

Final Research Report
Agreements T4118 Task 87, A72 196
VMT Reductions

TOOLS FOR ESTIMATING VMT REDUCTIONS FROM BUILT ENVIRONMENT CHANGES

by

Anne Vernez Moudon, Professor
Orion Stewart, MUP, Research Scientist
URBAN FORM LAB (UFL)
University of Washington, Box 354802
Seattle, Washington 98195

Washington State Transportation Center (TRAC)

University of Washington, Box 354802
Seattle, Washington 98105-4631

Washington State Department of Transportation Technical Monitors
Paula Reeves, Transportation Planning Supervisor
Ed Spilker, Transportation Planning Specialist

Prepared for
The State of Washington
Department of Transportation
Lynn A. Peterson, Secretary

June 2013

1. REPORT NO. WA-RD 806.3	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE TOOLS FOR ESTIMATING VMT REDUCTIONS FROM BUILT ENVIRONMENT CHANGES		5. REPORT DATE June 2013	
		6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) Anne Vernez Moudon, Orion Stewart		8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Transportation Center (TRAC) University of Washington, Box 354802 University District Building; 1107 NE 45th Street, Suite 535 Seattle, Washington 98105-4631		10. WORK UNIT NO.	
		11. CONTRACT OR GRANT NO. Agreement T4118 Task 87	
12. SPONSORING AGENCY NAME AND ADDRESS Research Office Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Project Manager: Kathy Lindquist, 360-705-7976		13. TYPE OF REPORT AND PERIOD COVERED Research Report	
		14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.			
16. ABSTRACT: Built environment characteristics are associated with walking, bicycling, transit use, and vehicle miles traveled (VMT). Developing built environments supportive of walking, bicycling, and transit use can help meet state VMT reduction goals. But tools are necessary to understand how changes to the built environment may translate into changes in travel. Such tools can help optimize land use and transportation investments for reduced VMT and communicate such changes to the public. This report reviews the built environment characteristics associated with travel and the tools available that utilize these built environment characteristics to estimate travel and related outcomes such as vehicle emissions and health co-benefits. Tools ranged from simple to complex, and a number of factors should be considered when applying a tool to a planning effort.			
17. KEY WORDS Walking, Bicycling, Transit, VMT, Transportation planning, Travel Behavior		18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616	
19. SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF. (of this page) None	21. NO. OF PAGES	22. PRICE

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Contents

1	Introduction	1
2	Factors associated with travel behavior and mode choice.....	2
2.1	Individual and household factors.....	2
2.2	Built environment factors	4
2.3	Summary of factors.....	11
3	Tools to estimate travel and related outcomes.....	13
3.1	Professionally oriented tools	13
3.2	Publically oriented tools	19
3.3	Summary of tools.....	19
4	Conclusion.....	21
	References	22

Tables

1	D's – Weighted average elasticities from Ewing and Cervero's 2010 meta-analysis of travel and the BE.	12
2	Professional tools for estimating travel and GHG based on land use and transportation inputs.....	15

1 Introduction

The transport sector accounts for nearly half the greenhouse gas (GHG) emissions in Washington State (WSDOT 2009). Addressing transport sector GHG emissions is a priority for mitigating the impact of climate change and achieving environmental sustainability. Efforts include state-level legislation, regional climate action plans, and analysis of GHG impacts in environmental review (ICF International 2013; WSDOT 2009). One strategy for decreasing GHG emissions is reducing the amount of vehicle miles traveled (VMT) per capita. In Washington state, House Bill 2815 was passed in 2008 and established a target to reduce light-duty VMT per capita 18 percent by 2020, 30 percent by 2035, and 50 percent by 2050. Environmental sustainability, however, is just one aspect of a sustainable transportation system. Social equity and economic vitality comprise the other two principles of the “triple bottom line” definition of sustainability and must also be addressed to achieve a sustainable transportation (FHWA 2012). Therefore any sustainable VMT reduction strategy must simultaneously maintain or increase accessibility – the ability for people to reach desired goods, services, and activities (Litman 2012) – so that all three principles of the triple bottom line are met.

Accessibility can be achieved with fewer VMT when transit as well as walk, bike, and other non-motorized travel (NMT) modes are viable alternatives to the automobile. Washington State Department of Transportation (WSDOT) and its partners can support accessibility while reducing VMT and associated GHG emissions through plans, programs, and investments that support transit and NMT. To do so decision-makers must understand how proposed transportation and land use changes will affect travel. Traditionally, Metropolitan Planning Organizations (MPOs) and Regional Transportation Organizations (RTPO's) use travel demand forecasting models to understand the impacts of alternative transportation investment scenarios. Unfortunately these models often fail to accurately forecast NMT (Transportation Research Board 2011). This is due to several factors: the relatively short distances these modes cover and the corresponding needs for high resolution data on land use and transportation systems conditions and infrastructure; the uncommon use of these travel modes beyond the more densely developed parts of towns, cities, and metropolitan areas; and the limited NMT travel data necessary to calibrate the models. Efforts are underway to address these shortcomings (Kuzmyak and Dill 2012)

Part of the research conducted for this project focused on identifying the indicators known to affect NMT and the tools that decision-makers can use to understand how proposed transportation and land use changes will affect travel. Extensive research has been conducted over the past two decades on the relationship between individual, household, land use and built environment (BE) *factors* associated with transit and NMT. This past research has provided a foundation for numerous *tools* that attempt to forecast the impact of land use and transportation system changes on transit, NMT, VMT, GHG emissions, and other travel-related outcomes. This report first summarizes the individual, household, and BE *factors* associated with NMT. It then reviews the *tools* that use those factors as inputs to predict travel behaviors and related outcomes.

2 Factors associated with travel behavior and mode choice

This section reviews the specific individual, household, and BE factors that have been identified and used as variables in research on transit, NMT, and VMT travel.

2.1 Individual and household factors

Socio-demographics and other individual or household characteristics have been found to be strongly related to travel behavior. These characteristics include income, age, education, gender, ethnicity, household size, number of cars, commute mode, and even dog ownership. Demographics are important to consider because of neighborhood self-selection. To the extent possible, individuals will choose to live in neighborhoods that support their preferred lifestyles. Those that prefer to walk or take transit may choose to live in dense, mixed use environments with good transit service. Those who prefer to drive may live in suburban, residential only neighborhoods. Self-selection prevents the identification of causal relationships between the BE and travel behavior because individuals cannot be and are not randomly assigned to environments. However, it confirms that identifying the socio-demographic characteristics of the population will help forecast changes in travel trends and BE preferences due to changing demographics. Additionally, to the extent that individual and household characteristics remain constant, these factors may also help adjust the estimated effects of proposed changes to the BE within an existing area.

Income measured at the household level tends to have a mixed relationship with walking, where greater rates of walking occur in low- and high-income compared to middle-income populations (Pratt, Evans, and Levinson 2012). This bimodal distribution could be capturing the effect of limited transportation options at the low end and interest in health and exercise at the high end of the income range. Income measured at the neighborhood level has been found to have a negative relationship with non-motorized travel in Lexington, Kentucky (An and Chen 2007). In the Puget Sound region, among households that made at least one non-motorized trip over a two-day travel diary assessment, income was positively associated with NMT trip-making (Khan, Kockelman, and Xiong 2013). The authors of this research speculated that it could be due to interest in exercise or safety in higher income neighborhoods. The same study also found households with higher incomes more likely to make trips within the same traffic analysis zone (TAZ), which would presumably be shorter trips.¹ But income was also positively associated with VMT in a separate King County study using the same travel data (Frank et al. 2011).

Age, in adults, is negatively associated with non-motorized transportation and transit use (Pratt, Evans, and Levinson 2012). In the Puget Sound area, younger adults were found to be more likely to cycle at least once a week in their neighborhood (Moudon, Lee et al. 2005) and cycle to work (Khan, Kockelman, and Xiong 2013). But age was positively related to the probability of cycling for the category of home-based other (HBO) trips (Khan, Kockelman, and Xiong 2013).

¹ This study used trips within a TAZ and between two TAZs as indicators of shorter and longer trips. However, this seems like a poor proxy, as any relationship is likely confounded by TAZ size. Larger TAZs are located in suburban and rural areas and small TAZs, sometimes no larger than a block, are located in urban areas.

Education follows a similar trend as its covariate income, in which higher rates of walking, bicycling, and transit use occur at low and high ends of the education spectrum (Pratt, Evans, and Levinson 2012). Research has found that education moderates the effects of environment on walking for transportation—those with higher levels of education in walkable neighborhoods tend to walk more than those in similar neighborhoods but with lower levels of education (Owen et al. 2007).

Gender is not related to walking (Pratt, Evans, and Levinson 2012). Males are, however, more likely to cycle than females (Moudon, Lee et al. 2005; Khan, Kockelman, and Xiong 2013). Data from the PSRC 2006 HTS also suggest that males with a driver’s license are the least likely to make trips within their a TAZ (Khan, Kockelman, and Xiong 2013).

