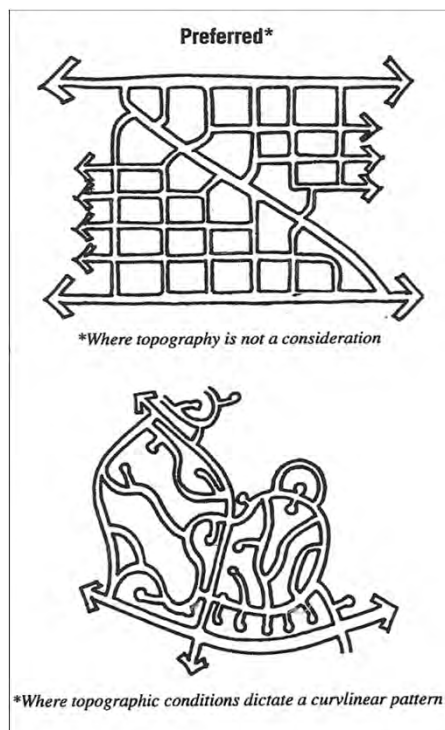


Source: Chicago (1995, p. 6)

The road network need not be a gridiron of parallel streets meeting at right angles. Reno (1992) offers the following on the subject of grid street patterns:

They have been criticized as being monotonous, ignoring topography, and increasing through traffic on residential streets. These shortcomings are not inherent to grid patterns, and they can be overcome through modifications in design. Through traffic can be directed to collectors. Monotony can be averted and topography incorporated by enhancing the grid with curves, landscaping and building patterns. The site need not be limited to geometrically straight lines, and all blocks do not need to be of equal size and shape (Reno 1992, p. 22).

Figure E-8. Street Networks Dependent on Topography



Source: Denver (1995, p. 4-10)

Kansas City (2001), Salt Lake City (2002), and Austin (2006) prescribe short blocks of 300 to 600 feet to keep walking distances short and provide alternative route options. Several TOD manuals emphasize the importance of collectors and arterials spaced no more than ½ mile apart (Oakland 1983a; Seattle 1987; Snohomish County 1989; TAC Canada 1991; Ontario 1992). Collectors that are widely spaced may fail to penetrate

residential areas and activity centers. Portland's solution to this dilemma involves the use of "connectors" to carry moderate levels of local traffic, maintain bicycling and pedestrian safety, and provide alternative paths within neighborhoods (Portland 1993, p. 75).

TOD manuals usually prescribe travel lanes wide enough to accommodate standard buses. Recognizing a standard bus width of 10 feet, including mirrors, 12-foot lanes are generally recommended (see Table E-6).

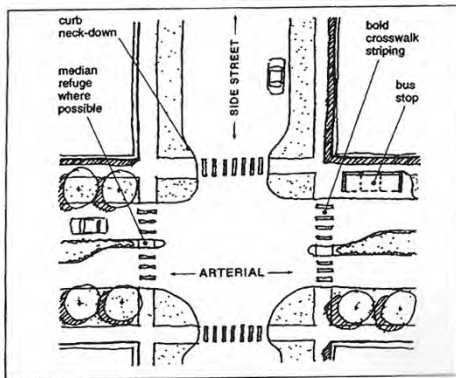
Table E-6. Minimum Lane Widths

9.5'	Salt Lake City
10'	Maryland; Minneapolis-St. Paul
11'	SE Michigan; Reno (when restricted by available width); Oakland, 1983b, Orlando; San Diego Metro
11.5'	Ontario; CUTA Canada
12'	Suburban Chicago; Orlando (for curb lanes); San Diego Metro (for curb lanes)

Oakland (1983a) requires transit to operate on collectors or arterials, which tend to be wider, higher speed roads. Winnipeg (1991) calls for transit to follow streets built to collector standards with respect to construction materials, width, depth, and roadway geometrics. Two TOD manuals specify minimum street widths, 9 meters, or just under 30 feet (Ontario 1992; TAC Canada 1991).

On the other hand, Portland, Raleigh-Durham, Sacramento, San Diego, and San Jose recommend minimizing road widths within TODs to reduce street crossing distances and create safer pedestrian environments. With the advent of traffic calming in the U.S., some of the newer TOD manuals call for measures such as traffic circles and intersection neckdowns to ensure that traffic speeds are not excessive (New Jersey 1994; Orlando 1994; Chicago 1996; Raleigh-Durham 1997; Salt Lake City 2002; San Francisco 2003; San Jose, undated). Traffic calming may be limited to local access routes to transit stops, or may extend up the street hierarchy to the arterials and collectors that serve as bus routes.