Ethnicity tends to be related to walking in a complex way. Minorities generally have higher rates of walking compared to non-Hispanic whites. However, when multivariate analyses are used to control for other BE and demographic factors, non-white minority status tends to explain little or be associated with less walking. It seems that other factors correlated with ethnicity explain walking better than ethnicity itself (Pratt, Evans, and Levinson 2012).

Household size is strongly associated with travel, which is intuitive since every individual within a household contributes to household-level travel. The total household size, total number of workers, and total number of children aged 16 or younger are were positively related to VMT in a King County study (Frank et al. 2011). A study using the same data, but within the entire 4-county Puget Sound region had similar results: household size, number of workers, and licensed drivers were all positively associated with household VMT. In this study however, household size and number of workers were also positively associated with household non-motorized miles traveled. The number of licensed drivers was negatively associated with household non-motorized miles traveled. Additionally, as household size increased, the probability of the household having zero non-motorized trips fell (as expected due to more trip-makers). But, for non-zero non-motorized trip households, household size and number of workers were also associated with a greater number of non-motorized trips. Finally, this study found that larger households were more likely to make trips entirely within a TAZ (i.e., a presumably short trip) (Khan, Kockelman, and Xiong 2013).

Number of cars owned by a household (sometimes measured per licensed driver) is positively associated with VMT (Frank et al. 2011) and negatively associated with walk and transit, but not bike, modes (Khan, Kockelman, and Xiong 2013). Also households that own more vehicles are more likely to make trips between different TAZs. In the Puget Sound region, lower household vehicle ownership is related to greater street connectivity, bus stop density, and a composite index of non-motorized accessibility after controlling for other variables (Khan, Kockelman, and Xiong 2013). This suggests that households in areas that can support non-motorized and transit travel may choose not to own a car, or those who cannot afford to own a car may choose to live in areas with alternative transportation.

Commute mode has also been found to be related to travel behaviors for other trips. A New Jersey study found that public transit commuters and those who walked or biked to work walked more frequently, not only during the commute, but for all purposes (Lachapelle and Noland 2012).

Dog ownership is related to walking, ostensibly because most dog owners walk their dogs on a regular basis. A New Jersey study that investigated the characteristics of dog owning households found that neighborhood BE was not as strong a predictor of dog ownership as characteristics of the household. Characteristics associated with a decreased likelihood of a household owning a dog were multi-family housing, rental housing, urban areas (Jersey City compared to the rest of the state), and higher income (Sehatzadeh, Noland, and Weiner 2012).

Cognitive constructs are used in surveys to capture an individual's attitude, enjoyment, perceived benefits and intention to participate in a specific activity. They are also used to assess a person's general perceived control over his or her behaviors. Applied to travel research, they are useful for measuring whether or not a person actually has an interest in participating in a particular travel mode and is likely to follow through with that interest. In studies of transportation-related physical activity (Cleland et al. 2010) active commuting (Lemieux and Godin 2009), and leisure-time walking (Janssen et al. 2010), such variables tended to be strongly associated with outcome variables.

2.2 Built environment factors

BE factors related to NMT and other travel behaviors are often organized into several "D's" (Ewing and Cervero 2010) that describe characteristics of an individual's neighborhood environment. Neighborhoods are commonly defined using ¼- to 1-mile buffers around an individual's residence/workplace or the Census or TAZ geographic unit in which the residence/workplace is located. Commonly researched D's include (1) density, which is a measure of any characteristic per unit area (2) diversity, which is the number of different land uses in a given area; (3) design, which measures street network characteristics; (4) destination accessibility, which measures ease of access to destinations, usually through distance or travel time; (5) distance to transit; and (6) demand management, such as parking costs. Demographics are sometimes considered a "D" but are not reviewed here as they have been discussed in the previous section. Factors at the scale of the route can also contribute to the decision to use NMT – particularly walking – and can influence the specific route choice within a neighborhood. These route-level factors include the perceptions of safety, comfort, sensory pleasure, and a sense of belonging (Mehta 2008). Although these factors are perceived and may vary from person to person, research has identified some of the underlying measurable physical and social characteristics of the BE that influence perceptions. This section discusses both measurable route- and neighborhood-level factors related to NMT.

Density is a measure of the concentration of people or households in a given area. It is most often a measure of the residential population, residential dwelling units (households), or employment per unit of land area. Greater density is consistently associated with utilitarian walking, transit and reduced VMT (Saelens and Handy 2008; Ewing and Cervero 2010). Density is correlated with many other BE factors that influence travel. Some of these factors are direct results of density: transit service, auto ownership, destination accessibility. Other associated factors are historically related to density, although not directly causing density: distance to CBD, land use mix, gridded street patterns, and low incomes. Because density may be an indicator variable for other BE factors that affect travel, it often shows a strong association with NMT in unadjusted analyses. However, the strength of association is weakened

considerably when associations are adjusted for BE covariates (Pratt, Evans, and Levinson 2012). In itself, a greater number of people in an area may not influence travel. Density is however, directly associated with other factors, such as land use mix, that do have an effect on reduced VMT.

Density has sometimes been measured at the individual level, such as living in a multi-family home, apartment, or condo (Sehatazadeh, Noland, and Weiner 2012) or the number of dwelling units per acre on an individual's household parcel (Lee and Moudon 2006). In both cases, individual household density was associated with more walking. It could be that living in a smaller home results in more activities that take place in nearby "third places" that are easily walkable.

Diversity is a measure of the variety of land uses in a given area. Diversity can be measured through entropy values or the percent of land, building square footage, or people (residents and jobs) that correspond to different uses in a given area. Other measures of diversity address the complementarity, not just the diversity, of land uses, targeting the presence and intensity of land uses that attract travel between them (e.g., housing or office and retail) (Frank et al. 2009). In the Puget Sound area, two studies using the PSRC 2006 household activity survey data found positive associations between mixed land uses and reduced VMT. In areas of King County, a mixed use index based on square footage of civic and education, entertainment, office, and retail in a 1-km network buffer was associated with less VMT (Frank et al. 2011). In Khan et al's (2013) study of the complete four-county area, a measure of land use balance that accounted for the proportion of jobs or dwelling units in each category of retail, office, industry, other employment, or residential in the home TAZ was negatively associated with VMT and positively associated with non-motorized miles traveled. Land use mix in the home TAZ was also very strongly associated with the probability of a trip by any mode occurring within the home TAZ, illustrating the importance of nearby destinations in reducing distances traveled (the average length of intrazonal trips was 1.36 miles while the average length of interzonal trips was 6.57 miles). Finally, in Khan et al's study, distance to CBD was strongly positively associated with VMT and negatively associated with non-motorized miles traveled.

Design refers to the spatial layout of streets and blocks. Street networks with a greater density of intersections support walking by providing more direct routes to and from destinations and allowing for routes that are along streets that carry less traffic and perhaps feel safer. To support walkability, recommended block lengths are 300 to 500 feet, with mid-block crosswalks and pass-throughs for block lengths of 600 feet or longer (Ewing 1998). Measures of street network connectivity are not consistently associated with utilitarian walking (Saelens and Handy 2008; Ewing and Cervero 2010). Lack of significance of street network variables may be due to their different roles in urban and suburban contexts. Small blocks in pre-1930s urban environments correspond with dense, diverse land uses, whereas in post-WWII suburbs, small blocks tend to correspond with low-density subdivisions and large blocks tend to correspond with dense, multi-family and retail development where utilitarian destinations may exist (Hess, Moudon, and Logsdon 2001). Furthermore, greater street network connectivity may allow for a greater number of route choices by any mode, but it also creates a greater number of streets that must be crossed to reach a destination, possibly contributing to walking and bicycling barriers.

Despite these ambiguities, street network measures appear to be associated with walking in the Puget Sound area. In King County, smaller size of the street-blocks where a household lives and measures of route directness (the ratio between airline and network distances) to certain destinations were associated with walking (Lee and Moudon 2006). Analysis of the 2006 PSRC travel survey data showed a strong negative association between street network connectivity and VMT and a strong positive association with non-motorized miles traveled (Khan, Kockelman, and Xiong 2013). This Puget Sound region study also found that the number of 3- and 4-way intersections in a half mile radius near home played a major role in mode choice for home-based other (HBO) trips within a TAZ and home-based work (HBW) trips between two TAZs: they were positively related to NMT modes and negatively related to drive alone or shared ride modes (Khan, Kockelman, and Xiong 2013).

The drawback to most objective, regional street network design measures is that they only account for street layout, and no other design elements such as traffic lanes, traffic speed and volumes, bike lanes, sidewalks, street trees, and on-street parking. These unmeasured characteristics could play a large role in influencing travel behavior. Some studies have attempted to analyze the effect of sidewalks. In select areas of King County, sidewalk coverage within a 1-km network buffer around a household was not associated with VMT (Frank et al. 2011). This study did not test the relationship between sidewalks and walking. However, an earlier King County study found that the total length of sidewalks within a 1-km neighborhood buffer was positively associated with walking (Lee and Moudon 2006). Similar results were found in a Lexington, Kentucky study where sidewalk coverage measured at the TAZ level was associated with non-motorized travel (An and Chen 2007). The mean slope in an individual's neighborhood has been found to have a positive association with recreational walking (Lee and Moudon 2006). A study of cycling in Portland, Oregon suggest that streets with bicycle infrastructure and low traffic volumes are preferred by cyclists, who also attempt to minimize waits at traffic signals and signs (or perhaps try to avoid pedaling more to regain momentum after a stop) (Dill and Gliebe 2008). A King County study found that proximity to a trail was one of the only objectively measured neighborhood BE correlates of cycling, similarly suggesting that cyclists prefer cycle infrastructure and attempt to avoid traffic (Moudon, Lee et al. 2005).

Destination accessibility is a measure of the proximity of specific destinations. It can be measured at the individual level as proximity from home to work, grocery stores, parks, the CBD, or any other number of specific places. At the areal level, it can be measured as jobs/housing balance or presence/variety of specific destinations or groups of destinations. It is a measure of opportunity to meet daily needs through walking, biking, shorter car trips, or transit. As may be expected, destinations have consistently strong relationships with utilitarian walking as well as reduced VMT (Saelens and Handy 2008; Ewing and Cervero 2010). Destinations that support daily life tend to have stronger associations with walking. These destinations include grocery stores, banks, and eating and drinking places. Furthermore, a strong effect on walking is observed when such destinations are located in close proximity to one another and form "neighborhood centers" (Lee and Moudon 2006). Even "non-utilitarian" land uses of parks and open spaces have been positively associated with utilitarian walking (Saelens and Handy 2008).

Distance to the CBD is consistently one of the strongest predictors of VMT (Ewing and Cervero 2010) and also has a strong effect on walking and biking. In a Puget Sound area study that matched suburban and

urban neighborhood centers on gross residential density, median income, automobile ownership, and intensity and type of neighborhood commercial development, urban sites were found to have on average three times the volume of pedestrian and bicycle traffic entering the site (37.7 people per hour compared to 12.5 people per hour) (Moudon et al. 1998). While this study demonstrates that non-motorized trips do in fact occur in suburban destinations near residential areas, it also demonstrates that urban areas see more pedestrian and bicycle travel, likely due to differences in street network design.

Differences in travel between the general population and households in close proximity to destinations or closer to the CBD is likely explained by mode choice and travel speed. In a Puget Sound region study (McCormack, Rutherford, and Wilkinson 2001), the average number of trips and time spent traveling were consistent across the region. However, households in Queen Anne and Wallingford, two traditionally designed neighborhoods in North Seattle, recorded fewer miles traveled and a greater percentage of walk trips relative to the surrounding North Seattle area. Similar results were found when comparing North Seattle to downtown Kirkland, a traditionally designed neighborhood in the inner suburbs. North Seattle households recorded fewer miles traveled and a greater percentage of walk trips relative to downtown Kirkland. Finally, this trend continued when comparing downtown Kirkland to the surrounding inner suburbs. Downtown Kirkland households recorded fewer miles traveled and a greater percentage of walk trips relative to the surrounding inner suburbs. Similar evidence that the BE affects mode choice and travel speed but not the number of trips comes from a Portland, Oregon study that found neighborhood land use diversity to be unrelated to the number of daily household trips, but strongly associated with VMT (Sun, Wilmot, and Kasturi 1998).

Distance to transit service is but one measure of transit accessibility. Other measures include count of stops within a buffer from a location and various measures of service, such as transit ridership at stops within a buffer, or when trips locations are known, imputed time and monetary travel costs. It may be no surprise that distance to the nearest transit stop and the number of transit stops near home are strongly related to transit travel (Ewing and Cervero 2010; Khan, Kockelman, and Xiong 2013). To the extent that transit trips offset vehicle trips, transit travel reduces VMT. Also, transit trips often involve a walk trip at either one or both ends of the transit service, and therefore contribute to walking.

The proportion of transit riders walking to transit is greatest within $\frac{1}{4}$ network miles or less of a stop, typically declining by half between $\frac{1}{4}$ and $\frac{1}{2}$ miles, and becoming very small beyond $\frac{1}{2}$ mile (Besser and Dannenberg 2005; Dill 2006; Ewing 1998; Guo 2009; O'Sullivan and Morrall 1996; Schlossberg et al. 2007). Distances people are willing to walk to transit tend to be shorter for bus compared to rail (Crowley, Shalaby, and Zarei 2009; O'Sullivan and Morrall 1996). This, however, could be more of a function of the transit service attributes, since bus and rail lines with similar service levels typically see the same levels of ridership (Ben-Akiva and Morikawa 2002). For commute trips, distances walked at the residential end of the trip tend to be longer than those at the employment end (Cervero 2006; Dill 2003; Kolko 2011). For light rail users in the Portland Metro and Bay Area who walked to a station, the first consideration for route choice was directness, suggesting that minimizing walk distances and travel times is important to all transit riders (Schlossberg et al. 2007).

Neighborhood transit service measured as the distance to the nearest bus stop was related to greater levels of walking and fewer VMT (Ewing and Cervero 2010). The distance to the closest bus stop was also found to increase the probability of a trip by any mode occurring within a TAZ, instead of between two TAZs (Khan, Kockelman, and Xiong 2013). A King County study using HTS data measured transit service as transit trip (in vehicle and wait) time and fares, which were imputed as if all of a household's trips had been made via transit even if other modes had been used (Frank et al. 2011). It found that households in areas with better transit service (i.e., lower imputed transit trip times and fares) tended to produce fewer VMT. It seems likely that the findings from these three studies are due only partially to the direct causal effect of transit service (i.e., use of transit offsetting VMT and resulting in more walk trips to and from transit stops) and partially to the confounding effect of transit servicing areas with higher densities of destinations, which also act to reduce VMT and support walk trips independently from transit service.

Demand management describes policies and programs in place to regulate transportation. Parking costs are one example of demand management. Higher parking costs and/or decreased parking availability likely act to discourage SOV trips. A study in selected areas of King County found that imputed parking charges at trip ends from the PSRC 2006 HTS were negatively associated with household VMT (Frank et al. 2011). On the other hand, a separate study by Khan et al. (2013) using the same HTS data set for the entire four-county area found that parking prices and free-parking availability near the home did not have much of an effect on the choice of travel mode for home-based other (HBO) trips within the same TAZ or HBO and home-based work (HBW) trips between TAZs. It did find that a higher estimated hourly parking price and fewer free parking spaces within a quarter mile of home was mildly associated with a greater number of household NMT trips.

Employer policies can also influence commute trip modes. Those who work or reside near a transit station and whose employers offer flex time programs or assistance with transit costs report higher levels of commute trips by transit; conversely those whose employers offer free parking or assistance with car costs report much lower levels (Canepa 2007). Commuting by transit declines as the ratio of parking to workforce size increases (Cervero 2006). However, commuting by transit rises as employers assist with transit commute costs. Commuters who lived in transit-oriented developments in the Portland, Oregon, area were more likely to use transit if they would have to pay to park at their school or workplace (Dill 2006).

Composite measures are often used to quantify the utility of the BE to support NMT, sometimes referred to as "walkability", due to the large number of explanatory variables that are covariates. One recently developed non-motorized accessibility index (NMT AI) was based on actual NMT trips in the Puget Sound Region from the 2006 PSRC household activity survey. It was a TAZ-level measure of the network distance from the trip origin to the destination, destination's distance to the CBD, natural log of the number of dwelling units in the destination TAZ, natural log of jobs at the destination TAZ, and land-use mix at the destination TAZ (Khan, Kockelman, and Xiong 2013). The index was associated with higher numbers of non-motorized trips among households that did make trips, but also a reduced probability of a trip occurring within the same TAZ, which was likely due to the small size of TAZs in denser, more non-motorized friendly areas like downtown Seattle. For HBO trips made within the same TAZ, the NMT AI

was positively associated with the probability of walking and negatively associated with the probability of drive modes (single or shared occupancy).