Figure E-9. Neckdowns on a Multimodal Street



Source: Raleigh-Durham (1997, unnumbered)

## Site Planning

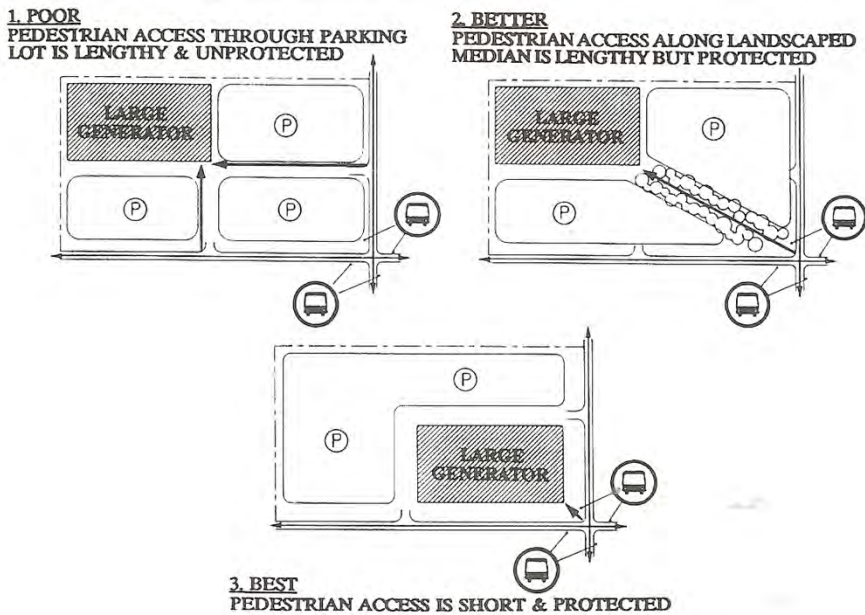
Guidelines for subdivision design and site planning emphasize transit and pedestrian accessibility within subdivisions, and connections to arterial roads and neighboring subdivisions. Barriers to transit, such as insufficient access roads into subdivisions, dead-end streets, and circuitous routes should be avoided (San Diego 1992), as should barriers to pedestrian access, including perimeter walls, berms, landscaping, and slopes between residences and bus stops (Snohomish County 1989).

The orientation of buildings is discussed in some detail by most manuals reviewed. The following is a summary of major recommendations and requirements:

- Commercial strip development with large parking lots that front on arterial roads should be avoided (CUTA Canada 1993; Buffalo 1997).
- Buildings should be oriented toward streets with transit facilities (Oakland 1983a; Ontario 1992; Snohomish County 1989; National 1991; Chicago 1996; Raleigh-Durham 1997; Frederick County 2001; Calgary 2004; Austin 2006; Ottawa 2007).
- To minimize walking distances, parking lots should be placed at the rear or side of buildings (see Figure E-10) (Seattle 1987; Snohomish County 1989; Sacramento 1990; TAC Canada 1991; San Diego 1992; Portland 1993; New Jersey 1994; Chicago 1996; Frederick County, 2001; Salt Lake City, 2002; Calgary, 2004; Austin, 2006; Ottawa 2007; San Jose, undated). If parking must be located between the building and the street, a walkway connecting the entrance of the building to the sidewalk should be provided.
- Building setbacks should be reduced or eliminated altogether (Snohomish County 1989; Suburban Chicago 1989; Ontario 1992; San Diego Metro 1993; Orlando 1994; Salt Lake City 2002; San Francisco 2003; Austin 2006; San Jose, undated). A number of manuals specify setback requirements (see Table E-7).

- Parking garages should be recessed behind the main facades of homes to reduce their visual prominence, and when parking garages front on commercial streets, they should be lined with retail uses (Salt Lake City 2002).