In the last example, a composite indicator was developed by researchers as a continuous variable with a clearly hypothesized relationship with travel. Another approach for measuring neighborhood environments is to group the various observed combinations of BE variables into exhaustive and mutually exclusive “neighborhood types” measured by a single categorical variable using the statistical techniques of cluster analysis. Cluster analysis techniques create groups that explain the greatest amount of variation in the input variables while reducing the sum of squares error – or the variation between the model estimate and the observed data. K-means cluster analysis was used in an analysis of the association between the BE within a half-mile buffer at trip destinations and non-personal vehicle (i.e., walk, bike or transit) mode choice from the PSRC 2006 HTS. Using measures of census-derived population, housing units, percent single-family housing units, median block perimeter, intersection density, total employment, and retail employment, K-means cluster analysis resulted in eight BE contexts. In descending order of non-personal vehicle mode split, the eight contexts were titled: CBD & Major Corridors, Dense Residential, Urban Core, Mixed Use Corridors, Exurban, Single-family Neighborhood/Mixed-use, Suburban, and Single-family Neighborhood (Clifton et al. 2012). Similarly, Multiple Correspondence Analysis (MCA) followed by cluster analysis based on hierarchical ascendant classification was used in a French study to classify neighborhoods (defined by geographies similar to census block groups) in the Ile-de-France based on green spaces, destinations, and cycle paths. Seven “neighborhood” types were identified. Individuals in neighborhoods classified as high accessibility to green areas and facilities and a high density of cycle paths were more likely to walk or cycle compared to similar individuals living in neighborhoods classified as having poor accessibility to green areas and facilities and an absence of cycle paths (Charreire et al. 2012).

Expert opinion can also be used to develop composite measures of land uses that support non-SOV travel. The Transportation Efficient Land Use Mapping Index (TELUMI) was developed with the input of a Delphi panel of nine local and national transportation and land use experts who identified thresholds of BE measures for supporting non-SOV travel. BE measures were based on a literature review and included density (residential and employment), mix of uses (shopping and school traffic, the presence of neighborhood centers), network connectivity (block size), parking supply (amount of parking at grade), and the pedestrian environment (slope). A composite measure of these nine BE variables was then developed based on a model of those variables that explained bus ridership. The significant variables in the model were weighted based on their relationship with bus ridership in a single composite variable used to identify areas with high, low, or latent transportation efficiency (Moudon, Kavage et al. 2005). Residential and employment density, the percentage of parking at grade, and neighborhood center variables showed relatively strong associations with the bus ridership, while the effects of school and retail traffic volumes were weak (Moudon, Kavage et al. 2005).

Safety, Comfort, sensory pleasure, and sense of belonging are among the perceived environmental constructs believed to represent quality walk environments on the scale of the walk route. A review of walking research found that perception of pedestrian infrastructure and aesthetics were sometimes related to increased recreational walking, while perception of personal safety and traffic concerns were

sometimes related to utilitarian walking (Saelens and Handy 2008). Therefore it seems that factors related to the quality, not necessarily the strict utility, of the BE can influence travel behaviors. These measurement and travel behavior associations of the constructs that capture the perceived quality of the pedestrian environment are discussed here.

Pedestrians prefer routes that provide **safety from traffic**. In a Portland Metro and San Francisco Bay Area survey of transit users who walked to the station, more than 80% agreed or strongly agreed that traffic devices, slower traffic speeds, and sidewalks were important factors in route choice (Schlossberg et al. 2007). In a Singapore study of walking to transit, each additional at-grade road crossing was estimated to add the equivalent of 182 ft (55.4 m) to the utility of the walk trip, and each traffic conflict added 119 ft (36.3 m) (Olszewski and Wibowo 2005).

Safety from crime acts to facilitate or constrain physical activity, including NMT, particularly among women and older adults (Foster and Giles-Corti 2008). However, much of the research is limited because it is derived from surveys that fail to ascertain the source of insecurity and have little variation in responses (Huston et al. 2003; Shores et al. 2009). Some surveys or audit instruments overcome this by asking about specific crimes (e.g., drunk driving or domestic violence) (Foster, Giles-Corti, and Knuiman 2010), specific undesirable behaviors (e.g., noisy neighbors) (Cleland et al. 2010), or physical evidence of specific crimes (e.g., graffiti or litter) (Evenson et al. 2009). Some measures of neighborhood insecurity are based on routine activity theory, which identifies three necessary elements necessary for a crime to occur: a target, an offender, and the absence of a capable guardian (Foster, Giles-Corti, and Knuiman 2010). Some safety variables measured characteristics of the BE that might contribute to the absence of a capable guardian (e.g., lack of pedestrian-oriented lighting or unoccupied houses) (Evenson et al. 2009; Foster, Giles-Corti, and Knuiman 2010), signs of potential offenders (e.g., loitering teenagers) (Foster, Giles-Corti, and Knuiman 2010), or capable guardians (e.g., neighborhood watch) (Evenson et al. 2009). Some variables identified whether people in the neighborhood were perceived as potential offenders or guardians through questions related to the social cohesion construct (Cleland et al. 2010). Finally, fears of crime are theorized to result in two changes in behavior: (1) constrained behavior, which would likely be reflected as less NMT; and (2) protective behavior, where security measures are implemented (Foster and Giles-Corti 2008). Some neighborhood safety variables capture these security measures (e.g., beware of dog signs) (Evenson et al. 2009). At the sub-neighborhood scale, Appleton's (1975) prospect-refuge theory provides insight into the types of physical environments that can contribute to a sense of safety from crime. Appleton's theory states that the ability to survey one's surroundings (prospect) from a place where one cannot easily be seen (refuge) is basic to many biological needs that developed with evolution and survival. According to this theory, pedestrian spaces that provide nearby shelter and edges with clear lines of sight into the surrounding area can increase perceived safety.

Comfort in the context of pedestrian travel refers to environments that allow for walking, but also standing, sitting, and impromptu social interactions (Gehl 2006). People walking from subway stations to destinations in downtown Boston were more likely to choose paths with wider sidewalks, through the Boston Common (a major park), and that avoided the hilly Beacon Hill neighborhood (Guo 2009). These choices could reflect the desire for ample walk space, less physically demanding routes, trees,

landscaping, benches, or reduced traffic noise. Elevation changes were found to represent a disutility to walking in other studies. Transit riders in Singapore were more likely to walk to stations rather than use other modes if their path avoided stairs. Each additional step was modeled to add the equivalent distance of 9.2 ft (2.8 m) to the utility of the walk trip (Olszewski and Wibowo 2005). Similarly, 87% of pedestrians crossing a street from a bus stop in Lund, Sweden, walked an additional 160 feet to a crosswalk while only 7% used a pedestrian underpass (Gehl 2006).

Sensory pleasure can make walk routes appear shorter and add to the utility of the travel mode (Gehl 2006). “Noticable differences” is the term given to sensory stimuli that people experience as they walk (Rapoport 1991). Noticeable differences include changes in the direction of the walk route, as well as number and frequency of such attributes as doors, trees, and windows. The presence of people along the walk route also can be considered noticeable differences (Whyte 1980). Noticeable differences along the walk route alters the sense of time that pedestrians feel they spend walking (Isaacs 2001), allowing people to focus on short stages within a walk rather than dwell on the overall length of the walk. Sensory pleasure results from variety and novelty as well as order and coherence (Kaplan and Kaplan 1989; Nasar 1998). Numerous features of the building-, parcel-, street-, and area-level environment can contribute to sensory pleasure, including: the characteristics of the edges of buildings that define the street (fenestration, canopies, awnings, and signage), the street and sidewalk (vehicles, street furniture, lighting), natural features (landscape elements and trees), and people (their activities, movements, and sounds).

2.3 Summary of factors

Extensive research on travel has helped quantify the relationship between the characteristics of individuals, households, land use, the BE and travel. Unfortunately, the magnitude of these relationships are difficult summarize in a concise manner due to the variations in measurement techniques, data sources, modeling approaches, and even variations on the effect of the BE across populations and geographies. For example, a meta-analysis of 50 research articles on travel and the BE identified only 13 BE variables that were reported in 3 or more studies (Ewing and Cervero 2010). For these variables, the weighted average elasticity was calculated (Table 1), which reflects the ratio of the percent change in travel behavior that results from a percentage change in the BE variable. From these calculations, it appears that destination accessibility has a strong relationship with VMT, design and diversity have a strong relationship with walking, and design and distance to transit have a strong relationship with transit use. The importance of density suggests that efforts to improve accessibility are best focused in areas that have or can support high residential and/or employment densities. The importance of street network design suggests that safety, comfort, and other perceived environmental characteristics of the walk route may be important for those who do have destinations to walk to, as areas with a greater number of streets will provide more options for pedestrians to select a preferred route.

Table 1: D's – Weighted average elasticities from Ewing and Cervero's 2010 meta-analysis of travel and the BE.

D category	Variable	Weighted average elasticities		
		VMT	Walk	Transit
Density	Household/population density	- 0.04	0.07	0.07
	Job density	0.00	0.04	0.01
	Commercial Floor Area Ratio (FAR)	n/a	0.07	n/a
Diversity	Land use mix	- 0.09	0.15	0.12
	Jobs/housing balance	- 0.02	0.19	n/a
	Distance to a store	n/a	0.25	n/a
Design	Intersection/street density	- 0.12	0.39	0.23
	Percent 4-way intersections	- 0.12	- 0.06	0.29
Destination accessibility	Job accessibility by auto	- 0.20	n/a	n/a
	Job accessibility by transit	- 0.05	n/a	n/a
	Job within one mile	n/a	0.15	n/a
	Distance to downtown	- 0.22	n/a	n/a
Distance to transit	Distance to nearest transit stop	- 0.05	0.15	0.29

The BE factors identified in Table 2 provide a foundation of estimating the effect size of changes to particular aspects of the BE on travel behavior. However, these variables are measured for the household residential location, thus it would be difficult to accurately estimate how adding jobs or residences to an area may change something like job accessibility for any one person or aggregation of people. These factors are also related to household travel and do not readily relate to travel that might occur through a corridor or street segment. The neighborhood environment measures are of a household neighborhood and do not reflect the BE of individuals at employment and commercial locations, which tend to have even greater effects (Walters et al. 2012). Finally, these estimated elasticities may not hold for all locations or all types of travel. Travel studies tend to be performed in large metro areas. A California study found that small and medium-size regions exhibited lower elasticities to transit proximity but higher elasticities to density and diversity variables (Walters et al. 2012). Also BE correlates of walking tend to differ for recreational and utilitarian walking (Saelens and Handy 2008).

The BE factors identified in Table 2 reflect neighborhood-scale measures of the BE that relate to populations across large areas or regions. They do not adequately account for micro-scale BE features that reflect the quality of the walk environment. Pedestrians prefer routes that are safe from traffic and crime, comfortable, and provide sensory pleasure. These subjective BE characteristics are difficult to quantify, but can be deconstructed through micro-scale studies of behavior in the BE, surveys, and theories of human behavior (Mehta 2008). They should not be overlooked, as they may be essential for the creation of a BE where NMT travel is not only feasible, but is also preferred to vehicular travel.

3 Tools to estimate travel and related outcomes

Numerous tools have been developed to help quantify the effects of planning activities on VMT, GHG emissions, and other outcomes. These tools range from simple spreadsheets to complex travel demand models. This section provides a brief review of tools available. The purpose of the review is to identify and summarize the essential characteristics of any tool devised for planning and prioritizing activities to increase accessibility while reducing VMT and GHG emissions. The tools are classified into two broad categories: professional-oriented sketch planning tools and models and publically oriented online mapping applications.

3.1 Professionally oriented tools

Planners must be able to estimate the impact of various land use and development scenarios on travel in order for decision makers to adopt the best alternative. Several tools have been developed to assist with this effort. Some are coarse alternatives to full travel demand models, which are useful when limited resources preclude the development of a full model. Others are more advanced versions of full models that better account for detailed BE factors. Some are designed to be used at the project development level while others are for state level planning. An extensive, yet perhaps incomplete, list of these tools (Table 2) was compiled from a list, which was previously available from the TRB-supported travel forecasting resources wiki page (Travel Forecasting Resource 2011) and a 2009 assessment of mobile source GHG analysis tools for the Washington State Department of Commerce (Fehr & Peers 2009). The Department of Commerce report evaluated eight tools based on (1) applicability across a range of community plans, (2) availability to public agencies, (3) sensitivity to land use and (4) transportation changes, (5) applicability to Washington state conditions, (6) availability of input data, (7) integration with readily available computing resources, and (8) accuracy. A decision tree was then developed to identify the most appropriate tool for the job based on such considerations as the existence of a travel demand forecasting model, the level of detail necessary, the resources available, and the significance of changes to land use or transportation facilities. Such a comprehensive review was not in the scope of this project. Instead, tools were identified and typical examples of tools are briefly described.

Table 2: Professional tools for estimating travel and GHG based on land use and transportation inputs

Tool	Developer	Description	URL	Applications
Spreadsheet tools				
CCAP Transportation Emissions Guidebook Emissions Calculator	Center for Clean Air Policy	Estimates GHG and other emissions based on TDM policies and Vehicle technologies	www.ccap.org/safe/guidebook/guide_complete.html	Unknown
COMMUTER	US EPA	Estimates travel and emissions impacts of commuting programs	www.epa.gov/otaq/stateresources/policy/pag_transp.htm#cp	Unknown
Conserve by Bicycling and Walking	FDOT	Estimates corridor-level NMT and co-benefits from area BE and demographic factors	http://www.dot.state.fl.us/safety/4-Reports/Bike-Ped-Reports.shtm#Conserve by Bicycle Phase 2 Study	Florida
King County State Environmental Policy Act (SEPA) GHG Emissions Worksheet	King County, Washington	Estimates all GHG emissions from a development project (has not been updated since 2007)	http://your.kingcounty.gov/ddes/forms/SEPA-GHG-EmissionsWorksheet-Bulletin26.xls	King County, WA
Rapid Fire	Calthorpe Associates	Models VMT, GHG emissions, etc. based on land use scenarios	www.calthorpe.com/scenario_modeling_tools	California, Honolulu
VMT reduction: Phase One	WSDOT	Estimates neighborhood residential VMT and CO ₂ based on BE and demographic factors	www.wsdot.wa.gov/research/reports/fullreports/765.1.pdf	Rainier Beach and Bitter lake, Seattle
VMT Spreadsheet	Fehr and Peers	Estimates mobile GHG emissions from land use development projects.	www.coolconnections.org/vmt	Northgate, Seattle
VMT Spreadsheet with Smart Growth Adjustments	Fehr and Peers	Estimates mobile GHG emissions from development adjusted for BE characteristics.	www.coolconnections.org/4ds .	Northgate, Seattle
GIS and/or model-based tools				
Bay Area Simplified Simulation of Travel, Energy and Greenhouse Gases (BASSTEGG)	Bay Area Metropolitan Transportation Commission	GIS simulation of Regional VO, VMT, and GHG based on TAZ-level BE and SES	ftp://ftp.abag.ca.gov/pub/mtc/planning/forecast/BASSTEGG/	Bay Area, CA
Clean Air and Climate Protection (CACP) 2009 Software	The International Council for Local Environmental Initiatives (ICLEI)	Estimates GHG emissions for communities based on wide range of local activity data	www.iclei.usa.org/action-center/tools/cacp-software	Fort Collins, CO; Missoula, MT; San Diego, CA
CommunityViz	Placeways LLC	GIS tool to visualize and quantify various aspects of planning	http://placeways.com/communityviz/	Boston, MA; Victor, ID
Energy and Emissions Reduction Policy Analysis Tool (EERPAT)	The Federal Highway Administration (FHWA)	State-level screening tool for GHG reduction policies on transport	www.planning.dot.gov/FHWA_tool/	Florida

Tool	Developer	Description	URL	Applications
Envision Tomorrow	Fregonese Associates	GIS tool that tests financial feasibility of development regulations and their impact on indicators	www.frego.com/services/envision-tomorrow/	Various, including Mountlake Terrace, WA
GreenSTEP	Oregon Department of Transportation (ODOT)	Adds GHG emissions to statewide or metro travel models that account for BE	www.oregon.gov/ODOT/TD/TP/Pages/GreenSTEP.aspx	Oregon
Improved Data and Tools for Integrated Land Use-Transportation Planning in California	UC Davis	Uses California-specific relationships of BE and travel for scenario planning at multiple scales using various tools	http://ultrans.its.ucdavis.edu/projects/improved-data-and-tools-integrated-land-use-transportation-planning-california	Various locations in California
INDEX/SPARC	Criterion Planners	Map-based tool for ranking scenarios based on various performance indicators	www.crit.com/the_tool.html	200+ organizations in 35 states, including PSRC
I-PLACE3S/PLACE3S	California Energy Commission and the Sacramento Area Council of Governments (SACOG)	Parcel-level GIS tool for estimating land use and transportation GHG emissions accounting for BE factors	www.sacog.org/services/scenario-planning/	Sacramento area, California
Local Sustainability Planning Tool	Southern California Association of Govts (SCAG)	GIS tool to model land use scenarios on VO, VMT, mode share, and GHG emissions.	http://rtpscs.scag.ca.gov/Pages/Local-Sustainability-Planning-Tool.aspx	Various communities in Southern California
Low-carb Land	Sonoma Technology, Inc.	Web tool for examining VMT and GHG under various growth and land use scenarios	www.sonomatech.com/project.cfm?uprojectid=672	Thurston County, WA; Marin County, CA
UPlan	UC Davis Information Center for the Environment (ICE)	Rule-based urban growth model that assigns land uses to parcels based on location attractiveness and plan requirements, for use at county or regional scale	http://ice.ucdavis.edu/doc/uplan	Shasta county, CA; Delaware Valley Transportation Commission
Urban Footprint	Calthorpe Associates	GIS scenario creation and modeling tool with full co-benefits analysis capacity	www.calthorpe.com/scenario_modeling_tools	California, Honolulu
Urbemis	Rimpo and Associates, Inc.	Estimates GHG emissions for development projects accounting for some BE	www.urbemis.com	California

Many professional tools are designed for multiple planning purposes, of which VMT and GHG emissions are one aspect. For example, the **Envision Tomorrow** tool (Fregonese Associates 2013) allows planners to model land use scenarios based on aggregate building level data and assess area outcomes such as housing and jobs (mix and density), jobs-housing balance, land consumption (vacant, agricultural, infill), impervious surface, open space, housing affordability, resource usage (energy and water), waste production (water, solid, carbon), transportation (travel mode choice, vehicle miles traveled), fiscal impact (local revenue and infrastructure costs), balanced housing index (how a scenario's housing mix matches the expected future demographic profile). Envision Tomorrow also explicitly addresses the regulatory and development aspect of land use change by allowing users to assess whether building typologies are feasible under different market and regulatory scenarios. While these various land use model inputs and outcomes are not directly relevant to VMT and GHG emissions, they are worth noting as any planning process is likely to have multiple goals and stakeholders.