Figure E-10. More and Less Preferred Site Designs



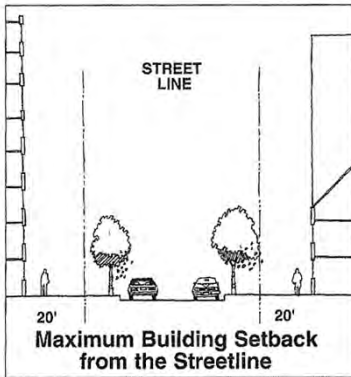
Source: Canada (1991, p. A-6)

Table E-7. Building Setbacks

Residential	
10-15 ft	San Diego, 1992; Portland, 1993
Commercial	
0-10 ft	Raleigh-Durham, 1997
0-20 ft	Sacramento, 1990, San Diego, 1992; Portland, 1993; New Jersey, 1994
0-25 ft	San Jose, undated
Large Buildings	
10-20 ft	Ottawa, 2007



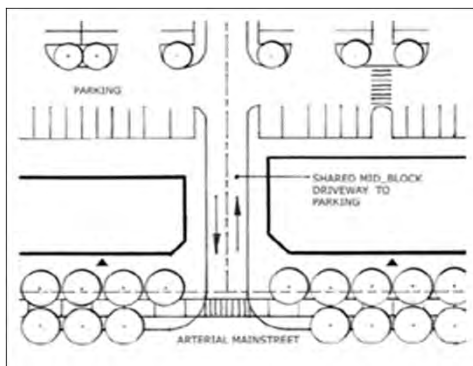
Figure E-11. Maximum Building Setback of 20 Feet



Source: New Jersey (1994, p. 29)

Suburban Chicago (1989), Ontario (1992), Calgary (2004), and Ottawa (2007) recommend that commercial curb cuts be kept to a minimum in order to facilitate pedestrian movement and access to transit, and to ease the flow of traffic on abutting roads. San Diego Metro (1993) likewise discourages "frequent driveways" to reduce the number of conflict points with pedestrians.

Figure E-12. Fewer Curb Cuts for Less Interruption to the Public Sidewalk



Source: Ottawa (2007, p. 15)

Many manuals call for off-street parking requirements in areas fully served by transit to be reduced, either unconditionally or tied to the provision of transit-related features (Seattle 1987; Snohomish County 1989; Sacramento 1991; National 1991; Suburban Chicago 1991; San Diego 1992; Ontario 1992; Portland 1993; New Jersey 1994; Salt Lake City 2002). San Diego (1992) suggests that parking lots occupy no more than 1/3 or 75 feet of the frontage of pedestrian-oriented streets. Raleigh-Durham (1997) recommends limiting surface lots to three acres, unless future development plans call for

transition of lots to buildings or parking garages. New Jersey (1994) recommends that parking structures be limited to 1/3 of street frontage. Salt Lake City (2002) sets a limit of 35-45% on the proportion of building facades occupied by garages so that streetscapes do not become garagescapes.

Strategies commonly recommended for reducing parking footprints include:

- low minimum and maximum parking requirements (New Jersey 1994; Frederick County 2001; Salt Lake City 2002; Calgary 2004; Austin 2006; San Jose, undated);
- shared parking (National 1991; Ontario 1992; San Diego 1992; Portland 1993; Denver 1995; Frederick County 2001; Kansas City 2001; Salt Lake City 2002; Ottawa 2007; San Jose, undated);
- institution of paid parking (Seattle 1987; Snohomish County 1989); San Diego Metro 1993; Salt Lake City 2002);
- preferential parking and reduced parking fees for HOVs (high occupancy vehicles) (Ottawa 2007);
- allowance for on-street parking (San Diego, 1992; Portland, 1993; Orlando, 1994; Raleigh-Durham, 1997; Frederick County, 2001; Kansas City, 2001; Salt Lake City, 2002; San Jose, undated); and
- structured parking (San Diego 1992; New Jersey 1994; Denver 1995; Kansas City 2001; Salt Lake City 2002).

## **Pedestrian and Bicycle Facilities**

Pedestrian paths should radiate out from transit stops, and be as direct and visually unobstructed as possible (Orange County 1991; New Jersey 1994; Buffalo 1997; Salt Lake City 2002; San Francisco 2003; Calgary 2004; San Jose, undated). Wherever possible, street crossings should be at grade rather than depressed in tunnels or elevated in bridges (New Jersey 1994; Raleigh-Durham 1997; San Francisco 2003; Calgary 2004; Ottawa 2007).