Other tools are oriented specifically toward GHG emissions. The **WSDOT VMT reduction: Phase One** tool (Frank et al. 2011) is an example of a spreadsheet tool that focuses on VMT and GHG emissions. It estimates household-level vehicle use (VMT in miles per day, month, year or other unit of time) and related CO₂ emission (grams per unit time) as well as the 95% confidence interval around each estimate. It can be used for baseline and forecasted estimates based on changes to input variables. Estimates are based on the relationships found in two Ordinary Least Squares (OLS) linear regression models of household VMT and CO₂. The OLS linear regression models were fitted using data from 1,929 households that responded to the 2006 PSRC household travel survey and who lived in King County jurisdictions where sidewalk data were available. Explanatory variables included household socio-demographic traits, neighborhood urban form measures taken within a 1-km network buffer of the household, transit accessibility, and monetary costs of travel.

This spreadsheet tool is designed to be applied to a neighborhood planning area. It requires 14 input variables under 4 categories:

- Household characteristics (5 variables): average number of workers per household, average number of children per household, average number of vehicles per licensed driver in household, percentage of households above county median income, number of households in planning area.
- Urban form characteristics (4 variables): signalized intersection density, land use mix, sidewalk ratio, jobs/population balance
- Transit accessibility (3 variables): number of transit routes servicing area, average transit travel time, average transit wait time
- Monetary cost of travel (2 variables): average hourly parking charge, average transit trip fare

The WSDOT VMT reduction: Phase One spreadsheet tool is simple to use and provides confidence intervals to provide a sense of the accuracy of the estimate. However, it applies relationships modeled at the household-level to neighborhood planning areas of varying and sizes and shapes, which results in ecological fallacy and the Modifiable Areal Unit Problem (MAUP). It relies on models of VMT and CO₂ based only on household neighborhood urban form, it does not account for the effect of destination

urban form characteristics on VMT. The tool also does not estimate travel for non-residential land uses in the planning area. Finally, it was developed from a sample of households located in a limited number of jurisdictions in King County, and therefore may not be generalizable to other parts of the state.

Most sketch planning tools are used for estimating VMT from households or developments. The **Conserve by Bicycling and Walking** tool developed for the Florida Department of Transportation is a departure from the household-level unit of analysis: it is designed to estimate corridor-level walking and bicycle use, as well as fuel and CO₂ generation savings and health benefits (Florida Department of Transportation 2009). The tool was developed based on an analysis of 28 corridors in Florida with various facility types and adjacent BE's. A multinomial logit mode shift model was used to predict the probabilities that a trip on a roadway under given conditions would be made by bicycle, transit, or on foot, relative to the probability of making the trip by private motor vehicle. A linear regression model was used for induced recreational trips. Finally, a benefits calculator was created to convert the predicted NMT trips into daily and annual fuel, CO₂ emission, and healthcare cost savings.

The Conserve by Bicycling and Walking spreadsheet tool requires detailed corridor-level data – a total of at least 39 input variables under 5 categories:

- roadway info: 15 variables, such as AADT, lanes, pavement conditions
- corridor characteristics: 7 variables, such as average trip length, auto occupancy, aesthetics
- Transit service: 4 variables, such as buses per hour, bus occupancy, transit LOS
- Influence area demographics: 4 variables, such as numbers and density of population and employment
- Roadway geometry: 9 variables, such as lane widths, parking, tree spacing

Of these 39 variables, four factors strongly predicted mode shift from auto to cycling:

- higher "bicycle Level of Service" (perceived safety and comfort for cyclists) of the main road, or of a parallel shared-use path where available (LOS defined by FDOT)
- greater "bicycle network friendliness", i.e., greater extent and perceived quality (bicycle LOS) of cycling accommodation in the street network in the area surrounding the roadway
- shorter average trip length of travelers using the roadway (intercept survey)
- greater density of the (arithmetic) product of population and employment in the area surrounding the roadway (from TAZ or census tract data)

Five variables strongly predicted induced demand for recreational cycling in a corridor:

- greater length of bicycle facility
- presence of a shared-use path, or roadway conditions with higher (perceived) quality of accommodation for cycling (LOS defined by FDOT)
- better aesthetic quality (including landscape interest) of a route (qualitative rating)
- more points of interest (including amenities) along a route
- greater distance-weighted density of population near the facility (from TAZ or census tract data)

Finally, three variables explained induced demand for recreational walking in a corridor:

- the corridor's pedestrian level of service (defined by FDOT)
- the number of people living within a half-mile of the midpoint of the corridor (from TAZ or census tract data)

The Conserve by Bicycling and Walking tool appears to be based on a comprehensive analysis of the factors that influence NMT along a corridor. However, due to this comprehensiveness, it requires a large number of inputs, some of which are subjective and others of which require potentially labor-intensive data collection efforts. Furthermore, the relationships that were observed in Florida may not apply to Washington State.

Perhaps the most comprehensive example of the tools available to estimate VMT and GHG emissions comes from the **Improved Data and Tools for Integrated Land Use-Transportation Planning in California** project (UC Davis Urban Land Use and Transportation Center 2012). This project consisted of a review of current research on the relationship between the BE and travel demand as well as the tools that integrate that relationship into the planning process. Original research was then conducted on the relationship between BE and travel demand and a suite of software tools was developed for use in local and regional integrated land use-transportation scenario planning processes in California. Three tools were developed: (1) a sketch planning spreadsheet, (2) a GIS-integrated sketch planning tool, and (3) a travel demand forecasting model post-processor.

The suite of tools was based on three statistical models for different regions: (1) small/medium MPOs, (2) large MPOs, and (3) major rail corridors. The models were fitted using GIS and travel survey data (NHTS and regional) from 13 smaller and medium-size MPOs, two major metropolitan areas, and several sub-regions within the two largest MPOs in California. The models quantified the influence of built environment "D" variables captured within a half-mile buffer around a household and household demographics on three outcomes: vehicle ownership (VO), vehicle trip generation (VT), and vehicle miles travelled (VMT). VMT was estimated through multiple steps: a binary logistic regression model to estimate the probability that a household will make a vehicle trip; then either one linear regression model to estimate household VMT or two linear regression models to estimate the number of vehicle trips and the average vehicle trip length, the product of which is VMT.

The tools developed through **the Improved Data and Tools for Integrated Land Use-Transportation Planning in California project** addressed two of the major limitations of previous sketch planning tools: (1) Travel mode choice differences associated with the BE at workplace and shopping destinations were modeled in addition to those at home locations; and (2) separate models were developed for study regions of varying sizes, which resulted in different relationships between the BE and travel. Additionally, the three formats available (spreadsheet, GIS, and travel demand model post-processor) add flexibility for planners working with various resources.

3.2 Publically oriented tools

Online mapping tools are available and approachable to the public. They are designed to inform and educate on the geographic distribution of travel behavior and the relevant BE characteristics that influence travel behavior. Online mapping tools often have no capabilities for scenario analysis – the input variables are fixed. However, they are sometimes used by professionals in baseline analyses or to assess trends over time. In the context of tools to estimate travel, their data sources, modeled relationships, and user interfaces could prove insightful.

Walk Score is an online mapping tool that provides a composite measure of nearby features that support day-to-day living, or “walkability” (Walk Score 2013). The Walk Score measure is a number on a scale of 1 to 100 and is not calibrated on actual travel behavior. However research has shown that it is related to transport-related physical activity (Frank, Ulmer, and Lerner 2013)., The U.S. Census bureau’s **OnTheMap** application uses synthetic residential and employment data to display estimated commuting distances for census geographies (U.S.Census Bureau 2012).

The **H+T (Housing and Transportation) Affordability Index** is an online mapping tool that links the BE and travel behaviors (Center for Neighborhood Technology 2012). The tool is designed primarily to account for the cost of transportation as part of the choice of home location. It uses census and other nationally available datasets to estimate auto ownership, auto use (VMT), and transit use. From these three estimates, it calculates various downstream outcomes, such as transportation costs and GHG emissions.

The H+T Affordability Index is based on the results of three regression models to estimate auto ownership, auto use (VMT), and transit use. Auto ownership data was obtained from the ACS as a ratio of autos and occupied households per block group. Auto use data came from Massachusetts odometer readings from 2005-2007 at a 250-meter grid cell level. Transit data were measured from the ACS as the percent of commuters using transit at the block group level. All three regression models employ 11 explanatory variables derived from readily available national and regional databases: (1) median income, (2) per capita income, (3) average household size, (4) average commuters per household, (5) residential density, (6) gross density, (7) average block size, (8) intersection density, (9) transit connectivity, (10) transit access shed, and (11) employment access.

The H+T Affordability Index is easy to view and adds value to readily available data. While it uses the same model coefficients nationwide, similar models have been developed in different regions with similar results, suggesting the relationships are generalizable. Its ease of use is limited to displaying current conditions; the underlying regression model coefficients would have to be used to explore how planned changes to the BE might affect travel outcomes. Finally, due to the use of census geographies, it is subject to the MAUP.

3.3 Summary of tools

Understanding how changes to the BE in an area may result in changes to travel behavior – specifically VMT reduced, trips switched to NMT, and NMT trips induced – is a challenge. When the time and

resources exist, travel demand models can provide regional forecasts of travel behaviors. Often, however, these models are limited in their ability to accurately account for the effect of small scale BE characteristics or changes to the BE. Sketch planning tools in the form of spreadsheets, GIS software add-ons, or travel demand model post-processors, can help planners to quickly, if roughly, account for BE influences on estimated travel. Online mapping tools can be used to display and communicate the geographic distribution of the BE as it relates to travel.

In identifying or creating a tool to assist planners develop and prioritize plans for reduced VMT and increased accessibility, several items should be considered:

- Is the tool developed on using data from a population that is generalizable to the planning area population?
- Is the tool outcome the same as the planning outcome of interest? (e.g., is the travel behavior of interest NMT along a facility, at the household level, or to a work or retail destination?)
- Are the input variables readily available and current; do resources exist to collect data if necessary?
- Do the input variables reflect the BE characteristics that are intended to be modified?
- Does the tool operate at the same scale as the planning area?
- Do subjective input variables add or detract from a tool utility?
- Is the tool subject to ecological fallacy? (i.e., does the tool apply aggregate BE-travel relationships to individuals or vice versa?)
- Is the tool subject to the MAUP? (i.e., will the results change arbitrarily when the planning area boundaries are changed?)
- Does the tool adequately quantify all outcomes of interest? Should it account for other planning goals?
- Does the tool rely on reasonable assumptions?
- Does the tool communicate the range/accuracy of the estimate?
- Is the tool readily usable? Are extensive training and resources necessary to use it? If it requires output from transportation demand model, is one available?

The answers to many of these questions will depend on the context of the tool's use, the resources available to purchase, develop, and/or modify the tool, and numerous other factors. These considerations must be carefully weighed to select the right tool for the job.

4 Conclusion

Sustainability can be achieved when VMT reduction strategies work to increase NMT and transit accessibility. Existing tools can help these efforts by providing estimates of travel behavior changes, GHG emissions, and health benefits due to modifications to land uses and transportation systems. These tools should be used carefully, with full knowledge of their limitations and drawbacks, as well as the foundation of research that they are built upon. When existing tools fail to meet the demands of the planning context, this knowledge can aid in the development of custom tools that will.

References

- An, Meiwu, and Mei Chen. 2007. Estimating Nonmotorized Travel Demand. *Transportation Research Record: Journal of the Transportation Research Board* 2002 (-1):18-25.
- Appleton, J. 1975. *The Experience of Landscape*. Berkeley, CA: Wiley.
- Ben-Akiva, Moshe, and Takayuki Morikawa. 2002. Comparing ridership attraction of rail and bus. *Transport Policy* 9 (2):107-116.
- Besser, Lilah M., and Andrew L. Dannenberg. 2005. Walking to Public Transit: Steps to Help Meet Physical Activity Recommendations. *American Journal of Preventive Medicine* 29 (4):273-280.
- Canepa, Brian. 2007. Bursting the Bubble: Determining the Transit-Oriented Development's Walkable Limits. *Transportation Research Record* 1992:28-34.
- Center for Neighborhood Technology. 2013. *H+T Affordability Index 2012* [cited April 08 2013]. Available from <http://htaindex.cnt.org>.
- Cervero, Robert. 2006. Office Development, Rail Transit, and Commuting Choices. *Journal of Public Transportation* 9 (5):41-55.
- Charreire, H., C. Weber, B. Chaix, P. Salze, R. Casey, A. Banos, D. Badariotti, E. Kesse-Guyot, S. Hercberg, C. Simon, and J. M. Oppert. 2012. Identifying built environmental patterns using cluster analysis and GIS: relationships with walking, cycling and body mass index in French adults. *Int J Behav Nutr Phys Act* 9:59.
- Cleland, V., K. Ball, C. Hume, A. Timperio, A. C. King, and D. Crawford. 2010. Individual, social and environmental correlates of physical activity among women living in socioeconomically disadvantaged neighbourhoods. *Soc Sci Med* 70 (12):2011-8.
- Clifton, Kelly J, Kristina M Currans, April C Cutter, and Robert Schneider. 2012. A Context-Based Approach for Adjusting Institute of Transportation Engineers Trip Generation Rates in Urban Contexts Using Household Travel Surveys. In *Transportation Research Board 91st Annual Meeting*. Washington DC.
- Crowley, David F., Amer S. Shalaby, and Hossein Zarei. 2009. Access Walking Distance, Transit Use, and Transit-Oriented Development in North York City Center, Toronto Canada. *Transportation Research Record* 2110:96-105.
- Dill, Jennifer. 2003. Transit Use and Proximity to Rail: Results from Large Employment Sites in the San Francisco, California, Bay Area. *Transportation Research Record* 1835:19-24.
- . 2006. *Travel and Transit Use at Portland Area Transit-Oriented Developments (TODs)*. Seattle, WA: Transportation Northwest Regional Center X (TransNow).
- Dill, Jennifer, and J. Gliebe. 2008. *Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route Choice: Oregon Transportation Research and Education Consortium*.
- Evenson, K. R., D. Sotres-Alvarez, A. H. Herring, L. Messer, B. A. Laraia, and D. A. Rodriguez. 2009. Assessing urban and rural neighborhood characteristics using audit and GIS data: derivation and reliability of constructs. *Int J Behav Nutr Phys Act* 6:44.
- Ewing, Reid. 1998. Pedestrian and Transit-Friendly Design. In *Third National Conference on Access Management*. Fort Lauderdale, FL: U.S. Department of Transportation Federal Highway Administration.
- Ewing, Reid, and Robert Cervero. 2010. Travel and the Built Environment. *Journal of the American Planning Association* 76 (3):265-294.
- Fehr & Peers. 2009. *Assessment of Greenhouse Gas Analysis Tools*: Washington State Department of Commerce.
- FHWA. 2013. *INVEST 2012* [cited April 08 2013]. Available from <https://www.sustainablehighways.org/>.