All path surfaces should be paved, made of durable construction materials, maintained year-round, and well-lit for nighttime safety (Maryland 1988; TAC Canada 1991; Winnipeg 1991; Ontario 1992). Paths must also be wheelchair accessible, with curb cuts at all intersections and a detectable warning surface (raised truncated domes) along the curb edge (Balog et al. 1992). Use of different pavement textures or colors can show “priority of the pedestrian in critical locations” or provide “visual identification of pedestrian routes” (Denver 1995; Ottawa 2007). Pedestrian-scale lighting is recommended (New Jersey 1994; Salt Lake City 2002).

TOD guidelines and literature recommend that sidewalks be provided on at least one side of transit routes (Seattle 1987; National 1991; Rabinowitz et al. 1991), both sides of all urban streets (Orlando 1994, p. 2-6); or, when feasible, both sides of transit routes and at least one side of residential and industrial streets leading to transit (Suburban Chicago 1989; TAC Canada 1991; Winnipeg 1991; Ontario 1992). In addition to sidewalks that run parallel to transit routes, it is recommended that walkways radiate from each transit stop to serve nearby buildings (National 1991), and connect building entrances and stops as directly as possible to avoid shortcuts across lawns (Maryland 1988).

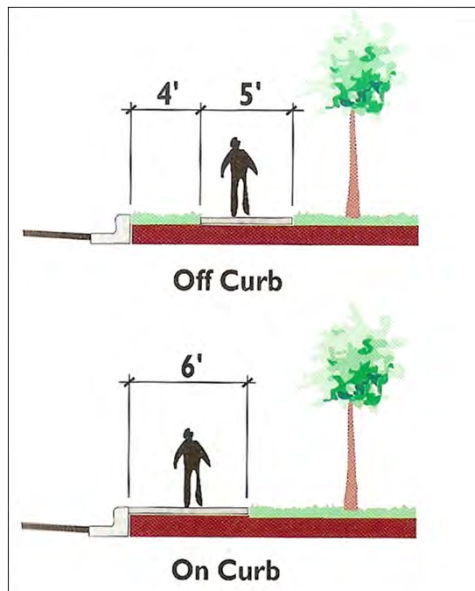
All sidewalks and walkways should be separated from roads by differences in grade, planting strips, amenity zones, or parking lanes (Snohomish County 1989; Raleigh-Durham 1997; Salt Lake City 2002). Several manuals call for delineated paths through parking lots to ensure pedestrian safety and ease transit access.

Some manuals recommend widths for sidewalks or walkways (see Table E-8 and Figure E-13). More specific recommendations, depending on density and land use, are provided by Bowman et al. (1989).

Table E-8. Minimum Widths for Sidewalks and Walkways

4 ft	at 4 units/acre or less (Bowman et al., 1989); in low-density residential areas (New Jersey, 1994)
5 ft	at more than 4 units/acre, arterial and collector streets, commercial/industrial areas (Bowman et al., 1989); in Urban and Neighborhood TODs (San Diego, 1992); in residential areas (Raleigh-Durham, 1997); in medium-density residential areas (Denver, 1995); at higher densities (New Jersey, 1994); in less traveled areas (Kansas City, 2001)
6 ft	on commercial streets (Chicago, 1996)
8 ft	on accessways to bus stops (Snohomish County, 1989; Orange County, 1992)
10-15 ft	in high activity areas (Denver, 1995); in heavily traveled areas (Kansas City, 2001)
15 ft	on access routes, including the planting strip or amenity zone (San Jose, undated)

Figure E-13. Minimum Sidewalk Width With and Without a Planting Strip



Source: Orlando (1994, p. 2-6)

Some TOD manuals specifically call for bicycle networks to be linked to transit stops (Suburban Chicago 1989; National 1991; Orlando 1994; Denver 1995; Raleigh-Durham 1997; Salt Lake City 2002). The Orlando guidelines designate four categories of bicycle facilities—bike lane, bike path, bike route, and bikeway—with corresponding design standards (Orlando 1994, p. 3-2). Additional consideration is given to bicycle storage facilities, bicycle parking standards, and signage clearly indicating bicycle facilities (Orlando 1994, pp. 3-3 - 3-4). Manuals call for bicycle paths to be from 5 to 6 feet wide for one-way systems and 8 feet wide for two-way systems (Suburban Chicago 1989; Buffalo 1997).