- Florida Department of Transportation. 2013. *Conserve by Bicycle Phase 2 Study* 2009 [cited April 08 2013]. Available from <http://www.dot.state.fl.us/safety/4-Reports/Bike-Ped-Reports.shtml#Conserve> by Bicycle Phase 2 Study.
- Foster, S., and B. Giles-Corti. 2008. The built environment, neighborhood crime and constrained physical activity: an exploration of inconsistent findings. *Prev Med* 47 (3):241-51.
- Foster, S., B. Giles-Corti, and M. Knuiaman. 2010. Neighbourhood design and fear of crime: a social-ecological examination of the correlates of residents' fear in new suburban housing developments. *Health Place* 16 (6):1156-65.
- Frank, L. D., J. F. Sallis, B. E. Saelens, L. Leary, K. Cain, T. L. Conway, and P. M. Hess. 2009. The development of a walkability index: application to the Neighborhood Quality of Life Study. *Br J Sports Med* 44 (13):924-33.
- Frank, Lawrence D., Michael J. Greenwald, Sarah Kavage, and Andrew Devlin. 2011. An Assessment of Urban Form and Pedestrian and Transit Improvements as an Integrated GHG Reduction Strategy: Washington State Department of Transportation.
- Frank, Lawrence, Jared Ulmer, and Matt Lerner. 2013. Enhancing Walk Score's Ability to Predict Physical Activity and Active Transportation. Paper read at Active Living Research Annual Conference, February 27, 2013, at San Diego, California.
- Fregonese Associates. 2013. *Envision Tomorrow* 2013 [cited April 08 2013]. Available from <http://www.frego.com/services/envision-tomorrow/>.
- Gehl, Jan. 2006. *Life Between Buildings: Using Public Space*. Sixth Edition ed. Skive, Denmark: The Danish Architectural Press.
- Guo, Zhan. 2009. Does the Pedestrian Environment Affect the Utility of Walking? A Case of Path Choice in Downtown Boston *Transportation Research Part D* 14:343-352.
- Hess, Paul M., Anne Vernez Moudon, and Miles G. Logsdon. 2001. Measuring Land Use Patterns for Transportation Research. *Transportation Research Record: Journal of the Transportation Research Board* 1780.
- Huston, S. L., K. R. Evenson, P. Bors, and Z. Gizlice. 2003. Neighborhood environment, access to places for activity, and leisure-time physical activity in a diverse North Carolina population. *Am J Health Promot* 18 (1):58-69.
- ICF International. 2013. *Transportation for Communities: Greenhouse Gas Examples from Practice* 2013 [cited April 08 2013]. Available from http://www.transportationforcommunities.com/shrpc01/ghg_application_kdps/26/0#examples.
- Isaacs, Raymond. 2001. The Subjective Duration of Time in the Experience of Urban Places. *Journal of Urban Design* 6 (2):109-127.
- Janssen, E., T. Sugiyama, E. Winkler, H. de Vries, F. te Poel, and N. Owen. 2010. Psychosocial correlates of leisure-time walking among Australian adults of lower and higher socio-economic status. *Health Educ Res* 25 (2):316-24.
- Kaplan, R., and S. Kaplan. 1989. *The Experience of Nature -- a Psychological Perspective*. New York: Cambridge University Press.
- Khan, Mobashwir, Kara M. Kockelman, and Xiaoxia Xiong. 2013. Models for Anticipating Non-motorized Travel Choices, and the Role of the Built Environment. In *Paper submitted to the Transportation Research Board 92nd Annual Meeting*. Washington DC.
- Kolko, Jed. 2011. Making the Most of Transit: Density, Employment Growth, and Ridership around New Stations: Public Policy Institute of California.
- Kuzmyak, J. Richard, and Jennifer Dill. 2012. Walking and bicycling in the United States: The Who, What, Where, and Why. *TR News*, 4-15.

- Lachapelle, Ugo, and Robert B. Noland. 2012. Does the commute mode affect the frequency of walking behavior? The public transit link. *Transport Policy* 21 (0):26-36.
- Lee, Chanam, and Anne Vernez Moudon. 2006. The 3Ds + R: Quantifying land use and urban form correlates of walking. *Transportation Research Part D: Transport and Environment* 1 (3):204-215.
- Lee, Chanama, and Anne Vernez Moudon. 2006. Correlates of Walking for Transportation or Recreation Purposes. *Journal of Physical Activity and Health* 3 (Suppl 1):S77-S98.
- Lemieux, M., and G. Godin. 2009. How well do cognitive and environmental variables predict active commuting? *Int J Behav Nutr Phys Act* 6:12.
- Litman, Todd. 2012. Are Vehicle Travel Reduction Targets Justified? Evaluating Mobility Management Policy Objectives Such as Targets to Reduce VMT and Increase Use of Alternative Modes. Victoria, Canada: Victoria Transport Policy Institute.
- McCormack, Edward, G. Scott Rutherford, and Martina Wilkinson. 2001. Travel Impacts of Mixed Land Use Neighborhoods in Seattle, Washington. *Transportation Research Record: Journal of the Transportation Research Board* 1780 (Paper No. 01-2588).
- Mehta, Vikas. 2008. Walkable streets: pedestrian behavior, perceptions and attitudes. *Journal of Urbanism* 1 (3):217-245.
- Moudon, Anne Vernez, Paul M. Hess, Mary Catherine Snyder, and Kiril Stanilov. 1998. Effects of Site Design on Pedestrian Travel in Mixed-Use, Medium-Density Environments. *Transportation Research Record: Journal of the Transportation Research Board* 1578 (Paper No. 971360).
- Moudon, Anne Vernez, Sarah E. Kavage, Jean E. Mabry, and D.W. Sohn. 2005. A Transportation-Efficient Land Use Mapping Index. *Transportation Research Record: Journal of the Transportation Research Board* 1902:134-144.
- Moudon, Anne Vernez, Chanam Lee, Allen D. Cheadle, Cheza W. Collier, Donna Johnson, Thomas L. Schmid, and Robert D. Weather. 2005. Cycling and the built environment, a U.S. perspective. *Transportation Research Part D: Transport and Environment* 10 (3):245-261.
- Nasar, J. 1998. *The Evaluative Image of the City*. Thousand Oaks, CA: Sage.
- O'Sullivan, Sean, and John Morrall. 1996. Walking Distance to and from Light-Rail Transit Stations. *Transportation Research Record* 1538:19-26.
- Olszewski, Piotr, and Sony Sulaksono Wibowo. 2005. Using Equivalent Walking Distance to Assess Pedestrian Accessibility to Transit Stations in Singapore. *Transportation Research Record* 1927:38-45.
- Owen, N., E. Cerin, E. Leslie, L. duToit, N. Coffee, L. D. Frank, A. E. Bauman, G. Hugo, B. E. Saelens, and J. F. Sallis. 2007. Neighborhood walkability and the walking behavior of Australian adults. *Am J Prev Med* 33 (5):387-95.
- Pratt, Richard H., John E. Evans, and Herbert S. Levinson. 2012. Chapter 16, Pedestrian and Bicycle Facilities. In *Report 95: Response to Transportation System Changes Handbook*, edited by Transit Cooperative Research Program. Washington DC.
- Rapoport, A. 1991. Pedestrian Street Use: Culture and Perception. In *Public Streets for Public Use*, edited by A. V. Moudon. New York: Columbia University Press.
- Saelens, Brian E., and Susan L. Handy. 2008. Built Environment Correlates of Walking: A Review. *Medicine & Science in Sports & Exercise*.
- Schlossberg, Marc, Asha Weinstein Agrawal, Katja Irvin, and Vanessa Louise Bekkouche. 2007. How Far, By Which Route, and Why? A Spatial Analysis of Pedestrian Preference. San Jose, CA: Mineta Transportation Institute.
- Sehatzadeh, Bahareh, Robert B. Noland, and Marc D. Weiner. 2012. Walking frequency, cars, dogs, and the built environment. *Transportation Research Part A: Policy and Practice* 45 (8):741-754.
- Shores, K. A., S. T. West, D. S. Theriault, and E. A. Davison. 2009. Extra-individual correlates of physical activity attainment in rural older adults. *J Rural Health* 25 (2):211-8.

- Sun, Xiaoduan, Chester Wilmot, and Tejonath Kasturi. 1998. Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Activity-Based Travel Survey. *Transportation Research Record: Journal of the Transportation Research Board* 1617 (-1):10-17.
- Transportation Research Board. 2011. How we travel, A sustainable national program for travel data, edited by Committee on National Statistics. Washington DC: National Research Council.
- Travel Forecasting Resource. 2013. *Sketch Planning Tools* 2011 [cited April 08 2013]. Available from http://www.tfresource.org/Topics/Model_Application/Climate_Change_and_Green_House_Gas/Sketch_Planning_Tools_-_Climate_Change.aspx.
- U.S.Census Bureau. 2013. *OnTheMap* 2012 [cited April 08 2013]. Available from <http://onthemap.ces.census.gov>.
- UC Davis Urban Land Use and Transportation Center. 2013. *Improved Data and Tools for Integrated Land Use-Transportation Planning in California* 2012 [cited April 08 2013]. Available from <http://ultrans.its.ucdavis.edu/projects/improved-data-and-tools-integrated-land-use-transportation-planning-california>.
- Walk Score. 2013. *Walk Score* 2013 [cited April 08 2013]. Available from <http://www.walkscore.com>.
- Walters, Jerry, Chris Breiland, Gus Jimenez, and Richard Lee. 2012. Improved Data & Tools for Integrated Land Use-Transportation Planning in California, Appendix D: Results of Analysis of Detailed Built Environment and Travel Data: University of California Davis Urban Land Use and Transportation Center.
- Whyte, William H. 1980. *The Social Life of Small Urban Spaces*. New York: Project for Public Spaces.
- WSDOT. 2013. *Washington State Activities to Reduce Transportation Greenhouse Gas Emissions* 2009 [cited April 09 2013]. Available from <http://www.stateinnovation.org/Events/Event-Listing/State-DOT-Sustainability-Roundtable/Washington-GhG-Activities.aspx>.