## Pedestrian Amenities

"Amenities are necessary to make places 'pedestrian-friendly' and encourage us to get out of our cars" (Portland 1993, p. 21). A hierarchy of public spaces (e.g., parks, plazas, courtyards, and paseos) should be provided along access routes to transit stops (San Jose, undated). These stopping and resting places can incorporate landscaping, benches, increased lighting, special paving materials, water fountains, and other landmark features (New Jersey 1994; Salt Lake City 2002; Calgary 2004).

Ottawa (2007) recommends that seating be provided along walkways and sidewalks greater than 50 meters (165 feet) in length and at scenic locations. It also recommends that shade trees and shrubs be planted along access routes to help reduce urban heat and to create a more comfortable microclimate.

Buildings themselves can be amenitized by incorporating the urban design qualities of complexity, transparency, and human scale (New Jersey 1994; Ottawa 2007). In commercial areas, shops, restaurants, and service establishments should open directly on the street because their window displays, signs, and frequent entrances add visual points of interest and give pedestrians a sense of security (Ontario 1992; San Francisco 2003). “The visual variety created by building elements such as storefront entrances, canopies, and signage, helps to shorten the sense of walking distances and reduce the monotony of pedestrian trips.... A minimum of 50% of the ground floor level of buildings along major pedestrian streets should be composed of clear transparent glass. Building entries should occur at least once for each 50 feet or less of frontage” (New Jersey 1994, pp. 26-27).

Similarly, “architectural variety on the lower three to four stories can define an interesting public realm. Articulated building facades incorporate attractive windows and varied architectural elements, and are built to the sidewalk. Upper floors of tall buildings can be set back to allow sunlight to reach the street and help reduce the sense of scale of the building” (Calgary 2004, p. 11). “Pedestrian-scale street and building variation heightens the interest of walking environments and can decrease the perception of the length of walking trips. A walking trip past uninteresting buildings with large footprints, vast parking lots, or monotonous home fronts can seem longer than it actually is.” (Salt Lake City 2002, p. 90).

San Jose (undated) recommends that building elevations and facades change approximately every 30 feet, and that floors above a height of 50 feet step back to maximize solar access (San Jose, undated). Examples of façade variations include porches, balconies, bay windows, and changes in materials (Salt Lake City 2002). Austin (2006) and Ottawa (2007) suggest that buildings at transit stops have awnings, overhangs, and colonnades for interest and weather protection (Austin 2006; Ottawa 2007). Long blank walls should be avoided (Raleigh-Durham 1997; San Francisco 2003; Austin 2006).

## Transit Stops

Most TOD manuals offer guidelines for bus stops and shelters, and, to a lesser extent, transit centers and park and rides. The Orlando manuals designate three bus stop types: local transit stops, primary local transit stops and super stops, with corresponding design guidelines (Orlando 1994; Orlando Amenities 1994).

Guidelines for bus stop spacing relate to the 1/4 mile (1,320 feet) comfortable walking distance. Stops placed about 1/2 mile apart will result in maximum walking distances of about 1/4 mile for areas closest to the transit route. In denser areas, or in areas with a higher proportion of elderly residents or riders, more frequent spacing may be used, usually about every 1/8 mile (660 feet or one to two blocks). Selected spacing guidelines are presented in Table E-9.

Table E-9. Bus Stop Spacing

450 ft	in high-density areas (Frederick County, 2001); downtown core (Brunswick,
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2006)	
600 ft	for local service (Denver, 1995)
750 ft	in urban areas (Brunswick, 2006)
1,000 ft	in suburban areas (Frederick County, 2001; Brunswick, 2006)
1 mile	for limited service (Denver, 1995)

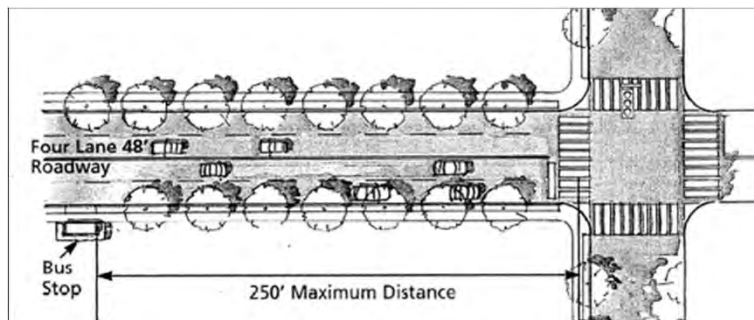
As the "primary interface between the patron and the transit system," transit stops and shelters should be located in areas that are inviting to waiting users (Bodmer and Reiner 1977, p. 48). A bus stop placed in front of a sidewalk cafe is more enticing than one placed in front of a parking lot (Woodhull 1991). Other placement guidelines include:

Unless dictated by the existence of a travel generator, stops should be placed at intersections, preferably signalized intersections, to increase access to service and reduce pedestrians crossing a street at mid-block.

At major transfer points, stops should be located so that transferring passengers do not need to cross a street to transfer. When there are multiple transfer movements at an intersection, the stop location should reflect the volume movements.

On roadways greater than 48 feet wide with a posted vehicle speed limit of 35 mph or higher and traffic volumes greater than 400 vehicles per lane in peak hours or 5,000 vehicles per lane per day, bus stops should be located as close to the intersection as possible with a maximum of 250 feet to the signalized pedestrian crossing (Brunswick 2006, p. 18).

Figure E-14. On-Street Bus Stop Placement



Source: Brunswick (2006, p. 18)

To increase safety, natural surveillance should be provided at transit stops (Rabinowitz et al. 1991). Waiting riders should be visible from abutting properties and streets (Orlando

Amenities 1994). Lighting should be provided, and landscaping and walls should not create hiding places or obstruct the view of drivers (Minneapolis/St. Paul 1983; Oakland 1983b; Chicago 1996; Buffalo 1997; San Francisco 2003; Ottawa 2007).

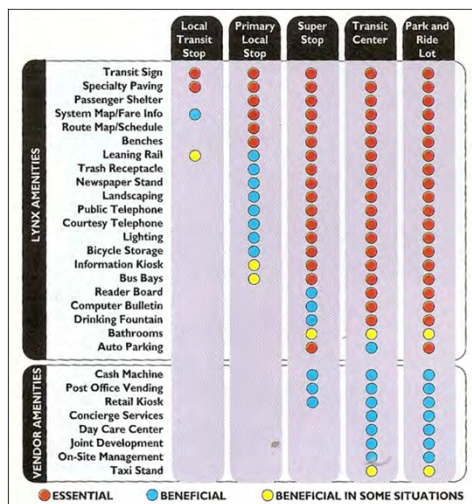
Benches and shelters may be warranted at transit stops, depending on passenger volumes. Benches should be safe, comfortable, placed so as to minimize obstruction of the public right-of-way, and have high resistance to vandalism and weathering (Orange County 1992). Shelters should be oriented so that pedestrian and vehicular sight distance is not impaired and so that passengers within the shelter are able to see and be seen by approaching buses (Frederick County 2001). Guidelines for bench and shelter setbacks are presented in Table E-10.

Table E-10. Minimum Distance from Benches/Shelters to Curb

2 ft	Oakland, 1983b
4 ft	Orange County, 1992; Reno, 1992 (30 mph zones)
5 ft	Suburban Chicago, 1989; Orlando, 1994 (residential areas); Frederick County, 2001
8-10 ft	Reno, 1992 (45 mph zones)

Beyond shelters and benches, common amenities called for at stops include trash receptacles, newspaper boxes, and bicycle parking. Less common but worth consideration at major stops are landscaping, artwork, and decorative paving (Chicago 1996). Orlando (1995) relates the number and type of amenities to the importance of transit stops (see Figure E-15).

Figure E-15. Essential and Beneficial Amenities for Transit Stops



Source: Orlando (1994, p. 6-4)





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<sup>1</sup> Linear regression is used where the travel variable is continuous, Poisson regression where the travel variable is a count, logistic regression where the dependent variable is a probability, and so forth.

<sup>2</sup> Several studies have applied ordered probit regression to data on counts of walk and transit trips. All but one of these studies is excluded from the meta-analysis because the breakpoint parameters for the ordered categories (the Mu's) were unavailable, which meant we could not calculate marginal effects. For one ordered probit study, by Greenwald and Boarnet (2001), Mu's were available, and Jason Cao computed elasticities for us. We used elasticities for the median ordered category.

<sup>3</sup> Due to a dearth of solid research, certain important travel outcomes could not be studied through meta-analysis. Most notably, this article is silent regarding the effects of the built environment on trip chaining.

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in multipurpose tours, internal capture of trips within mixed-use developments, and the choice of bicycling as a travel mode.